SPIR-V Extended Instructions for GLSL

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Chapter 1. Introduction

This specifies the GLSL.std.450 extended instruction set. It provides instructions for the GLSL built-in functions that do not directly map to native SPIR-V instructions.

Import this extended instruction set using an **OpExtInstImport** "GLSL.std.450" instruction.

Chapter 2. Binary Form

Documentation form for each extended instruction:

Extended Instruction Name Instruction description. *Result Type* will describe the *Result Type* for the **OpExtInst** instruction. *Number* is the extended instruction number to use in the **OpExtInst** instruction. *Operand 1*, *Operand 2*,… are the operands listed for the **OpExtInst** instruction. Any **Capability** restrictions.			
Number	*Operand 1*	*Operand 2*	…

Extended instructions:

Round Result is the value equal to the nearest whole number to *x*. The fraction 0.5 rounds in a direction chosen by the implementation, presumably the direction that is fastest. This includes the possibility that **Round** *x* is the same value as **RoundEven** *x* for all values of *x*. The operand *x* must be a scalar or vector whose component type is floating-point. *Result Type* and the type of *x* must be the same type. Results are computed per component.	
1	*<id>* *x*

RoundEven Result is the value equal to the nearest whole number to *x*. A fractional part of 0.5 rounds toward the nearest even whole number. (Both 3.5 and 4.5 for *x* round to 4.0.) The operand *x* must be a scalar or vector whose component type is floating-point. *Result Type* and the type of *x* must be the same type. Results are computed per component.	
2	*<id>* *x*

Trunc

Result is the value equal to the nearest whole number to *x* whose absolute value is not larger than the absolute value of *x*.

The operand *x* must be a scalar or vector whose component type is floating-point.

Result Type and the type of *x* must be the same type. Results are computed per component.

3	*<id>* *x*

FAbs

Result is *+0.0* if *x* is ±*0.0*, *x* if *x > 0.0*, and *-x* if *x < 0.0*.

The operand *x* must be a scalar or vector whose component type is floating-point.

Result Type and the type of *x* must be the same type. Results are computed per component.

4	*<id>* *x*

SAbs

Result is *x* if *x >= 0*; otherwise result is *-x*, where *x* is interpreted as a signed integer.

Result Type and the type of *x* must both be integer scalar or integer vector types. *Result Type* and operand types must have the same number of components with the same component width. Results are computed per component.

This instruction can be decorated with **NoSignedWrap**.

5	*<id>* *x*

FSign

Result is *1.0* if *x > 0*, *-1.0* if *x < 0*, *+0.0* if *x = +0.0*, and ±*0.0* if *x = -0.0*. If *x* = ±*NaN*, the result can be any of ±*1.0* or ±*0.0*, regardless of whether shader_float_controls is in use.

The operand *x* must be a scalar or vector whose component type is floating-point.

Result Type and the type of *x* must be the same type. Results are computed per component.

6	*<id>* *x*

SSign Result is 1 if *x > 0*, *0* if *x = 0*, or *-1* if *x < 0*, where *x* is interpreted as a signed integer. *Result Type* and the type of *x* must both be integer scalar or integer vector types. *Result Type* and operand types must have the same number of components with the same component width. Results are computed per component.	
7	*<id>* *x*

Floor Result is the value equal to the nearest whole number that is less than or equal to *x*. The operand *x* must be a scalar or vector whose component type is floating-point. *Result Type* and the type of *x* must be the same type. Results are computed per component.	
8	*<id>* *x*

Ceil Result is the value equal to the nearest whole number that is greater than or equal to *x*. The operand *x* must be a scalar or vector whose component type is floating-point. *Result Type* and the type of *x* must be the same type. Results are computed per component.	
9	*<id>* *x*

Fract Result is *x* - **floor** *x*. The operand *x* must be a scalar or vector whose component type is floating-point. *Result Type* and the type of *x* must be the same type. Results are computed per component.	
10	*<id>* *x*

Radians

Converts *degrees* to radians, i.e., *degrees* * pi / 180.

The operand *degrees* must be a scalar or vector whose component type is 16-bit or 32-bit floating-point.

Result Type and the type of *degrees* must be the same type. Results are computed per component.

11	*<id>* *degrees*

Degrees Converts *radians* to degrees, i.e., *radians* * 180 / pi. The operand *radians* must be a scalar or vector whose component type is 16-bit or 32-bit floating-point. *Result Type* and the type of *radians* must be the same type. Results are computed per component.	
12	*<id>* *radians*

Sin The standard trigonometric sine of *x* radians. The operand *x* must be a scalar or vector whose component type is 16-bit or 32-bit floating-point. *Result Type* and the type of *x* must be the same type. Results are computed per component.	
13	*<id>* *x*

Cos The standard trigonometric cosine of *x* radians. The operand *x* must be a scalar or vector whose component type is 16-bit or 32-bit floating-point. *Result Type* and the type of *x* must be the same type. Results are computed per component.	
14	*<id>* *x*

Tan The standard trigonometric tangent of *x* radians. The operand *x* must be a scalar or vector whose component type is 16-bit or 32-bit floating-point. *Result Type* and the type of *x* must be the same type. Results are computed per component.	
15	*<id>* *x*

Asin Arc sine. Result is an angle, in radians, whose sine is *x*. The range of result values is [-pi / 2, pi / 2]. The resulting value is undefined if **abs** *x* > 1. The operand *x* must be a scalar or vector whose component type is 16-bit or 32-bit floating-point. *Result Type* and the type of *x* must be the same type. Results are computed per component.	
16	*<id>* *x*

Acos Arc cosine. Result is an angle, in radians, whose cosine is *x*. The range of result values is [0, pi]. The resulting value is undefined if **abs** *x* > 1. The operand *x* must be a scalar or vector whose component type is 16-bit or 32-bit floating-point. *Result Type* and the type of *x* must be the same type. Results are computed per component.	
17	*<id>* *x*

Atan Arc tangent. Result is an angle, in radians, whose tangent is *y_over_x*. The range of result values is [-pi / 2, pi / 2]. The operand *y_over_x* must be a scalar or vector whose component type is 16-bit or 32-bit floating-point. *Result Type* and the type of *y_over_x* must be the same type. Results are computed per component.	
18	*<id>* *y_over_x*

Sinh Hyperbolic sine of *x* radians. The operand *x* must be a scalar or vector whose component type is 16-bit or 32-bit floating-point. *Result Type* and the type of *x* must be the same type. Results are computed per component.	
19	*<id>* *x*

Cosh

Hyperbolic cosine of *x* radians.

The operand *x* must be a scalar or vector whose component type is 16-bit or 32-bit floating-point.

Result Type and the type of *x* must be the same type. Results are computed per component.

20	*<id>* *x*

Tanh

Hyperbolic tangent of *x* radians.

The operand *x* must be a scalar or vector whose component type is 16-bit or 32-bit floating-point.

Result Type and the type of *x* must be the same type. Results are computed per component.

21	*<id>* *x*

Asinh

Arc hyperbolic sine; result is the inverse of **sinh**.

The operand *x* must be a scalar or vector whose component type is 16-bit or 32-bit floating-point.

Result Type and the type of *x* must be the same type. Results are computed per component.

22	*<id>* *x*

Acosh

Arc hyperbolic cosine; Result is the non-negative inverse of **cosh**. The resulting value is undefined if $x < 1$.

The operand *x* must be a scalar or vector whose component type is 16-bit or 32-bit floating-point.

Result Type and the type of *x* must be the same type. Results are computed per component.

23	*<id>* *x*

Atanh Arc hyperbolic tangent; result is the inverse of tanh. The resulting value is undefined if **abs** *x* >= 1. The operand *x* must be a scalar or vector whose component type is 16-bit or 32-bit floating-point. *Result Type* and the type of *x* must be the same type. Results are computed per component.	
24	*<id>* *x*

Atan2 Arc tangent. Result is an angle, in radians, whose tangent is *y* / *x*. The signs of *x* and *y* are used to determine what quadrant the angle is in. The range of result values is [-pi, pi]. The resulting value is undefined if *x* and *y* are both 0. The operand *x* and *y* must be a scalar or vector whose component type is 16-bit or 32-bit floating-point. *Result Type* and the type of all operands must be the same type. Results are computed per component.		
25	*<id>* *y*	*<id>* *x*

Pow Result is *x* raised to the *y* power; x^y. The resulting value is undefined if *x* < 0. Result is undefined if *x* = 0 and *y* <= 0. The operand *x* and *y* must be a scalar or vector whose component type is 16-bit or 32-bit floating-point. *Result Type* and the type of all operands must be the same type. Results are computed per component.		
26	*<id>* *x*	*<id>* *y*

Exp Result is the natural exponentiation of *x*; e^x. The operand *x* must be a scalar or vector whose component type is 16-bit or 32-bit floating-point. *Result Type* and the type of *x* must be the same type. Results are computed per component.	
27	*<id>* *x*

Log

Result is the natural logarithm of *x*, i.e., the value *y* which satisfies the equation $x = e^y$. The resulting value is undefined if *x* <= 0.

The operand *x* must be a scalar or vector whose component type is 16-bit or 32-bit floating-point.

Result Type and the type of *x* must be the same type. Results are computed per component.

28	*<id>* *x*

Exp2

Result is 2 raised to the *x* power; 2^x.

The operand *x* must be a scalar or vector whose component type is 16-bit or 32-bit floating-point.

Result Type and the type of *x* must be the same type. Results are computed per component.

29	*<id>* *x*

Log2

Result is the base-2 logarithm of *x*, i.e., the value *y* which satisfies the equation $x = 2^y$. The resulting value is undefined if *x* <= 0.

The operand *x* must be a scalar or vector whose component type is 16-bit or 32-bit floating-point.

Result Type and the type of *x* must be the same type. Results are computed per component.

30	*<id>* *x*

Sqrt

Result is the square root of *x*. The resulting value is undefined if *x* < 0.

The operand *x* must be a scalar or vector whose component type is floating-point.

Result Type and the type of *x* must be the same type. Results are computed per component.

31	*<id>* *x*

InverseSqrt

Result is the reciprocal of **sqrt** *x*. The resulting value is undefined if *x* <= 0.

The operand *x* must be a scalar or vector whose component type is floating-point.

Result Type and the type of *x* must be the same type. Results are computed per component.

32	*<id>* *x*

Determinant Result is the determinant of *x*. The operand *x* must be a square matrix. *Result Type* must be the same type as the component type in the columns of *x*.	
33	*<id>* *x*

MatrixInverse Result is a matrix that is the inverse of *x*. The resulting values are undefined if *x* is singular or poorly conditioned (nearly singular). The operand *x* must be a square matrix. *Result Type* and the type of *x* must be the same type.	
34	*<id>* *x*

Modf **Modf** is deprecated, use **ModfStruct** instead. Result is the fractional part of *x*, and stores through *i* the whole-number part as a whole-number floating-point value. Both the result and the output parameter have the same sign as *x*. The operand *x* must be a scalar or vector whose component type is floating-point. The operand *i* must have a pointer type. *Result Type*, the type of *x*, and the type *i* points to must all be the same type and have a floating-point component type. Results are computed per component.		
35	*<id>* *x*	*<id>* *i*

ModfStruct Result is a structure containing both the fractional part of *x* and the whole number part of *x*. *Result Type* must be an **OpTypeStruct** with two members. Member 0 holds the fractional part. Member 1 holds the whole number part. Both members get the same sign as *x*. These two members and *x* must all be the same type. Results are computed per component. The operand *x* must be a scalar or vector whose component type is floating-point.

36	*<id>* *x*

FMin

Result is *y* if *y* < *x*, either *x* or *y* if both *x* and *y* are zeros, otherwise *x*. Which operand is the result is undefined if one of the operands is a NaN.

The operands must all be a scalar or vector whose component type is floating-point.

Result Type and the type of all operands must be the same type. Results are computed per component.

37	*<id>* *x*	*<id>* *y*

UMin

Result is *y* if *y* < *x*; otherwise result is *x*, where *x* and *y* are interpreted as unsigned integers.

Result Type and the type of *x* and *y* must both be integer scalar or integer vector types. *Result Type* and operand types must have the same number of components with the same component width. Results are computed per component.

38	*<id>* *x*	*<id>* *y*

SMin

Result is *y* if *y* < *x*; otherwise result is *x*, where *x* and *y* are interpreted as signed integers.

Result Type and the type of *x* and *y* must both be integer scalar or integer vector types. *Result Type* and operand types must have the same number of components with the same component width. Results are computed per component.

39	*<id>* *x*	*<id>* *y*

FMax

Result is *y* if *x* < *y*, either *x* or *y* if both *x* and *y* are zeros, otherwise *x*. Which operand is the result is undefined if one of the operands is a NaN.

The operands must all be a scalar or vector whose component type is floating-point.

Result Type and the type of all operands must be the same type. Results are computed per component.

40	*<id>* *x*	*<id>* *y*

UMax

Result is *y* if *x* < *y*; otherwise result is *x*, where *x* and *y* are interpreted as unsigned integers.

Result Type and the type of *x* and *y* must both be integer scalar or integer vector types. *Result Type* and operand types must have the same number of components with the same component width. Results are computed per component.

41	*<id>* *x*	*<id>* *y*

SMax

Result is *y* if *x* < *y*; otherwise result is *x*, where *x* and *y* are interpreted as signed integers.

Result Type and the type of *x* and *y* must both be integer scalar or integer vector types. *Result Type* and operand types must have the same number of components with the same component width. Results are computed per component.

42	*<id>* *x*	*<id>* *y*

FClamp

Result is min(max(*x*, *minVal*), *maxVal*). The resulting value is undefined if *minVal* > *maxVal*. The semantics used by min() and max() are those of FMin and FMax.

The operands must all be a scalar or vector whose component type is floating-point.

Result Type and the type of all operands must be the same type. Results are computed per component.

43	*<id>* *x*	*<id>* *minVal*	*<id>* *maxVal*

UClamp

Result is min(max(*x*, *minVal*), *maxVal*), where *x*, *minVal* and *maxVal* are interpreted as unsigned integers. The resulting value is undefined if *minVal* > *maxVal*.

Result Type and the type of the operands must both be integer scalar or integer vector types. *Result Type* and operand types must have the same number of components with the same component width. Results are computed per component.

44	*<id>* *x*	*<id>* *minVal*	*<id>* *maxVal*

SClamp

Result is min(max(*x*, *minVal*), *maxVal*), where *x*, *minVal* and *maxVal* are interpreted as signed integers. The resulting value is undefined if *minVal* > *maxVal*.

Result Type and the type of the operands must both be integer scalar or integer vector types. *Result Type* and operand types must have the same number of components with the same component width. Results are computed per component.

45	*<id>* *x*	*<id>* *minVal*	*<id>* *maxVal*

FMix

Result is the linear blend of *x* and *y*, i.e., *x* * (1 - *a*) + *y* * *a*.

The operands must all be a scalar or vector whose component type is floating-point.

Result Type and the type of all operands must be the same type. Results are computed per component.

46	*<id>* *x*	*<id>* *y*	*<id>* *a*

Step

Result is 0.0 if *x* < *edge*; otherwise result is 1.0.

The operands must all be a scalar or vector whose component type is floating-point.

Result Type and the type of all operands must be the same type. Results are computed per component.

48	*<id>* *edge*	*<id>* *x*

SmoothStep

Result is 0.0 if *x* <= *edge0* and 1.0 if *x* >= *edge1* and performs smooth Hermite interpolation between 0 and 1 if *edge0* < *x* < *edge1*. This is equivalent to:

t * *t* * (3 - 2 * *t*), where *t* = clamp ((*x* - *edge0*) / (*edge1* - *edge0*), 0, 1)

The resulting value is undefined if *edge0* >= *edge1*.

The operands must all be a scalar or vector whose component type is floating-point.

Result Type and the type of all operands must be the same type. Results are computed per component.

49	*<id>* *edge0*	*<id>* *edge1*	*<id>* *x*

Fma

Computes *a* * *b* + *c*.

The operands must all be a scalar or vector whose component type is floating-point.

Result Type and the type of all operands must be the same type. Results are computed per component.

50	*<id>* *a*	*<id>* *b*	*<id>* *c*

Frexp

Frexp is deprecated, use **FrexpStruct** instead.

Splits *x* into a floating-point significand in the range (-1.0, 0.5] or [0.5, 1.0) and an integral exponent of 2, such that:

$x = significand * 2^{exponent}$

The *significand* is the instruction result. An *x* of *-0.0* results in a significand *-0.0*, while an *x* of *0.0* results in *0.0*. For a floating-point value that is an infinity or is not a number, the significand is undefined.

The operand *x* must be a scalar or vector whose component type is floating-point.

The exponent is returned through the pointer-parameter *exp*. The *exp* operand must be a pointer to a scalar or vector with integer component type, with 32-bit component width. The number of components in *x* and what *exp* points to must be the same. If *x* is a zero, the exponent is 0.0. If *x* is an infinity or a NaN, the exponent is undefined.

Result Type must be the same type as the type of *x*. Results are computed per component.

51	*<id>* *x*	*<id>* *exp*

FrexpStruct

Result is a structure containing *x* split into a floating-point significand in the range (-1.0, 0.5] or [0.5, 1.0) and an integral exponent of 2, such that:

$x = significand * 2^{exponent}$

If *x* is a zero, the exponent is 0.0. If *x* is an infinity or a NaN, the exponent is undefined. If *x* is *0.0*, the significand is *0.0*. If *x* is *-0.0*, the significand is *-0.0*

Result Type must be an **OpTypeStruct** with two members. Member 0 must have the same type as the type of *x*. Member 0 holds the significand. Member 1 must be a scalar or vector with integer component type, with 32-bit component width. Member 1 holds the exponent. These two members and *x* must have the same number of components.

The operand *x* must be a scalar or vector whose component type is floating-point.

52	*<id>* *x*

Ldexp

Builds a floating-point number from *x* and the corresponding integral exponent of two in *exp*:

$significand * 2^{exponent}$

If this product is too large to be finitely represented in the floating-point type, the resulting value is undefined. If *exp* is greater than +128 (single precision) or +1024 (double precision), the resulting value is undefined. If *exp* is less than -126 (single precision) or -1022 (double precision), the result may be flushed to zero. Additionally, splitting the value into a significand and exponent using **frexp** and then reconstructing a floating-point value using **ldexp** should yield the original input for zero and all finite non-denormalized values.

The operand *x* must be a scalar or vector whose component type is floating-point.

The *exp* operand must be a scalar or vector with integer component type. The number of components in *x* and *exp* must be the same.

Result Type must be the same type as the type of *x*. Results are computed per component.

53	*<id>* *x*	*<id>* *exp*

PackSnorm4x8

First, converts each component of the normalized floating-point value *v* into 8-bit integer values. These are then packed into the result.

The conversion for component *c* of *v* to fixed point is done as follows:

round(clamp(*c*, -1, +1) * 127.0)

The first component of the vector is written to the least significant bits of the output; the last component is written to the most significant bits.

The *v* operand must be a vector of 4 components whose type is a 32-bit floating-point.

Result Type must be a 32-bit integer type.

54	*<id>* *v*

PackUnorm4x8 First, converts each component of the normalized floating-point value *v* into 8-bit integer values. These are then packed into the result. The conversion for component *c* of *v* to fixed point is done as follows: round(clamp(*c*, 0, +1) * 255.0) The first component of the vector is written to the least significant bits of the output; the last component is written to the most significant bits. The *v* operand must be a vector of 4 components whose type is a 32-bit floating-point. *Result Type* must be a 32-bit integer type.	
55	*<id>* *v*

PackSnorm2x16 First, converts each component of the normalized floating-point value *v* into 16-bit integer values. These are then packed into the result. The conversion for component *c* of *v* to fixed point is done as follows: round(clamp(*c*, -1, +1) * 32767.0) The first component of the vector is written to the least significant bits of the output; the last component is written to the most significant bits. The *v* operand must be a vector of 2 components whose type is a 32-bit floating-point. *Result Type* must be a 32-bit integer type.	
56	*<id>* *v*

PackUnorm2x16

First, converts each component of the normalized floating-point value *v* into 16-bit integer values. These are then packed into the result.

The conversion for component *c* of *v* to fixed point is done as follows:

round(clamp(*c*, 0, +1) * 65535.0)

The first component of the vector is written to the least significant bits of the output; the last component is written to the most significant bits.

The *v* operand must be a vector of 2 components whose type is a 32-bit floating-point.

Result Type must be a 32-bit integer type.

57	*<id>* *v*

PackHalf2x16

Result is the unsigned integer obtained by converting the components of a two-component floating-point vector to the 16-bit **OpTypeFloat**, and then packing these two 16-bit integers into a 32-bit unsigned integer. The first vector component specifies the 16 least-significant bits of the result; the second component specifies the 16 most-significant bits.

The *v* operand must be a vector of 2 components whose type is a 32-bit floating-point.

Result Type must be a 32-bit integer type.

58	*<id>* *v*

PackDouble2x32

Result is the double-precision value obtained by packing the components of *v* into a 64-bit value. If an IEEE 754 Inf or NaN is created, it will not signal, and the resulting floating-point value is unspecified. Otherwise, the bit-level representation of *v* is preserved. The first vector component specifies the 32 least significant bits; the second component specifies the 32 most significant bits.

The *v* operand must be a vector of 2 components whose type is a 32-bit integer.

Result Type must be a 64-bit floating-point scalar.

Use of this instruction requires declaration of the **Float64** capability.

59	*<id>* *v*

UnpackSnorm2x16

First, unpacks a single 32-bit unsigned integer *p* into a pair of 16-bit signed integers. Then, each component is converted to a normalized floating-point value to generate the result. The conversion for unpacked fixed-point value *f* to floating point is done as follows:

clamp(*f* / 32767.0, -1, +1)

The first component of the result is extracted from the least significant bits of the input; the last component is extracted from the most significant bits.

The *p* operand must be a scalar with 32-bit integer type.

Result Type must be a vector of 2 components whose type is 32-bit floating point.

60	*<id>* *p*

UnpackUnorm2x16

First, unpacks a single 32-bit unsigned integer *p* into a pair of 16-bit unsigned integers. Then, each component is converted to a normalized floating-point value to generate the result. The conversion for unpacked fixed-point value *f* to floating point is done as follows:

f / 65535.0

The first component of the result is extracted from the least significant bits of the input; the last component is extracted from the most significant bits.

The *p* operand must be a scalar with 32-bit integer type.

Result Type must be a vector of 2 components whose type is 32-bit floating point.

61	*<id>* *p*

UnpackHalf2x16

Result is the two-component floating-point vector with components obtained by unpacking a 32-bit unsigned integer into a pair of 16-bit values, interpreting those values as 16-bit floating-point numbers according to the OpenGL Specification, and converting them to 32-bit floating-point values. Subnormal numbers are either preserved or flushed to zero, consistently within an implemenation.

The first component of the vector is obtained from the 16 least-significant bits of *v*; the second component is obtained from the 16 most-significant bits of *v*.

The *v* operand must be a scalar with 32-bit integer type.

Result Type must be a vector of 2 components whose type is 32-bit floating point.

62	*<id>* *v*

UnpackSnorm4x8

First, unpacks a single 32-bit unsigned integer *p* into four 8-bit signed integers. Then, each component is converted to a normalized floating-point value to generate the result. The conversion for unpacked fixed-point value *f* to floating point is done as follows:

clamp(*f* / 127.0, -1, +1)

The first component of the result is extracted from the least significant bits of the input; the last component is extracted from the most significant bits.

The *p* operand must be a scalar with 32-bit integer type.

Result Type must be a vector of 4 components whose type is 32-bit floating point.

63	*<id>* *p*

UnpackUnorm4x8

First, unpacks a single 32-bit unsigned integer *p* into four 8-bit unsigned integers. Then, each component is converted to a normalized floating-point value to generate the result. The conversion for unpacked fixed-point value *f* to floating point is done as follows:

f / 255.0

The first component of the result is extracted from the least significant bits of the input; the last component is extracted from the most significant bits.

The *p* operand must be a scalar with 32-bit integer type.

Result Type must be a vector of 4 components whose type is 32-bit floating point.

64	*<id>* *p*

UnpackDouble2x32

Result is the two-component unsigned integer vector representation of *v*. The bit-level representation of *v* is preserved. The first component of the vector contains the 32 least significant bits of the double; the second component consists of the 32 most significant bits.

The *v* operand must be a scalar whose type is 64-bit floating point.

Result Type must be a vector of 2 components whose type is a 32-bit integer.

Use of this instruction requires declaration of the **Float64** capability.

65	*<id>* *v*

Length Result is the length of vector *x*, i.e., sqrt(*x* [0] ^{2} + *x* [1] ^{2} + …). The operand *x* must be a scalar or vector whose component type is floating-point. *Result Type* must be a scalar of the same type as the component type of *x*.	
66	*<id>* *x*

Distance Result is the distance between *p0* and *p1*, i.e., length(*p0* - *p1*). The operands must all be a scalar or vector whose component type is floating-point. *Result Type* must be a scalar of the same type as the component type of the operands.		
67	*<id>* *p0*	*<id>* *p1*

Cross Result is the cross product of *x* and *y*, i.e., the resulting components are, in order: *x*[1] * *y*[2] - *y*[1] * *x*[2] *x*[2] * *y*[0] - *y*[2] * *x*[0] *x*[0] * *y*[1] - *y*[0] * *x*[1] All the operands must be vectors of 3 components of a floating-point type. *Result Type* and the type of all operands must be the same type.		
68	*<id>* *x*	*<id>* *y*

Normalize Result is the vector in the same direction as *x* but with a length of 1. The operand *x* must be a scalar or vector whose component type is floating-point. *Result Type* and the type of *x* must be the same type.

69	*<id>* *x*

FaceForward

If the dot product of *Nref* and *I* is negative, the result is *N*, otherwise it is -*N*.

The operands must all be a scalar or vector whose component type is floating-point.

Result Type and the type of all operands must be the same type.

70	*<id>* *N*	*<id>* *I*	*<id>* *Nref*

Reflect

For the incident vector *I* and surface orientation *N*, returns *I* - 2 * dot(*N*, *I*) * *N*.

If *N* is normalized then this corresponds to *I* reflected from a surface with normal *N*.

The operands must all be a scalar or vector whose component type is floating-point.

Result Type and the type of all operands must be the same type.

71	*<id>* *I*	*<id>* *N*

Refract

For the incident vector *I* and surface normal *N*, and the ratio of indices of refraction *eta*, the result is the refraction vector. The result is computed by

k = 1.0 - *eta* * *eta* * (1.0 - dot(*N*, *I*) * dot(*N*, *I*))

if k < 0.0 the result is 0.0

otherwise, the result is *eta* * *I* - (*eta* * dot(*N*, *I*) + sqrt(k)) * *N*

This computation assumes the input parameters for the incident vector *I* and the surface normal *N* are already normalized.

The type of *I* and *N* must be a scalar or vector with a floating-point component type.

The type of *eta* must be a floating-point scalar.

Result Type, the type of *I*, the type of *N*, and the type of *eta* must all have the same component type.

72	*<id>* *I*	*<id>* *N*	*<id>* *eta*

FindILsb Integer least-significant bit. Results in the bit number of the least-significant 1-bit in the binary representation of *Value*. If *Value* is 0, the result has all bits set (e.g., -1 if interpreted as signed). *Result Type* and the type of *Value* must both be integer scalar or integer vector types. *Result Type* and operand types must have the same number of components with the same component width. Results are computed per component. This instruction is currently limited to 32-bit width components.	
73	*<id>* *Value*

FindSMsb Signed-integer most-significant bit, with *Value* interpreted as a signed integer. For positive numbers, the result is the bit number of the most significant 1-bit. For negative numbers, the result is the bit number of the most significant 0-bit. For a *Value* of 0 or -1, the result has all bits set (e.g., -1 if interpreted as signed). *Result Type* and the type of *Value* must both be integer scalar or integer vector types. *Result Type* and operand types must have the same number of components with the same component width. Results are computed per component. This instruction is currently limited to 32-bit width components.	
74	*<id>* *Value*

FindUMsb Unsigned-integer most-significant bit. Results in the bit number of the most-significant 1-bit in the binary representation of *Value*. If *Value* is 0, the result has all bits set (e.g., -1 if interpreted as signed). *Result Type* and the type of *Value* must both be integer scalar or integer vector types. *Result Type* and operand types must have the same number of components with the same component width. Results are computed per component. This instruction is currently limited to 32-bit width components.	
75	*<id>* *Value*

InterpolateAtCentroid

Result is the value of the input *interpolant* sampled at a location inside both the fragment and the primitive being processed. The value obtained would be the same value assigned to the input variable if it were decorated as **Centroid**.

The operand *interpolant* must be a pointer to the **Input** Storage Class.

The operand *interpolant* must be a pointer to a scalar or vector whose component type is 32-bit floating-point.

This instruction is only valid in the **Fragment** execution model.

Result Type and the type that *interpolant* points to must be the same type.

Use of this instruction requires declaration of the **InterpolationFunction** capability.

76	*<id>* *interpolant*

InterpolateAtSample

Result is the value of the input *interpolant* variable at the location of sample number *sample*. If sample *sample* does not exist, the position used to interpolate the input variable is undefined.

The operand *interpolant* must be a pointer to the **Input** Storage Class.

The operand *interpolant* must be a pointer to a scalar or vector whose component type is 32-bit floating-point.

This instruction is only valid in the **Fragment** execution model.

The *sample* operand must be a scalar 32-bit integer.

Result Type and the type that *interpolant* points to must be the same type.

Use of this instruction requires declaration of the **InterpolationFunction** capability.

77	*<id>* *interpolant*	*<id>* *sample*

InterpolateAtOffset Result is the value of the input *interpolant* variable sampled at an offset from the center of the fragment specified by *offset*. The two floating-point components of *offset*, give the offset in pixels in the *x* and *y* directions, respectively. An *offset* of (0, 0) identifies the center of the fragment. The range and granularity of offsets supported are implementation-dependent. The operand *interpolant* must be a pointer to the **Input** Storage Class. The operand *interpolant* must be a pointer to a scalar or vector whose component type is 32-bit floating-point. This instruction is only valid in the **Fragment** execution model. The *offset* operand must be a vector of 2 components of 32-bit floating-point type. *Result Type* and the type that *interpolant* points to must be the same type. Use of this instruction requires declaration of the **InterpolationFunction** capability.		
78	*<id>* *interpolant*	*<id>* *offset*

NMin Result is *y* if *y* < *x*, either *x* or *y* if both *x* and *y* are zeros, otherwise *x*. If one operand is a NaN, the other operand is the result. If both operands are NaN, the result is a NaN. The operands must all be a scalar or vector whose component type is floating-point. *Result Type* and the type of all operands must be the same type. Results are computed per component.		
79	*<id>* *x*	*<id>* *y*

NMax Result is *y* if *x* < *y*, either *x* or *y* if both *x* and *y* are zeros, otherwise *x*. If one operand is a NaN, the other operand is the result. If both operands are NaN, the result is a NaN. The operands must all be a scalar or vector whose component type is floating-point. *Result Type* and the type of all operands must be the same type. Results are computed per component.		
80	*<id>* *x*	*<id>* *y*

NClamp Result is min(max(*x*, *minVal*), *maxVal*). The resulting value is undefined if *minVal* > *maxVal*. The semantics used by min() and max() are those of NMin and NMax. The operands must all be a scalar or vector whose component type is floating-point. *Result Type* and the type of all operands must be the same type. Results are computed per component.			
81	*<id>* *x*	*<id>* *minVal*	*<id>* *maxVal*

Chapter 3. Appendix A: Changes

3.1. Changes from Version 0.99, Revision 1

- Fork the revision stream, changes section, etc. from the core specification, so this specification has its own, starting numbering at revision 1. This document now lives independently.
- Added integer versions of abs, sign, min, max, and clamp.
- Removed floatBitsToInt, floatBitsToUint, intBitsToFloat, and uintBitsToFloat; these can be handled with **OpBitcast**.
- Removed fTransform, not needed.
- Fixed internal bugs
  - 13721: Add **OpTypeStruct**-result versions of **Modf** and **Frexp**: **ModfStruct** and **FrexpStruct**.
- Fixed public bugs
  - 1322: GLSL.std.450 frexp wasn't saying the *exp* argument was a pointer to the result

3.2. Changes from Version 0.99, Revision 2

- Moved AddCarry, SubBorrow, and MulExtended type of instructions to the core specification.
- Added integer variant of **Mix**, creating **FMix** and **IMix** (14480).
- Modified spellings to be more regular (14614).

3.3. Changes from Version 0.99, Revision 3

- Add "**N**" version of **Min**, **Max**, and **Clamp**, creating a version that favors non-NaN operands over NaN operands.
- Bug 15452 Remove **IMix**.
- Bug 15300 Be more consistent that the **InterpolateAt** instructions take a pointer.
- Bug 14548 Document the **Capability** needed for **Double2x32** and **InterpolateAt** instructions.

3.4. Changes from Version 1.00, Revision 1

- Bug 14548 Document the **Capability** needed for **UnpackDouble2x32**.

3.5. Changes from Version 1.00, Revision 2

- Change **precise** to **NoContraction**

3.6. Changes from Version 1.00, Revision 3

- Allow both 16-bit and 32-bit floating-point types in most places where before only 32-bit floating-point types were allowed. This does not effect whether 16-bit floating point types are allowed, which is selected independently. Since 16-bit types were historically disallowed, this is a backward compatible change.
- Fix Khronos internal issue #109: be more clear for NMin/NMax: If both operands are NaN, the result is a NaN.

3.7. Changes from Version 1.00, Revision 4

- Be clear about **UnpackHalf2x16** denorm rules.

3.8. Changes from Version 1.00, Revision 5

Fixed:

- Khronos SPIR-V Issue #211: As with **FindSMsb** and **FindUMsb**, **FindILsb** needs 32-bit components.

3.9. Changes from Version 1.00, Revision 6

Fixed:

- Khronos SPIR-V Issue #337: The component types of the operands for **Refract** must all be the same.
- Khronos SPIR-V Issue #331: Correct the types in **ModfStruct**.

3.10. Changes from Version 1.00, Revision 7

Support SPV_KHR_no_integer_wrap_decoration, in the **SAbs** instruction.

3.11. Changes from Version 1.00, Revision 8

Fixed:

- Khronos SPIR-V Issue #466: **FAbs** of *-0.0* is *+0.0*, **FSign** of *-0.0* can be either ±*0.0*. **FMin**, **FMax**, **NMin**, and **NMax** are allowed to return either operand when both are zeros.
- Khronos SPIR-V Issue #458: For **Frexp**, be more clear about negative values, and also about which returned value is being discussed.

3.12. Changes from Version 1.00, Revision 9

- Corrected the output range of **Atan**.

3.13. Changes from Version 1.00, Revision 10

- State what **FSign** of ±*NaN* is.

3.14. Changes from Version 1.00, Revision 11

- Khronos SPIR-V Issue #555: Deprecate **Modf**, use **ModfStruct** instead. Deprecate **Frexp**, use **FrexpStruct** instead.
- Khronos SPIR-V Issue #284: Say all bits are set, instead of saying -1, for some results of **FindILsb**, **FindSMsb**, and **FindUMsb**.
- Khronos SPIR-V MR #181: Use "fragment" instead of "pixel" in **InterpolateAtCentroid**, **InterpolateAtSample**, and **InterpolateAtOffset**.

3.15. Changes from Version 1.00, Revision 12

- Khronos SPIR-V Issue #705: Clarify the computation provided for **Reflect** is used regardless of input normalization.