

The OpenGL[®] Shading Language

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1 Introduction

This document specifies only version 4.60 of the OpenGL Shading Language. It requires `__VERSION__` to substitute 460, and requires `#version` to accept only 460. If `#version` is declared with a smaller number, the language accepted is a previous version of the shading language, which will be supported depending on the version and type of context in the OpenGL API. See the OpenGL Graphics System Specification for details on what language versions are supported.

Previous versions of the OpenGL Shading Language, as well as the OpenGL ES Shading Language, are not strict subsets of the version specified here, particularly with respect to precision, name-hiding rules, and treatment of interface variables. See the specification corresponding to a particular language version for details specific to that version of the language.

The OpenGL API will specify the OpenGL commands used to manipulate SPIR-V shaders. Independent offline tool chains will compile GLSL down to the SPIR-V intermediate language. SPIR-V generation is not enabled with a `#extension`, `#version`, or a profile. Instead, use of GLSL for SPIR-V is determined by offline tool-chain use. See the documentation of such tools to see how to request generation of SPIR-V for OpenGL.

GLSL → SPIR-V compilers must be directed as to what SPIR-V **Capabilities** are legal at run-time and give errors for GLSL feature use outside those capabilities. This is also true for implementation-dependent limits that can be error checked by the front-end against built-in constants present in the GLSL source: the front-end can be informed of such limits, and report errors when they are exceeded.

All OpenGL Graphics System Specification references in this specification are to version 4.6.

1.1 Acknowledgments

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1.2 Changes

1.2.1 Changes from Revision 3 of GLSL 4.6

- Private GLSL issue 13: Fix misspelling of `allInvocationsEqual()`. (The one in the table was incorrectly listed as `anyInvocationsEqual()`, other spellings were correct.)

1.2.2 Summary of Changes from Revision 7 of GLSL Version 4.50

- Incorporated the `GL_ARB_shader_atomic_counter_ops` extension.
- Incorporated the `GL_ARB_shader_draw_parameters` extension.
- Incorporated the `GL_ARB_shader_group_vote` extension.
- Incorporated the `GL_ARB_gl_spirv` extension.
- Private Bug 16070: Allow extra semi-colons at global scope.
- Private GLSL Issue 5: Be explicit that “fail to link” is really “a compile-time or link-time error”, for some forms of error.
- Private GLSL Issue 7: Change `gl_MaxComputeUniformComponents` to 1024.
- Private OpenGL API Issue 35: Require **location** on transparent individual uniform variables for SPIR-V.
- Private GLSL Issue 8: Be more clear an **interpolateAt()** interpolant can be a structure member.
- Private GLSL Issue 9: Specify how **xfb_buffer** interacts with a block array: the capturing buffer increments for each block array element.

1.3 Overview

This document describes *The OpenGL Shading Language*, version 4.60.

Independent compilation units written in this language are called *shaders*. A *program* is a set of shaders that are compiled and linked together, completely creating one or more of the programmable stages of the OpenGL pipeline. All the shaders for a single programmable stage must be within the same program. A complete set of programmable stages can be put into a single program or the stages can be partitioned across multiple programs. The aim of this document is to thoroughly specify the programming language. The OpenGL Graphics System Specification will specify the OpenGL entry points used to manipulate and communicate with programs and shaders.

1.4 Error Handling

Compilers, in general, accept programs that are ill-formed, due to the impossibility of detecting all ill-formed programs. Portability is only ensured for well-formed programs, which this specification describes. Compilers are encouraged to detect ill-formed programs and issue diagnostic messages, but are not required to do so for all cases. Compile-time errors must be returned for lexically or grammatically incorrect shaders. Other errors are reported at compile time or link time as indicated. Code that is “dead” must still be error checked. For example:

```
if (false)      // changing false to true cannot uncover additional errors
    statement; // statement must be error checked regardless
```

1.5 Typographical Conventions

Italic, bold, and font choices have been used in this specification primarily to improve readability. Code fragments use a fixed width font. Identifiers embedded in text are italicized. Keywords embedded in text are bold. Operators are called by their name, followed by their symbol in bold in parentheses. The clarifying grammar fragments in the text use bold for literals and italics for non-terminals. The official grammar in section 9 “Shading Language Grammar” uses all capitals for terminals and lower case for non-terminals.

1.6 Deprecation

The OpenGL Shading Language has deprecated some features. These are clearly called out in this specification as “deprecated”. They are still present in this version of the language, but are targeted for potential removal in a future version of the shading language. The OpenGL API has a forward compatibility mode that will disallow use of deprecated features. If compiling in a mode where use of deprecated features is disallowed, their use causes compile-time or link-time errors. See the OpenGL Graphics System Specification for details on what causes deprecated language features to be accepted or to return an error.

2 Overview of OpenGL Shading

The OpenGL Shading Language is actually several closely related languages. These languages are used to create shaders for each of the programmable processors contained in the OpenGL processing pipeline. Currently, these processors are the vertex, tessellation control, tessellation evaluation, geometry, fragment, and compute processors.

Unless otherwise noted in this paper, a language feature applies to all languages, and common usage will refer to these languages as a single language. The specific languages will be referred to by the name of the processor they target: vertex, tessellation control, tessellation evaluation, geometry, fragment, or compute.

Most OpenGL state is not tracked or made available to shaders. Typically, user-defined variables will be used for communicating between different stages of the OpenGL pipeline. However, a small amount of state is still tracked and automatically made available to shaders, and there are a few built-in variables for interfaces between different stages of the OpenGL pipeline.

2.1 Vertex Processor

The *vertex processor* is a programmable unit that operates on incoming vertices and their associated data. Compilation units written in the OpenGL Shading Language to run on this processor are called *vertex shaders*. When a set of vertex shaders are successfully compiled and linked, they result in a *vertex shader executable* that runs on the vertex processor.

The vertex processor operates on one vertex at a time. It does not replace graphics operations that require knowledge of several vertices at a time.

2.2 Tessellation Control Processor

The tessellation control processor is a programmable unit that operates on a patch of incoming vertices and their associated data, emitting a new output patch. Compilation units written in the OpenGL Shading Language to run on this processor are called tessellation control shaders. When a set of tessellation control shaders are successfully compiled and linked, they result in a *tessellation control shader executable* that runs on the tessellation control processor.

The tessellation control shader is invoked for each vertex of the output patch. Each invocation can read the attributes of any vertex in the input or output patches, but can only write per-vertex attributes for the corresponding output patch vertex. The shader invocations collectively produce a set of per-patch attributes for the output patch. After all tessellation control shader invocations have completed, the output vertices and per-patch attributes are assembled to form a patch to be used by subsequent pipeline stages.

Tessellation control shader invocations run mostly independently, with undefined relative execution order. However, the built-in function `barrier()` can be used to control execution order by synchronizing invocations, effectively dividing tessellation control shader execution into a set of phases. Tessellation control shaders will get undefined results if one invocation reads from a per-vertex or per-patch attribute

32-bit component written by another invocation at any point during the same phase, or if two invocations attempt to write different values to the same per-patch output 32-bit component in a single phase.

2.3 Tessellation Evaluation Processor

The tessellation evaluation processor is a programmable unit that evaluates the position and other attributes of a vertex generated by the tessellation primitive generator, using a patch of incoming vertices and their associated data. Compilation units written in the OpenGL Shading Language to run on this processor are called tessellation evaluation shaders. When a set of tessellation evaluation shaders are successfully compiled and linked, they result in a *tessellation evaluation shader executable* that runs on the tessellation evaluation processor.

Each invocation of the tessellation evaluation executable computes the position and attributes of a single vertex generated by the tessellation primitive generator. The executable can read the attributes of any vertex in the input patch, plus the tessellation coordinate, which is the relative location of the vertex in the primitive being tessellated. The executable writes the position and other attributes of the vertex.

2.4 Geometry Processor

The *geometry processor* is a programmable unit that operates on data for incoming vertices for a primitive assembled after vertex processing and outputs a sequence of vertices forming output primitives. Compilation units written in the OpenGL Shading Language to run on this processor are called *geometry shaders*. When a set of geometry shaders are successfully compiled and linked, they result in a *geometry shader executable* that runs on the geometry processor.

A single invocation of the geometry shader executable on the geometry processor will operate on a declared input primitive with a fixed number of vertices. This single invocation can emit a variable number of vertices that are assembled into primitives of a declared output primitive type and passed to subsequent pipeline stages.

2.5 Fragment Processor

The *fragment processor* is a programmable unit that operates on fragment values and their associated data. Compilation units written in the OpenGL Shading Language to run on this processor are called *fragment shaders*. When a set of fragment shaders are successfully compiled and linked, they result in a *fragment shader executable* that runs on the fragment processor.

A fragment shader cannot change a fragment's (x, y) position. Access to neighboring fragments is not allowed. The values computed by the fragment shader are ultimately used to update framebuffer memory or texture memory, depending on the current OpenGL state and the OpenGL command that caused the fragments to be generated.

2.6 Compute Processor

The *compute processor* is a programmable unit that operates independently from the other shader processors. Compilation units written in the OpenGL Shading Language to run on this processor are called *compute shaders*. When a set of compute shaders are successfully compiled and linked, they result in a *compute shader executable* that runs on the compute processor.

2 Overview of OpenGL Shading

A compute shader has access to many of the same resources as fragment and other shader processors, including textures, buffers, image variables, and atomic counters. It does not have fixed-function outputs. It is not part of the graphics pipeline and its visible side effects are through changes to images, storage buffers, and atomic counters.

A compute shader operates on a group of work items called a work group. A work group is a collection of shader invocations that execute the same code, potentially in parallel. An invocation within a work group may share data with other members of the same work group through shared variables and issue memory and control barriers to synchronize with other members of the same work group.

3 Basics

3.1 Character Set and Phases of Compilation

The source character set used for the OpenGL shading languages is Unicode in the UTF-8 encoding scheme. After preprocessing, only the following characters are allowed in the resulting stream of GLSL tokens:

The letters **a-z**, **A-Z**, and the underscore (`_`).

The numbers **0-9**.

The symbols period (`.`), plus (`+`), dash (`-`), slash (`/`), asterisk (`*`), percent (`%`), angled brackets (`<` and `>`), square brackets (`[` and `]`), parentheses (`(` and `)`), braces (`{` and `}`), caret (`^`), vertical bar (`|`), ampersand (`&`), tilde (`~`), equals (`=`), exclamation point (`!`), colon (`:`), semicolon (`;`), comma (`,`), and question mark (`?`).

A compile-time error will be given if any other character is used in a GLSL token.

There are no digraphs or trigraphs. There are no escape sequences or uses of the backslash beyond use as the line-continuation character.

Lines are relevant for compiler diagnostic messages and the preprocessor. They are terminated by carriage-return or line-feed. If both are used together, it will count as only a single line termination. For the remainder of this document, any of these combinations is simply referred to as a new line.

In general, the language's use of this character set is case sensitive.

There are no character or string data types, so no quoting characters are included.

There is no end-of-file character.

More formally, compilation happens as if the following logical phases were executed in order:

1. Source strings are concatenated to form a single input. All provided new lines are retained.
2. Line numbering is noted, based on all present new lines, and does not change when new lines are later eliminated.
3. Wherever a backslash (`\`) occurs immediately before a new line, both are eliminated. (Note no white space is substituted, allowing a single token to span a new line.) Any newly formed backslash followed by a new line is not eliminated; only those pairs originally occurring after phase 1 are eliminated.
4. All comments are replaced with a single space. (Note that `/*!` style comments end before their terminating new lines and white space is generally relevant to preprocessing.)
5. Preprocessing is done, resulting in a sequence of GLSL tokens, formed from the character set stated above.
6. GLSL processing is done on the sequence of GLSL tokens.

Details that fully define source strings, comments, line numbering, new line elimination, and preprocessing are all discussed in upcoming sections. Sections beyond those describe GLSL processing.

3.2 Source Strings

The source for a single shader is an array of strings of characters from the character set. A single shader is made from the concatenation of these strings. Each string can contain multiple lines, separated by new lines. No new lines need be present in a string; a single line can be formed from multiple strings. No new lines or other characters are inserted by the implementation when it concatenates the strings to form a single shader. Multiple shaders can be linked together to form a single program.

Diagnostic messages returned from compiling a shader must identify both the line number within a string and which source string the message applies to. Source strings are counted sequentially with the first string being string 0. Line numbers are one more than the number of new lines that have been processed, including counting the new lines that will be removed by the line-continuation character (`\`).

Lines separated by the line-continuation character preceding a new line are concatenated together before either comment processing or preprocessing. No white space is substituted for the line-continuation character. That is, a single token could be formed by the concatenation by taking the characters at the end of one line concatenating them with the characters at the beginning of the next line.

```
float f\  
oo;  
// forms a single line equivalent to "float foo;"  
// (assuming '\\' is the last character before the new line and "oo" are  
// the first two characters of the next line)
```

3.3 Preprocessor

There is a preprocessor that processes the source strings as part of the compilation process. Except as noted below, it behaves as the C++ standard preprocessor (see section 10 “Normative References”).

The complete list of preprocessor directives is as follows.

```
#
#define
#undef

#if
#ifdef
#ifndef
#else
#elif
#endif

#error
#pragma

#extension
#version

#line
```

The following operators are also available

```
defined
##
```

Each number sign (#) can be preceded in its line only by spaces or horizontal tabs. It may also be followed by spaces and horizontal tabs, preceding the directive. Each directive is terminated by a new line. Preprocessing does not change the number or relative location of new lines in a source string. Preprocessing takes place after new lines have been removed by the line-continuation character.

The number sign (#) on a line by itself is ignored. Any directive not listed above will cause a diagnostic message and make the implementation treat the shader as ill-formed.

#define and **#undef** functionality are defined as is standard for C++ preprocessors for macro definitions both with and without macro parameters.

Implementations must support macro-name lengths of up to 1024 characters. Implementations are allowed to generate an error for a macro name of length greater than 1024 characters, but are also allowed to support lengths greater than 1024.

The following predefined macros are available

```
__LINE__
__FILE__
__VERSION__
```

`__LINE__` will substitute a decimal integer constant that is one more than the number of preceding new lines in the current source string.

`__FILE__` will substitute a decimal integer constant that says which source string number is currently being processed.

`__VERSION__` will substitute a decimal integer reflecting the version number of the OpenGL shading language. The version of the shading language described in this document will have `__VERSION__` substitute the decimal integer 460.

By convention, all macro names containing two consecutive underscores (`__`) are reserved for use by underlying software layers. Defining or undefining such a name in a shader does not itself result in an error, but may result in unintended behaviors that stem from having multiple definitions of the same name. All macro names prefixed with “GL_” (“GL” followed by a single underscore) are also reserved, and defining or undefining such a name results in a compile-time error.

`#if`, `#ifndef`, `#ifdef`, `#else`, `#elif`, and `#endif` are defined to operate as is standard for C++ preprocessors. Expressions following `#if` and `#elif` are further restricted to expressions operating on literal integer constants, plus identifiers consumed by the `defined` operator. Character constants are not supported. The operators available are as follows.

Precedence	Operator class	Operators	Associativity
1 (highest)	parenthetical grouping	()	NA
2	unary	defined + - ~ !	Right to Left
3	multiplicative	* / %	Left to Right
4	additive	+ -	Left to Right
5	bit-wise shift	<< >>	Left to Right
6	relational	< > <= >=	Left to Right
7	equality	== !=	Left to Right
8	bit-wise and	&	Left to Right
9	bit-wise exclusive or	^	Left to Right
10	bit-wise inclusive or		Left to Right
11	logical and	&&	Left to Right
12 (lowest)	logical inclusive or		Left to Right

The `defined` operator can be used in either of the following ways:

```
defined identifier
defined ( identifier )
```

Two tokens in a macro can be concatenated into one token using the token pasting (`##`) operator, as is standard for C++ preprocessors. The result must be a valid single token, which will then be subject to macro expansion. That is, macro expansion happens only after token pasting. There are no other number sign based operators (e.g., no `#` or `#@`), nor is there a `sizeof` operator.

The semantics of applying operators to integer literals in the preprocessor match those standard in the C++ preprocessor, not those in the OpenGL Shading Language.

Preprocessor expressions will be evaluated according to the behavior of the host processor, not the processor targeted by the shader.

#error will cause the implementation to put a compile-time diagnostic message into the shader object's information log (see section 7.12 "Shader and Program Queries" in the OpenGL Graphics System Specification for how to access a shader object's information log). The message will be the tokens following the **#error** directive, up to the first new line. The implementation must then consider the shader to be ill-formed.

#pragma allows implementation dependent compiler control. Tokens following **#pragma** are not subject to preprocessor macro expansion. If an implementation does not recognize the tokens following **#pragma**, then it will ignore that pragma. The following pragmas are defined as part of the language.

```
#pragma STDGL
```

The **STDGL** pragma is used to reserve pragmas for use by future revisions of this language. No implementation may use a pragma whose first token is **STDGL**.

```
#pragma optimize(on)
#pragma optimize(off)
```

can be used to turn off optimizations as an aid in developing and debugging shaders. It can only be used outside function definitions. By default, optimization is turned on for all shaders. The debug pragma

```
#pragma debug(on)
#pragma debug(off)
```

can be used to enable compiling and annotating a shader with debug information, so that it can be used with a debugger. It can only be used outside function definitions. By default, debug is turned off.

Shaders should declare the version of the language they are written to. The language version a shader is written to is specified by

```
#version number profileopt
```

where *number* must be a version of the language, following the same convention as `__VERSION__` above. The directive "**#version 460**" is required in any shader that uses version 4.60 of the language. Any *number* representing a version of the language a compiler does not support will cause a compile-time error to be generated. Version 1.10 of the language does not require shaders to include this directive, and shaders that do not include a **#version** directive will be treated as targeting version 1.10. Shaders that specify **#version 100** will be treated as targeting version 1.00 of the OpenGL ES Shading Language. Shaders that specify **#version 300** will be treated as targeting version 3.00 of the OpenGL ES Shading Language. Shaders that specify **#version 310** will be treated as targeting version 3.10 of the OpenGL ES Shading Language.

If the optional *profile* argument is provided, it must be the name of an OpenGL profile. Currently, there are three choices:

```
core
compatibility
es
```

A *profile* argument can only be used with version 150 or greater. If no profile argument is provided and the version is 150 or greater, the default is **core**. If version 300 or 310 is specified, the profile argument is not optional and must be **es**, or a compile-time error results. The Language Specification for the **es** profile is specified in The OpenGL ES Shading Language specification.

Shaders for the **core** or **compatibility** profiles that declare different versions can be linked together. However, **es** profile shaders cannot be linked with non-**es** profile shaders or with **es** profile shaders of a different version, or a link-time error will result. When linking shaders of versions allowed by these rules, remaining link-time errors will be given as per the linking rules in the GLSL version corresponding to the version of the context the shaders are linked under. Shader compile-time errors must still be given strictly based on the version declared (or defaulted to) within each shader.

Unless otherwise specified, this specification is documenting the core profile, and everything specified for the core profile is also available in the compatibility profile. Features specified as belonging specifically to the compatibility profile are not available in the core profile. Compatibility-profile features are not available when generating SPIR-V.

There is a built-in macro definition for each profile the implementation supports. All implementations provide the following macro:

```
#define GL_core_profile 1
```

Implementations providing the **compatibility** profile provide the following macro:

```
#define GL_compatibility_profile 1
```

Implementations providing the **es** profile provide the following macro:

```
#define GL_es_profile 1
```

The **#version** directive must occur in a shader before anything else, except for comments and white space.

By default, compilers of this language must issue compile-time lexical and grammatical errors for shaders that do not conform to this specification. Any extended behavior must first be enabled. Directives to control the behavior of the compiler with respect to extensions are declared with the **#extension** directive

```
#extension extension_name : behavior
#extension all : behavior
```

where *extension_name* is the name of an extension. Extension names are not documented in this specification. The token **all** means the behavior applies to all extensions supported by the compiler.

The *behavior* can be one of the following:

<i>behavior</i>	Effect
require	Behave as specified by the extension <i>extension_name</i> . Give a compile-time error on the #extension if the extension <i>extension_name</i> is not supported, or if all is specified.
enable	Behave as specified by the extension <i>extension_name</i> . Warn on the #extension if the extension <i>extension_name</i> is not supported. Give a compile-time error on the #extension if all is specified.
warn	Behave as specified by the extension <i>extension_name</i> , except issue warnings on any detectable use of that extension, unless such use is supported by other enabled or required extensions. If all is specified, then warn on all detectable uses of any extension used. Warn on the #extension if the extension <i>extension_name</i> is not supported.
disable	Behave (including issuing errors and warnings) as if the extension <i>extension_name</i> is not part of the language definition. If all is specified, then behavior must revert back to that of the non-extended core version of the language being compiled to. Warn on the #extension if the extension <i>extension_name</i> is not supported.

The **extension** directive is a simple, low-level mechanism to set the behavior for each extension. It does not define policies such as which combinations are appropriate, those must be defined elsewhere. Order of directives matters in setting the behavior for each extension: Directives that occur later override those seen earlier. The **all** variant sets the behavior for all extensions, overriding all previously issued **extension** directives, but only for the *behaviors* **warn** and **disable**.

The initial state of the compiler is as if the directive

```
#extension all : disable
```

was issued, telling the compiler that all error and warning reporting must be done according to this specification, ignoring any extensions.

Each extension can define its allowed granularity of scope. If nothing is said, the granularity is a shader (that is, a single compilation unit), and the extension directives must occur before any non-preprocessor tokens. If necessary, the linker can enforce granularities larger than a single compilation unit, in which case each involved shader will have to contain the necessary extension directive.

Macro expansion is not done on lines containing **#extension** and **#version** directives.

#line must have, after macro substitution, one of the following forms:

```
#line line
#line line source-string-number
```

where *line* and *source-string-number* are constant integer expressions. After processing this directive (including its new line), the implementation will behave as if it is compiling at line number *line* and source string number *source-string-number*. Subsequent source strings will be numbered sequentially, until another **#line** directive overrides that numbering.

When shaders are compiled for OpenGL SPIR-V, the following predefined macro is available:

```
#define GL_SPIRV 100
```

3.4 Comments

Comments are delimited by `/*` and `*/`, or by `//` and a new line. The begin comment delimiters (`/*` or `//`) are not recognized as comment delimiters inside of a comment, hence comments cannot be nested. A `/*` comment includes its terminating delimiter (`*/`). However, a `//` comment does not include (or eliminate) its terminating new line.

Inside comments, any byte values may be used, except a byte whose value is 0. No errors will be given for the content of comments and no validation on the content of comments need be done.

Removal of new lines by the line-continuation character (`\`) logically occurs before comments are processed. That is, a single-line comment ending in the line-continuation character (`\`) includes the next line in the comment.

```
// a single-line comment containing the next line \
a = b; // this is still in the first comment
```

3.5 Tokens

The language, after preprocessing, is a sequence of GLSL tokens. A token can be

```
token:
    keyword
    identifier
    integer-constant
    floating-constant
    operator
    ; { }
```

3.6 Keywords

The following are the language's keywords and (after preprocessing) can only be used as described in this specification, or a compile-time error results:

```
attribute const uniform varying buffer shared
coherent volatile restrict readonly writeonly
```

atomic_uint
layout
centroid flat smooth noperspective
patch sample
break continue do for while switch case default
if else
subroutine
in out inout
float double int void bool true false
invariant precise
discard return
mat2 mat3 mat4 dmat2 dmat3 dmat4
mat2x2 mat2x3 mat2x4 dmat2x2 dmat2x3 dmat2x4
mat3x2 mat3x3 mat3x4 dmat3x2 dmat3x3 dmat3x4
mat4x2 mat4x3 mat4x4 dmat4x2 dmat4x3 dmat4x4
vec2 vec3 vec4 ivec2 ivec3 ivec4 bvec2 bvec3 bvec4 dvec2 dvec3 dvec4
uint uvec2 uvec3 uvec4
lowp mediump highp precision
sampler1D sampler2D sampler3D samplerCube
sampler1DShadow sampler2DShadow samplerCubeShadow
sampler1DArray sampler2DArray
sampler1DArrayShadow sampler2DArrayShadow
isampler1D isampler2D isampler3D isamplerCube
isampler1DArray isampler2DArray
usampler1D usampler2D usampler3D usamplerCube
usampler1DArray usampler2DArray
sampler2DRect sampler2DRectShadow isampler2DRect usampler2DRect
samplerBuffer isamplerBuffer usamplerBuffer
sampler2DMS isampler2DMS usampler2DMS
sampler2DMSArray isampler2DMSArray usampler2DMSArray
samplerCubeArray samplerCubeArrayShadow isamplerCubeArray usamplerCubeArray
image1D iimage1D uimage1D
image2D iimage2D uimage2D

image3D iimage3D uimage3D
image2DRect iimage2DRect uimage2DRect
imageCube iimageCube uimageCube
imageBuffer iimageBuffer uimageBuffer
image1DArray iimage1DArray uimage1DArray
image2DArray iimage2DArray uimage2DArray
imageCubeArray iimageCubeArray uimageCubeArray
image2DMS iimage2DMS uimage2DMS
image2DMSArray iimage2DMSArray uimage2DMSArray
struct

The following are the keywords reserved for future use. Using them will result in a compile-time error:

common partition active
asm
class union enum typedef template this
resource
goto
inline noinline public static extern external interface
long short half fixed unsigned superp
input output
hvec2 hvec3 hvec4 fvec2 fvec3 fvec4
sampler3DRect
filter
sizeof cast
namespace using

In addition, all identifiers containing two consecutive underscores (__) are reserved for use by underlying software layers. Defining such a name in a shader does not itself result in an error, but may result in unintended behaviors that stem from having multiple definitions of the same name.

3.7 Identifiers

Identifiers are used for variable names, function names, structure names, and field selectors (field selectors select components of vectors and matrices similar to structure members, as discussed in section 5.5 “Vector and Scalar Components” and section 5.6 “Matrix Components”). Identifiers have the form

identifier:

nondigit

identifier nondigit

identifier digit

nondigit: one of

_ a b c d e f g h i j k l m n o p q r s t u v w x y z

A B C D E F G H I J K L M N O P Q R S T U V W X Y Z

digit: one of

0 1 2 3 4 5 6 7 8 9

Identifiers starting with “gl_” are reserved for use by OpenGL, and may not be declared in a shader; this results in a compile-time error. However, as noted in the specification, there are some cases where previously declared variables can be redeclared, and predeclared “gl_” names are allowed to be redeclared in a shader only for these specific purposes. More generally, it is a compile-time error to redeclare a variable, including those starting “gl_”.

Implementations must support identifier lengths of up to 1024 characters. Implementations are allowed to generate an error for an identifier of length greater than 1024 characters, but are also allowed to support lengths greater than 1024.

3.8 Definitions

Some language rules described below depend on the following definitions.

3.8.1 Static Use

A shader contains a *static use* of (or *static assignment* to) a variable x if, after preprocessing, the shader contains a statement that would read (or write) x , whether or not flow of control will cause that statement to be executed.

3.8.2 Dynamically Uniform Expressions and Uniform Control Flow

Some operations require an expression to be *dynamically uniform*, or that it be located in *uniform control flow*. These requirements are defined by the following set of definitions.

An *invocation* is a single execution of *main()* for a particular stage, operating only on the amount of data explicitly exposed within that stage's shaders. (Any implicit operation on additional instances of data would comprise additional invocations.) For example, in compute execution models, a single invocation operates only on a single work item, or, in a vertex execution model, a single invocation operates only on a single vertex.

An *invocation group* is the complete set of invocations collectively processing a particular compute workgroup or graphical operation, where the scope of a "graphical operation" is implementation dependent, but at least as large as a single triangle or patch, and at most as large as a single rendering command, as defined by the client API.

Within a single invocation, a single shader statement can be executed multiple times, giving multiple *dynamic instances* of that instruction. This can happen when the instruction is executed in a loop, or in a function called from multiple call sites, or combinations of multiple of these. Different loop iterations and different dynamic function-call-site chains yield different dynamic instances of such an instruction. Dynamic instances are distinguished by their control-flow path within an invocation, not by which invocation executed it. That is, different invocations of *main()* execute the same dynamic instances of an instruction when they follow the same control-flow path.

An expression is *dynamically uniform* for a dynamic instance consuming it when its value is the same for all invocations (in the invocation group) that execute that dynamic instance.

Uniform control flow (or converged control flow) occurs when all invocations in the invocation group execute the same control-flow path (and hence the same sequence of dynamic instances of instructions). Uniform control flow is the initial state at the entry into *main()*, and lasts until a conditional branch takes different control paths for different invocations (non-uniform or divergent control flow). Such divergence can reconverge, with all the invocations once again executing the same control-flow path, and this re-establishes the existence of uniform control flow. If control flow is uniform upon entry into a selection or loop, and all invocations in the invocation group subsequently leave that selection or loop, then control flow reconverges to be uniform.

For example:

```
main()
{
    float a = ...; // this is uniform flow control
    if (a < b) { // this expression is true for some fragments, not all
        ....; // non-uniform flow control
    } else {
        ....; // non-uniform flow control
    }
    ....; // uniform flow control again
}
```

Note that constant expressions are trivially dynamically uniform. It follows that typical loop counters based on these are also dynamically uniform.

4 Variables and Types

All variables and functions must be declared before being used. Variable and function names are identifiers.

There are no default types. All variable and function declarations must have a declared type, and optionally qualifiers. A variable is declared by specifying its type followed by one or more names separated by commas. In many cases, a variable can be initialized as part of its declaration by using the assignment operator (=).

User-defined types may be defined using **struct** to aggregate a list of existing types into a single name.

The OpenGL Shading Language is type safe. There are some implicit conversions between types. Exactly how and when this can occur is described in section 4.1.10 “Implicit Conversions” and as referenced by other sections in this specification.

4.1 Basic Types

The OpenGL Shading Language supports the following basic data types, grouped as follows.

Transparent types

Type	Meaning
void	for functions that do not return a value
bool	a conditional type, taking on values of true or false
int	a signed integer
uint	an unsigned integer
float	a single-precision floating-point scalar
double	a double-precision floating-point scalar
vec2	a two-component single-precision floating-point vector
vec3	a three-component single-precision floating-point vector
vec4	a four-component single-precision floating-point vector
dvec2	a two-component double-precision floating-point vector
dvec3	a three-component double-precision floating-point vector
dvec4	a four-component double-precision floating-point vector
bvec2	a two-component Boolean vector
bvec3	a three-component Boolean vector
bvec4	a four-component Boolean vector
ivec2	a two-component signed integer vector

Type	Meaning
ivec3	a three-component signed integer vector
ivec4	a four-component signed integer vector
uvec2	a two-component unsigned integer vector
uvec3	a three-component unsigned integer vector
uvec4	a four-component unsigned integer vector
mat2	a 2×2 single-precision floating-point matrix
mat3	a 3×3 single-precision floating-point matrix
mat4	a 4×4 single-precision floating-point matrix
mat2x2	same as a mat2
mat2x3	a single-precision floating-point matrix with 2 columns and 3 rows
mat2x4	a single-precision floating-point matrix with 2 columns and 4 rows
mat3x2	a single-precision floating-point matrix with 3 columns and 2 rows
mat3x3	same as a mat3
mat3x4	a single-precision floating-point matrix with 3 columns and 4 rows
mat4x2	a single-precision floating-point matrix with 4 columns and 2 rows
mat4x3	a single-precision floating-point matrix with 4 columns and 3 rows
mat4x4	same as a mat4
dmat2	a 2×2 double-precision floating-point matrix
dmat3	a 3×3 double-precision floating-point matrix
dmat4	a 4×4 double-precision floating-point matrix
dmat2x2	same as a dmat2
dmat2x3	a double-precision floating-point matrix with 2 columns and 3 rows
dmat2x4	a double-precision floating-point matrix with 2 columns and 4 rows
dmat3x2	a double-precision floating-point matrix with 3 columns and 2 rows
dmat3x3	same as a dmat3
dmat3x4	a double-precision floating-point matrix with 3 columns and 4 rows
dmat4x2	a double-precision floating-point matrix with 4 columns and 2 rows
dmat4x3	a double-precision floating-point matrix with 4 columns and 3 rows
dmat4x4	same as a dmat4

Floating-Point Opaque Types

Type	Meaning
sampler1D image1D	a handle for accessing a 1D texture
sampler2D image2D	a handle for accessing a 2D texture
sampler3D image3D	a handle for accessing a 3D texture
samplerCube imageCube	a handle for accessing a cube mapped texture
sampler2DRect image2DRect	a handle for accessing a rectangle texture
sampler1DArray image1DArray	a handle for accessing a 1D array texture
sampler2DArray image2DArray	a handle for accessing a 2D array texture
samplerBuffer imageBuffer	a handle for accessing a buffer texture
sampler2DMS image2DMS	a handle for accessing a 2D multi-sample texture
sampler2DMSArray image2DMSArray	a handle for accessing a 2D multi-sample array texture
samplerCubeArray imageCubeArray	a handle for accessing a cube map array texture
sampler1DShadow	a handle for accessing a 1D depth texture with comparison
sampler2DShadow	a handle for accessing a 2D depth texture with comparison
sampler2DRectShadow	a handle for accessing a rectangle texture with comparison
sampler1DArrayShadow	a handle for accessing a 1D array depth texture with comparison
sampler2DArrayShadow	a handle for accessing a 2D array depth texture with comparison
samplerCubeShadow	a handle for accessing a cube map depth texture with comparison
samplerCubeArrayShadow	a handle for accessing a cube map array depth texture with comparison

Signed Integer Opaque Types

Type	Meaning
isampler1D iimage1D	a handle for accessing an integer 1D texture

Type	Meaning
isampler2D iimage2D	a handle for accessing an integer 2D texture
isampler3D iimage3D	a handle for accessing an integer 3D texture
isamplerCube iimageCube	a handle for accessing an integer cube mapped texture
isampler2DRect iimage2DRect	a handle for accessing an integer 2D rectangle texture
isampler1DArray iimage1DArray	a handle for accessing an integer 1D array texture
isampler2DArray iimage2DArray	a handle for accessing an integer 2D array texture
isamplerBuffer iimageBuffer	a handle for accessing an integer buffer texture
isampler2DMS iimage2DMS	a handle for accessing an integer 2D multi-sample texture
isampler2DMSArray iimage2DMSArray	a handle for accessing an integer 2D multi-sample array texture
isamplerCubeArray iimageCubeArray	a handle for accessing an integer cube map array texture

Unsigned Integer Opaque Types

Type	Meaning
atomic_uint	a handle for accessing an unsigned integer atomic counter
usampler1D uimage1D	a handle for accessing an unsigned integer 1D texture
usampler2D uimage2D	a handle for accessing an unsigned integer 2D texture
usampler3D uimage3D	a handle for accessing an unsigned integer 3D texture
usamplerCube uimageCube	a handle for accessing an unsigned integer cube mapped texture
usampler2DRect uimage2DRect	a handle for accessing an unsigned integer rectangle texture
usampler1DArray uimage1DArray	a handle for accessing an unsigned integer 1D array texture
usampler2DArray uimage2DArray	a handle for accessing an unsigned integer 2D array texture

Type	Meaning
usamplerBuffer uimageBuffer	a handle for accessing an unsigned integer buffer texture
usampler2DMS uimage2DMS	a handle for accessing an unsigned integer 2D multi-sample texture
usampler2DMSArray uimage2DMSArray	a handle for accessing an unsigned integer 2D multi-sample texture array
usamplerCubeArray uimageCubeArray	a handle for accessing an unsigned integer cube map array texture

In addition, a shader can aggregate these basic types using arrays and structures to build more complex types.

There are no pointer types.

In this specification, an *aggregate* will mean a structure or array. (Matrices and vectors are not by themselves aggregates.) Aggregates, matrices, and vectors will collectively be referred to as *composites*.

4.1.1 Void

Functions that do not return a value must be declared as **void**. There is no default function return type. The keyword **void** cannot be used in any other declarations (except for empty formal or actual parameter lists), or a compile-time error results.

4.1.2 Booleans

To make conditional execution of code easier to express, the type **bool** is supported. There is no expectation that hardware directly supports variables of this type. It is a genuine Boolean type, holding only one of two values meaning either true or false. Two keywords **true** and **false** can be used as literal Boolean constants. Booleans are declared and optionally initialized as in the follow example:

```
bool success;          // declare "success" to be a Boolean
bool done = false;    // declare and initialize "done"
```

The right side of the assignment operator (=) must be an expression whose type is **bool**.

Expressions used for conditional jumps (**if**, **for**, **?:**, **while**, **do-while**) must evaluate to the type **bool**.

4.1.3 Integers

Signed and unsigned integer variables are fully supported. In this document, the term *integer* is meant to generally include both signed and unsigned integers. Unsigned integers have exactly 32 bits of precision. Signed integers use 32 bits, including a sign bit, in two's complement form. Addition, subtraction, and shift operations resulting in overflow or underflow will not cause any exception, nor will they saturate, rather they will "wrap" to yield the low-order 32 bits of the result. Division and multiplication operations resulting in overflow or underflow will not cause any exception but will result in an undefined value.

Integers are declared and optionally initialized with integer expressions, as in the following example:

```
int i, j = 42; // default integer literal type is int
uint k = 3u;  // "u" establishes the type as uint
```

Literal integer constants can be expressed in decimal (base 10), octal (base 8), or hexadecimal (base 16) as follows.

integer-constant :

decimal-constant integer-suffix_{opt}

octal-constant integer-suffix_{opt}

hexadecimal-constant integer-suffix_{opt}

integer-suffix: one of

u U

decimal-constant :

nonzero-digit

decimal-constant digit

octal-constant :

0

octal-constant octal-digit

hexadecimal-constant :

0x hexadecimal-digit

0X hexadecimal-digit

hexadecimal-constant hexadecimal-digit

digit :

0

nonzero-digit

nonzero-digit : one of

1 2 3 4 5 6 7 8 9

octal-digit : one of

0 1 2 3 4 5 6 7

hexadecimal-digit : one of

0 1 2 3 4 5 6 7 8 9

a b c d e f

A B C D E F

No white space is allowed between the digits of an integer constant, including after the leading **0** or after the leading **0x** or **0X** of a constant, or before the suffix **u** or **U**. When tokenizing, the maximal token matching the above will be recognized before a new token is started. When the suffix **u** or **U** is present, the literal has type **uint**, otherwise the type is **int**. A leading unary minus sign (-) is interpreted as an arithmetic unary negation, not as part of the constant. Hence, literals themselves are always expressed with non-negative syntax, though they could result in a negative value.

It is a compile-time error to provide a literal integer whose bit pattern cannot fit in 32 bits. The bit pattern of the literal is always used unmodified. So a signed literal whose bit pattern includes a set sign bit creates a negative value. For example,

```
int a = 0xffffffff; // 32 bits, a gets the value -1
int b = 0xffffffffU; // ERROR: can't convert uint to int
uint c = 0xffffffff; // 32 bits, c gets the value 0xFFFFFFFF
uint d = 0xffffffffU; // 32 bits, d gets the value 0xFFFFFFFF
int e = -1; // the literal is "1", then negation is performed,
           // and the resulting non-literal 32-bit signed
           // bit pattern of 0xFFFFFFFF is assigned, giving e
           // the value of -1.
uint f = -1u; // the literal is "1u", then negation is performed,
            // and the resulting non-literal 32-bit unsigned
            // bit pattern of 0xFFFFFFFF is assigned, giving f
            // the value of 0xFFFFFFFF.
int g = 3000000000; // a signed decimal literal taking 32 bits,
                 // setting the sign bit, g gets -1294967296
int h = 0xA0000000; // okay, 32-bit signed hexadecimal
int i = 5000000000; // ERROR: needs more than 32 bits
int j = 0xFFFFFFFF; // ERROR: needs more than 32 bits
int k = 0x80000000; // k gets -2147483648 == 0x80000000
int l = 2147483648; // l gets -2147483648 (the literal set the sign bit)
```

Despite all these examples initializing variables, literals are recognized and given values and types independently of their context.

4.1.4 Floating-Point Variables

Single-precision and double-precision floating-point variables are available for use in a variety of scalar calculations. Generally, the term *floating-point* will refer to both single- and double-precision floating point. Floating-point variables are defined as in the following examples:

```
float a, b = 1.5; // single-precision floating-point
double c, d = 2.0LF; // double-precision floating-point
```

As an input value to one of the processing units, a single-precision or double-precision floating-point variable is expected to match the corresponding IEEE 754 floating-point definition for precision and dynamic range. Floating-point variables within a shader are also encoded according to the IEEE 754 specification for single-precision floating-point values (logically, not necessarily physically). While encodings are logically IEEE 754, operations (addition, multiplication, etc.) are not necessarily performed as required by IEEE 754. See section 4.7.1 “Range and Precision” for more details on precision and usage of NaNs (Not a Number) and Infs (positive or negative infinities).

Floating-point constants are defined as follows.

```

floating-constant :
    fractional-constant exponent-partopt floating-suffixopt
    digit-sequence exponent-part floating-suffixopt

fractional-constant :
    digit-sequence . digit-sequence
    digit-sequence .
    . digit-sequence

exponent-part :
    e signopt digit-sequence
    E signopt digit-sequence

sign : one of
    + -

digit-sequence :
    digit
    digit-sequence digit

floating-suffix: one of
    f F lf LF
  
```

A decimal point (.) is not needed if the exponent part is present. No white space may appear anywhere within a floating-point constant, including before a suffix. When tokenizing, the maximal token matching the above will be recognized before a new token is started. When the suffix "lf" or "LF" is present, the literal has type **double**. Otherwise, the literal has type **float**. A leading unary minus sign (-) is interpreted as a unary operator and is not part of the floating-point constant.

4.1.5 Vectors

The OpenGL Shading Language includes data types for generic 2-, 3-, and 4-component vectors of floating-point values, integers, or Booleans. Floating-point vector variables can be used to store colors, normals, positions, texture coordinates, texture lookup results and the like. Boolean vectors can be used for component-wise comparisons of numeric vectors. Some examples of vector declaration are:

```

vec2 texcoord1, texcoord2;
vec3 position;
vec4 myRGBA;
ivec2 textureLookup;
bvec3 less;
  
```

Initialization of vectors can be done with constructors, which are discussed shortly.

4.1.6 Matrices

The OpenGL Shading Language has built-in types for 2×2, 2×3, 2×4, 3×2, 3×3, 3×4, 4×2, 4×3, and 4×4 matrices of floating-point numbers. Matrix types beginning with "mat" have single-precision components

while matrix types beginning with "dmat" have double-precision components. The first number in the type is the number of columns, the second is the number of rows. If there is only one number, the matrix is square. Example matrix declarations:

```
mat2 mat2D;
mat3 optMatrix;
mat4 view, projection;
mat4x4 view; // an alternate way of declaring a mat4
mat3x2 m;    // a matrix with 3 columns and 2 rows
dmat4 highPrecisionMVP;
dmat2x4 dm;
```

Initialization of matrix values is done with constructors (described in section 5.4 “Constructors”) in column-major order.

4.1.7 Opaque Types

The opaque types declare variables that are effectively opaque handles to other objects. These objects are accessed through built-in functions, not through direct reading or writing of the declared variable. They can only be declared as function parameters or in **uniform**-qualified variables. The only opaque types that take memory qualifiers are the image types. Except for array indexing, structure member selection, and parentheses, opaque variables are not allowed to be operands in expressions; such use results in a compile-time error.

Opaque variables cannot be treated as l-values; hence cannot be used as **out** or **inout** function parameters, nor can they be assigned into. Any such use results in a compile-time error. However, they can be passed as **in** parameters with matching type and memory qualifiers. They cannot be declared with an initializer.

Because a single opaque type declaration effectively declares two objects, the opaque handle itself and the object it is a handle to, there is room for both a storage qualifier and a memory qualifier. The storage qualifier will qualify the opaque handle, while the memory qualifier will qualify the object it is a handle to.

4.1.7.1 Samplers

Sampler types (e.g., **sampler2D**) are opaque types, declared and behaving as described above for opaque types. When aggregated into arrays within a shader, samplers can only be indexed with a dynamically uniform integral expression, otherwise results are undefined.

Sampler variables are handles to one-, two-, and three- dimensional textures, cube maps, depth textures (shadowing), etc., as enumerated in the basic types tables. There are distinct sampler types for each texture target, and for each of float, integer, and unsigned integer data types. Texture accesses are done through built-in texture functions (described in section 8.9 “Texture Functions”) and samplers are used to specify which texture to access and how it is to be filtered.

4.1.7.2 Images

Image types are opaque types, declared and behaving as described above for opaque types. They can be further qualified with memory qualifiers. When aggregated into arrays within a shader, images can only be indexed with a dynamically uniform integral expression, otherwise results are undefined.

Image variables are handles to one-, two-, or three-dimensional images corresponding to all or a portion of a single level of a texture image bound to an image unit. There are distinct image types for each texture target, and for each of float, integer, and unsigned integer data types. Image accesses should use an image type that matches the target of the texture whose level is bound to the image unit, or for non-layered bindings of 3D or array images should use the image type that matches the dimensionality of the layer of the image (i.e., a layer of 3D, 2DArray, Cube, or CubeArray should use **image2D**, a layer of 1DArray should use **image1D**, and a layer of 2DMSArray should use **image2DMS**). If the image target type does not match the bound image in this manner, if the data type does not match the bound image, or if the format layout qualifier does not match the image unit format as described in section 8.25 “Texture Image Loads and Stores” of the OpenGL Specification, the results of image accesses are undefined but cannot include program termination.

Image variables are used in the image load, store, and atomic functions described in section 8.12 “Image Functions” to specify an image to access.

4.1.7.3 Atomic Counters

Atomic counter types (**atomic_uint**) are opaque handles to counters, declared and behaving as described above for opaque types. The variables they declare specify which counter to access when using the built-in atomic counter functions as described in section 8.10 “Atomic Counter Functions”. They are bound to buffers as described in section 4.4.6.1 “Atomic Counter Layout Qualifiers”. When aggregated into arrays within a shader, atomic counters can only be indexed with a dynamically uniform integral expression, otherwise results are undefined. Members of structures cannot be declared as atomic counter types.

4.1.8 Structures

User-defined types can be created by aggregating other already defined types into a structure using the **struct** keyword. For example,

```
struct light {
    float intensity;
    vec3 position;
} lightVar;
```

In this example, *light* becomes the name of the new type, and *lightVar* becomes a variable of type *light*. To declare variables of the new type, use its name (without the keyword **struct**).

```
light lightVar2;
```

More formally, structures are declared as follows. However, the complete correct grammar is as given in section 9 “Shading Language Grammar” .

```

struct-definition :
    qualifieropt struct nameopt { member-list } declaratorsopt ;

member-list :
    member-declaration;
    member-declaration member-list;

member-declaration :
    basic-type declarators;

```

where *name* becomes the user-defined type, and can be used to declare variables to be of this new type. The *name* shares the same name space as other variables, types, and functions. All previously visible variables, types, constructors, or functions with that name are hidden. The optional *qualifier* only applies to any *declarators*, and is not part of the type being defined for *name*.

Structures must have at least one member declaration. Member declarators may contain precision qualifiers, but use of any other qualifier results in a compile-time error. Bit fields are not supported. Member types must be already defined (there are no forward references). A compile-time error results if a member declaration contains an initializer. Member declarators can contain arrays. Such arrays must have a size specified, and the size must be an integral constant expression that's greater than zero (see section 4.3.3 “Constant Expressions”). Each level of structure has its own name space for names given in member declarators; such names need only be unique within that name space.

Anonymous structures are not supported. Embedded structure definitions are not supported. These result in compile-time errors.

```

struct S { float f; };

struct T {
    S; // Error: anonymous structures disallowed
    struct { ... }; // Error: embedded structures disallowed
    S s; // Okay: nested structures with name are allowed
};

```

Structures can be initialized at declaration time using constructors, as discussed in section 5.4.3 “Structure Constructors”.

Any restrictions on the usage of a type or qualifier also apply to any structure that contains a member of that type or qualifier. This also applies to structure members that are structures, recursively.

4.1.9 Arrays

Variables of the same type can be aggregated into arrays by declaring a name followed by brackets ([]) enclosing an optional size. When an array size is specified in a declaration, it must be an integral constant expression (see section 4.3.3 “Constant Expressions”) greater than zero. Except for the last declared member of a shader storage block (section 4.3.9 “Interface Blocks”), the size of an array must be declared (*explicitly sized*) before it is indexed with anything other than an integral constant expression. The size of any array must be declared before passing it as an argument to a function. Violation of any of these rules

result in compile-time errors. It is legal to declare an array without a size (*unsized*) and then later redeclare the same name as an array of the same type and specify a size, or index it only with integral constant expressions (*implicitly sized*). However, unless noted otherwise, blocks cannot be redeclared; an unsized array in a user-declared block cannot be sized by a block redeclaration. It is a compile-time error to declare an array with a size, and then later (in the same shader) index the same array with an integral constant expression greater than or equal to the declared size. It is a compile-time error to redeclare an unsized array with a size equal to or smaller than any index used earlier in the shader to index the array. It is also a compile-time error to index an array with a negative constant expression. Arrays declared as formal parameters in a function declaration must specify a size. Undefined behavior results from indexing an array with a non-constant expression that's greater than or equal to the array's size or less than 0. Arrays only have a single dimension (a single entry within "[]"), however, arrays of arrays can be declared. All types (basic types, structures, arrays) can be formed into an array.

All arrays are inherently homogeneous; made of elements all having the same type and size, with one exception. The exception is a shader storage block having an unsized array as its last member (*run-time sized*); an array can be formed from such a shader storage block, even if the storage blocks have differing lengths for their last member.

Some examples are:

```
float frequencies[3];
uniform vec4 lightPosition[4];
light lights[];
const int numLights = 2;
light lights[numLights];

// a shader storage block, introduced in section 4.3.7 "buffer variables"
buffer b {
    float u[]; // an error, unless u gets statically sized by link time
    vec4 v[]; // okay, v will be sized dynamically, if not statically
} name[3]; // when the block is arrayed, all u will be the same size,
// but not necessarily all v, if sized dynamically
```

An array type can be formed by specifying non-array type followed by an array specifier. All dimensions of such an array specifier must include a size.

```
float[5] // an array of size [5] of float
float[2][3] // an array of size [2][3] of float, not size [3] of float[2]
```

This type can be used anywhere any other type can be used, including as the return value from a function

```
float[5] foo() { }
```

as a constructor of an array

```
float[5](3.4, 4.2, 5.0, 5.2, 1.1)
```

as an unnamed parameter

```
void foo(float[5])
```

and as an alternate way of declaring a variable or function parameter.

```
float[5] a;
```

Arrays can have initializers formed from array constructors:

```
float a[5] = float[5](3.4, 4.2, 5.0, 5.2, 1.1);
float a[5] = float[](3.4, 4.2, 5.0, 5.2, 1.1); // same thing
```

An array of arrays can be declared as

```
vec4 a[3][2]; // size-3 array of size-2 array of vec4
```

which declares a one-dimensional array of size 3 of one-dimensional arrays of size 2 of **vec4**s. These following declarations do the same thing:

```
vec4[2] a[3]; // size-3 array of size-2 array of vec4
vec4[3][2] a; // size-3 array of size-2 array of vec4
```

When in transparent memory (like in a uniform block), the layout is that the inner-most (right-most in declaration) dimensions iterate faster than outer dimensions. That is, for the above, the order in memory would be:

Low address : a[0][0] : a[0][1] : a[1][0] : a[1][1] : a[2][0] : a[2][1] : High address

The type of *a* needed for both constructors and nameless parameters is “vec4[3][2]”:

```
vec4 b[2] = vec4[2](vec4(0.0), vec4(0.1));
vec4[3][2] a = vec4[3][2](b, b, b); // constructor
void foo(vec4[3][2]); // prototype with unnamed parameter
```

Alternatively, the initializer-list syntax can be used to initialize an array of arrays:

```
vec4 a[3][2] = { vec4[2](vec4(0.0), vec4(1.0)),
                vec4[2](vec4(0.0), vec4(1.0)),
                vec4[2](vec4(0.0), vec4(1.0)) };
```

Unsize arrays can be explicitly sized by an initializer at declaration time:

```
float a[5];
...
float b[] = a; // b is explicitly size 5
float b[5] = a; // means the same thing
float b[] = float[](1,2,3,4,5); // also explicitly sizes to 5
```

However, it is a compile-time error to assign to an unsized array. Note, this is a rare case that initializers and assignments appear to have different semantics. For arrays of arrays, any unsized dimension is explicitly sized by the initializer:

```
vec4 a[][] = { vec4[2](vec4(0.0), vec4(1.0)), // okay, size to a[3][2]
              vec4[2](vec4(0.0), vec4(1.0)),
              vec4[2](vec4(0.0), vec4(1.0)) };
```

Arrays know the number of elements they contain. This can be obtained by using the **length** method:

```
float a[5];
a.length(); // returns 5
```

This returns a type **int**. If an array has been explicitly sized, the value returned by the **length** method is a constant expression. If an array has not been explicitly sized and is not the last declared member of a shader storage block, the value returned by the **length** method is not a constant expression and will be determined when a program is linked. If an array has not been explicitly sized and is the last declared member of a shader storage block, the value returned will not be a constant expression and will be determined at run time based on the size of the buffer object providing storage for the block. For such arrays, the value returned by the **length** method will be undefined if the array is contained in an array of shader storage blocks that is indexed with a non-constant expression less than zero or greater than or equal to the number of blocks in the array.

The **length** method cannot be called on an array that has not yet been explicitly sized; this results in a compile-time error.

The **length** method works equally well for arrays of arrays:

```
vec4 a[3][2];
a.length() // this is 3
a[x].length() // this is 2
```

When the **length** method returns a compile-time constant, the expression in brackets (x above) will be evaluated and subjected to the rules required for array indexes, but the array will not be dereferenced. Thus, behavior is well defined even if the run-time value of the expression is out of bounds.

When the **length** method returns a run-time value, the array will be dereferenced with the value x . If x is not a compile-time constant and is out of range, an undefined value results.

```
// for an array b containing a member array a:
b[++x].a.length(); // b is never dereferenced, but "++x" is evaluated

// for an array s of a shader storage object containing a member array a:
s[x].a.length(); // s is dereferenced; x needs to be a valid index
```

4 Variables and Types

For implicitly-sized or run-time-sized arrays, only the outermost dimension can be lacking a size. A type that includes an unknown array size cannot be formed into an array until it gets an explicit size, except for shader storage blocks where the only unsized array member is the last member of the block.

In a shader storage block, the last member may be declared without an explicit size. In this case, the effective array size is inferred at run-time from the size of the data store backing the interface block. Such run-time-sized arrays may be indexed with general integer expressions. However, it is a compile-time error to pass them as an argument to a function or index them with a negative constant expression.

4.1.10 Implicit Conversions

In some situations, an expression and its type will be implicitly converted to a different type. The following table shows all allowed implicit conversions:

Type of expression	Can be implicitly converted to
int	uint
int uint	float
int uint float	double
ivec2	uvec2
ivec3	uvec3
ivec4	uvec4
ivec2 uvec2	vec2
ivec3 uvec3	vec3
ivec4 uvec4	vec4
ivec2 uvec2 vec2	dvec2
ivec3 uvec3 vec3	dvec3
ivec4 uvec4 vec4	dvec4
mat2	dmat2
mat3	dmat3
mat4	dmat4
mat2x3	dmat2x3
mat2x4	dmat2x4
mat3x2	dmat3x2
mat3x4	dmat3x4
mat4x2	dmat4x2
mat4x3	dmat4x3

There are no implicit array or structure conversions. For example, an array of **int** cannot be implicitly converted to an array of **float**.

When an implicit conversion is done, it is not a re-interpretation of the expression's bit pattern, but a conversion of its value to an equivalent value in the new type. For example, the integer value **-5** will be converted to the floating-point value **-5.0**. Integer values having more bits of precision than a single-precision floating-point mantissa will lose precision when converted to **float**.

When performing implicit conversion for binary operators, there may be multiple data types to which the two operands can be converted. For example, when adding an **int** value to a **uint** value, both values can be implicitly converted to **uint**, **float**, and **double**. In such cases, a floating-point type is chosen if either operand has a floating-point type. Otherwise, an unsigned integer type is chosen if either operand has an unsigned integer type. Otherwise, a signed integer type is chosen. If operands can be implicitly converted to multiple data types deriving from the same base data type, the type with the smallest component size is used.

The conversions in the table above are done only as indicated by other sections of this specification.

4.1.11 Initializers

At declaration, an initial value for a variable may be provided, specified as an equals (=) followed by an initializer. The initializer is either an *assignment-expression* or a list of initializers enclosed in curly braces. The grammar for the initializer is:

```

initializer :
    assignment-expression
    { initializer-list }
    { initializer-list , }

initializer-list :
    initializer
    initializer-list , initializer
  
```

The *assignment-expression* is a normal expression except that a comma (,) outside parentheses is interpreted as the end of the initializer, not as the sequence operator. As explained in more detail below, this allows creation of nested initializers: The variable type and its initializer must exactly match in terms of nesting, number of components/elements/members present at each level, and types of components/elements/members. An *assignment-expression* at global scope can include calls to user-defined functions.

An *assignment-expression* in an initializer must be either the same type as the object it initializes or be a type that can be converted to the object's type according to section 4.1.10 "Implicit Conversions". Since these include constructors, a composite variable can be initialized by either a constructor or an initializer list; and an element in an initializer list can be a constructor.

If an initializer is a list of initializers enclosed in curly braces, the variable being declared must be a vector, a matrix, an array, or a structure.

```
int i = { 1 };      // illegal, i is not a composite
```

4 Variables and Types

A list of initializers enclosed in a matching set of curly braces is applied to one composite. This may be the variable being declared or a composite contained in the variable being declared. Individual initializers from the initializer list are applied to the elements/members of the composite, in order.

If the composite has a vector type, initializers from the list are applied to the components of the vector, in order, starting with component 0. The number of initializers must match the number of components.

If the composite has a matrix type, initializers from the list must be vector initializers and are applied to the columns of the matrix, in order, starting with column 0. The number of initializers must match the number of columns.

If the composite has a structure type, initializers from the list are applied to the members of the structure, in the order declared in the structure, starting with the first member. The number of initializers must match the number of members.

Applying these rules, the following matrix declarations are equivalent:

```
mat2x2 a = mat2( vec2( 1.0, 0.0 ), vec2( 0.0, 1.0 ) );
mat2x2 b =      { vec2( 1.0, 0.0 ), vec2( 0.0, 1.0 ) };
mat2x2 c =      {      { 1.0, 0.0 },      { 0.0, 1.0 } };
```

All of the following declarations result in a compile-time error.

```
float a[2] = { 3.4, 4.2, 5.0 };           // illegal
vec2 b = { 1.0, 2.0, 3.0 };              // illegal
mat3x3 c = { vec3(0.0), vec3(1.0), vec3(2.0), vec3(3.0) }; // illegal
mat2x2 d = { 1.0, 0.0, 0.0, 1.0 };       // illegal, can't flatten nesting
struct {
    float a;
    int b;
} e = { 1.2, 2, 3 };                     // illegal
```

In all cases, the innermost initializer (i.e., not a list of initializers enclosed in curly braces) applied to an object must have the same type as the object being initialized or be a type that can be converted to the object's type according to section 4.1.10 "Implicit Conversions". In the latter case, an implicit conversion will be done on the initializer before the assignment is done.

```
struct {
    float a;
    int b;
} e = { 1.2, 2 };                        // legal, all types match
```

```

struct {
    float a;
    int   b;
} e = { 1, 3 };           // legal, first initializer is converted

```

All of the following declarations result in a compile-time error.

```

int a = true;           // illegal
vec4 b[2] = { vec4(0.0), 1.0 }; // illegal
mat4x2 c = { vec3(0.0), vec3(1.0) }; // illegal

struct S1 {
    vec4 a;
    vec4 b;
};

struct {
    float s;
    float t;
} d[] = { S1(vec4(0.0), vec4(1.1)) }; // illegal

```

If an initializer (of either form) is provided for an unsized array, the size of the array is determined by the number of top-level (non-nested) initializers within the initializer. All of the following declarations create arrays explicitly sized with five elements:

```

float a[] = float[](3.4, 4.2, 5.0, 5.2, 1.1);
float b[] = { 3.4, 4.2, 5.0, 5.2, 1.1 };
float c[] = a;           // c is explicitly size 5
float d[5] = b;         // means the same thing

```

It is a compile-time error to have too few or too many initializers in an initializer list for the composite being initialized. That is, all elements of an array, all members of a structure, all columns of a matrix, and all components of a vector must have exactly one initializer expression present, with no unconsumed initializers.

4.2 Scoping

The scope of a variable is determined by where it is declared. If it is declared outside all function definitions, it has global scope, which starts from where it is declared and persists to the end of the shader it is declared in. If it is declared in a **while** test or a **for** statement, then it is scoped to the end of the following sub-statement. If it is declared in an **if** or **else** statement, it is scoped to the end of that statement. (See section 6.2 “Selection” and section 6.3 “Iteration” for the location of statements and sub-statements.) Otherwise, if it is declared as a statement within a compound statement, it is scoped to the end of that compound statement. If it is declared as a parameter in a function definition, it is scoped until the end of that function definition. A function's parameter declarations and body together form a single scope nested in the global scope. The **if** statement's expression does not allow new variables to be declared, hence does not form a new scope.

Within a declaration, the scope of a name starts immediately after the initializer if present or immediately after the name being declared if not. Several examples:

```
int x = 1;
{
    int x = 2, y = x; // y is initialized to 2
}

struct S
{
    int x;
};

{
    S s = S(0); // 'S' is only visible as a struct and constructor
    S;          // 'S' is now visible as a variable
}

int x = x; // Error if x has not been previously defined.
           // If the previous definition of x was in this
           // same scope, this causes a redeclaration error.

int f( /* nested scope begins here */ int k)
{
    int k = k + 3; // redeclaration error of the name k
    ...
}

int f(int k)
{
    {
        int k = k + 3; // 2nd k is parameter, initializing nested first k
        int m = k      // use of new k, which is hiding the parameter
    }
}
```

For both **for** and **while** loops, the sub-statement itself does not introduce a new scope for variable names, so the following has a redeclaration compile-time error:

```
for ( /* nested scope begins here */ int i = 0; i < 10; i++) {
    int i; // redeclaration error
}
```

The body of a **do-while** loop introduces a new scope lasting only between the **do** and **while** (not including the while test expression), whether or not the body is simple or compound:

```
int i = 17;
do
    int i = 4; // okay, in nested scope
while (i == 0); // i is 17, scoped outside the do-while body
```

The statement following a **switch** (...) forms a nested scope.

All variable names, structure type names, and function names in a given scope share the same name space. Function names can be redeclared in the same scope, with the same or different parameters, without error. An implicitly-sized array can be redeclared in the same scope as an array of the same base type. Otherwise, within one compilation unit, a declared name cannot be redeclared in the same scope; doing so results in a redeclaration compile-time error. If a nested scope redeclares a name used in an outer scope, it hides all existing uses of that name. There is no way to access the hidden name or make it unhidden, without exiting the scope that hid it.

The built-in functions are scoped in a scope outside the global scope that users declare global variables in. That is, a shader's global scope, available for user-defined functions and global variables, is nested inside the scope containing the built-in functions. When a function name is redeclared in a nested scope, it hides all functions declared with that name in the outer scope. Function declarations (prototypes) cannot occur inside of functions; they must be at global scope, or for the built-in functions, outside the global scope, otherwise a compile-time error results.

Shared globals are global variables declared with the same name in independently compiled units (shaders) within the same language (i.e., same stage, e.g., vertex) that are linked together when making a single program. (Globals forming the interface between two different shader languages are discussed in other sections.) Shared globals share the same name space, and must be declared with the same type. They will share the same storage.

Shared global arrays must have the same base type and the same explicit size. An array implicitly sized in one shader can be explicitly sized by another shader in the same stage. If no shader in a stage has an explicit size for the array, the largest implicit size (one more than the largest index used) in that stage is used. There is no cross-stage array sizing. If there is no static access to an implicitly sized array within the stage declaring it, then the array is given a size of 1, which is relevant when the array is declared within an interface block that is shared with other stages or the application (other unused arrays might be eliminated by the optimizer).

Shared global scalars must have exactly the same type name and type definition. Structures must have the same name, sequence of type names, and type definitions, and member names to be considered the same type. This rule applies recursively for nested or embedded types. If a shared global has multiple initializers, the initializers must all be constant expressions, and they must all have the same value. Otherwise, a link-time error will result. (A shared global having only one initializer does not require that initializer to be a constant expression.)

4.3 Storage Qualifiers

Variable declarations may have at most one storage qualifier specified in front of the type. These are summarized as

Storage Qualifier	Meaning
< none: default >	local read/write memory, or an input parameter to a function
const	a variable whose value cannot be changed
in	linkage into a shader from a previous stage, variable is copied in
out	linkage out of a shader to a subsequent stage, variable is copied out
attribute	compatibility profile only and vertex language only; same as in when in a vertex shader
uniform	value does not change across the primitive being processed, uniforms form the linkage between a shader, OpenGL, and the application
varying	compatibility profile only and vertex and fragment languages only; same as out when in a vertex shader and same as in when in a fragment shader
buffer	value is stored in a buffer object, and can be read or written both by shader invocations and the OpenGL API
shared	compute shader only; variable storage is shared across all work items in a local work group

Some input and output qualified variables can be qualified with at most one additional auxiliary storage qualifier:

Auxiliary Storage Qualifier	Meaning
centroid	centroid-based interpolation
sample	per-sample interpolation
patch	per-tessellation-patch attributes

Not all combinations of qualification are allowed. Auxiliary storage qualifiers can only be used with the **in** or **out** storage qualifiers. Additional qualifier rules are defined in upcoming sections.

Local variables can only use the **const** storage qualifier (or use no storage qualifier).

Function parameters can use **const**, **in**, and **out** qualifiers, but as *parameter qualifiers*. Parameter qualifiers are discussed in section 6.1.1 “Function Calling Conventions”.

Function return types and structure members do not use storage qualifiers.

Initializers in global declarations may only be used in declarations of global variables with no storage qualifier, with a **const** qualifier, or with a **uniform** qualifier. Global variables without storage qualifiers that are not initialized in their declaration or by the application will not be initialized by OpenGL, but rather will enter *main()* with undefined values.

When comparing an output from one shader stage to an input of a subsequent shader stage, the input and output don't match if their auxiliary qualifiers (or lack thereof) are not the same.

4.3.1 Default Storage Qualifier

If no qualifier is present on a global variable, then the variable has no linkage to the application or shaders running on other pipeline stages. For either global or local unqualified variables, the declaration will appear to allocate memory associated with the processor it targets. This variable will provide read/write access to this allocated memory.

4.3.2 Constant Qualifier

Named compile-time constants or read-only variables can be declared using the **const** qualifier. The **const** qualifier can be used with any of the non-void transparent basic data types, as well as with structures and arrays of these. It is a compile-time error to write to a **const** variable outside of its declaration, so they must be initialized when declared. For example,

```
const vec3 zAxis = vec3 (0.0, 0.0, 1.0);
const float ceiling = a + b; // a and b not necessarily constants
```

Structure members may not be qualified with **const**. Structure variables can be declared as **const**, and initialized with a structure constructor or initializer.

Initializers for **const** declarations at global scope must be constant expressions, as defined in section 4.3.3 “Constant Expressions.”

4.3.3 Constant Expressions

SPIR-V specialization constants are expressed in GLSL as **const** with the layout qualifier **constant_id**, as described in section 4.4.11 “Specialization-Constant Qualifier.”

A *constant expression* is one of:

- A literal value (e.g., **5** or **true**).
- A variable declared with the **const** qualifier and an initializer, where the initializer is a constant expression. This includes both **const** declared with a specialization-constant layout qualifier, e.g., `layout(constant_id = ...)`, and those declared without a specialization-constant layout qualifier.
- An expression formed by an operator on operands that are all constant expressions, including getting an element of a constant array, or a member of a constant structure, or components of a constant vector. However, the lowest precedence operators of the sequence operator (,) and the assignment operators (=, +=, ...) are not included in the operators that can create a constant expression. Also, an array access with a specialization constant as an index does not result in a constant expression.
- Valid use of the **length()** method on an explicitly sized object, whether or not the object itself is constant (implicitly sized or run-time sized arrays do not return a constant expression).
- A constructor whose arguments are all constant expressions.

- For non-specialization-constants only: the value returned by certain built-in function calls whose arguments are all constant expressions, including at least the list below. Any other built-in function that does not access memory (not the texture lookup functions, image access, atomic counter, etc.), that has a non-**void** return type, that has no **out** parameter, and is not a noise function might also be considered a constant. When any function is called with an argument that is a specialization constant, the result is not a constant expression.

Angle and Trigonometric Functions

radians
degrees
sin
cos
asin
acos

Exponential Functions

pow
exp
log
exp2
log2
sqrt
inversesqrt

Common Functions

abs
sign
floor
trunc
round
ceil
mod
min
max
clamp

Geometric Functions

length
dot
normalize

Function calls to user-defined functions (non-built-in functions) cannot be used to form constant expressions.

An *integral constant expression* is a constant expression that evaluates to a scalar signed or unsigned integer.

Constant expressions will always be evaluated in an invariant way, independent of use of **invariant** and **precise** qualification, so as to create the same value in multiple shaders when the same constant expressions appear in those shaders. See section 4.8.1 “The Invariant Qualifier” and section 4.9 “The Precise Qualifier” for more details on how to create invariant expressions.

Non-specialization constant expressions may be evaluated by the compiler's host platform, and are therefore not required to compute the same value that the same expression would evaluate to on the shader execution target. However, the host must use the same or greater precision than the target would use.

Specialization-constant expressions are never evaluated by the compiler front end, but instead retain the expression's operations needed to evaluate them later on the host.

4.3.4 Input Variables

Shader input variables are declared with the storage qualifier **in**. They form the input interface between previous stages of the OpenGL pipeline and the declaring shader. Input variables must be declared at global scope. Values from the previous pipeline stage are copied into input variables at the beginning of shader execution. It is a compile-time error to write to a variable declared as an input.

Only the input variables that are statically read need to be written by the previous stage; it is allowed to have superfluous declarations of input variables. This is shown in the following table.

Treatment of Mismatched Input Variables		Consuming Shader (input variables)		
		No Declaration	Declared but no Static Use	Declared and Static Use
Generating Shader (output variables)	No Declaration	Allowed	Allowed	Link-Time Error
	Declared but no Static Use	Allowed	Allowed	Allowed (values are undefined)
	Declared and Static Use	Allowed	Allowed	Allowed (values are potentially undefined)

Consumption errors are based on static use only. Compilation may generate a warning, but not an error, for any dynamic use the compiler can deduce that might cause consumption of undefined values.

See section 7 “Built-in Variables” for a list of the built-in input names.

Vertex shader input variables (or attributes) receive per-vertex data. They are declared in a vertex shader with the **in** qualifier. It is a compile-time error to use any auxiliary or interpolation qualifier on a vertex shader input. The values copied in are established by the OpenGL API or through the use of the layout identifier *location*. It is a compile-time error to declare a vertex shader input containing any of the following:

- A Boolean type (**bool**, **bvec2**, **bvec3**, **bvec4**)
- An opaque type
- A structure

Example declarations in a vertex shader:

```
in vec4 position;
in vec3 normal;
in vec2 texCoord[4];
```

It is expected that graphics hardware will have a small number of fixed vector locations for passing vertex inputs. Therefore, the OpenGL Shading language defines each non-matrix input variable as taking up one such vector location. There is an implementation dependent limit on the number of locations that can be used, and if this is exceeded it will cause a link-time error. (Declared input variables that are not statically used do not count against this limit.) A scalar input counts the same amount against this limit as a **vec4**, so applications may want to consider packing groups of four unrelated float inputs together into a vector to better utilize the capabilities of the underlying hardware. A matrix input will use up multiple locations. The number of locations used will equal the number of columns in the matrix.

Tessellation control, evaluation, and geometry shader input variables get the per-vertex values written out by output variables of the same names in the previous active shader stage. For these inputs, **centroid** and interpolation qualifiers are allowed, but have no effect. Since tessellation control, tessellation evaluation, and geometry shaders operate on a set of vertices, each input variable (or input block, see interface blocks below) needs to be declared as an array. For example,

```
in float foo[]; // geometry shader input for vertex "out float foo"
```

Each element of such an array corresponds to one vertex of the primitive being processed. Each array can optionally have a size declared. For geometry shaders, the array size will be set by, (or if provided must be consistent with) the input **layout** declaration(s) establishing the type of input primitive, as described later in section 4.4.1 “Input Layout Qualifiers”.

Some inputs and outputs are *arrayed*, meaning that for an interface between two shader stages either the input or output declaration requires an extra level of array indexing for the declarations to match. For example, with the interface between a vertex shader and a geometry shader, vertex shader output variables and geometry shader input variables of the same name must have matching types, except that the geometry shader will have one more array dimension than the vertex shader, to allow for vertex indexing. If such an arrayed interface variable is not declared with the necessary additional input or output array dimension, a link-time error will result. Geometry shader inputs, tessellation control shader inputs and outputs, and tessellation evaluation inputs all have an additional level of arrayness relative to other shader inputs and outputs. Component limits for arrayed interfaces (e.g., *gl_MaxTessControlInputComponents*) are limits per vertex, not limits for the entire interface.

For non-arrayed interfaces (meaning array dimensionally stays the same between stages), it is a link-time error if the input variable is not declared with the same type, including array dimensionality, as the matching output variable.

The link-time type-matching rules apply to all declared input and output variables, whether or not they are used.

Additionally, tessellation evaluation shaders support per-patch input variables declared with the **patch** and **in** qualifiers. Per-patch input variables are filled with the values of per-patch output variables written by the tessellation control shader. Per-patch inputs may be declared as one-dimensional arrays, but are not indexed by vertex number. Applying the **patch** qualifier to inputs can only be done in tessellation evaluation shaders. As with other input variables, per-patch inputs must be declared using the same type

and qualification as per-patch outputs from the previous (tessellation control) shader stage. It is a compile-time error to use **patch** with inputs in any other stage.

Fragment shader inputs get per-fragment values, typically interpolated from a previous stage's outputs. They are declared in fragment shaders with the **in** storage qualifier. The auxiliary storage qualifiers **centroid** and **sample** can also be applied, as well as the interpolation qualifiers **flat**, **noperspective**, and **smooth**. It is a compile-time error to declare a fragment shader input containing any of the following:

- A Boolean type (**bool**, **bvec2**, **bvec3**, **bvec4**)
- An opaque type

Fragment shader inputs that are, or contain, signed or unsigned integers, integer vectors, or any double-precision floating-point type must be qualified with the interpolation qualifier **flat**.

Fragment inputs are declared as in the following examples:

```
in vec3 normal;
centroid in vec2 TexCoord;
invariant centroid in vec4 Color;
noperspective in float temperature;
flat in vec3 myColor;
noperspective centroid in vec2 myTexCoord;
```

The fragment shader inputs form an interface with the last active shader in the vertex processing pipeline. For this interface, the last active shader stage output variables and fragment shader input variables of the same name must match in type and qualification, with a few exceptions: The storage qualifiers must, of course, differ (one is **in** and one is **out**). Also, interpolation qualification (e.g., **flat**) and auxiliary qualification (e.g. **centroid**) may differ. These mismatches are allowed between any pair of stages. When interpolation or auxiliary qualifiers do not match, those provided in the fragment shader supersede those provided in previous stages. If any such qualifiers are completely missing in the fragment shaders, then the default is used, rather than any qualifiers that may have been declared in previous stages. That is, what matters is what is declared in the fragment shaders, not what is declared in shaders in previous stages.

When an interface between shader stages is formed using shaders from two separate program objects, it is not possible to detect mismatches between inputs and outputs when the programs are linked. When there are mismatches between inputs and outputs on such interfaces, the values passed across the interface will be partially or completely undefined. Shaders can ensure matches across such interfaces either by using input and output layout qualifiers (sections 4.4.1 “Input Layout Qualifiers” and 4.4.2 “Output Layout Qualifiers”) or by using identical input and output declarations of blocks or variables. Complete rules for interface matching between programs are found in section 7.4.1 “Shader Interface Matching” of the OpenGL Graphics System Specification.

Compute shaders do not permit user-defined input variables and do not form a formal interface with any other shader stage. See section 7.1 “Built-In Variables” for a description of built-in compute shader input variables. All other input to a compute shader is retrieved explicitly through image loads, texture fetches, loads from uniforms or uniform buffers, or other user supplied code. Redclaration of built-in input variables in compute shaders is not permitted.

4.3.5 Uniform Variables

The **uniform** qualifier is used to declare global variables whose values are the same across the entire primitive being processed. All **uniform** variables are read-only and are initialized externally either at link time or through the API. The link-time initial value is either the value of the variable's initializer, if present, or 0 if no initializer is present. Opaque types cannot have initializers, or a compile-time error results.

Example declarations are:

```
uniform vec4 lightPosition;
uniform vec3 color = vec3(0.7, 0.7, 0.2); // value assigned at link time
```

The **uniform** qualifier can be used with any of the basic data types, or when declaring a variable whose type is a structure, or an array of any of these.

There is an implementation dependent limit on the amount of storage for uniforms that can be used for each type of shader and if this is exceeded it will cause a compile-time or link-time error. Uniform variables that are declared but not used do not count against this limit. The number of user-defined uniform variables and the number of built-in uniform variables that are used within a shader are added together to determine whether available uniform storage has been exceeded.

If multiple shaders are linked together, then they will share a single global uniform name space, including within a language as well as across languages. Hence, the types and initializers of all declared uniform variables with the same name must match across all shaders that are linked into a single program. While this single uniform name space is cross stage, a uniform variable name's scope is per stage: If a uniform variable name is declared in one stage (e.g., a vertex shader) but not in another (e.g., a fragment shader), then that name is still available in the other stage for a different use.

It is legal for some shaders to provide an initializer for a particular uniform variable, while another shader does not, but all provided initializers must be equal. Similarly, when a layout location is used, it is not required that all declarations of that name include the location; only that those that include a location use the same location.

4.3.6 Output Variables

Shader output variables are declared with a storage qualifier using the storage qualifier **out**. They form the output interface between the declaring shader and the subsequent stages of the OpenGL pipeline. Output variables must be declared at global scope. During shader execution they will behave as normal unqualified global variables. Their values are copied out to the subsequent pipeline stage on shader exit. Only output variables that are read by the subsequent pipeline stage need to be written; it is allowed to have superfluous declarations of output variables.

There is *not* an **inout** storage qualifier for declaring a single variable name as both input and output to a shader. Also, a variable cannot be declared with both the **in** and the **out** qualifiers, this will result in a compile-time or link-time error. Output variables must be declared with different names than input variables. However, nesting an input or output inside an interface block with an instance name allows the same names with one referenced through a block instance name.

Vertex, tessellation evaluation, and geometry output variables output per-vertex data and are declared using the **out** storage qualifier. Applying **patch** to an output can only be done in a tessellation control shader. It is a compile-time error to use **patch** on outputs in any other stage.

It is a compile-time error to declare a vertex, tessellation evaluation, tessellation control, or geometry shader output that contains any of the following:

- A Boolean type (**bool**, **bvec2**, **bvec3**, **bvec4**)
- An opaque type

Individual vertex, tessellation evaluation, and geometry outputs are declared as in the following examples:

```
out vec3 normal;
centroid out vec2 TexCoord;
invariant centroid out vec4 Color;
noperspective out float temperature;
flat out vec3 myColor;
noperspective centroid out vec2 myTexCoord;
sample out vec4 perSampleColor;
```

These can also appear in interface blocks, as described in section 4.3.9 “Interface Blocks”. Interface blocks allow simpler addition of arrays to the interface from vertex to geometry shader. They also allow a fragment shader to have the same input interface as a geometry shader for a given vertex shader.

Tessellation control shader output variables may be used to output per-vertex and per-patch data. Per-vertex output variables are arrayed (see *arrayed* under 4.3.4 Inputs) and declared using the **out** qualifier without the **patch** qualifier. Per-patch output variables are declared using the **patch** and **out** qualifiers. Since tessellation control shaders produce an arrayed primitive comprising multiple vertices, each per-vertex output variable (or output block, see interface blocks below) needs to be declared as an array. For example,

```
out float foo[]; // feeds next stage input "in float foo[]"
```

Each element of such an array corresponds to one vertex of the primitive being produced. Each array can optionally have a size declared. The array size will be set by (or if provided must be consistent with) the output layout declaration(s) establishing the number of vertices in the output patch, as described later in section 4.4.2.1 “Tessellation Control Outputs”.

Each tessellation control shader invocation has a corresponding output patch vertex, and may assign values to per-vertex outputs only if they belong to that corresponding vertex. If a per-vertex output variable is used as an l-value, it is a compile-time or link-time error if the expression indicating the vertex index is not the identifier *gl_InvocationID*.

The order of execution of a tessellation control shader invocation relative to the other invocations for the same input patch is undefined unless the built-in function **barrier()** is used. This provides some control over relative execution order. When a shader invocation calls **barrier()**, its execution pauses until all other invocations have reached the same point of execution. Output variable assignments performed by any invocation executed prior to calling **barrier()** will be visible to any other invocation after the call to **barrier()** returns.

Because tessellation control shader invocations execute in undefined order between barriers, the values of per-vertex or per-patch output variables will sometimes be undefined. Consider the beginning and end of shader execution and each call to **barrier()** as synchronization points. The value of an output variable will be undefined in any of the three following cases:

1. At the beginning of execution.
2. At each synchronization point, unless
 - the value was well-defined after the previous synchronization point and was not written by any invocation since, or
 - the value was written by exactly one shader invocation since the previous synchronization point, or
 - the value was written by multiple shader invocations since the previous synchronization point, and the last write performed by all such invocations wrote the same value.
3. When read by a shader invocation, if
 - the value was undefined at the previous synchronization point and has not been written by the same shader invocation since, or
 - the output variable is written to by any other shader invocation between the previous and next synchronization points, even if that assignment occurs in code following the read.

Fragment outputs output per-fragment data and are declared using the **out** storage qualifier. It is a compile-time error to use auxiliary storage qualifiers or interpolation qualifiers on an output in a fragment shader. It is a compile-time error to declare a fragment shader output that contains any of the following:

- A Boolean type (**bool**, **bvec2**, **bvec3**, **bvec4**)
- A double-precision scalar or vector (**double**, **dvec2**, **dvec3**, **dvec4**)
- An opaque type
- Any matrix type
- A structure

Fragment outputs are declared as in the following examples:

```
out vec4 FragmentColor;
out uint Luminosity;
```

Compute shaders have no built-in output variables, do not support user-defined output variables and do not form a formal interface with any other shader stage. All outputs from a compute shader take the form of the side effects such as image stores and operations on atomic counters.

4.3.7 Buffer Variables

The **buffer** qualifier is used to declare global variables whose values are stored in the data store of a buffer object bound through the OpenGL API. Buffer variables can be read and written with the underlying storage shared among all active shader invocations. Buffer variable memory reads and writes within a single shader invocation are processed in order. However, the order of reads and writes performed in one invocation relative to those performed by another invocation is largely undefined.

Buffer variables may be qualified with memory qualifiers affecting how the underlying memory is accessed, as described in section 4.10 “Memory Qualifiers”.

The **buffer** qualifier can be used to declare interface blocks (section 4.3.9 “Interface Blocks”), which are then referred to as shader storage blocks. It is a compile-time error to declare buffer variables outside of a block.

```
// use buffer to create a buffer block (shader storage block)
buffer BufferName { // externally visible name of buffer
    int count;      // typed, shared memory...
    ...            // ...
    vec4 v[];       // last member may be an array that is not sized
                  // until after link time (dynamically sized)
} Name;           // name of block within the shader
```

There are implementation-dependent limits on the number of shader storage blocks used for each type of shader, the combined number of shader storage blocks used for a program, and the amount of storage required by each individual shader storage block. If any of these limits are exceeded, it will cause a compile-time or link-time error.

If multiple shaders are linked together, then they will share a single global buffer variable name space, including within a language as well as across languages. Hence, the types of all declared buffer variables with the same name must match across all shaders that are linked into a single program.

4.3.8 Shared Variables

The **shared** qualifier is used to declare global variables that have storage shared between all work items compute shader local work group. Variables declared as **shared** may only be used in compute shaders (see section 2.6 “Compute Processor”). Any other declaration of a shared variable is a compile-time error. Shared variables are implicitly coherent. That is, writes to shared variables from one shader invocation will eventually be seen by other invocations within the same local work group.

Variables declared as **shared** may not have initializers and their contents are undefined at the beginning of shader execution. Any data written to shared variables will be visible to other shader processors executing the same shader within the same local work group. Order of execution with respect to reads and writes to the same shared variable by different invocations of a shader is not defined. In order to achieve ordering with respect to reads and writes to shared variables, memory barriers must be employed using the **barrier()** function (see section 8.16 “Shader Invocation Control Functions”).

There is a limit to the total size of all variables declared as shared in a single program. This limit, expressed in units of basic machine units may be determined by using the OpenGL API to query the value of `MAX_COMPUTE_SHARED_MEMORY_SIZE`.

4.3.9 Interface Blocks

Input, output, uniform, and buffer variable declarations can be grouped into named interface blocks to provide coarser granularity backing than is achievable with individual declarations. They can have an optional instance name, used in the shader to reference their members. An output block of one programmable stage is backed by a corresponding input block in the subsequent programmable stage. A uniform block is backed by the application with a buffer object. A block of buffer variables, called a

shader storage block, is also backed by the application with a buffer object. It is a compile-time error to have an input block in a vertex shader or an output block in a fragment shader; these uses are reserved for future use.

An interface block is started by an **in**, **out**, **uniform**, or **buffer** keyword, followed by a block name, followed by an open curly brace ({) as follows:

```

interface-block :
    layout-qualifieropt interface-qualifier block-name { member-list } instance-nameopt ;
    // Note: Order of qualifiers is not actually fixed; qualifiers can be in any order.

interface-qualifier :
    in
    out
    patch in      // Note: Qualifiers can be in any order.
    patch out
    uniform
    buffer
    // Note: Not shown for simplicity, but memory qualifiers may also be used

member-list :
    member-declaration
    member-declaration member-list

member-declaration :
    layout-qualifieropt qualifiersopt type declarators ; // Note: Qualifiers can be in any order.

instance-name :
    identifier
    identifier [ ]
    identifier [ integral-constant-expression ] // Note: Arrays of arrays are also allowed

```

Each of the above elements is discussed below, with the exception of layout qualifiers (*layout-qualifier*), which are defined in the next section.

First, an example,

```

uniform Transform {
    mat4 ModelViewMatrix;
    mat4 ModelViewProjectionMatrix;
    uniform mat3 NormalMatrix;      // allowed restatement of qualifier
    float Deformation;
};

```

The above establishes a uniform block named “Transform” with four uniforms grouped inside it.

Types and declarators are the same as for other input, output, uniform, and buffer variable declarations outside blocks, with these exceptions:

- initializers are not allowed
- opaque types are not allowed
- structure definitions cannot be nested inside a block

Any of these would result in a compile-time error. Otherwise, built-in types, previously declared structures, and arrays of these are allowed as the type of a declarator in the same manner they are allowed outside a block.

If no optional qualifier is used in a member-declaration, the qualification of the member includes all **in**, **out**, **patch**, **uniform**, or **buffer** as determined by *interface-qualifier*. If optional qualifiers are used, they can include interpolation qualifiers, auxiliary storage qualifiers, and storage qualifiers and they must declare an input, output, or uniform member consistent with the interface qualifier of the block: Input variables, output variables, uniform variables, and **buffer** members can only be in **in** blocks, **out** blocks, **uniform** blocks, and shader storage blocks, respectively. Repeating an **in**, **out**, **patch**, **uniform**, or **buffer** interface qualifier for a member's storage qualifier is optional. For example,

```
in Material {
    smooth in vec4 Color1; // legal, input inside in block
    smooth vec4 Color2;   // legal, 'in' inherited from 'in Material'
    vec2 TexCoord;       // legal, TexCoord is an input
    uniform float Atten;  // illegal, mismatched storage qualifier
};
```

For this section, define a *shader interface* to be one of these

- All the uniform variables and uniform blocks declared in a program. This spans all compilation units linked together within one program.
- All the **buffer** blocks declared in a program.
- The boundary between adjacent programmable pipeline stages: This spans all the outputs declared in all compilation units of the first stage and all the inputs declared in all compilation units of the second stage.

The block name (*block-name*) is used to match within shader interfaces: an output block of one pipeline stage will be matched to an input block with the same name in the subsequent pipeline stage. For uniform blocks, the application uses the block name to identify the block. Block names have no other use within a shader beyond interface matching; it is a compile-time error to use a block name at global scope for anything other than as a block name (e.g., use of a block name for a global variable name or function name is currently reserved). It is a compile-time error to use the same block name for more than one block declaration in the same shader interface (as defined above) within one shader, even if the block contents are identical.

Matched block names within a shader interface (as defined above) must match in terms of having the same number of declarations with the same sequence of types and the same sequence of member names, as well as having the same member-wise layout qualification (see next section). Matched uniform block names (but not input or output block names) must also either all be lacking an instance name or all having an instance name, putting their members at the same scoping level. When instance names are present on matched block names, it is allowed for the instance names to differ; they need not match for the blocks to match. Furthermore, if a matching block is declared as an array, then the array sizes must also match (or follow array matching rules for the shader interface between a vertex and a geometry shader). Any mismatch will generate a link-time error. A block name is allowed to have different definitions in different shader interfaces within the same shader, allowing, for example, an input block and output block to have the same name.

If an instance name (*instance-name*) is not used, the names declared inside the block are scoped at the global level and accessed as if they were declared outside the block. If an instance name (*instance-name*) is used, then it puts all the members inside a scope within its own name space, accessed with the field selector (`.`) operator (analogously to structures). For example,

```
in Light {
    vec4 LightPos;
    vec3 LightColor;
};
in ColoredTexture {
    vec4 Color;
    vec2 TexCoord;
} Material;           // instance name
vec3 Color;           // different Color than Material.Color
vec4 LightPos;       // illegal, already defined
...
... = LightPos;      // accessing LightPos
... = Material.Color; // accessing Color in ColoredTexture block
```

Outside the shading language (i.e., in the API), members are similarly identified except the block name is always used in place of the instance name (API accesses are to shader interfaces, not to shaders). If there is no instance name, then the API does not use the block name to access a member, just the member name.

Within a shader interface, all declarations of the same global name must be for the same object and must match in type and in whether they declare a variable or member of a block with no instance name. The API also needs this name to uniquely identify an object in the shader interface. It is a link-time error if any particular shader interface contains

- two different blocks, each having no instance name, and each having a member of the same name, or
- a variable outside a block, and a block with no instance name, where the variable has the same name as a member in the block.

4 Variables and Types

```
out Vertex {
    vec4 Position; // API transform/feedback will use "Vertex.Position"
    vec2 Texture;
} Coords; // shader will use "Coords.Position"

out Vertex2 {
    vec4 Color; // API will use "Color"
    float Color2;
};

// in same program as Vertex2 above:
out Vertex3 {
    float Intensity;
    vec4 Color; // ERROR, name collision with Color in Vertex2
};
float Color2; // ERROR, collides with Color2 in Vertex2
```

For blocks declared as arrays, the array index must also be included when accessing members, as in this example

```
uniform Transform { // API uses "Transform[2]" to refer to instance 2
    mat4      ModelViewMatrix;
    mat4      ModelViewProjectionMatrix;
    vec4      a[]; // array will get implicitly sized
    float     Deformation;
} transforms[4];
...
... = transforms[2].ModelViewMatrix; // shader access of instance 2
// API uses "Transform.ModelViewMatrix" to query an offset or other query
transforms[x].a.length(); // same length for 'a' for all x
Transform[x]; // illegal, must use 'transforms'
Transform.a.length(); // illegal, must use 'transforms'
...transforms[2].a[3]... // if these are the only two dereferences of 'a',
...transforms[3].a[7]... // then 'a' must be size 8, for all transforms[x]
```

For uniform or shader storage blocks declared as an array, each individual array element corresponds to a separate buffer-object bind range, backing one instance of the block. As the array size indicates the number of buffer objects needed, uniform and shader storage block array declarations must specify an array size. A uniform or shader storage block array can only be indexed with a dynamically uniform integral expression, otherwise results are undefined.

When using OpenGL API entry points to identify the name of an individual block in an array of blocks, the name string may include an array index (e.g., *Transform[2]*). When using OpenGL API entry points to refer to offsets or other characteristics of a block member, an array index must not be specified (e.g., *Transform.ModelViewMatrix*).

Geometry shader input blocks must be declared as arrays and follow the array declaration and linking rules for all geometry shader inputs. All other input and output block arrays must specify an array size.

There are implementation dependent limits on the number of uniform blocks and the number of shader storage blocks that can be used per stage. If either limit is exceeded, it will cause a link-time error.

4.4 Layout Qualifiers

Layout qualifiers can appear in several forms of declaration. They can appear as part of an interface-block definition or block member, as shown in the grammar in the previous section. They can also appear with just an interface qualifier (a storage qualifier that is **in**, **out**, or **uniform**) to establish layouts of other declarations made with that interface qualifier:

layout-qualifier interface-qualifier ;

Or, they can appear with an individual variable declared with an interface qualifier:

layout-qualifier interface-qualifier declaration ;

Declarations of layouts can only be made at global scope or block members, and only where indicated in the following subsections; their details are specific to what the interface qualifier is, and are discussed individually.

The *layout-qualifier* expands to

layout-qualifier :
layout (*layout-qualifier-id-list*)

layout-qualifier-id-list :
layout-qualifier-id
layout-qualifier-id , *layout-qualifier-id-list*

layout-qualifier-id
layout-qualifier-name
layout-qualifier-name = *layout-qualifier-value*
shared

The tokens used for *layout-qualifier-name* are identifiers, not keywords, however, the **shared** keyword is allowed as a *layout-qualifier-id*. Generally, they can be listed in any order. Order-dependent meanings exist only if explicitly called out below. Similarly, these identifiers are not case sensitive, unless explicitly noted otherwise.

More than one layout qualifier may appear in a single declaration. Additionally, the same *layout-qualifier-name* can occur multiple times within a layout qualifier or across multiple layout qualifiers in the same declaration. When the same *layout-qualifier-name* occurs multiple times, in a single declaration, the last occurrence overrides the former occurrence(s). Further, if such a *layout-qualifier-name* will affect subsequent declarations or other observable behavior, it is only the last occurrence that will have any effect, behaving as if the earlier occurrence(s) within the declaration are not present. This is also true for overriding *layout-qualifier-name*, where one overrides the other (e.g., **row_major** vs. **column_major**); only the last occurrence has any effect.

The following table summarizes the use of layout qualifiers applied to non-opaque types. It shows for each one what kinds of declarations it may be applied to. These are all discussed in detail in the following sections. Layout qualifiers applied to opaque types are not show in this table, but are discussed subsequently in section 4.4.6 “Opaque-Uniform Layout Qualifiers”.

4 Variables and Types

Layout Qualifier	Qualifier Only	Individual Variable	Block	Block Member	Allowed Interfaces
shared packed std140 std430	X		X		uniform/buffer
row_major column_major	X		X	X	
binding =		opaque types only	X		
offset =		atomic counters only		X	
align =			X	X	
location =		X			uniform/buffer and subroutine variables
location =		X	X	X	all in/out , except for compute
component =		X		X	
index =		X			fragment out and subroutine functions
triangles quads isolines	X				tessellation evaluation in
equal_spacing fractional_even_spacing fractional_odd_spacing	X				tessellation evaluation in
cw ccw	X				tessellation evaluation in
point_mode	X				tessellation evaluation in
points	X				geometry in/out
[points] lines lines_adjacency triangles triangles_adjacency	X				geometry in
invocations =	X				geometry in
origin_upper_left pixel_center_integer		<i>gl_FragCoord</i> only			fragment in
early_fragment_tests	X				

Layout Qualifier	Qualifier Only	Individual Variable	Block	Block Member	Allowed Interfaces
local_size_x = local_size_y = local_size_z =	X				compute in
local_size_x_id = local_size_y_id = local_size_z_id =	X				compute in SPIR-V generation only
xfb_buffer = xfb_stride =	X	X	X	X	vertex, tessellation, and geometry out
xfb_offset =		X	X	X	
vertices =	X				tessellation control out
[points] line_strip triangle_strip	X				geometry out
max_vertices =	X				
stream =	X	X	X	X	
depth_any depth_greater depth_less depth_unchanged		<i>gl_FragDepth</i> only			fragment out
constant_id		scalar only			const SPIR-V generation only

4.4.1 Input Layout Qualifiers

Some input layout qualifiers apply to all shader languages and some apply only to specific languages. The latter are discussed in separate sections below.

All shaders, except compute shaders, allow **location** layout qualifiers on input variable declarations, input block declarations, and input block member declarations. Of these, variables and block members (but not blocks) additionally allow the **component** layout qualifier.

The layout qualifier identifiers for inputs are:

layout-qualifier-id :

location = *integer-constant-expression*

component = *integer-constant-expression*

Where *integer-constant-expression* is defined in section 4.3.3 “Constant Expressions” as “*integral constant expression*”, with it being a compile-time error for *integer-constant-expression* to be a specialization constant: The constant used to set a layout identifier X in `layout(layout-qualifier-name = X)` must evaluate to a constant containing no specialization constants..

For example,

```
layout(location = 3) in vec4 normal;
const int start = 6;
layout(location = start + 2) in vec4 v;
```

will establish that the shader input *normal* is assigned to vector location number 3 and *v* is assigned location number 8. For vertex shader inputs, the location specifies the number of the generic vertex attribute from which input values are taken. For inputs of all other shader types, the location specifies a vector number that can be used to match against outputs from a previous shader stage, even if that shader is in a different program object.

The following language describes how many locations are consumed by a given type. However, geometry shader inputs, tessellation control shader inputs and outputs, and tessellation evaluation inputs all have an additional level of arrayness relative to other shader inputs and outputs. This outer array level is removed from the type before considering how many locations the type consumes.

If a vertex shader input is any scalar or vector type, it will consume a single location. If a non-vertex shader input is a scalar or vector type other than **dvec3** or **dvec4**, it will consume a single location, while types **dvec3** or **dvec4** will consume two consecutive locations. Inputs of type **double** and **dvec2** will consume only a single location, in all stages.

If the declared input (after potentially removing an outer array level as just described above) is an array of size *n* and each element takes *m* locations, it will be assigned *m * n* consecutive locations starting with the location specified. For example,

```
layout(location = 6) in vec4 colors[3];
```

will establish that the shader input *colors* is assigned to vector location numbers 6, 7, and 8.

If the declared input is an *n* x *m* single- or double-precision matrix, it will be assigned multiple locations starting with the location specified. The number of locations assigned for each matrix will be the same as for an *n*-element array of *m*-component vectors. For example,

```
layout(location = 9) in mat4 transforms[2];
```

will establish that shader input *transforms* is assigned to vector locations 9-16, with *transforms[0]* being assigned to locations 9-12 and *transforms[1]* being assigned to locations 13-16.

If the declared input is a structure or block, its members will be assigned consecutive locations in their order of declaration, with the first member assigned the location provided in the layout qualifier. For a structure, this process applies to the entire structure. It is a compile-time error to use a **location** qualifier on a member of a structure. For a block, this process applies to the entire block, or until the first member is reached that has a location layout qualifier. When a block member is declared with a location qualifier, its location comes from that qualifier: The member's **location** qualifier overrides the block-level declaration. Subsequent members are again assigned consecutive locations, based on the newest location, until the next member declared with a **location** qualifier. The values used for locations do not have to be declared in increasing order.

If a block has no block-level **location** layout qualifier, it is required that either all or none of its members have a **location** layout qualifier, or a compile-time error results. For some blocks declared as arrays, the **location** can only be applied at the block level: When a block is declared as an array where additional

locations are needed for each member for each block array element, it is a compile-time error to specify locations on the block members. That is, when locations would be under specified by applying them on block members, they are not allowed on block members. For *arrayed* interfaces (those generally having an extra level of arrayness due to interface expansion), the outer array is stripped before applying this rule.

When generating SPIR-V, all **in** and **out** qualified user-declared (non built-in) variables and blocks (or all their members) must have a shader-specified **location**. Otherwise, a compile-time error is generated.

The locations consumed by block and structure members are determined by applying the rules above recursively as though the structure member were declared as an input variable of the same type. For example:

```

layout(location = 3) in struct S {
    vec3 a;                // gets location 3
    mat2 b;                // gets locations 4 and 5
    vec4 c[2];             // gets locations 6 and 7
    layout(location = 8) vec2 A; // ERROR, can't use on struct member
} s;

layout(location = 4) in block {
    vec4 d;                // gets location 4
    vec4 e;                // gets location 5
    layout(location = 7) vec4 f; // gets location 7
    vec4 g;                // gets location 8
    layout(location = 1) vec4 h; // gets location 1
    vec4 i;                // gets location 2
    vec4 j;                // gets location 3
    vec4 k;                // ERROR, location 4 already used
};

```

The number of input locations available to a shader is limited. For vertex shaders, the limit is the advertised number of vertex attributes. For all other shaders, the limit is implementation-dependent and must be no less than one fourth of the advertised maximum input component count. A program will fail to link if any attached shader uses a location greater than or equal to the number of supported locations, unless device-dependent optimizations are able to make the program fit within available hardware resources.

A program will fail to link if explicit location assignments leave the linker unable to find space for other variables without explicit assignments.

For the purposes of determining if a non-vertex input matches an output from a previous shader stage, the location layout qualifier (if any) must match.

If a vertex shader input variable with no location assigned in the shader text has a location specified through the OpenGL API, the API-assigned location will be used. Otherwise, such variables will be assigned a location by the linker. See section 11.1.1 “Vertex Attributes” of the OpenGL Graphics System Specification for more details. A link-time error will occur if an input variable is declared in multiple shaders of the same language with conflicting locations.

The **component** qualifier allows the location to be more finely specified for scalars and vectors, down to the individual components within a location that are consumed. It is a compile-time error to use **component** without also specifying the **location** qualifier (order does not matter). The components within a location are 0, 1, 2, and 3. A variable or block member starting at component N will consume components $N, N+1, N+2, \dots$ up through its size. It is a compile-time error if this sequence of components gets larger than 3. A scalar **double** will consume two of these components, and a **dvec2** will consume all four components available within a location. A **dvec3** or **dvec4** can only be declared without specifying a **component**. A **dvec3** will consume all four components of the first location and components 0 and 1 of the second location. This leaves components 2 and 3 available for other component-qualified declarations.

For example:

```
// a consumes components 2 and 3 of location 4
layout(location = 4, component = 2) in vec2 a;

// b consumes component 1 of location 4
layout(location = 4, component = 1) in float b;

// ERROR: c overflows component 3
layout(location = 3, component = 2) in vec3 c;

// d consumes components 2 and 3 of location 5
layout(location = 5, component = 2) in double d;

// ERROR: e overflows component 3 of location 6
layout(location = 6, component = 2) in dvec2 e;

// ERROR: f overlaps with g
layout(location = 7, component = 0) double f;
layout(location = 7, component = 1) float g;

layout(location = 8) in dvec3 h; // components 0,1,2 and 3 of location 8
                               // and components 0 and 1 of location 9
layout(location = 9, component = 2) in float i; // okay, compts 2 and 3
```

If the variable is an array, each element of the array, in order, is assigned to consecutive locations, but all at the same specified component within each location. For example:

```
// component 3 in 6 locations are consumed
layout(location = 2, component = 3) in float d[6];
```

That is, location 2 component 3 will hold $d[0]$, location 3 component 3 will hold $d[1]$, ..., up through location 7 component 3 holding $d[5]$.

This allows packing of two arrays into the same set of locations:

```
// e consumes beginning (components 0, 1 and 2) of each of 6 slots
layout(location = 0, component = 0) in vec3 e[6];

// f consumes last component of the same 6 slots
layout(location = 0, component = 3) in float f[6];
```

If applying this to an array of arrays, all levels of arrayness are removed to get to the elements that are assigned per location to the specified component. These non-arrayed elements will fill the locations in the order specified for arrays of arrays in section 4.1.9 "Arrays".

It is a compile-time error to apply the **component** qualifier to a matrix, a structure, a block, or an array containing any of these. It is a compile-time error to use **component** 1 or 3 as the beginning of a **double** or **dvec2**. It is a link-time error to specify different components for the same variable within a program.

Location aliasing is causing two variables or block members to have the same location number. *Component aliasing* is assigning the same (or overlapping) component numbers for two location aliases. (Recall if **component** is not used, components are assigned starting with 0.) With one exception, location aliasing is allowed only if it does not cause component aliasing; it is a compile-time or link-time error to cause component aliasing. Further, when location aliasing, the aliases sharing the location must have the same underlying numerical type (floating-point or integer) and the same auxiliary storage and interpolation qualification. The one exception where component aliasing is permitted is for two input variables (not block members) to a vertex shader, which are allowed to have component aliasing. This vertex-variable component aliasing is intended only to support vertex shaders where each execution path accesses at most one input per each aliased component. Implementations are permitted, but not required, to generate link-time errors if they detect that every path through the vertex shader executable accesses multiple inputs aliased to any single component.

4.4.1.1 Tessellation Evaluation Inputs

Additional input layout qualifier identifiers allowed for tessellation evaluation shaders are:

```
layout-qualifier-id :
    triangles
    quads
    isolines
    equal_spacing
    fractional_even_spacing
    fractional_odd_spacing
    cw
    ccw
    point_mode
```

One subset of these identifiers, *primitive mode*, is used to specify a tessellation primitive mode to be used by the tessellation primitive generator. To specify a primitive mode, the identifier must be one of **triangles**, **quads**, or **isolines**, which specify that the tessellation primitive generator should subdivide a triangle into smaller triangles, a quad into triangles, or a quad into a collection of lines, respectively.

A second subset of these identifiers, *vertex spacing*, is used to specify the spacing used by the tessellation primitive generator when subdividing an edge. To specify vertex spacing, the identifier must be one of the following.

equal_spacing signifying that edges should be divided into a collection of equal-sized segments.

fractional_even_spacing signifying that edges should be divided into an even number of equal-length segments plus two additional shorter "fractional" segments.

fractional_odd_spacing signifying that edges should be divided into an odd number of equal-length segments plus two additional shorter "fractional" segments.

A third subset of these identifiers, *ordering*, specifies whether the tessellation primitive generator produces triangles in clockwise or counter-clockwise order, according to the coordinate system depicted in the OpenGL specification. The ordering identifiers **cw** and **ccw** indicate clockwise and counter-clockwise triangles, respectively. If the tessellation primitive generator does not produce triangles, ordering is ignored.

Finally, *point mode*, is specified with the identifier **point_mode** indicating the tessellation primitive generator should produce a point for each distinct vertex in the subdivided primitive, rather than generating lines or triangles.

Any or all of these identifiers may be specified one or more times in a single input layout declaration. If primitive mode, vertex spacing, or ordering is declared more than once in the tessellation evaluation shaders of a program, all such declarations must use the same identifier.

At least one tessellation evaluation shader (compilation unit) in a program must declare a primitive mode in its input layout. Declaring vertex spacing, ordering, or point mode identifiers is optional. It is not required that all tessellation evaluation shaders in a program declare a primitive mode. If spacing or vertex ordering declarations are omitted, the tessellation primitive generator will use equal spacing or counter-clockwise vertex ordering, respectively. If a point mode declaration is omitted, the tessellation primitive generator will produce lines or triangles according to the primitive mode.

4.4.1.2 Geometry Shader Inputs

Additional layout qualifier identifiers for geometry shader inputs include *primitive* identifiers and an *invocation count* identifier:

```
layout-qualifier-id :
    points
    lines
    lines_adjacency
    triangles
    triangles_adjacency
    invocations = integer-constant-expression
```

The identifiers **points**, **lines**, **lines_adjacency**, **triangles**, and **triangles_adjacency** are used to specify the type of input *primitive* accepted by the geometry shader, and only one of these is accepted. At least one geometry shader (compilation unit) in a program must declare this input primitive layout, and all geometry shader input layout declarations in a program must declare the same layout. It is not required that all geometry shaders in a program declare an input primitive layout.

The identifier **invocations** is used to specify the number of times the geometry shader executable is invoked for each input primitive received. Invocation count declarations are optional. If no invocation count is declared in any geometry shader in a program, the geometry shader will be run once for each input primitive. If an invocation count is declared, all such declarations must specify the same count. If a shader specifies an invocation count greater than the implementation-dependent maximum, or less than or equal to zero, a compile-time error results.

For example,

```
layout(triangles, invocations = 6) in;
```

will establish that all inputs to the geometry shader are triangles and that the geometry shader executable is run six times for each triangle processed.

All geometry shader input unsized array declarations will be sized by an earlier input primitive layout qualifier, when present, as per the following table.

Layout	Size of Input Arrays
points	1
lines	2
lines_adjacency	4
triangles	3
triangles_adjacency	6

The intrinsically declared input array `gl_in[]` will also be sized by any input primitive-layout declaration. Hence, the expression

```
gl_in.length()
```

will return the value from the table above.

For inputs declared without an array size, including intrinsically declared inputs (i.e., `gl_in`), a layout must be declared before any use of the method **length** or other any array use that requires the array size to be known.

It is a compile-time error if a layout declaration's array size (from table above) does not match all the explicit array sizes specified in declarations of an input variables in the same shader. The following includes examples of compile-time errors:

```
// code sequence within one shader...
in vec4 Color1[];    // legal, size still unknown
in vec4 Color2[2];  // legal, size is 2
in vec4 Color3[3];  // illegal, input sizes are inconsistent
layout(lines) in;   // legal for Color2, input size is 2, matching Color2
in vec4 Color4[3];  // illegal, contradicts layout of lines
layout(lines) in;   // legal, matches other layout() declaration
layout(triangles) in; // illegal, does not match earlier layout() declaration
```

It is a link-time error if not all provided sizes (sized input arrays and layout size) match across all geometry shaders in a program.

4.4.1.3 Fragment Shader Inputs

Additional fragment layout qualifier identifiers include the following for *gl_FragCoord* :

layout-qualifier-id :
origin_upper_left
pixel_center_integer

By default, *gl_FragCoord* assumes a lower-left origin for window coordinates and assumes pixel centers are located at half-pixel coordinates. For example, the (x, y) location $(0.5, 0.5)$ is returned for the lower-left-most pixel in a window. The origin can be changed by redeclaring *gl_FragCoord* with the **origin_upper_left** identifier, moving the origin of *gl_FragCoord* to the upper left of the window, with y increasing in value toward the bottom of the window. The values returned can also be shifted by half a pixel in both x and y by **pixel_center_integer** so it appears the pixels are centered at whole number pixel offsets. This moves the (x, y) value returned by *gl_FragCoord* of $(0.5, 0.5)$ by default, to $(0.0, 0.0)$ with **pixel_center_integer**.

Redeclarations are done as follows

```
in vec4 gl_FragCoord;      // redeclaration that changes nothing is allowed

// All the following are allowed redeclaration that change behavior
layout(origin_upper_left) in vec4 gl_FragCoord;
layout(pixel_center_integer) in vec4 gl_FragCoord;
layout(origin_upper_left, pixel_center_integer) in vec4 gl_FragCoord;
```

If *gl_FragCoord* is redeclared in any fragment shader in a program, it must be redeclared in all the fragment shaders in that program that have a static use of *gl_FragCoord*. All redeclarations of *gl_FragCoord* in all fragment shaders in a single program must have the same set of qualifiers. Within any shader, the first redeclarations of *gl_FragCoord* must appear before any use of *gl_FragCoord*. The built-in *gl_FragCoord* is only predeclared in fragment shaders, so redeclaring it in any other shader language results in a compile-time error.

Redeclaring *gl_FragCoord* with **origin_upper_left** and/or **pixel_center_integer** qualifiers only affects *gl_FragCoord.x* and *gl_FragCoord.y*. It has no effect on rasterization, transformation, or any other part of the OpenGL pipeline or language features.

Fragment shaders also allow the following layout qualifier on **in** only (not with variable declarations)

layout-qualifier-id :
early_fragment_tests

to request that fragment tests be performed before fragment shader execution, as described in section 15.2.4 “Early Fragment Tests” of the OpenGL Specification.

For example,

```
layout(early_fragment_tests) in;
```

Specifying this will make per-fragment tests be performed before fragment shader execution. If this is not declared, per-fragment tests will be performed after fragment shader execution. Only one fragment shader (compilation unit) need declare this, though more than one can. If at least one declares this, then it is enabled.

4.4.1.4 Compute Shader Inputs

There are no layout location qualifiers for compute shader inputs.

Layout qualifier identifiers for compute shader inputs are the work-group size qualifiers:

```
layout-qualifier-id :
    local_size_x = integer-constant-expression
    local_size_y = integer-constant-expression
    local_size_z = integer-constant-expression
```

The **local_size_x**, **local_size_y**, and **local_size_z** qualifiers are used to declare a fixed local group size by the compute shader in the first, second, and third dimension, respectively. The default size in each dimension is 1. If a shader does not specify a size for one of the dimensions, that dimension will have a size of 1.

For example, the following declaration in a compute shader

```
layout(local_size_x = 32, local_size_y = 32) in;
```

is used to declare a two-dimensional compute shader with a local size of 32 X 32 elements, which is equivalent to a three-dimensional compute shader where the third dimension has size one.

As another example, the declaration

```
layout(local_size_x = 8) in;
```

effectively specifies that a one-dimensional compute shader is being compiled, and its size is 8 elements.

If the fixed local group size of the shader in any dimension is greater than the maximum size supported by the implementation for that dimension, a compile-time error results. Also, if such a layout qualifier is declared more than once in the same shader, all those declarations must set the same set of local work-group sizes and set them to the same values; otherwise a compile-time error results. If multiple compute shaders attached to a single program object declare a fixed local group size, the declarations must be identical; otherwise a link-time error results. It is a compile-time error to declare a local group size to be less than or equal to zero.

Furthermore, if a program object contains any compute shaders, at least one must contain an input layout qualifier specifying a fixed local group size for the program, or a link-time error will occur.

4.4.2 Output Layout Qualifiers

Some output layout qualifiers apply to all shader languages and some apply only to specific languages. The latter are discussed in separate sections below.

As with input layout qualifiers, all shaders except compute shaders allow **location** layout qualifiers on output variable declarations, output block declarations, and output block member declarations. Of these, variables and block members (but not blocks) additionally allow the **component** layout qualifier.

The layout qualifier identifiers for outputs are:

layout-qualifier-id :
location = *integer-constant-expression*
component = *integer-constant-expression*

The usage and rules for using the **component** qualifier, and applying **location** qualifier to blocks and structures, are exactly as described in section 4.4.1 "Input Layout Qualifiers". Additionally, for fragment shader outputs, if two variables are placed within the same location, they must have the same underlying type (floating-point or integer). No component aliasing of output variables or members is allowed.

Fragment shaders allow an additional **index** output layout qualifier:

layout-qualifier-id :
index = *integer-constant-expression*

Each of these qualifiers may appear at most once. If **index** is specified, **location** must also be specified. If **index** is not specified, the value 0 is used. For example, in a fragment shader,

```
layout(location = 3) out vec4 color;
```

will establish that the fragment shader output *color* is assigned to fragment color 3 as the first (index zero) input to the blend equation. And,

```
layout(location = 3, index = 1) out vec4 factor;
```

will establish that the fragment shader output *factor* is assigned to fragment color 3 as the second (index one) input to the blend equation.

For fragment-shader outputs, the location and index specify the color output number and index receiving the values of the output. For outputs of all other shader stages, the location specifies a vector number that can be used to match against inputs in a subsequent shader stage, even if that shader is in a different program object.

If a declared output is a scalar or vector type other than **dvec3** or **dvec4**, it will consume a single location. Outputs of type **dvec3** or **dvec4** will consume two consecutive locations. Outputs of type **double** and **dvec2** will consume only a single location, in all stages.

If the declared output is an array, it will be assigned consecutive locations starting with the location specified. For example,

```
layout(location = 2) out vec4 colors[3];
```

will establish that *colors* is assigned to vector location numbers 2, 3, and 4.

If the declared output is an $n \times m$ single- or double-precision matrix, it will be assigned multiple locations starting with the location specified. The number of locations assigned will be the same as for an n -element array of m -component vectors.

If the declared output is a structure, its members will be assigned consecutive locations in the order of declaration, with the first member assigned the location specified for the structure. The number of locations consumed by a structure member is determined by applying the rules above recursively as though the structure member were declared as an output variable of the same type.

Location layout qualifiers may be used on output variables declared as structures. However, it is a compile-time error to use a location qualifier on a structure member.

The number of output locations available to a shader is limited. For fragment shaders, the limit is the advertised number of draw buffers. For all other shaders, the limit is implementation-dependent and must be no less than one fourth of the advertised maximum output component count. (Compute shaders have no outputs.) A program will fail to link if any attached shader uses a location greater than or equal to the number of supported locations, unless device-dependent optimizations are able to make the program fit within available hardware resources. Compile-time errors may also be given if at compile time it is known the link will fail. A negative output location will result in a compile-time error. It is also a compile-time error if a fragment shader sets a layout index to less than 0 or greater than 1.

It is a compile-time or link-time error if any of the following occur:

- any two fragment shader output variables are assigned to the same location and index, or
- any two geometry shader output variables are assigned the same location and stream, or
- if any two output variables from the same vertex or tessellation shader stage are assigned to the same location.

For fragment shader outputs, locations can be assigned using either a layout qualifier or via the OpenGL API. For all shader types, a program will fail to link if explicit location assignments leave the linker unable to find space for other variables without explicit assignments.

If an output variable with no location or index assigned in the shader text has a location specified through the OpenGL API, the API-assigned location will be used. Otherwise, such variables will be assigned a location by the linker. All such assignments will have a color index of zero. See section 15.2 “Shader Execution” of the OpenGL Graphics System Specification for more details. A link-time error will occur if an output variable is declared in multiple shaders of the same language with conflicting location or index values.

For the purposes of determining if a non-fragment output matches an input from a subsequent shader stage, the location layout qualifier (if any) must match.

4.4.2.1 Transform Feedback Layout Qualifiers

The vertex, tessellation, and geometry stages allow shaders to control transform feedback. When doing this, shaders will dictate which transform feedback buffers are in use, which output variables will be written to which buffers, and how each buffer is laid out. To accomplish this, shaders allow the following layout qualifier identifiers on output declarations:

```
layout-qualifier-id :
    xfb_buffer = integer-constant-expression
    xfb_offset = integer-constant-expression
    xfb_stride = integer-constant-expression
```

Any shader making any static use (after preprocessing) of any of these **xfb_** qualifiers will cause the shader to be in a transform feedback capturing mode and hence responsible for describing the transform feedback setup. This mode will capture any output selected by **xfb_offset**, directly or indirectly, to a transform feedback buffer.

The **xfb_buffer** qualifier specifies which transform feedback buffer will capture outputs selected with **xfb_offset**. The **xfb_buffer** qualifier can be applied to the qualifier **out**, to output variables, to output blocks, and to output block members. Shaders in the transform feedback capturing mode have an initial global default of

```
layout(xfb_buffer = 0) out;
```

This default can be changed by declaring a different buffer with **xfb_buffer** on the interface qualifier **out**. This is the only way the global default can be changed. When a variable or output block is declared without an **xfb_buffer** qualifier, it inherits the global default buffer. When a variable or output block is declared with an **xfb_buffer** qualifier, it has that declared buffer. All members of a block inherit the block's buffer. A member is allowed to declare an **xfb_buffer**, but it must match the buffer inherited from its block, or a compile-time error results.

```
layout(xfb_buffer=2, xfb_offset=0) out block { // block's buffer is 2
    layout(xfb_buffer = 2) vec4 v; // okay, matches the inherited 2
    layout(xfb_buffer = 3) vec4 u; // ERROR, mismatched buffer
    vec4 w; // inherited
};
layout(xfb_offset=16) out vec4 t; // initial default is buffer 0
layout(xfb_buffer=1) out; // new global default of 1
out block { // block has buffer 1
    vec4 x; // x has buffer 1 (not captured)
    layout(xfb_buffer = 1) vec4 y; // okay (not captured)
    layout(xfb_buffer = 0) vec4 z; // ERROR, mismatched buffer
};
layout(xfb_offset=0) out vec4 g; // g has buffer 1
layout(xfb_buffer=2) out vec4 h; // does not change global default
layout(xfb_offset=16) out vec4 j; // j has buffer 1
```

Note this means all members of a block that go to a transform feedback buffer will go to the same buffer.

When a block is declared as an array, all members of block array-element 0 are captured, as previously described, by the declared or inherited **xfb_buffer**. Generally, an array of size N of blocks is captured by N consecutive buffers, with all members of block array-element E captured by buffer B , where B equals the declared or inherited **xfb_buffer** plus E .

It is a compile-time or link-time error to specify an **xfb_buffer**, including any additional buffers needed to capture an arrays of blocks, that is less than zero or greater than or equal to the implementation-dependent constant `gl_MaxTransformFeedbackBuffers`.

The **xfb_offset** qualifier assigns a byte offset within a transform feedback buffer. Only variables, block members, or blocks can be qualified with **xfb_offset**. If a block is qualified with **xfb_offset**, all its members are assigned transform feedback buffer offsets. If a block is not qualified with **xfb_offset**, any members of that block not qualified with an **xfb_offset** will not be assigned transform feedback buffer offsets. Only variables and block members that are assigned offsets will be captured (thus, a proper subset of a block can be captured). Each time such a variable or block member is written in a shader, the written value is captured at the assigned offset. If such a block member or variable is not written during a shader invocation, the buffer contents at the assigned offset will be undefined. Even if there are no static

writes to a variable or member that is assigned a transform feedback offset, the space is still allocated in the buffer and still affects the stride.

Variables and block members qualified with **xfb_offset** can be scalars, vectors, matrices, structures, and (sized) arrays of these. The offset must be a multiple of the size of the first component of the first qualified variable or block member, or a compile-time error results. Further, if applied to an aggregate containing a **double**, the offset must also be a multiple of 8, and the space taken in the buffer will be a multiple of 8. The given offset applies to the first component of the first member of the qualified entity. Then, within the qualified entity, subsequent components are each assigned, in order, to the next available offset aligned to a multiple of that component's size. Aggregate types are flattened down to the component level to get this sequence of components. It is a compile-time error to apply **xfb_offset** to the declaration of an unsized array.

No aliasing in output buffers is allowed: It is a compile-time or link-time error to specify variables with overlapping transform feedback offsets.

The **xfb_stride** qualifier specifies how many bytes are consumed by each captured vertex. It applies to the transform feedback buffer for that declaration, whether it is inherited or explicitly declared. It can be applied to variables, blocks, block members, or just the qualifier **out**. If the buffer is capturing any outputs with double-precision components, the stride must be a multiple of 8, otherwise it must be a multiple of 4, or a compile-time or link-time error results. It is a compile-time or link-time error to have any **xfb_offset** that overflows **xfb_stride**, whether stated on declarations before or after the **xfb_stride**, or in different compilation units. While **xfb_stride** can be declared multiple times for the same buffer, it is a compile-time or link-time error to have different values specified for the stride for the same buffer.

For example:

```
// buffer 1 has 32-byte stride
layout(xfb_buffer = 1, xfb_stride = 32) out;

// same as previous example; order within layout does not matter
layout(xfb_stride = 32, xfb_buffer = 1) out;

// everything in this block goes to buffer 0
layout(xfb_buffer = 0, xfb_stride = 32) out block1 {
    layout(xfb_offset = 0) vec4 a; // a goes to byte offset 0 of buffer 0
    layout(xfb_offset = 16) vec4 b; // b goes to offset 16 of buffer 0
};

layout(xfb_buffer = 3, xfb_offset = 12) out block2 {
    vec4 v; // v will be written to byte offsets 12 through 27 of buffer
    float u; // u will be written to offset 28
    layout(xfb_offset = 40) vec4 w;
    vec4 x; // x will be written to offset 56, the next available offset
};

layout(xfb_buffer = 2, xfb_stride = 32) out block3 {
    layout(xfb_offset = 12) vec3 c;
    layout(xfb_offset = 24) vec3 d; // ERROR, requires stride of 36
    layout(xfb_offset = 0) vec3 g; // okay, increasing order not required
};
```

When no **xfb_stride** is specified for a buffer, the stride of the buffer will be the smallest needed to hold the variable placed at the highest offset, including any required padding. For example:

```
// if there no other declarations for buffer 3, it has stride 32
layout(xfb_buffer = 3) out block4 {
    layout(xfb_offset = 0)  vec4 e;
    layout(xfb_offset = 16) vec4 f;
};
```

The resulting stride (implicit or explicit), when divided by 4, must be less than or equal to the implementation-dependent constant *gl_MaxTransformFeedbackInterleavedComponents*.

4.4.2.2 Tessellation Control Outputs

Other than for the transform feedback layout qualifiers, tessellation control shaders allow output layout qualifiers only on the interface qualifier **out**, not on an output block, block member, or variable declaration. The output layout qualifier identifiers allowed for tessellation control shaders include the vertex-count layout qualifier:

layout-qualifier-id :
vertices = *integer-constant-expression*

The identifier **vertices** specifies the number of vertices in the output patch produced by the tessellation control shader, which also specifies the number of times the tessellation control shader is invoked. It is a compile- or link-time error for the output vertex count to be less than or equal to zero, or greater than the implementation-dependent maximum patch size.

The intrinsically declared tessellation control output array **gl_out[]** will also be sized by any output layout declaration. Hence, the expression

```
gl_out.length()
```

will return the output patch vertex count specified in a previous output layout qualifier. For outputs declared without an array size, including intrinsically declared outputs (i.e., **gl_out**), a layout must be declared before any use of the method **length()** or other array use requires its size to be known.

It is a compile-time error if the output patch vertex count specified in an output layout qualifier does not match the array size specified in any output variable declaration in the same shader.

All tessellation control shader layout declarations in a program must specify the same output patch vertex count. There must be at least one layout qualifier specifying an output patch vertex count in any program containing tessellation control shaders; however, such a declaration is not required in all tessellation control shaders.

4.4.2.3 Geometry Outputs

Geometry shaders can have three additional types of output layout identifiers: an output *primitive type*, a maximum output *vertex count*, and per-output *stream* numbers. The primitive type and vertex count identifiers are allowed only on the interface qualifier **out**, not on an output block, block member, or variable declaration. The stream identifier is allowed on the interface qualifier **out**, on output blocks, and on variable declarations.

The layout qualifier identifiers for geometry shader outputs are

layout-qualifier-id :

- points**
- line_strip**
- triangle_strip**
- max_vertices** = *integer-constant-expression*
- stream** = *integer-constant-expression*

The primitive type identifiers **points**, **line_strip**, and **triangle_strip** are used to specify the type of output primitive produced by the geometry shader, and only one of these is accepted. At least one geometry shader (compilation unit) in a program must declare an output primitive type, and all geometry shader output primitive type declarations in a program must declare the same primitive type. It is not required that all geometry shaders in a program declare an output primitive type.

The vertex count identifier **max_vertices** is used to specify the maximum number of vertices the shader will ever emit in a single invocation. At least one geometry shader (compilation unit) in a program must declare a maximum output vertex count, and all geometry shader output vertex count declarations in a program must declare the same count. It is not required that all geometry shaders in a program declare a count.

In this example,

```
layout(triangle_strip, max_vertices = 60) out; // order does not matter
layout(max_vertices = 60) out;           // redeclaration okay
layout(triangle_strip) out;             // redeclaration okay
layout(points) out;                     // error, contradicts triangle_strip
layout(max_vertices = 30) out;          // error, contradicts 60
```

all outputs from the geometry shader are triangles and at most 60 vertices will be emitted by the shader. It is an error for the maximum number of vertices to be greater than *gl_MaxGeometryOutputVertices*.

The identifier **stream** is used to specify that a geometry shader output variable or block is associated with a particular vertex stream (numbered beginning with zero). A default stream number may be declared at global scope by qualifying interface qualifier **out** as in this example:

```
layout(stream = 1) out;
```

The stream number specified in such a declaration replaces any previous default and applies to all subsequent block and variable declarations until a new default is established. The initial default stream number is zero.

Each output block or non-block output variable is associated with a vertex stream. If the block or variable is declared with the stream identifier, it is associated with the specified stream; otherwise, it is associated with the current default stream. A block member may be declared with a stream identifier, but the specified stream must match the stream associated with the containing block. One example:

```

layout(stream=1) out;           // default is now stream 1
out vec4 var1;                 // var1 gets default stream (1)
layout(stream=2) out Block1 {  // "Block1" belongs to stream 2
    layout(stream=2) vec4 var2; // redundant block member stream decl
    layout(stream=3) vec2 var3; // ILLEGAL (must match block stream)
    vec3 var4;                 // belongs to stream 2
};
layout(stream=0) out;         // default is now stream 0
out vec4 var5;               // var5 gets default stream (0)
out Block2 {                 // "Block2" gets default stream (0)
    vec4 var6;
};
layout(stream=3) out vec4 var7; // var7 belongs to stream 3

```

Each vertex emitted by the geometry shader is assigned to a specific stream, and the attributes of the emitted vertex are taken from the set of output blocks and variables assigned to the targeted stream. After each vertex is emitted, the values of all output variables become undefined. Additionally, the output variables associated with each vertex stream may share storage. Writing to an output variable associated with one stream may overwrite output variables associated with any other stream. When emitting each vertex, a geometry shader should write to all outputs associated with the stream to which the vertex will be emitted and to no outputs associated with any other stream.

If a geometry shader output block or variable is declared more than once, all such declarations must associate the variable with the same vertex stream. If any stream declaration specifies a non-existent stream number, the shader will fail to compile.

Built-in geometry shader outputs are always associated with vertex stream zero.

All geometry shader output layout declarations in a program must declare the same layout and same value for **max_vertices**. If geometry shaders are in a program, there must be at least one geometry output layout declaration somewhere in that program, but not all geometry shaders (compilation units) are required to declare it.

4.4.2.4 Fragment Outputs

The built-in fragment shader variable *gl_FragDepth* may be redeclared using one of the following layout qualifiers.

```

layout-qualifier-id :
    depth_any
    depth_greater
    depth_less
    depth_unchanged

```

For example:

```
layout(depth_greater) out float gl_FragDepth;
```

The layout qualifier for *gl_FragDepth* constrains intentions of the final value of *gl_FragDepth* written by any shader invocation. GL implementations are allowed to perform optimizations assuming that the depth test fails (or passes) for a given fragment if all values of *gl_FragDepth* consistent with the layout qualifier would fail (or pass). This potentially includes skipping shader execution if the fragment is discarded because it is occluded and the shader has no side effects. If the final value of *gl_FragDepth* is inconsistent with its layout qualifier, the result of the depth test for the corresponding fragment is undefined. However, no error will be generated in this case. If the depth test passes and depth writes are enabled, the value written to the depth buffer is always the value of *gl_FragDepth*, whether or not it is consistent with the layout qualifier.

By default, *gl_FragDepth* is qualified as *depth_any*. When the layout qualifier for *gl_FragDepth* is *depth_any*, the shader compiler will note any assignment to *gl_FragDepth* modifying it in an unknown way, and depth testing will always be performed after the shader has executed. When the layout qualifier is *depth_greater*, the GL can assume that the final value of *gl_FragDepth* is greater than or equal to the fragment's interpolated depth value, as given by the *z* component of *gl_FragCoord*. When the layout qualifier is *depth_less*, the GL can assume that any modification of *gl_FragDepth* will only decrease its value. When the layout qualifier is *depth_unchanged*, the shader compiler will honor any modification to *gl_FragDepth*, but the rest of the GL can assume that *gl_FragDepth* is not assigned a new value.

Redeclarations of *gl_FragDepth* are performed as follows:

```
// redeclaration that changes nothing is allowed
out float gl_FragDepth;

// assume it may be modified in any way
layout(depth_any) out float gl_FragDepth;

// assume it may be modified such that its value will only increase
layout(depth_greater) out float gl_FragDepth;

// assume it may be modified such that its value will only decrease
layout(depth_less) out float gl_FragDepth;

// assume it will not be modified
layout(depth_unchanged) out float gl_FragDepth;
```

If *gl_FragDepth* is redeclared in any fragment shader in a program, it must be redeclared in all fragment shaders in that program that have static assignments to *gl_FragDepth*. All redeclarations of *gl_FragDepth* in all fragment shaders in a single program must have the same set of qualifiers. Within any shader, the first redeclarations of *gl_FragDepth* must appear before any use of *gl_FragDepth*. The built-in *gl_FragDepth* is only predeclared in fragment shaders, so redeclaring it in any other shader language results in a compile-time error.

4.4.3 Uniform Variable Layout Qualifiers

Layout qualifiers can be used for uniform variables and subroutine uniforms. The layout qualifier identifiers for uniform variables and subroutine uniforms are:

layout-qualifier-id :
location = *integer-constant-expression*

The location identifier can be used with default-block uniform variables and subroutine uniforms. The location specifies the location by which the OpenGL API can reference the uniform and update its value. Individual elements of a uniform array are assigned consecutive locations with the first element taking location *location*. No two default-block uniform variables in the program can have the same location, even if they are unused, otherwise a compile-time or link-time error will be generated. No two subroutine uniform variables can have the same location in the same shader stage, otherwise a compile-time or link-time error will be generated. Valid locations for default-block uniform variable locations are in the range of 0 to the implementation-defined maximum number of uniform locations minus one. Valid locations for subroutine uniforms are in the range of 0 to the implementation-defined per-stage maximum number of subroutine uniform locations minus one.

Locations can be assigned to default-block uniform arrays and structures. The first inner-most scalar, vector or matrix member or element takes the specified *location* and the compiler assigns the next inner-most member or element the next incremental location value. Each subsequent inner-most member or element gets incremental locations for the entire structure or array. This rule applies to nested structures and arrays and gives each inner-most scalar, vector, or matrix type a unique location. For arrays without an explicit size, the size is calculated based on its static usage. When the linker generates locations for uniforms without an explicit location, it assumes for all uniforms with an explicit location all their array elements and structure members are used and the linker will not generate a conflicting location, even if that element of member is deemed unused.

When generating SPIR-V for OpenGL, it is a compile-time error to not include a location for individual (default block) non-opaque uniform variables.

4.4.4 Subroutine Function Layout Qualifiers

Layout qualifiers can be used for subroutine functions. The layout qualifier identifiers for subroutine functions are:

layout-qualifier-id :
index = *integer-constant-expression*

Each subroutine with an index qualifier in the shader must be given a unique index, otherwise a compile- or link-time error will be generated. The indices must be in the range of 0 to the implementation defined maximum number of subroutines minus one. It is recommended, but not required, that the shader assigns a range of tightly packed *index* values starting from zero so that the OpenGL subroutine function enumeration API returns a non-empty name for all active indices.

4.4.5 Uniform and Shader Storage Block Layout Qualifiers

Layout qualifiers can be used for uniform and shader storage blocks, but not for non-block uniform declarations. The layout qualifier identifiers (and **shared** keyword) for uniform and shader storage blocks are

```
layout-qualifier-id :
    shared
    packed
    std140
    std430
    row_major
    column_major
    binding = integer-constant-expression
    offset = integer-constant-expression
    align = integer-constant-expression
```

None of these have any semantic effect at all on the usage of the variables being declared; they only describe how data is laid out in memory. For example, matrix semantics are always column-based, as described in the rest of this specification, no matter what layout qualifiers are being used.

Uniform and shader storage block layout qualifiers can be declared for global scope, on a single uniform or shader storage block, or on a single block member declaration.

Default layouts for **shared**, **packed**, **std140**, **std430**, **row_major**, and **column_major** are established at global scope for uniform blocks as

```
layout(layout-qualifier-id-list) uniform;
```

and for shader storage blocks as

```
layout(layout-qualifier-id-list) buffer;
```

When this is done, the previous default qualification is first inherited and then overridden as per the override rules listed below for each qualifier listed in the declaration. The result becomes the new default qualification scoped to subsequent uniform or shader storage block definitions.

The initial state of compilation when generating SPIR-V is as if the following were declared:

```
layout(std140, column_major) uniform;
layout(std430, column_major) buffer;
```

The initial state of compilation when not generating SPIR-V is as if the following were declared:

```
layout(shared, column_major) uniform;
layout(shared, column_major) buffer;
```

Uniform and shader storage blocks can be declared with optional layout qualifiers, and so can their individual member declarations. Such block layout qualification is scoped only to the content of the block. As with global layout declarations, block layout qualification first inherits from the current default

qualification and then overrides it. Similarly, individual member layout qualification is scoped just to the member declaration, and inherits from and overrides the block's qualification.

The **shared** qualifier overrides only the **std140**, **std430**, and **packed** qualifiers; other qualifiers are inherited. The compiler/linker will ensure that multiple programs and programmable stages containing this definition will share the same memory layout for this block, as long as all arrays are declared with explicit sizes and all matrices have matching **row_major** and/or **column_major** qualifications (which may come from a declaration outside the block definition). This allows use of the same buffer to back the same block definition across different programs. It is a compile-time error to use the **shared** qualifier when generating SPIR-V.

The **packed** qualifier overrides only **std140**, **std430**, and **shared**; other qualifiers are inherited. When **packed** is used, no shareable layout is guaranteed. The compiler and linker can optimize memory use based on what variables actively get used and on other criteria. Offsets must be queried, as there is no other way of guaranteeing where (and which) variables reside within the block. It is a link-time error to access the same packed uniform or shader storage block in multiple stages within a program. Attempts to access the same packed uniform or shader storage block across programs can result in conflicting member offsets and in undefined values being read. However, implementations may aid application management of packed blocks by using canonical layouts for packed blocks. It is a compile-time error to use the **packed** qualifier when generating SPIR-V.

The **std140** and **std430** qualifiers override only the **packed**, **shared**, **std140**, and **std430** qualifiers; other qualifiers are inherited. The **std430** qualifier is supported only for shader storage blocks; using **std430** on a uniform block will result in a compile-time error. The layout is explicitly determined by this, as described in section 7.6.2 “Uniform Blocks” under Standard Uniform Block Layout of the OpenGL Graphics System Specification. Hence, as in **shared** above, the resulting layout is shareable across programs.

Layout qualifiers on member declarations cannot use the **shared**, **packed**, **std140**, or **std430** qualifiers. These can only be used at global scope (without an object) or on a block declaration, or a compile-time error results.

The **row_major** and **column_major** qualifiers affect the layout of matrices, including all matrices contained in structures and arrays they are applied to, to all depths of nesting. These qualifiers can be applied to other types, but will have no effect.

The **row_major** qualifier overrides only the **column_major** qualifier; other qualifiers are inherited. Elements within a matrix row will be contiguous in memory.

The **column_major** qualifier overrides only the **row_major** qualifier; other qualifiers are inherited. Elements within a matrix column will be contiguous in memory.

The **binding** identifier specifies the uniform buffer binding point corresponding to the uniform or shader storage block, which will be used to obtain the values of the member variables of the block. It is a compile-time error to specify the **binding** identifier for the global scope or for block member declarations. Any uniform or shader storage block declared without a **binding** identifier is initially assigned to block binding point zero. After a program is linked, the binding points used for uniform and shader storage blocks declared with or without a **binding** identifier can be updated by the OpenGL API.

If the **binding** identifier is used with a uniform or shader storage block instantiated as an array, the first element of the array takes the specified block binding and each subsequent element takes the next

consecutive uniform block binding point. For an array of arrays, each element (e.g., 6 elements for `a[2][3]`) gets a binding point, and they are ordered per the array of array ordering described in section 4.1.9 “Arrays.”

If the binding point for any uniform or shader storage block instance is less than zero, or greater than or equal to the implementation-dependent maximum number of uniform buffer bindings, a compile-time error will occur. When the **binding** identifier is used with a uniform or shader storage block instanced as an array of size N , all elements of the array from **binding** through **binding** + $N - 1$ must be within this range. It is a compile-time or link-time error to use the same **binding** number for more than one uniform block or for more than one buffer block.

When multiple arguments are listed in a **layout** declaration, the effect will be the same as if they were declared one at a time, in order from left to right, each in turn inheriting from and overriding the result from the previous qualification.

For example

```
layout(row_major, column_major)
```

results in the qualification being *column_major*. Other examples:

```
layout(shared, row_major) uniform; // default is now shared and row_major

layout(std140) uniform Transform { // layout of this block is std140
    mat4 M1;                        // row_major
    layout(column_major) mat4 M2;   // column major
    mat3 N1;                        // row_major
};

uniform T2 { // layout of this block is shared
    ...
};

layout(column_major) uniform T3 { // shared and column_major
    mat4 M3;                        // column_major
    layout(row_major) mat4 m4;     // row major
    mat3 N2;                        // column_major
};
```

The **offset** qualifier can only be used on block members of blocks declared with **std140** or **std430** layouts. The **offset** qualifier forces the qualified member to start at or after the specified *integral-constant-expression*, which will be its byte offset from the beginning of the buffer. It is a compile-time error to have any offset, explicit or assigned, that lies within another member of the block. When not generating SPIR-V, it is a compile-time error to specify an offset that is smaller than the offset of the previous member in the block. Two blocks linked together in the same program with the same block name must have the exact same set of members qualified with **offset** and their *integral-constant-expression* values must be the same, or a link-time error results. The specified offset must be a multiple of the base alignment of the type of the block member it qualifies, or a compile-time error results.

The **align** qualifier can only be used on blocks or block members, and only for blocks declared with **std140** or **std430** layouts. The **align** qualifier makes the start of each block member have a minimum byte alignment. It does not affect the internal layout within each member, which will still follow the **std140** or **std430** rules. The specified alignment must be greater than 0 and a power of 2, or a compile-time error results.

The *actual alignment* of a member will be the greater of the specified **align** alignment and the standard (e.g., **std140**) base alignment for the member's type. The *actual offset* of a member is computed as follows: If **offset** was declared, start with that offset, otherwise start with the next available offset. If the resulting offset is not a multiple of the *actual alignment*, increase it to the first offset that is a multiple of the *actual alignment*. This results in the *actual offset* the member will have.

When **align** is applied to an array, it affects only the start of the array, not the array's internal stride. Both an **offset** and an **align** qualifier can be specified on a declaration.

The **align** qualifier, when used on a block, has the same effect as qualifying each member with the same **align** value as declared on the block, and gets the same compile-time results and errors as if this had been done. As described in general earlier, an individual member can specify its own **align**, which overrides the block-level **align**, but just for that member.

Examples:

```
layout(std140) uniform block {
    vec4    a;           // a takes offsets 0-15
    layout(offset = 32) vec3    b;           // b takes offsets 32-43
    layout(offset = 40) vec2    c;           // ERROR, lies within previous member
    layout(offset = 48) vec2    d;           // d takes offsets 48-55
    layout(align = 16) float    e;           // e takes offsets 64-67
    layout(align = 2)   double  f;           // f takes offsets 72-79
    layout(align = 6)   double  g;           // ERROR, 6 is not a power of 2
    layout(offset = 80) float    h;           // h takes offsets 80-83
    layout(align = 64) dvec3    i;           // i takes offsets 128-151
    layout(offset = 164, align = 8)
        float    j;           // j takes offsets 168-171
};
```

4.4.6 Opaque-Uniform Layout Qualifiers

Uniform layout qualifiers can be used to bind opaque uniform variables to specific buffers or units. Texture image units can be bound to samplers, image units can be bound to images, and atomic counters can be bound to buffers.

Details for specific to image formats and atomic counter bindings are given in the subsections below.

Image and sampler types both take the uniform layout qualifier identifier for binding:

```
layout-qualifier-id :
    binding = integer-constant-expression
```

The identifier *binding* specifies which unit will be bound. Any uniform sampler or image variable declared without a *binding* qualifier is initially bound to unit zero. After a program is linked, the unit

referenced by a sampler or image uniform variable declared with or without a binding identifier can be updated by the OpenGL API.

If the *binding* identifier is used with an array, the first element of the array takes the specified unit and each subsequent element takes the next consecutive unit.

If the *binding* is less than zero, or greater than or equal to the implementation-dependent maximum supported number of units, a compile-time error will occur. When the *binding* identifier is used with an array of size N , all elements of the array from *binding* through $binding + N - 1$ must be within this range. It is a compile-time or link-time error to use the same *binding* number for more than one image or more than one sampler. It is a compile-time or link-time error to use the same *binding* number for more than one atomic counter, unless the *offset* for the atomic counters sharing the same *binding* are all different.

A link-time error will result if two compilation units in a program specify different *integer-constant-expression* bindings for the same opaque-uniform name. However, it is not an error to specify a binding on some but not all declarations for the same name, as shown in the examples below.

```
// in one compilation unit...
layout(binding=3) uniform sampler2D s; // s bound to unit 3

// in another compilation unit...
uniform sampler2D s; // okay, s still bound at 3

// in another compilation unit...
layout(binding=4) uniform sampler2D s; // ERROR: contradictory bindings
```

4.4.6.1 Atomic Counter Layout Qualifiers

The atomic counter qualifiers are

```
layout-qualifier-id :
    binding = integer-constant-expression
    offset = integer-constant-expression
```

For example,

```
layout(binding = 2, offset = 4) uniform atomic_uint a;
```

will establish that the opaque handle to the atomic counter *a* will be bound to atomic counter buffer binding point 2 at an offset of 4 basic machine units into that buffer. The default *offset* for binding point 2 will be post incremented by 4 (the size of an atomic counter).

A subsequent atomic counter declaration will inherit the previous (post incremented) offset. For example, a subsequent declaration of

```
layout(binding = 2) uniform atomic_uint bar;
```

will establish that the atomic counter *bar* has a binding to buffer binding point 2 at an offset of 8 basic machine units into that buffer. The offset for binding point 2 will again be post-incremented by 4 (the size of an atomic counter).

When multiple variables are listed in a layout declaration, the effect will be the same as if they were declared one at a time, in order from left to right.

Binding points are not inherited, only offsets. Each binding point tracks its own current default *offset* for inheritance of subsequent variables using the same *binding*. The initial state of compilation is that all *binding* points have an *offset* of 0. The *offset* can be set per binding point at global scope (without declaring a variable). For example,

```
layout(binding = 2, offset = 4) uniform atomic_uint;
```

Establishes that the next **atomic_uint** declaration for binding point 2 will inherit *offset* 4 (but does not establish a default *binding*):

```
layout(binding = 2) uniform atomic_uint bar; // offset is 4
layout(offset = 8) uniform atomic_uint bar; // error, no default binding
```

Atomic counters may share the same binding point, but if a binding is shared, their offsets must be either explicitly or implicitly (from inheritance) unique and non overlapping.

Example valid uniform declarations, assuming top of shader:

```
layout(binding=3, offset=4) uniform atomic_uint a; // offset = 4
layout(binding=2) uniform atomic_uint b;          // offset = 0
layout(binding=3) uniform atomic_uint c;          // offset = 8
layout(binding=2) uniform atomic_uint d;          // offset = 4
```

Example of an invalid uniform declaration:

```
layout(offset=4) ... // error, must include binding
layout(binding=1, offset=0) ... a; // okay
layout(binding=2, offset=0) ... b; // okay
layout(binding=1, offset=0) ... c; // error, offsets must not be shared
// between a and c
layout(binding=1, offset=2) ... d; // error, overlaps offset 0 of a
```

It is a compile-time error to bind an atomic counter with a binding value greater than or equal to `gl_MaxAtomicCounterBindings`. It is a compile-time error to declare an unsized array of **atomic_uint**.

4.4.6.2 Format Layout Qualifiers

Format layout qualifiers can be used on image variable declarations (those declared with a basic type having “**image**” in its keyword). The format layout qualifier identifiers for image variable declarations are

```
layout-qualifier-id :
    float-image-format-qualifier
    int-image-format-qualifier
    uint-image-format-qualifier
    binding = integer-constant-expression
```

float-image-format-qualifier

rgba32f
rgba16f
rg32f
rg16f
r11f_g11f_b10f
r32f
r16f
rgba16
rgb10_a2
rgba8
rg16
rg8
r16
r8
rgba16_snorm
rgba8_snorm
rg16_snorm
rg8_snorm
r16_snorm
r8_snorm

int-image-format-qualifier

rgba32i
rgba16i
rgba8i
rg32i
rg16i
rg8i
r32i
r16i
r8i

uint-image-format-qualifier

rgba32ui
rgba16ui
rgb10_a2ui
rgba8ui
rg32ui
rg16ui
rg8ui
r32ui
r16ui
r8ui

A format layout qualifier specifies the image format associated with a declared image variable. Only one format qualifier may be specified for any image variable declaration. For image variables with floating-point component types (keywords starting with “**image**”), signed integer component types (keywords

starting with “**iimage**”), or unsigned integer component types (keywords starting with “**uimage**”), the format qualifier used must match the *float-image-format-qualifier*, *int-image-format-qualifier*, or *uint-image-format-qualifier* grammar rules, respectively. It is a compile-time error to declare an image variable where the format qualifier does not match the image variable type.

Any image variable used for image loads or atomic operations must specify a format layout qualifier; it is a compile-time error to pass an image uniform variable or function parameter declared without a format layout qualifier to an image load or atomic function.

The *binding* identifier was described in section 4.4.5 “Uniform and Shader Storage Block Layout Qualifiers”.

Uniforms not qualified with **writeonly** must have a format layout qualifier. Note that an image variable passed to a function for read access cannot be declared as **writeonly** and hence must have been declared with a format layout qualifier.

4.5 Interpolation Qualifiers

Inputs and outputs that could be interpolated can be further qualified by at most one of the following interpolation qualifiers:

Qualifier	Meaning
smooth	perspective correct interpolation
flat	no interpolation
noperspective	linear interpolation

The presence of and type of interpolation is controlled by the above interpolation qualifiers as well as the auxiliary storage qualifiers **centroid** and **sample**. The auxiliary storage qualifier **patch** is not used for interpolation; it is a compile-time error to use interpolation qualifiers with **patch**.

A variable qualified as **flat** will not be interpolated. Instead, it will have the same value for every fragment within a triangle. This value will come from a single provoking vertex, as described by the OpenGL Graphics System Specification. A variable may be qualified as **flat** can also be qualified as **centroid** or **sample**, which will mean the same thing as qualifying it only as **flat**.

A variable qualified as **smooth** will be interpolated in a perspective-correct manner over the primitive being rendered. Interpolation in a perspective correct manner is specified in equation 14.7 in the OpenGL Graphics System Specification, section 14.5 “Line Segments”.

A variable qualified as **noperspective** must be interpolated linearly in screen space, as described in equation 3.7 in the OpenGL Graphics System Specification, section 3.5 “Line Segments”.

When multi-sample rasterization is disabled, or for fragment shader input variables qualified with neither **centroid** nor **sample**, the value of the assigned variable may be interpolated anywhere within the pixel and a single value may be assigned to each sample within the pixel, to the extent permitted by the OpenGL Graphics System Specification.

When multisample rasterization is enabled, **centroid** and **sample** may be used to control the location and frequency of the sampling of the qualified fragment shader input. If a fragment shader input is qualified

with **centroid**, a single value may be assigned to that variable for all samples in the pixel, but that value must be interpolated to a location that lies in both the pixel and in the primitive being rendered, including any of the pixel's samples covered by the primitive. Because the location at which the variable is interpolated may be different in neighboring pixels, and derivatives may be computed by computing differences between neighboring pixels, derivatives of centroid-sampled inputs may be less accurate than those for non-centroid interpolated variables. If a fragment shader input is qualified with **sample**, a separate value must be assigned to that variable for each covered sample in the pixel, and that value must be sampled at the location of the individual sample.

It is a link-time error if, within the same stage, the interpolation qualifiers of variables of the same name do not match.

4.5.1 Redeclaring Built-in Interpolation Variables in the Compatibility Profile

The following predeclared variables can be redeclared with an interpolation qualifier when using the compatibility profile:

Vertex, tessellation control, tessellation evaluation, and geometry languages:

```
gl_FrontColor
gl_BackColor
gl_FrontSecondaryColor
gl_BackSecondaryColor
```

Fragment language:

```
gl_Color
gl_SecondaryColor
```

For example,

```
in vec4 gl_Color;           // predeclared by the fragment language
flat in vec4 gl_Color;     // redeclared by user to be flat
flat in vec4 gl_FrontColor; // input to geometry shader, no "gl_in[]"
flat out vec4 gl_FrontColor; // output from geometry shader
```

Ideally, these are redeclared as part of the redeclaration of an interface block, as described in section 7.1.1 “Compatibility Profile Built-In Language Variables”. However, for the above purpose, they can be redeclared as individual variables at global scope, outside an interface block. Such redeclarations also allow adding the transform-feedback qualifiers **xfb_buffer**, **xfb_stride**, and **xfb_offset** to output variables. (Using **xfb_buffer** on a variable does not change the global default buffer.) A compile-time error will result if a shader has both an interface-block redeclaration and a separate redeclaration of a member of that interface block outside the interface-block redeclaration.

If *gl_Color* is redeclared with an interpolation qualifier, then *gl_FrontColor* and *gl_BackColor* (if they are written to) must also be redeclared with the same interpolation qualifier, and vice versa. If *gl_SecondaryColor* is redeclared with an interpolation qualifier, then *gl_FrontSecondaryColor* and *gl_BackSecondaryColor* (if they are written to) must also be redeclared with the same interpolation qualifier, and vice versa. This qualifier matching on predeclared variables is only required for variables that are statically used within the shaders in a program.

4.6 Parameter Qualifiers

In addition to precision qualifiers and memory qualifiers, parameters can have these parameter qualifiers.

Qualifier	Meaning
< none: default >	same as in
const	for function parameters that cannot be written to
in	for function parameters passed into a function
out	for function parameters passed back out of a function, but not initialized for use when passed in
inout	for function parameters passed both into and out of a function

Parameter qualifiers are discussed in more detail in section 6.1.1 “Function Calling Conventions”.

4.7 Precision and Precision Qualifiers

Precision qualifiers are added for code portability with OpenGL ES, not for functionality. They have the same syntax as in OpenGL ES, as described below, but they have no semantic meaning, which includes no effect on the precision used to store or operate on variables.

If an extension adds in the same semantics and functionality in the OpenGL ES 2.0 specification for precision qualifiers, then the extension is allowed to reuse the keywords below for that purpose.

For the purposes of determining if an output from one shader stage matches an input of the next stage, the precision qualifier need not match.

4.7.1 Range and Precision

The precision of stored single- and double-precision floating-point variables is defined by the IEEE 754 standard for 32-bit and 64-bit floating-point numbers. This includes support for NaNs (Not a Number) and Infs (positive or negative infinities) and positive and negative zeros.

The following rules apply to both single and double-precision operations: Positive and negative Infs and positive and negative zeros are generated as dictated by IEEE, but subject to the precisions allowed in the following table. Dividing a non-zero by a zero results in the appropriately signed IEEE Inf. Any denormalized value input into a shader or potentially generated by any operation in a shader can be flushed to 0. The rounding mode cannot be set and is undefined. NaNs are not required to be generated. Support for signaling NaNs is not required and exceptions are never raised. Operations and built-in functions that operate on a NaN are not required to return a NaN as the result.

Precisions are expressed in terms of maximum relative error in units of ULP (units in the last place), unless otherwise noted.

For single precision operations, precisions are required as follows:

Operation	Precision
$a + b$, $a - b$, $a * b$	Correctly rounded.
$<$, $<=$, $=$, $>$, $>=$	Correct result.
a / b , $1.0 / b$	2.5 ULP for b in the range $[2^{-126}, 2^{126}]$.
$a * b + c$	Correctly rounded single operation or sequence of two correctly rounded operations.
<code>fma()</code>	Inherited from $a * b + c$.
<code>pow(x, y)</code>	Inherited from <code>exp2(y * log2(x))</code> .
<code>exp(x)</code> , <code>exp2(x)</code>	$(3 + 2 * x)$ ULP.
<code>log()</code> , <code>log2()</code>	3 ULP outside the range $[0.5, 2.0]$. Absolute error $< 2^{-21}$ inside the range $[0.5, 2.0]$.
<code>sqrt()</code>	Inherited from $1.0 / \text{inversesqrt}()$.
<code>inversesqrt()</code>	2 ULP.
implicit and explicit conversions between types	Correctly rounded.

Built-in functions defined in the specification with an equation built from the above operations inherit the above errors. These include, for example, the geometric functions, the common functions, and many of the matrix functions. Built-in functions not listed above and not defined as equations of the above have undefined precision. These include, for example, the trigonometric functions and determinant.

The precision of double-precision operations is at least that of single precision.

4.7.2 Precision Qualifiers

Any single-precision floating-point declaration, integer declaration, or opaque-type declaration can have the type preceded by one of these precision qualifiers:

Qualifier	Meaning
<code>highp</code>	None.
<code>mediump</code>	None.
<code>lowp</code>	None.

For example:

```
lowp float color;
out mediump vec2 P;
lowp ivec2 foo(lowp mat3);
highp mat4 m;
```

Literal constants do not have precision qualifiers. Neither do Boolean variables. Neither do floating-point constructors nor integer constructors when none of the constructor arguments have precision qualifiers.

Precision qualifiers, as with other qualifiers, do not affect the basic type of the variable. In particular, there are no constructors for precision conversions; constructors only convert types. Similarly, precision qualifiers, as with other qualifiers, do not contribute to function overloading based on parameter types. As discussed in the next chapter, function input and output is done through copies, and therefore qualifiers do not have to match.

4.7.3 Default Precision Qualifiers

The precision statement

```
precision precision-qualifier type;
```

can be used to establish a default precision qualifier. The *type* field can be either **int**, or **float**, or any of the opaque types, and the *precision-qualifier* can be **lowp**, **mediump**, or **highp**. Any other types or qualifiers will result in a compile-time error. If *type* is **float**, the directive applies to non-precision-qualified single-precision floating-point type (scalar, vector, and matrix) declarations. If *type* is **int**, the directive applies to all non-precision-qualified integer type (scalar, vector, signed, and unsigned) declarations. This includes global variable declarations, function return declarations, function parameter declarations, and local variable declarations.

Non-precision qualified declarations will use the precision qualifier specified in the most recent **precision** statement that is still in scope. The **precision** statement has the same scoping rules as variable declarations. If it is declared inside a compound statement, its effect stops at the end of the innermost statement it was declared in. Precision statements in nested scopes override precision statements in outer scopes. Multiple precision statements for the same basic type can appear inside the same scope, with later statements overriding earlier statements within that scope.

The vertex, tessellation, and geometry languages have the following predeclared globally scoped default precision statements:

```
precision highp float;
precision highp int;
```

The fragment language has the following predeclared globally scoped default precision statements:

```
precision mediump int;
precision highp float;
```

There are no errors for omission of a precision qualifier; so the above is just for reference of what may happen in OpenGL ES versions of the shading languages.

4.7.4 Available Precision Qualifiers

The built-in macro `GL_FRAGMENT_PRECISION_HIGH` is defined to 1:

```
#define GL_FRAGMENT_PRECISION_HIGH 1
```

This macro is available in the vertex, tessellation, geometry, and fragment languages.

4.8 Variance and the Invariant Qualifier

In this section, *variance* refers to the possibility of getting different values from the same expression in different programs. For example, say two vertex shaders, in different programs, each set `gl_Position` with the same expression in both shaders, and the input values into that expression are the same when both shaders run. It is possible, due to independent compilation of the two shaders, that the values assigned to `gl_Position` are not exactly the same when the two shaders run. In this example, this can cause problems with alignment of geometry in a multi-pass algorithm.

In general, such variance between shaders is allowed. When such variance does not exist for a particular output variable, that variable is said to be *invariant*.

4.8.1 The Invariant Qualifier

To ensure that a particular output variable is invariant, it is necessary to use the **invariant** qualifier. It can either be used to qualify a previously declared variable as being invariant

```
invariant gl_Position;    // make existing gl_Position be invariant

out vec3 Color;
invariant Color;        // make existing Color be invariant
```

or as part of a declaration when a variable is declared

```
invariant centroid out vec3 Color;
```

Only variables output from a shader (including those that are then input to a subsequent shader) can be candidates for invariance. This includes user-defined output variables and the built-in output variables. As only outputs need be declared with **invariant**, an output from one shader stage will still match an input of a subsequent stage without the input being declared as **invariant**.

Input or output instance names on blocks are not used when redeclaring built-in variables.

The **invariant** keyword can be followed by a comma separated list of previously declared identifiers. All uses of **invariant** must be on global scope variables or on block members, and before any use of the variables being declared as invariant.

To guarantee invariance of a particular output variable across two programs, the following must also be true:

- The output variable is declared as invariant in both programs.
- The same values must be input to all shader input variables consumed by expressions and flow control contributing to the value assigned to the output variable.
- The texture formats, texel values, and texture filtering are set the same way for any texture function calls contributing to the value of the output variable.
- All input values are all operated on in the same way. All operations in the consuming expressions and any intermediate expressions must be the same, with the same order of operands and same associativity, to give the same order of evaluation. Intermediate variables and functions must be declared as the same type with the same explicit or implicit precision qualifiers. Any control flow

affecting the output value must be the same, and any expressions consumed to determine this control flow must also follow these invariance rules.

- All the data flow and control flow leading to setting the invariant output variable reside in a single compilation unit.

Essentially, all the data flow and control flow leading to an invariant output must match.

Initially, by default, all output variables are allowed to be variant. To force all output variables to be invariant, use the pragma

```
#pragma STDGL invariant(all)
```

before all declarations in a shader. If this pragma is used after the declaration of any variables or functions, then the set of outputs that behave as invariant is undefined.

Generally, invariance is ensured at the cost of flexibility in optimization, so performance can be degraded by use of invariance. Hence, use of this pragma is intended as a debug aid, to avoid individually declaring all output variables as invariant.

4.8.2 Invariance of Constant Expressions

Invariance must be guaranteed for constant expressions. A particular constant expression must evaluate to the same result if it appears again in the same shader or a different shader. This includes the same expression appearing two shaders of the same language or shaders of two different languages.

Constant expressions must evaluate to the same result when operated on as already described above for invariant variables, whether or not the **invariant** qualifier is used.

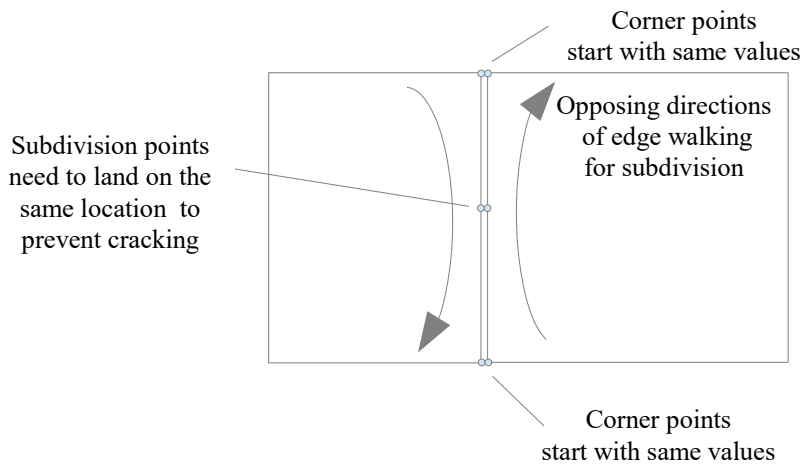
4.9 The Precise Qualifier

Some algorithms require floating-point computations to exactly follow the order of operations specified in the source code and to treat all operations consistently, even if the implementation supports optimizations that could produce nearly equivalent results with higher performance. For example, many GL implementations support a "multiply-add" instruction that can compute a floating-point expression such as

```
result = (a * b) + (c * d);
```

in two operations instead of three operations; one multiply and one multiply-add instead of two multiplies and one add. The result of a floating-point multiply-add might not always be identical to first doing a multiply yielding a floating-point result and then doing a floating-point add. Hence, in this example, the two multiply operations would not be treated consistently; the two multiplies could effectively appear to have differing precisions.

The key computation that needs to be made consistent appears when tessellating, where intermediate points for subdivision are synthesized in different directions, yet need to yield the same result, as shown in the diagram below.



Without any qualifiers, implementations are permitted to perform such optimizations that effectively modify the order or number of operations used to evaluate an expression, even if those optimizations may produce slightly different results relative to unoptimized code.

The qualifier **precise** will ensure that operations contributing to a variable's value are done in their stated order and are done with operator consistency. Order is determined by operator precedence and parenthesis, as described in section 5.1 “Operators”. Operator consistency means for each particular operator, for example the multiply operator (`*`), its operation is always computed with the same precision. Specifically, values computed by compiler-generated code must adhere to the following identities:

1. $a + b = b + a$
2. $a * b = b * a$
3. $a * b + c * d = b * a + c * d = d * c + b * a = \langle \text{any other mathematically valid combination} \rangle$

While the following are prevented:

4. $a + (b + c)$ is not allowed to become $(a + b) + c$
5. $a * (b * c)$ is not allowed to become $(a * b) * c$
6. $a * b + c$ is not allowed to become a single operation **fma**(a, b, c)

Where a , b , c , and d , are scalars or vectors, not matrices. (Matrix multiplication generally does not commute.) It is the shader writer's responsibility to express the computation in terms of these rules and the compiler's responsibility to follow these rules. See the description of `gl_TessCoord` for the rules the tessellation stages are responsible for following, which in conjunction with the above allow avoiding cracking when subdividing.

For example,

```
precise out vec4 position;
```


declares that operations used to produce the value of *position* must be performed in exactly the order specified in the source code and with all operators being treated consistently. As with the invariant qualifier (section 4.8.1 “The Invariant Qualifier”), the precise qualifier may be used to qualify a built-in or previously declared user-defined variable as being precise:

```
out vec3 Color;
precise Color;           // make existing Color be precise
```

When applied to a block, a structure type, or a variable of structure type, **precise** applies to each contained member, recursively.

This qualifier will affect the evaluation of an r-value in a particular function if and only if the result is eventually consumed in the same function by an l-value qualified as **precise**. Any other expressions within a function are not affected, including return values and output parameters not declared as **precise** but that are eventually consumed outside the function by a variable qualified as **precise**.

Some examples of the use of **precise**:

```

in vec4 a, b, c, d;
precise out vec4 v;

float func(float e, float f, float g, float h)
{
    return (e*f) + (g*h);           // no constraint on order or
                                   // operator consistency
}

float func2(float e, float f, float g, float h)
{
    precise float result = (e*f) + (g*h); // ensures same precision for
                                           // the two multiplies
    return result;
}

float func3(float i, float j, precise out float k)
{
    k = i * i + j;                 // precise, due to <k> declaration
}

void main()
{
    vec3 r = vec3(a * b);          // precise, used to compute v.xyz
    vec3 s = vec3(c * d);          // precise, used to compute v.xyz
    v.xyz = r + s;                 // precise
    v.w = (a.w * b.w) + (c.w * d.w); // precise
    v.x = func(a.x, b.x, c.x, d.x); // values computed in func()
                                   // are NOT precise
    v.x = func2(a.x, b.x, c.x, d.x); // precise!
    func3(a.x * b.x, c.x * d.x, v.x); // precise!
}

```

For the purposes of determining if an output from one shader stage matches an input of the next stage, the **precise** qualifier need not match between the input and the output.

All constant expressions are evaluated as if **precise** was present, whether or not it is present. However, as described in section 4.3.3 “Constant Expressions”, there is no requirement that a compile-time constant expression evaluates to the same value as a corresponding non-constant expression.

4.10 Memory Qualifiers

Variables declared as image types (the basic opaque types with “**image**” in their keyword) can be further qualified with one or more of the following memory qualifiers:

Qualifier	Meaning
coherent	memory variable where reads and writes are coherent with reads and writes from other shader invocations
volatile	memory variable whose underlying value may be changed at any point during shader execution by some source other than the current shader invocation
restrict	memory variable where use of that variable is the only way to read and write the underlying memory in the relevant shader stage
readonly	memory variable that can be used to read the underlying memory, but cannot be used to write the underlying memory
writeonly	memory variable that can be used to write the underlying memory, but cannot be used to read the underlying memory

Memory accesses to image variables declared using the **coherent** qualifier are performed coherently with similar accesses from other shader invocations. In particular, when reading a variable declared as **coherent**, the values returned will reflect the results of previously completed writes performed by other shader invocations. When writing a variable declared as **coherent**, the values written will be reflected in subsequent coherent reads performed by other shader invocations. As described in section 7.11 “Shader Memory Access” of the OpenGL Specification, shader memory reads and writes complete in a largely undefined order. The built-in function **memoryBarrier()** can be used if needed to guarantee the completion and relative ordering of memory accesses performed by a single shader invocation.

When accessing memory using variables not declared as **coherent**, the memory accessed by a shader may be cached by the implementation to service future accesses to the same address. Memory stores may be cached in such a way that the values written might not be visible to other shader invocations accessing the same memory. The implementation may cache the values fetched by memory reads and return the same values to any shader invocation accessing the same memory, even if the underlying memory has been modified since the first memory read. While variables not declared as **coherent** might not be useful for communicating between shader invocations, using non-coherent accesses may result in higher performance.

Memory accesses to image variables declared using the **volatile** qualifier must treat the underlying memory as though it could be read or written at any point during shader execution by some source other than the executing shader invocation. When a volatile variable is read, its value must be re-fetched from the underlying memory, even if the shader invocation performing the read had previously fetched its value from the same memory. When a volatile variable is written, its value must be written to the underlying memory, even if the compiler can conclusively determine that its value will be overwritten by a subsequent write. Since the external source reading or writing a volatile variable may be another shader invocation, variables declared as **volatile** are automatically treated as coherent.

Memory accesses to image variables declared using the **restrict** qualifier may be compiled assuming that the variable used to perform the memory access is the only way to access the underlying memory using the shader stage in question. This allows the compiler to coalesce or reorder loads and stores using **restrict**-qualified image variables in ways that wouldn't be permitted for image variables not so qualified, because the compiler can assume that the underlying image won't be read or written by other code. Applications are responsible for ensuring that image memory referenced by variables qualified with

restrict will not be referenced using other variables in the same scope; otherwise, accesses to **restrict**-qualified variables will have returned undefined values.

Memory accesses to image variables declared using the **readonly** qualifier may only read the underlying memory, which is treated as read-only memory and cannot be written to. It is a compile-time error to pass an image variable qualified with **readonly** to **imageStore()** or other built-in functions that modify image memory.

Memory accesses to image variables declared using the **writeonly** qualifier may only write the underlying memory; the underlying memory cannot be read. It is a compile-time error to pass an image variable qualified with **writeonly** to **imageLoad()** or other built-in functions that read image memory. A variable could be qualified as both **readonly** and **writeonly**, disallowing both read and write, but still be passed to **imageSize()** to have the size queried.

The memory qualifiers **coherent**, **volatile**, **restrict**, **readonly**, and **writeonly** may be used in the declaration of buffer variables (i.e., members of shader storage blocks). When a buffer variable is declared with a memory qualifier, the behavior specified for memory accesses involving image variables described above applies identically to memory accesses involving that buffer variable. It is a compile-time error to assign to a buffer variable qualified with **readonly** or to read from a buffer variable qualified with **writeonly**.

Additionally, memory qualifiers may also be used in the declaration of shader storage blocks. When a block declaration is qualified with a memory qualifier, it is as if all of its members were declared with the same memory qualifier. For example, the block declaration

```
coherent buffer Block {
    readonly vec4 member1;
    vec4 member2;
};
```

is equivalent to

```
buffer Block {
    coherent readonly vec4 member1;
    coherent vec4 member2;
};
```

Memory qualifiers are only supported in the declarations of image variables, buffer variables, and shader storage blocks; it is an error to use such qualifiers in any other declarations.

Variables qualified with **coherent**, **volatile**, **readonly**, or **writeonly** may not be passed to functions whose formal parameters lack such qualifiers. (See section 6.1 “Function Definitions” for more detail on function calling.) It is legal to have any additional memory qualifiers on a formal parameter, but only **restrict** can be taken away from a calling argument, by a formal parameter that lacks the **restrict** qualifier. When a built-in function is called, the code generated is to be based on the actual qualification of the calling argument, not on the list of memory qualifiers specified on the formal parameter in the prototype.

```

vec4 funcA(restrict image2D a)  { ... }
vec4 funcB(image2D a)           { ... }
layout(rgba32f) uniform image2D img1;
layout(rgba32f) coherent uniform image2D img2;

funcA(img1);                    // OK, adding "restrict" is allowed
funcB(img2);                    // illegal, stripping "coherent" is not

```

Layout qualifiers cannot be used on formal function parameters, and layout qualification is not included in parameter matching.

Note that the use of **const** in an image variable declaration is qualifying the const-ness of the variable being declared, not the image it refers to: The qualifier **readonly** qualifies the image memory (as accessed through that variable) while **const** qualifies the variable itself.

4.11 Specialization-Constant Qualifier

Specialization constants are used only for SPIR-V and declared using the **constant_id** layout qualifier. For example:

```
layout(constant_id = 17) const int arraySize = 12;
```

The above makes a specialization constant with a default value of 12. The number 17 is an example author-chosen id by which the API or other tools can later refer to this specific specialization constant. If it is never changed before final lowering, it will retain the value of 12. It is a compile-time error to use the **constant_id** qualifier on anything but SPIR-V generation of a scalar **bool**, **int**, **uint**, **float**, or **double**.

Built-in constants can be declared to be specialization constants. For example:

```
layout(constant_id = 31) gl_MaxClipDistances; // add specialization id
```

The declaration uses just the name of the previously declared built-in variable, with a **constant_id** layout-qualifier declaration. It is a compile-time error to do this after the constant has been used: Constants are strictly either non-specialization constants or specialization constants, not both.

The built-in constant vector *gl_WorkGroupSize* can be specialized using the **local_size_{xyz}_id** qualifiers, to individually give the components an id. For example:

```
layout(local_size_x_id = 18, local_size_z_id = 19) in;
```

This leaves *gl_WorkGroupSize.y* as a non-specialization constant, with *gl_WorkGroupSize* being a partially specialized vector. Its *x* and *z* components can be later specialized, after generating SPIR-V, using the ids 18 and 19. These ids are declared independently from declaring the work-group size:

```

layout(local_size_x = 32, local_size_y = 32) in; // size is (32,32,1)
layout(local_size_x_id = 18) in;                // constant_id for x
layout(local_size_z_id = 19) in;                // constant_id for z

```

Existing rules for declaring **local_size_x**, **local_size_y**, and **local_size_z** are not changed. For the local-size ids, it is a compile-time error to provide different id values for the same local-size id, or to provide

them after any use. Otherwise, order, placement, number of statements, and replication do not cause errors.

Two arrays sized with specialization constants are the same type only if sized with the same symbol, and involving no operations. For example:

```
layout(constant_id = 51) const int aSize = 20;
const int pad = 2;
const int total = aSize + pad; // specialization constant
int a[total], b[total];      // a and b have the same type
int c[22];                  // different type than a or b
int d[aSize + pad];         // different type than a, b, or c
int e[aSize + 2];          // different type than a, b, c, or d
```

Types containing arrays sized with a specialization constant cannot be compared, assigned as aggregates, declared with an initializer, or used as an initializer. They can, however, be passed as arguments to functions having formal parameters of the same type. Only the outer-most dimension of a variable declared as an array of arrays can be a specialization constant, otherwise a compile-time error results.

Arrays inside a block may be sized with a specialization constant, but the block will have a static layout. Changing the specialized size will not re-layout the block. In the absence of explicit offsets, the layout will be based on the default size of the array.

4.12 Order and Repetition of Qualification

When multiple qualifiers are present in a variable or parameter declaration, they may appear in any order, but they must all appear before the type. The **layout** qualifier is the only qualifier that can appear more than once. Further, a declaration can have at most one storage qualifier, at most one auxiliary storage qualifier, and at most one interpolation qualifier. If **inout** is used, neither **in** nor **out** may be used. Multiple memory qualifiers can be used. Any violation of these rules will cause a compile-time error.

4.13 Empty Declarations

Empty declarations are declarations without a variable name, meaning no object is instantiated by the declaration. Generally, empty declarations are allowed. Some are useful when declaring structures, while many others have no effect.

The combinations of types and qualifiers that cause compile-time or link-time errors are the same whether or not the declaration is empty.

5 Operators and Expressions

5.1 Operators

The OpenGL Shading Language has the following operators.

Precedence	Operator Class	Operators	Associativity
1 (highest)	parenthetical grouping	()	NA
2	array subscript function call and constructor structure field or method selector, swizzle post fix increment and decrement	[] () . ++ --	Left to Right
3	prefix increment and decrement unary	++ -- + - ~ !	Right to Left
4	multiplicative	* / %	Left to Right
5	additive	+ -	Left to Right
6	bit-wise shift	<< >>	Left to Right
7	relational	< > <= >=	Left to Right
8	equality	== !=	Left to Right
9	bit-wise and	&	Left to Right
10	bit-wise exclusive or	^	Left to Right
11	bit-wise inclusive or		Left to Right
12	logical and	&&	Left to Right
13	logical exclusive or	^^	Left to Right
14	logical inclusive or		Left to Right
15	selection	? :	Right to Left
16	Assignment arithmetic assignments	= += -= *= /= %= <<= >>= &= ^= =	Right to Left
17 (lowest)	sequence	,	Left to Right

There is no address-of operator nor a dereference operator. There is no typecast operator; constructors are used instead.

5.2 Array Operations

These are now described in section 5.7 “Structure and Array Operations”.

5.3 Function Calls

If a function returns a value, then a call to that function may be used as an expression, whose type will be the type that was used to declare or define the function.

Function definitions and calling conventions are discussed in section 6.1 “Function Definitions” .

5.4 Constructors

Constructors use the function call syntax, where the function name is a type, and the call makes an object of that type. Constructors are used the same way in both initializers and expressions. (See section 9 “Shading Language Grammar” for details.) The parameters are used to initialize the constructed value. Constructors can be used to request a data type conversion to change from one scalar type to another scalar type, or to build larger types out of smaller types, or to reduce a larger type to a smaller type.

In general, constructors are not built-in functions with predetermined prototypes. For arrays and structures, there must be exactly one argument in the constructor for each element or member. For the other types, the arguments must provide a sufficient number of components to perform the initialization, and it is a compile-time error to include so many arguments that they cannot all be used. Detailed rules follow. The prototypes actually listed below are merely a subset of examples.

5.4.1 Conversion and Scalar Constructors

Converting between scalar types is done as the following prototypes indicate:

```
int(uint)      // converts an unsigned integer to a signed integer
int(bool)     // converts a Boolean value to an int
int(float)    // converts a float value to an int
int(double)   // converts a double value to a signed integer
uint(int)     // converts a signed integer value to an unsigned integer
uint(bool)    // converts a Boolean value to an unsigned integer
uint(float)   // converts a float value to an unsigned integer
uint(double)  // converts a double value to an unsigned integer
bool(int)     // converts a signed integer value to a Boolean
bool(uint)    // converts an unsigned integer value to a Boolean value
bool(float)   // converts a float value to a Boolean
bool(double)  // converts a double value to a Boolean
float(int)    // converts a signed integer value to a float
float(uint)   // converts an unsigned integer value to a float value
float(bool)   // converts a Boolean value to a float
float(double) // converts a double value to a float
double(int)   // converts a signed integer value to a double
double(uint)  // converts an unsigned integer value to a double
double(bool)  // converts a Boolean value to a double
double(float) // converts a float value to a double
```


When constructors are used to convert any floating-point type to an integer type, the fractional part of the floating-point value is dropped. It is undefined to convert a negative floating-point value to an **uint**.

When a constructor is used to convert any integer or floating-point type to a **bool**, 0 and 0.0 are converted to **false**, and non-zero values are converted to **true**. When a constructor is used to convert a **bool** to any integer or floating-point type, **false** is converted to 0 or 0.0, and **true** is converted to 1 or 1.0.

The constructor **int(uint)** preserves the bit pattern in the argument, which will change the argument's value if its sign bit is set. The constructor **uint(int)** preserves the bit pattern in the argument, which will change its value if it is negative.

Identity constructors, like **float(float)** are also legal, but of little use.

Scalar constructors with non-scalar parameters can be used to take the first element from a non-scalar. For example, the constructor **float(vec3)** will select the first component of the **vec3** parameter.

5.4.2 Vector and Matrix Constructors

Constructors can be used to create vectors or matrices from a set of scalars, vectors, or matrices. This includes the ability to shorten vectors.

If there is a single scalar parameter to a vector constructor, it is used to initialize all components of the constructed vector to that scalar's value. If there is a single scalar parameter to a matrix constructor, it is used to initialize all the components on the matrix's diagonal, with the remaining components initialized to 0.0.

If a vector is constructed from multiple scalars, one or more vectors, or one or more matrices, or a mixture of these, the vector's components will be constructed in order from the components of the arguments. The arguments will be consumed left to right, and each argument will have all its components consumed, in order, before any components from the next argument are consumed. Similarly for constructing a matrix from multiple scalars or vectors, or a mixture of these. Matrix components will be constructed and consumed in column major order. In these cases, there must be enough components provided in the arguments to provide an initializer for every component in the constructed value. It is a compile-time error to provide extra arguments beyond this last used argument.

If a matrix is constructed from a matrix, then each component (column i , row j) in the result that has a corresponding component (column i , row j) in the argument will be initialized from there. All other components will be initialized to the identity matrix. If a matrix argument is given to a matrix constructor, it is a compile-time error to have any other arguments.

If the basic type (**bool**, **int**, **float**, or **double**) of a parameter to a constructor does not match the basic type of the object being constructed, the scalar construction rules (above) are used to convert the parameters.

5 Operators and Expressions

Some useful vector constructors are as follows:

```
vec3(float)      // initializes each component of the vec3 with the float
vec4(ivec4)      // makes a vec4 with component-wise conversion
vec4(mat2)      // the vec4 is column 0 followed by column 1

vec2(float, float)          // initializes a vec2 with 2 floats
ivec3(int, int, int)       // initializes an ivec3 with 3 ints
bvec4(int, int, float, float) // uses 4 Boolean conversions

vec2(vec3)              // drops the third component of a vec3
vec3(vec4)              // drops the fourth component of a vec4

vec3(vec2, float)       // vec3.x = vec2.x, vec3.y = vec2.y, vec3.z = float
vec3(float, vec2)       // vec3.x = float, vec3.y = vec2.x, vec3.z = vec2.y
vec4(vec3, float)
vec4(float, vec3)
vec4(vec2, vec2)
```

Some examples of these are:

```
vec4 color = vec4(0.0, 1.0, 0.0, 1.0);
vec4 rgba  = vec4(1.0);           // sets each component to 1.0
vec3 rgb   = vec3(color);        // drop the 4th component
```

To initialize the diagonal of a matrix with all other elements set to zero:

```
mat2(float)
mat3(float)
mat4(float)
```

That is, $result[i][j]$ is set to the *float* argument for all $i = j$ and set to 0 for all $i \neq j$.

To initialize a matrix by specifying vectors or scalars, the components are assigned to the matrix elements in column-major order.

```

mat2(vec2, vec2);           // one column per argument
mat3(vec3, vec3, vec3);    // one column per argument
mat4(vec4, vec4, vec4, vec4); // one column per argument
mat3x2(vec2, vec2, vec2);  // one column per argument

dmat2(dvec2, dvec2);
dmat3(dvec3, dvec3, dvec3);
dmat4(dvec4, dvec4, dvec4, dvec4);

mat2(float, float,        // first column
      float, float);     // second column

mat3(float, float, float,  // first column
      float, float, float, // second column
      float, float, float); // third column

mat4(float, float, float, float, // first column
      float, float, float, float, // second column
      float, float, float, float, // third column
      float, float, float, float); // fourth column

mat2x3(vec2, float,        // first column
        vec2, float);     // second column

dmat2x4(dvec3, double,    // first column
        double, dvec3);   // second column

```

A wide range of other possibilities exist, to construct a matrix from vectors and scalars, as long as enough components are present to initialize the matrix. To construct a matrix from a matrix:

```

mat3x3(mat4x4); // takes the upper-left 3x3 of the mat4x4
mat2x3(mat4x2); // takes the upper-left 2x2 of the mat4x4, last row is 0,0
mat4x4(mat3x3); // puts the mat3x3 in the upper-left, sets the lower right
                // component to 1, and the rest to 0

```

5.4.3 Structure Constructors

Once a structure is defined, and its type is given a name, a constructor is available with the same name to construct instances of that structure. For example:

```

struct light {
    float intensity;
    vec3 position;
};

light lightVar = light(3.0, vec3(1.0, 2.0, 3.0));

```

The arguments to the constructor will be used to set the structure's members, in order, using one argument per member. Each argument must be the same type as the member it sets, or be a type that can be converted to the member's type according to section 4.1.10 “Implicit Conversions.”

Structure constructors can be used as initializers or in expressions.

5.4.4 Array Constructors

Array types can also be used as constructor names, which can then be used in expressions or initializers. For example,

```
const float c[3] = float[3](5.0, 7.2, 1.1);
const float d[3] = float[](5.0, 7.2, 1.1);

float g;
...
float a[5] = float[5](g, 1, g, 2.3, g);
float b[3];

b = float[3](g, g + 1.0, g + 2.0);
```

There must be exactly the same number of arguments as the size of the array being constructed. If no size is present in the constructor, then the array is explicitly sized to the number of arguments provided. The arguments are assigned in order, starting at element 0, to the elements of the constructed array. Each argument must be the same type as the element type of the array, or be a type that can be converted to the element type of the array according to section 4.1.10 “Implicit Conversions.”

Arrays of arrays are similarly constructed, and the size for any dimension is optional:

```
vec4 b[2] = ...;
vec4[3][2](b, b, b);           // constructor
vec4[][2](b, b, b);           // constructor, valid, size deduced
vec4[3][](b, b, b);           // constructor, valid, size deduced
vec4[][](b, b, b);           // constructor, valid, both sizes deduced
```

5.5 Vector and Scalar Components and Length

The names of the components of a vector or scalar are denoted by a single letter. As a notational convenience, several letters are associated with each component based on common usage of position, color or texture coordinate vectors. The individual components can be selected by following the variable name with period (.) and then the component name.

The component names supported are:

$\{x, y, z, w\}$	Useful when accessing vectors that represent points or normals
$\{r, g, b, a\}$	Useful when accessing vectors that represent colors
$\{s, t, p, q\}$	Useful when accessing vectors that represent texture coordinates

5 Operators and Expressions

The component names x , r , and s are, for example, synonyms for the same (first) component in a vector. They are also the names of the only component in a scalar.

Note that the third component of the texture coordinate set, r in OpenGL, has been renamed p so as to avoid the confusion with r (for red) in a color.

Accessing components beyond those declared for the type is a compile-time error so, for example:

```
vec2 pos;
float height;
pos.x      // is legal
pos.z      // is illegal
height.x   // is legal
height.y   // is illegal
```

The component selection syntax allows multiple components to be selected by appending their names (from the same name set) after the period (`.`).

```
vec4 v4;
v4.rgba; // is a vec4 and the same as just using v4,
v4.rgb;  // is a vec3,
v4.b;    // is a float,
v4.xy;   // is a vec2,
v4.xgba; // is illegal - the component names do not come from
//                the same set.
```

The order of the components can be different to swizzle them, or replicated:

```
vec4 pos = vec4(1.0, 2.0, 3.0, 4.0);
vec4 swiz = pos.wzyx; // swiz = (4.0, 3.0, 2.0, 1.0)
vec4 dup = pos.xxyy; // dup = (1.0, 1.0, 2.0, 2.0)
float f = 1.2;
vec4 dup = f.xxxx;   // dup = (1.2, 1.2, 1.2, 1.2)
```

This notation is more concise than the constructor syntax. To form an r-value, it can be applied to any expression that results in a vector or scalar r-value. Any resulting vector of any operation must be a valid vector in the language; hence the following results in a compile-time error:

```
vec4 f;
vec4 g = pos.xyzwxy.xyzw; // illegal; pos.xyzwxy is non-existent "vec6"
```

The component group notation can occur on the left hand side of an expression.

```
vec4 pos = vec4(1.0, 2.0, 3.0, 4.0);
pos.xw = vec2(5.0, 6.0);           // pos = (5.0, 2.0, 3.0, 6.0)
pos.wx = vec2(7.0, 8.0);           // pos = (8.0, 2.0, 3.0, 7.0)
pos.xx = vec2(3.0, 4.0);           // illegal - 'x' used twice
pos.xy = vec3(1.0, 2.0, 3.0);      // illegal - mismatch between vec2 and
vec3
```

To form an l-value, swizzling must be applied to an l-value of vector or scalar type, contain no duplicate components, and it results in an l-value of scalar or vector type, depending on number of components specified.

Array subscripting syntax can also be applied to vectors (but not to scalars) to provide numeric indexing. So in

```
vec4 pos;
```

`pos[2]` refers to the third element of `pos` and is equivalent to `pos.z`. This allows variable indexing into a vector, as well as a generic way of accessing components. Any integer expression can be used as the subscript. The first component is at index zero. Reading from or writing to a vector using a constant integral expression with a value that is negative or greater than or equal to the size of the vector results in a compile-time error. When indexing with non-constant expressions, behavior is undefined if the index is negative, or greater than or equal to the size of the vector.

The **length** method may be applied to vectors (but not scalars). The result is the number of components in the vector. For example,

```
vec3 v;
const int L = v.length();
```

sets the constant `L` to 3. The type returned by **.length()** on a vector is **int**, and the value returned is a constant expression.

5.6 Matrix Components

The components of a matrix can be accessed using array subscripting syntax. Applying a single subscript to a matrix treats the matrix as an array of column vectors, and selects a single column, whose type is a vector of the same size as the matrix. The leftmost column is column 0. A second subscript would then operate on the resulting vector, as defined earlier for vectors. Hence, two subscripts select a column and then a row.

```
mat4 m;
m[1] = vec4(2.0);           // sets the second column to all 2.0
m[0][0] = 1.0;             // sets the upper left element to 1.0
m[2][3] = 2.0;             // sets the 4th element of the third column to 2.0
```

Behavior is undefined when accessing a component outside the bounds of a matrix with a non-constant expression. It is a compile-time error to access a matrix with a constant expression that is outside the bounds of the matrix.

The **length** method may be applied to matrices. The result is the number of columns of the matrix. For example,

```
mat3x4 v;
const int L = v.length();
```

sets the constant `L` to 3. The type returned by **.length()** on a matrix is **int**, and the value returned is a constant expression.

5.7 Structure and Array Operations

The members of a structure and the **length** method of an array are selected using the period (`.`).

In total, only the following operators are allowed to operate on arrays and structures as whole entities:

field selector	.
equality	== !=
assignment	=
indexing (arrays only)	[]

The equality operators and assignment operator are only allowed if the two operands are same size and type. The operands cannot contain any opaque types. Structure types must be of the same declared structure. Both array operands must be explicitly sized. When using the equality operators, two structures are equal if and only if all the members are component-wise equal, and two arrays are equal if and only if all the elements are element-wise equal.

Array elements are accessed using the array subscript operator ([]). An example of accessing an array element is

```
diffuseColor += lightIntensity[3] * NdotL;
```

Array indices start at zero. Array elements are accessed using an expression whose type is **int** or **uint**.

Behavior is undefined if a shader subscripts an array with an index less than 0 or greater than or equal to the size the array was declared with.

Arrays can also be accessed with the method operator (.) and the **length** method to query the size of the array:

```
lightIntensity.length() // return the size of the array
```

5.8 Assignments

Assignments of values to variable names are done with the assignment operator (=):

```
lvalue-expression = rvalue-expression
```

The *lvalue-expression* evaluates to an l-value. The assignment operator stores the value of *rvalue-expression* into the l-value and returns that r-value with the type and precision of *lvalue-expression*. The *lvalue-expression* and *rvalue-expression* must have the same type, or the expression must have a type in the table in section 4.1.10 “Implicit Conversions” that converts to the type of *lvalue-expression*, in which case an implicit conversion will be done on the *rvalue-expression* before the assignment is done. Any other desired type-conversions must be specified explicitly via a constructor. L-values must be writable. Variables that are built-in types, entire structures or arrays, structure members, l-values with the field selector (.) applied to select components or swizzles without repeated fields, l-values within parentheses, and l-values dereferenced with the array subscript operator ([]) are all l-values. Other binary or unary expressions, function names, swizzles with repeated fields, and constants cannot be l-values. The ternary operator (?:) is also not allowed as an l-value. Using an incorrect expression as an l-value results in a compile-time error.

Expressions on the left of an assignment are evaluated before expressions on the right of the assignment.

The other assignment operators are

- add into (`+=`)
- subtract from (`-=`)
- multiply into (`*=`)
- divide into (`/=`)
- modulus into (`%=`)
- left shift by (`<<=`)
- right shift by (`>>=`)
- and into (`&=`)
- inclusive-or into (`|=`)
- exclusive-or into (`^=`)

where the general expression

```
lvalue op= expression
```

is equivalent to

```
lvalue = lvalue op expression
```

where *op* is as described below, and the l-value and expression must satisfy the semantic requirements of both *op* and equals (`=`).

Reading a variable before writing (or initializing) it is legal, however the value is undefined.

5.9 Expressions

Expressions in the shading language are built from the following:

- Constants of type **bool**, all integer types, all floating-point types, all vector types, and all matrix types.
- Constructors of all types.
- Variable names of all types.
- An array, vector, or matrix expression with the **length** method applied.
- Subscripted array names.
- Function calls that return values.
- Component field selectors and array subscript results.
- Parenthesized expression. Any expression can be parenthesized. Parentheses can be used to group operations. Operations within parentheses are done before operations across parentheses.

5 Operators and Expressions

- The arithmetic binary operators add (+), subtract (-), multiply (*), and divide (/) operate on integer and floating-point scalars, vectors, and matrices. If the fundamental types in the operands do not match, then the conversions from section 4.1.10 “Implicit Conversions” are applied to create matching types. All arithmetic binary operators result in the same fundamental type (signed integer, unsigned integer, single-precision floating point, or double-precision floating point) as the operands they operate on, after operand type conversion. After conversion, the following cases are valid
 - The two operands are scalars. In this case the operation is applied, resulting in a scalar.
 - One operand is a scalar, and the other is a vector or matrix. In this case, the scalar operation is applied independently to each component of the vector or matrix, resulting in the same size vector or matrix.
 - The two operands are vectors of the same size. In this case, the operation is done component-wise resulting in the same size vector.
 - The operator is add (+), subtract (-), or divide (/), and the operands are matrices with the same number of rows and the same number of columns. In this case, the operation is done component-wise resulting in the same size matrix.
 - The operator is multiply (*), where both operands are matrices or one operand is a vector and the other a matrix. A right vector operand is treated as a column vector and a left vector operand as a row vector. In all these cases, it is required that the number of columns of the left operand is equal to the number of rows of the right operand. Then, the multiply (*) operation does a linear algebraic multiply, yielding an object that has the same number of rows as the left operand and the same number of columns as the right operand. Section 5.10 “Vector and Matrix Operations” explains in more detail how vectors and matrices are operated on.

All other cases result in a compile-time error.

Dividing by zero does not cause an exception but does result in an unspecified value. Use the built-in functions **dot**, **cross**, **matrixCompMult**, and **outerProduct**, to get, respectively, vector dot product, vector cross product, matrix component-wise multiplication, and the matrix product of a column vector times a row vector.

- The operator modulus (%) operates on signed or unsigned integer scalars or integer vectors. If the fundamental types in the operands do not match, then the conversions from section 4.1.10 “Implicit Conversions” are applied to create matching types. The operands cannot be vectors of differing size; this is a compile time error. If one operand is a scalar and the other vector, then the scalar is applied component-wise to the vector, resulting in the same type as the vector. If both are vectors of the same size, the result is computed component-wise. The resulting value is undefined for any component computed with a second operand that is zero, while results for other components with non-zero second operands remain defined. If both operands are non-negative, then the remainder is non-negative. Results are undefined if one or both operands are negative. The operator modulus (%) is not defined for any other data types (non-integer types).
- The arithmetic unary operators negate (-), post- and pre-increment and decrement (-- and ++) operate on integer or floating-point values (including vectors and matrices). All unary operators work component-wise on their operands. These result with the same type they operated on. For post- and pre-increment and decrement, the expression must be one that could be assigned to (an l-value). Pre-increment and pre-decrement add or subtract 1 or 1.0 to the contents of the expression they operate on,

and the value of the pre-increment or pre-decrement expression is the resulting value of that modification. Post-increment and post-decrement expressions add or subtract 1 or 1.0 to the contents of the expression they operate on, but the resulting expression has the expression's value before the post-increment or post-decrement was executed.

- The relational operators greater than (>), less than (<), greater than or equal (>=), and less than or equal (<=) operate only on scalar integer and scalar floating-point expressions. The result is scalar Boolean. Either the operands' types must match, or the conversions from section 4.1.10 "Implicit Conversions" will be applied to obtain matching types. To do component-wise relational comparisons on vectors, use the built-in functions **lessThan**, **lessThanEqual**, **greaterThan**, and **greaterThanEqual**.
- The equality operators **equal** (==), and not equal (!=) operate on all types except opaque types, aggregates that contain opaque types, subroutine uniforms, and aggregates that contain subroutine uniforms. They result in a scalar Boolean. If the operand types do not match, then there must be a conversion from section 4.1.10 "Implicit Conversions" applied to one operand that can make them match, in which case this conversion is done. For vectors, matrices, structures, and arrays, all components, members, or elements of one operand must equal the corresponding components, members, or elements in the other operand for the operands to be considered equal. To get a vector of component-wise equality results for vectors, use the built-in functions **equal** and **notEqual**.
- The logical binary operators and (&&), or (||), and exclusive or (^) operate only on two Boolean expressions and result in a Boolean expression. And (&&) will only evaluate the right hand operand if the left hand operand evaluated to **true**. Or (||) will only evaluate the right hand operand if the left hand operand evaluated to **false**. Exclusive or (^) will always evaluate both operands.
- The logical unary operator not (!). It operates only on a Boolean expression and results in a Boolean expression. To operate on a vector, use the built-in function **not**.
- The sequence (,) operator that operates on expressions by returning the type and value of the right-most expression in a comma separated list of expressions. All expressions are evaluated, in order, from left to right.
- The ternary selection operator (? :). It operates on three expressions (*exp1 ? exp2 : exp3*). This operator evaluates the first expression, which must result in a scalar Boolean. If the result is true, it selects to evaluate the second expression, otherwise it selects to evaluate the third expression. Only one of the second and third expressions is evaluated. The second and third expressions can be any type, as long their types match, or there is a conversion in section 4.1.10 "Implicit Conversions" that can be applied to one of the expressions to make their types match. This resulting matching type is the type of the entire expression.
- The one's complement operator (~). The operand must be of type signed or unsigned integer or integer vector, and the result is the one's complement of its operand; each bit of each component is complemented, including any sign bits.
- The shift operators (<<) and (>>). For both operators, the operands must be signed or unsigned integers or integer vectors. One operand can be signed while the other is unsigned. In all cases, the resulting type will be the same type as the left operand. If the first operand is a scalar, the second operand has to be a scalar as well. If the first operand is a vector, the second operand must be a scalar or a vector, and the result is computed component-wise. The result is undefined if the right operand is negative, or greater than or equal to the number of bits in the left expression's base type. The value of

$E1 \ll E2$ is $E1$ (interpreted as a bit pattern) left-shifted by $E2$ bits. The value of $E1 \gg E2$ is $E1$ right-shifted by $E2$ bit positions. If $E1$ is a signed integer, the right-shift will extend the sign bit. If $E1$ is an unsigned integer, the right-shift will zero-extend.

- The bitwise operators and (**&**), exclusive-or (**^**), and inclusive-or (**|**). The operands must be of type signed or unsigned integers or integer vectors. The operands cannot be vectors of differing size; this is a compile-time error. If one operand is a scalar and the other a vector, the scalar is applied component-wise to the vector, resulting in the same type as the vector. If the fundamental types in the operands do not match, then the conversions from section 4.1.10 “Implicit Conversions” are applied to create matching types, and this will be the resulting fundamental type. For and (**&**), the result is the bitwise-and function of the operands. For exclusive-or (**^**), the result is the bitwise exclusive-or function of the operands. For inclusive-or (**|**), the result is the bitwise inclusive-or function of the operands.

For a complete specification of the syntax of expressions, see section 9 “Shading Language Grammar.”

5.10 Vector and Matrix Operations

With a few exceptions, operations are component-wise. Usually, when an operator operates on a vector or matrix, it is operating independently on each component of the vector or matrix, in a component-wise fashion. For example,

```
vec3 v, u;
float f;

v = u + f;
```

will be equivalent to

```
v.x = u.x + f;
v.y = u.y + f;
v.z = u.z + f;
```

And

```
vec3 v, u, w;
w = v + u;
```

will be equivalent to

```
w.x = v.x + u.x;
w.y = v.y + u.y;
w.z = v.z + u.z;
```

and likewise for most operators and all integer and floating-point vector and matrix types. The exceptions are matrix multiplied by vector, vector multiplied by matrix, and matrix multiplied by matrix. These do not operate component-wise, but rather perform the correct linear algebraic multiply.

```
vec3 v, u;
mat3 m;
```

```
u = v * m;
```

is equivalent to

```
u.x = dot(v, m[0]); // m[0] is the left column of m
u.y = dot(v, m[1]); // dot(a,b) is the inner (dot) product of a and b
u.z = dot(v, m[2]);
```

And

```
u = m * v;
```

is equivalent to

```
u.x = m[0].x * v.x + m[1].x * v.y + m[2].x * v.z;
u.y = m[0].y * v.x + m[1].y * v.y + m[2].y * v.z;
u.z = m[0].z * v.x + m[1].z * v.y + m[2].z * v.z;
```

And

```
mat3 m, n, r;
```

```
r = m * n;
```

is equivalent to

```
r[0].x = m[0].x * n[0].x + m[1].x * n[0].y + m[2].x * n[0].z;
r[1].x = m[0].x * n[1].x + m[1].x * n[1].y + m[2].x * n[1].z;
r[2].x = m[0].x * n[2].x + m[1].x * n[2].y + m[2].x * n[2].z;

r[0].y = m[0].y * n[0].x + m[1].y * n[0].y + m[2].y * n[0].z;
r[1].y = m[0].y * n[1].x + m[1].y * n[1].y + m[2].y * n[1].z;
r[2].y = m[0].y * n[2].x + m[1].y * n[2].y + m[2].y * n[2].z;

r[0].z = m[0].z * n[0].x + m[1].z * n[0].y + m[2].z * n[0].z;
r[1].z = m[0].z * n[1].x + m[1].z * n[1].y + m[2].z * n[1].z;
r[2].z = m[0].z * n[2].x + m[1].z * n[2].y + m[2].z * n[2].z;
```

and similarly for other sizes of vectors and matrices.

5.11 Out-of-Bounds Accesses

In the subsections described above for array, vector, matrix and structure accesses, any out-of-bounds access produced undefined behavior. However, if robust buffer access is enabled via the OpenGL API, such accesses will be bound within the memory extent of the active program. It will not be possible to access memory from other programs, and accesses will not result in abnormal program termination. Out-of-bounds reads return undefined values, which include values from other variables of the active program or zero. Out-of-bounds writes may be discarded or overwrite other variables of the active program, depending on the value of the computed index and how this relates to the extent of the active program's

memory. Applications that require defined behavior for out-of-bounds accesses should range check all computed indices before dereferencing an array.

5.12 Specialization Constant Operations

Only some operations discussed in this section may be applied to a specialization constant and still yield a result that is a specialization constant. The operations that do so are listed below. When a specialization constant is operated on with one of these operators and with another constant or specialization constant, the result is implicitly a specialization constant.

- **int()**, **uint()**, and **bool()** constructors for type conversions from any of the following types to any of the following types:
 - **int**
 - **uint**
 - **bool**
- vector versions of the above conversion constructors
- allowed implicit conversions of the above
- swizzles (e.g., `foo.yx`)
- the following when applied to integer or unsigned integer types:
 - unary negative (`-`)
 - binary operations (`+` , `-` , `*` , `/` , `%`)
 - shift (`<<` , `>>`)
 - bitwise operations (`&` , `|` , `^`)
- the following when applied to integer or unsigned integer scalar types:
 - comparison (`==` , `!=` , `>` , `>=` , `<` , `<=`)
- The following when applied to the Boolean scalar type:
 - not (`!`)
 - logical operations (`&&` , `||` , `^^`)
 - comparison (`==` , `!=`)
- the ternary operator (`? :`)

6 Statements and Structure

The fundamental building blocks of the OpenGL Shading Language are:

- statements and declarations
- function definitions
- selection (**if-else** and **switch-case-default**)
- iteration (**for**, **while**, and **do-while**)
- jumps (**discard**, **return**, **break**, and **continue**)

The overall structure of a shader is as follows

translation-unit:
global-declaration
translation-unit global-declaration

global-declaration:
function-definition
declaration

That is, a shader is a sequence of declarations and function bodies. Function bodies are defined as

function-definition:
function-prototype { statement-list }

statement-list:
statement
statement-list statement

statement:
compound-statement
simple-statement

Curly braces are used to group sequences of statements into compound statements.

compound-statement:
 { *statement-list* }

simple-statement:
 declaration-statement
 expression-statement
 selection-statement
 iteration-statement
 jump-statement

Simple declaration, expression, and jump statements end in a semi-colon.

This above is slightly simplified, and the complete grammar specified in section 9 “Shading Language Grammar” should be used as the definitive specification.

Declarations and expressions have already been discussed.

6.1 Function Definitions

As indicated by the grammar above, a valid shader is a sequence of global declarations and function definitions. A function is declared as the following example shows:

```
// prototype
returnType functionName (type0 arg0, type1 arg1, ..., typen argn);
```

and a function is defined like

```
// definition
returnType functionName (type0 arg0, type1 arg1, ..., typen argn)
{
    // do some computation
    return returnValue;
}
```

where *returnType* must be present and include a type. If the type of *returnValue* does not match *returnType*, there must be an implicit conversion in section 4.1.10 “Implicit Conversions” that converts the type of *returnValue* to *returnType*, or a compile-time error will result.

Each of the *typeN* must include a type and can optionally include parameter qualifiers. The formal argument names (*args* above) in the declarations are optional for both the declaration and definition forms.

A function is called by using its name followed by a list of arguments in parentheses.

Arrays are allowed as arguments and as the return type. In both cases, the array must be explicitly sized. An array is passed or returned by using just its name, without brackets, and the size of the array must match the size specified in the function's declaration.

Structures are also allowed as argument types. The return type can also be structure.

See section 9 “Shading Language Grammar” for the definitive reference on the syntax to declare and define functions.

All functions must be either declared with a prototype or defined with a body before they are called. For example:

```
float myfunc (float f,          // f is an input parameter
             out float g);    // g is an output parameter
```

Functions that return no value must be declared as **void**. A **void** function can only use **return** without a return argument, even if the return argument has void type. Return statements only accept values:

```
void func1() { }
void func2() { return func1(); } // illegal return statement
```

Only a precision qualifier is allowed on the return type of a function. Formal parameters can have parameter, precision, and memory qualifiers, but no other qualifiers.

Functions that accept no input arguments need not use **void** in the argument list because prototypes (or definitions) are required and therefore there is no ambiguity when an empty argument list “()” is declared. The idiom “**(void)**” as a parameter list is provided for convenience.

Function names can be overloaded. The same function name can be used for multiple functions, as long as the parameter types differ. If a function name is declared twice with the same parameter types, then the return types and all qualifiers must also match, and it is the same function being declared. For example,

```
vec4 f(in  vec4 x, out  vec4 y);    // (A)
vec4 f(in  vec4 x, out uvec4 y);    // (B) okay, different argument type
vec4 f(in  ivec4 x, out dvec4 y);    // (C) okay, different argument type

int  f(in  vec4 x, out  vec4 y);    // error, only return type differs
vec4 f(in  vec4 x, in  vec4 y);    // error, only qualifier differs
vec4 f(const in vec4 x, out vec4 y); // error, only qualifier differs
```

When function calls are resolved, an exact type match for all the arguments is sought. If an exact match is found, all other functions are ignored, and the exact match is used. If no exact match is found, then the implicit conversions in section 4.1.10 “Implicit Conversions” will be applied to find a match.

Mismatched types on input parameters (**in** or **inout** or default) must have a conversion from the calling argument type to the formal parameter type. Mismatched types on output parameters (**out** or **inout**) must have a conversion from the formal parameter type to the calling argument type.

If implicit conversions can be used to find more than one matching function, a single best-matching function is sought. To determine a best match, the conversions between calling argument and formal parameter types are compared for each function argument and pair of matching functions. After these comparisons are performed, each pair of matching functions are compared. A function declaration *A* is considered a better match than function declaration *B* if

- for at least one function argument, the conversion for that argument in *A* is better than the corresponding conversion in *B*; and

- there is no function argument for which the conversion in *B* is better than the corresponding conversion in *A*.

If a single function declaration is considered a better match than every other matching function declaration, it will be used. Otherwise, a compile-time semantic error for an ambiguous overloaded function call occurs.

To determine whether the conversion for a single argument in one match is better than that for another match, the following rules are applied, in order:

1. An exact match is better than a match involving any implicit conversion.
2. A match involving an implicit conversion from **float** to **double** is better than a match involving any other implicit conversion.
3. A match involving an implicit conversion from either **int** or **uint** to **float** is better than a match involving an implicit conversion from either **int** or **uint** to **double**.

If none of the rules above apply to a particular pair of conversions, neither conversion is considered better than the other.

For the example function prototypes (A), (B), and (C) above, the following examples show how the rules apply to different sets of calling argument types:

```
f(vec4, vec4);           // exact match of vec4 f(in vec4 x, out vec4 y)
f(vec4, uvec4);          // exact match of vec4 f(in vec4 x, out uvec4 y)
f(vec4, ivec4);          // matched to vec4 f(in vec4 x, out vec4 y)
                        // (C) not relevant, can't convert vec4 to
                        // ivec4. (A) better than (B) for 2nd
                        // argument (rule 3), same on first argument.
f(ivec4, vec4);          // NOT matched. All three match by implicit
                        // conversion. (C) is better than (A) and (B)
                        // on the first argument. (A) is better than
                        // (B) and (C).
```

User-defined functions can have multiple declarations, but only one definition. A shader can redefine built-in functions. If a built-in function is redeclared in a shader (i.e., a prototype is visible) before a call to it, then the linker will only attempt to resolve that call within the set of shaders that are linked with it.

The function *main* is used as the entry point to a shader executable. A shader need not contain a function named *main*, but one shader in a set of shaders linked together to form a single shader executable must, or a link-time error results. This function takes no arguments, returns no value, and must be declared as type **void**:

```
void main()
{
    ...
}
```

The function *main* can contain uses of **return**. See section 6.4 “Jumps” for more details.

It is a compile-time or link-time error to declare or define a function **main** with any other parameters or return type.

6.1.1 Function Calling Conventions

Functions are called by value-return. This means input arguments are copied into the function at call time, and output arguments are copied back to the caller before function exit. Because the function works with local copies of parameters, there are no issues regarding aliasing of variables within a function. To control what parameters are copied in and/or out through a function definition or declaration:

- The keyword **in** is used as a qualifier to denote a parameter is to be copied in, but not copied out.
- The keyword **out** is used as a qualifier to denote a parameter is to be copied out, but not copied in. This should be used whenever possible to avoid unnecessarily copying parameters in.
- The keyword **inout** is used as a qualifier to denote the parameter is to be both copied in and copied out. It means the same thing as specifying both **in** and **out**.
- A function parameter declared with no such qualifier means the same thing as specifying **in**.

All arguments are evaluated at call time, exactly once, in order, from left to right. Evaluation of an **in** parameter results in a value that is copied to the formal parameter. Evaluation of an **out** parameter results in an l-value that is used to copy out a value when the function returns. Evaluation of an **inout** parameter results in both a value and an l-value; the value is copied to the formal parameter at call time and the l-value is used to copy out a value when the function returns.

The order in which output parameters are copied back to the caller is undefined.

If the function matching described in the previous section required argument type conversions, these conversions are applied at copy-in and copy-out times.

In a function, writing to an input-only parameter is allowed. Only the function's copy is modified. This can be prevented by declaring a parameter with the **const** qualifier.

When calling a function, expressions that do not evaluate to l-values cannot be passed to parameters declared as **out** or **inout**, or a compile-time error results

function-prototype :

precision-qualifier type function-name(parameter-qualifiers precision-qualifier type name array-specifier; ...)

type :

any basic type, array type, structure name, or *structure definition*

parameter-qualifiers :

empty
list of *parameter-qualifier*

parameter-qualifier :

const
in
out
inout
precise
memory qualifier
precision qualifier

name :

empty
identifier

array-specifier :

empty
[*integral-constant-expression*]

The **const** qualifier cannot be used with **out** or **inout**, or a compile-time error results. The above is used both for function declarations (i.e., prototypes) and for function definitions. Hence, function definitions can have unnamed arguments.

Recursion is not allowed, not even statically. Static recursion is present if the static function-call graph of a program contains cycles. This includes all potential function calls through variables declared as **subroutine uniform** (described below). It is a compile-time or link-time error if a single compilation unit (shader) contains either static recursion or the potential for recursion through subroutine variables.

6.1.2 Subroutines

Subroutines provide a mechanism allowing shaders to be compiled in a manner where the target of one or more function calls can be changed at run-time without requiring any shader recompilation. For example, a single shader may be compiled with support for multiple illumination algorithms to handle different kinds of lights or surface materials. An application using such a shader may switch illumination algorithms by changing the value of its subroutine uniforms. To use subroutines, a subroutine type is declared, one or more functions are associated with that subroutine type, and a subroutine variable of that type is declared. The function currently assigned to the variable function is then called by using function calling syntax replacing a function name with the name of the subroutine variable. Subroutine variables

are uniforms, and are assigned to specific functions only through commands (**UniformSubroutinesuiv**) in the OpenGL API.

Subroutine functionality is not available when generating SPIR-V.

Subroutine types are declared using a statement similar to a function declaration, with the **subroutine** keyword, as follows:

```
subroutine returnType subroutineTypeName(type0 arg0, type1 arg1,
                                        ..., typen argn);
```

As with function declarations, the formal argument names (*args* above) are optional. Functions are associated with subroutine types of matching declarations by defining the function with the **subroutine** keyword and a list of subroutine types the function matches:

```
subroutine(subroutineTypeName0, ..., subroutineTypeNameN)
returnType functionName(type0 arg0, type1 arg1, ..., typen argn)
{ ... } // function body
```

It is a compile-time error if arguments and return type don't match between the function and each associated subroutine type.

Functions declared with **subroutine** must include a body. An overloaded function cannot be declared with **subroutine**; a program will fail to compile or link if any shader or stage contains two or more functions with the same name if the name is associated with a subroutine type.

A function declared with **subroutine** can also be called directly with a static use of *functionName*, as is done with non-subroutine function declarations and calls.

Subroutine type variables are required to be *subroutine uniforms*, and are declared with a specific subroutine type in a subroutine uniform variable declaration:

```
subroutine uniform subroutineTypeName subroutineVarName;
```

Subroutine uniform variables are called the same way functions are called. When a subroutine variable (or an element of a subroutine variable array) is associated with a particular function, all function calls through that variable will call that particular function.

Unlike other uniform variables, subroutine uniform variables are scoped to the shader execution stage the variable is declared in.

Subroutine variables may be declared as explicitly-sized arrays, which can be indexed only with dynamically uniform expressions.

It is a compile-time error to use the **subroutine** keyword in any places other than (as shown above) to

- declare a subroutine type at global scope,
- declare a function as a subroutine, or
- declare a subroutine variable at global scope.

6.2 Selection

Conditional control flow in the shading language is done by either **if**, **if-else**, or **switch** statements:

```

selection-statement :
    if ( bool-expression ) statement
    if ( bool-expression ) statement else statement
    switch ( init-expression ) { switch-statement-listopt }

```

Where *switch-statement-list* is a nested scope containing a list of zero or more *switch-statement* and other statements defined by the language, where *switch-statement* adds some forms of labels. That is

```

switch-statement-list :
    switch-statement
    switch-statement-list switch-statement

switch-statement :
    case constant-expression :
    default :
    statement

```

Note the above grammar's purpose is to aid discussion in this section; the normative grammar is in section 9.

If an **if**-expression evaluates to **true**, then the first *statement* is executed. If it evaluates to **false** and there is an **else** part then the second *statement* is executed.

Any expression whose type evaluates to a Boolean can be used as the conditional expression *bool-expression*. Vector types are not accepted as the expression to **if**.

Conditionals can be nested.

The type of the *init-expression* value in a **switch** statement must be a scalar **int** or **uint**. The type of the *constant-expression* value in a case label also must be a scalar **int** or **uint**. When any pair of these values is tested for "equal value" and the types do not match, an implicit conversion will be done to convert the **int** to a **uint** (see section 4.1.10 "Implicit Conversions") before the compare is done. If a **case** label has a *constant-expression* of equal value to *init-expression*, execution will continue after that label. It is a compile-time error to have two case label *constant-expression* of equal value. Otherwise, if there is a **default** label, execution will continue after that label. Otherwise, execution skips the rest of the switch statement. It is a compile-time error to have more than one **default**. A **break** statement not nested in a loop or other switch statement (either not nested or nested only in **if** or **if-else** statements) will also skip the rest of the switch statement. Fall through labels are allowed. No statements are allowed in a switch statement before the first **case** statement.

The **case** and **default** labels can only appear within a switch statement. No **case** or **default** labels can be nested inside other statement or compound statement within their corresponding **switch**.

6.3 Iteration

For, while, and do loops are allowed as follows:

```

for (init-expression; condition-expression; loop-expression)
    sub-statement

while (condition-expression)
    sub-statement

do
    statement
while (condition-expression)

```

See section 9 “Shading Language Grammar” for the definitive specification of loops.

The **for** loop first evaluates the *init-expression*, then the *condition-expression*. If the *condition-expression* evaluates to **true**, then the body of the loop is executed. After the body is executed, a **for** loop will then evaluate the *loop-expression*, and then loop back to evaluate the *condition-expression*, repeating until the *condition-expression* evaluates to **false**. The loop is then exited, skipping its body and skipping its *loop-expression*. Variables modified by the *loop-expression* maintain their value after the loop is exited, provided they are still in scope. Variables declared in *init-expression* or *condition-expression* are only in scope until the end of the sub-statement of the **for** loop.

The **while** loop first evaluates the *condition-expression*. If **true**, then the body is executed. This is then repeated, until the *condition-expression* evaluates to **false**, exiting the loop and skipping its body. Variables declared in the *condition-expression* are only in scope until the end of the sub-statement of the **while** loop.

The **do-while** loop first executes the body, then executes the *condition-expression*. This is repeated until *condition-expression* evaluates to **false**, and then the loop is exited.

Expressions for *condition-expression* must evaluate to a Boolean.

Both the *condition-expression* and the *init-expression* can declare and initialize a variable, except in the **do-while** loop, which cannot declare a variable in its *condition-expression*. The variable’s scope lasts only until the end of the sub-statement that forms the body of the loop.

Loops can be nested.

Non-terminating loops are allowed. The consequences of very long or non-terminating loops are platform dependent.

6.4 Jumps

These are the jumps:

```
jump_statement:
    continue;
    break;
    return;
    return expression;
    discard; // in the fragment shader language only
```

There is no “goto” nor other non-structured flow of control.

The **continue** jump is used only in loops. It skips the remainder of the body of the inner most loop of which it is inside. For **while** and **do-while** loops, this jump is to the next evaluation of the loop *condition-expression* from which the loop continues as previously defined. For **for** loops, the jump is to the *loop-expression*, followed by the *condition-expression*.

The **break** jump can also be used only in loops and **switch** statements. It is simply an immediate exit of the inner-most loop or **switch** statements containing the **break**. No further execution of *condition-expression*, *loop-expression*, or *switch-statement* is done.

The **discard** keyword is only allowed within fragment shaders. It can be used within a fragment shader to abandon the operation on the current fragment. This keyword causes the fragment to be discarded and no updates to any buffers will occur. Control flow exits the shader, and subsequent implicit or explicit derivatives are undefined when this exit is non-uniform. It would typically be used within a conditional statement, for example:

```
if (intensity < 0.0)
    discard;
```

A fragment shader may test a fragment’s alpha value and discard the fragment based on that test. However, it should be noted that coverage testing occurs after the fragment shader runs, and the coverage test can change the alpha value.

The **return** jump causes immediate exit of the current function. If it has *expression* then that is the return value for the function.

The function *main* can use **return**. This simply causes *main* to exit in the same way as when the end of the function had been reached. It does not imply a use of **discard** in a fragment shader. Using **return** in *main* before defining outputs will have the same behavior as reaching the end of *main* before defining outputs.

7 Built-in Variables

7.1 Built-In Language Variables

Some OpenGL operations occur in fixed functionality and need to provide values to or receive values from shader executables. Shaders communicate with fixed-function OpenGL pipeline stages, and optionally with other shader executables, through the use of built-in input and output variables.

In the compute language, the built-in variables are declared as follows:

```
// work group dimensions
in   uvec3 gl_NumWorkGroups;
const uvec3 gl_WorkGroupSize;

// work group and invocation IDs
in   uvec3 gl_WorkGroupID;
in   uvec3 gl_LocalInvocationID;

// derived variables
in   uvec3 gl_GlobalInvocationID;
in   uint  gl_LocalInvocationIndex;
```

In the vertex language, the built-ins are intrinsically declared as:

```
in  int  gl_VertexID;
in  int  gl_InstanceID;
in  int  gl_DrawID;
in  int  gl_BaseVertex;
in  int  gl_BaseInstance;

out gl_PerVertex {
    vec4  gl_Position;
    float gl_PointSize;
    float gl_ClipDistance[];
    float gl_CullDistance[];
};
```


In the geometry language, the built-in variables are intrinsically declared as:

```

in gl_PerVertex {
    vec4  gl_Position;
    float gl_PointSize;
    float gl_ClipDistance[];
    float gl_CullDistance[];
} gl_in[];

in int gl_PrimitiveIDIn;
in int gl_InvocationID;

out gl_PerVertex {
    vec4  gl_Position;
    float gl_PointSize;
    float gl_ClipDistance[];
    float gl_CullDistance[];
};

out int gl_PrimitiveID;
out int gl_Layer;
out int gl_ViewportIndex;

```

In the tessellation control language, built-in variables are intrinsically declared as:

```

in gl_PerVertex {
    vec4  gl_Position;
    float gl_PointSize;
    float gl_ClipDistance[];
    float gl_CullDistance[];
} gl_in[gl_MaxPatchVertices];

in int gl_PatchVerticesIn;
in int gl_PrimitiveID;
in int gl_InvocationID;

out gl_PerVertex {
    vec4  gl_Position;
    float gl_PointSize;
    float gl_ClipDistance[];
    float gl_CullDistance[];
} gl_out[];

patch out float gl_TessLevelOuter[4];
patch out float gl_TessLevelInner[2];

```

In the tessellation evaluation language, built-in variables are intrinsically declared as:

```

in gl_PerVertex {
    vec4 gl_Position;
    float gl_PointSize;
    float gl_ClipDistance[];
    float gl_CullDistance[];
} gl_in[gl_MaxPatchVertices];

in int gl_PatchVerticesIn;
in int gl_PrimitiveID;
in vec3 gl_TessCoord;
patch in float gl_TessLevelOuter[4];
patch in float gl_TessLevelInner[2];

out gl_PerVertex {
    vec4 gl_Position;
    float gl_PointSize;
    float gl_ClipDistance[];
    float gl_CullDistance[];
};

```

In the fragment language, built-in variables are intrinsically declared as:

```

in vec4 gl_FragCoord;
in bool gl_FrontFacing;
in float gl_ClipDistance[];
in float gl_CullDistance[];
in vec2 gl_PointCoord;
in int gl_PrimitiveID;
in int gl_SampleID;
in vec2 gl_SamplePosition;
in int gl_SampleMaskIn[];
in int gl_Layer;
in int gl_ViewportIndex;
in bool gl_HelperInvocation;

out float gl_FragDepth;
out int gl_SampleMask[];

```

Each of the above variables is discussed below.

The built-in variable *gl_NumWorkGroups* is a compute-shader input variable containing the total number of global work items in each dimension of the work group that will execute the compute shader. Its content is equal to the values specified in the *num_groups_x*, *num_groups_y*, and *num_groups_z* parameters passed to the *DispatchCompute* API entry point.

The built-in constant *gl_WorkGroupSize* is a compute-shader constant containing the local work-group size of the shader. The size of the work group in the *X*, *Y*, and *Z* dimensions is stored in the *x*, *y*, and *z* components. The constants values in *gl_WorkGroupSize* will match those specified in the required

local_size_x, **local_size_y**, and **local_size_z** layout qualifiers for the current shader. This is a constant so that it can be used to size arrays of memory that can be shared within the local work group. It is a compile-time error to use *gl_WorkGroupSize* in a shader that does not declare a fixed local group size, or before that shader has declared a fixed local group size, using **local_size_x**, **local_size_y**, and **local_size_z**. When a size is given for some of these identifiers, but not all, the corresponding *gl_WorkGroupSize* will have a size of 1.

The built-in variable *gl_WorkGroupID* is a compute-shader input variable containing the three-dimensional index of the global work group that the current invocation is executing in. The possible values range across the parameters passed into *DispatchCompute*, i.e., from (0, 0, 0) to (*gl_NumWorkGroups.x* - 1, *gl_NumWorkGroups.y* - 1, *gl_NumWorkGroups.z* - 1).

The built-in variable *gl_LocalInvocationID* is a compute-shader input variable containing the t-dimensional index of the local work group within the global work group that the current invocation is executing in. The possible values for this variable range across the local work group size, i.e., (0,0,0) to (*gl_WorkGroupSize.x* - 1, *gl_WorkGroupSize.y* - 1, *gl_WorkGroupSize.z* - 1).

The built-in variable *gl_GlobalInvocationID* is a compute shader input variable containing the global index of the current work item. This value uniquely identifies this invocation from all other invocations across all local and global work groups initiated by the current *DispatchCompute* call. This is computed as:

```
gl_GlobalInvocationID =
    gl_WorkGroupID * gl_WorkGroupSize + gl_LocalInvocationID;
```

The built-in variable *gl_LocalInvocationIndex* is a compute shader input variable that contains the one-dimensional representation of the *gl_LocalInvocationID*. This is useful for uniquely identifying a unique region of shared memory within the local work group for this invocation to use. This is computed as:

```
gl_LocalInvocationIndex =
    gl_LocalInvocationID.z * gl_WorkGroupSize.x * gl_WorkGroupSize.y +
    gl_LocalInvocationID.y * gl_WorkGroupSize.x +
    gl_LocalInvocationID.x;
```

The variable *gl_VertexID* is a vertex language input variable that holds an integer index for the vertex, as defined under “Shader Inputs” in section 11.1.3.9 “Shader Inputs” in the OpenGL Graphics System Specification. While the variable *gl_VertexID* is always present, its value is not always defined.

The variable *gl_InstanceID* is a vertex language input variable that holds the instance number of the current primitive in an instanced draw call (see “Shader Inputs” in section 11.1.3.9 “Shader Inputs” in the OpenGL Graphics System Specification). If the current primitive does not come from an instanced draw call, the value of *gl_InstanceID* is zero.

The variable *gl_DrawID* is a vertex language input variable that holds the integer index of the drawing command to which the current vertex belongs (see “Shader Inputs” in section 11.1.3.9 of the OpenGL Graphics System Specification). If the vertex is not invoked by a **Multi*** form of a draw command, then the value of *gl_DrawID* is zero.

The variable *gl_BaseVertex* is a vertex language input variable that holds the integer value passed to the *baseVertex* parameter of the command that resulted in the current shader invocation (see “Shader Inputs” in section 11.1.3.9 of the OpenGL Graphics System Specification).

The variable *gl_BaseInstance* is a vertex language input variable that holds the integer value passed to the *baseInstance* parameter of the command that resulted in the current shader invocation (see "Shader Inputs" in section 11.1.3.9 of the OpenGL Graphics System Specification).

As an output variable, *gl_Position* is intended for writing the homogeneous vertex position. It can be written at any time during shader execution. This value will be used by primitive assembly, clipping, culling, and other fixed functionality operations, if present, that operate on primitives after vertex processing has occurred. Its value is undefined after the vertex processing stage if the vertex shader executable does not write *gl_Position*, and it is undefined after geometry processing if the geometry executable calls **EmitVertex()** without having written *gl_Position* since the last **EmitVertex()** (or hasn't written it at all). As an input variable, *gl_Position* reads the output written in the previous shader stage to *gl_Position*.

As an output variable, *gl_PointSize* is intended for a shader to write the size of the point to be rasterized. It is measured in pixels. If *gl_PointSize* is not written to, its value is undefined in subsequent pipe stages. As an input variable, *gl_PointSize* reads the output written in the previous shader stage to *gl_PointSize*.

The variable *gl_ClipDistance* provides the forward compatible mechanism for controlling user clipping. The element *gl_ClipDistance[i]* specifies a clip distance for each plane *i*. A distance of 0 means the vertex is on the plane, a positive distance means the vertex is inside the clip plane, and a negative distance means the point is outside the clip plane. The clip distances will be linearly interpolated across the primitive and the portion of the primitive with interpolated distances less than 0 will be clipped.

The *gl_ClipDistance* array is predeclared as unsized and must be explicitly sized by the shader either redeclaring it with a size or implicitly sized by indexing it only with integral constant expressions. This needs to size the array to include all the clip planes that are enabled via the OpenGL API; if the size does not include all enabled planes, results are undefined. The size can be at most *gl_MaxClipDistances*. The number of varying components (see *gl_MaxVaryingComponents*) consumed by *gl_ClipDistance* will match the size of the array, no matter how many planes are enabled. The shader must also set all values in *gl_ClipDistance* that have been enabled via the OpenGL API, or results are undefined. Values written into *gl_ClipDistance* for planes that are not enabled have no effect.

As an output variable, *gl_ClipDistance* provides the place for the shader to write these distances. As an input in all but the fragment language, it reads the values written in the previous shader stage. In the fragment language, *gl_ClipDistance* array contains linearly interpolated values for the vertex values written by a shader to the *gl_ClipDistance* vertex output variable. Only elements in this array that have clipping enabled will have defined values.

The variable *gl_CullDistance* provides a mechanism for controlling user culling. The element *gl_CullDistance[i]* specifies a cull distance for plane *i*. A distance of 0 means the vertex is on the plane, a positive distance means the vertex is inside the cull volume, and a negative distance means the point is outside the cull volume. Primitives whose vertices all have a negative clip distance for plane *i* will be discarded.

The *gl_CullDistance* array is predeclared as unsized and must be sized by the shader either redeclaring it with a size or indexing it only with integral constant expressions. The size determines the number and set of enabled cull distances and can be at most *gl_MaxCullDistances*. The number of varying components (see *gl_MaxVaryingComponents*) consumed by *gl_CullDistance* will match the size of the array. Shaders writing *gl_CullDistance* must write all enabled distances, or culling results are undefined.

As an output variable, *gl_CullDistance* provides the place for the shader to write these distances. As an input in all but the fragment language, it reads the values written in the previous shader stage. In the fragment language, *gl_CullDistance* array contains linearly interpolated values for the vertex values written by a shader to the *gl_CullDistance* vertex output variable.

It is a compile-time or link-time error for the set of shaders forming a program to have the sum of the sizes of the *gl_ClipDistance* and *gl_CullDistance* arrays to be larger than *gl_MaxCombinedClipAndCullDistances*.

The output variable *gl_PrimitiveID* is available only in the geometry language and provides a single integer that serves as a primitive identifier. This is then available to fragment shaders as the fragment input *gl_PrimitiveID*, which will select the written primitive ID from the provoking vertex in the primitive being shaded. If a fragment shader using *gl_PrimitiveID* is active and a geometry shader is also active, the geometry shader must write to *gl_PrimitiveID* or the fragment shader input *gl_PrimitiveID* is undefined. See section 11.3.4.5 "Geometry Shader Outputs" of the OpenGL Graphics System Specification for more information.

For tessellation control and evaluation languages the input variable *gl_PrimitiveID* is filled with the number of primitives processed by the shader since the current set of rendering primitives was started. For the fragment language, it is filled with the value written to the *gl_PrimitiveID* geometry shader output if a geometry shader is present. Otherwise, it is assigned in the same manner as with tessellation control and evaluation shaders.

The geometry language input variable *gl_PrimitiveIDIn* behaves identically to the tessellation control and evaluation language input variable *gl_PrimitiveID*.

The input variable *gl_InvocationID* is available only in the tessellation control and geometry languages. In the tessellation control shader, it identifies the number of the output patch vertex assigned to the tessellation control shader invocation. In the geometry shader, it identifies the invocation number assigned to the geometry shader invocation. In both cases, *gl_InvocationID* is assigned integer values in the range $[0, N-1]$, where N is the number of output patch vertices or geometry shader invocations per primitive.

The variable *gl_Layer* is available as an output variable in the geometry language and an input variable in the fragment language. In the geometry language, it is used to select a specific layer (or face and layer of a cube map) of a multi-layer framebuffer attachment. The actual layer used will come from one of the vertices in the primitive being shaded. Which vertex the layer comes from is discussed in section 11.3.4.6 "Layer and Viewport Selection" of the OpenGL Specification. It might be undefined, so it is best to write the same layer value for all vertices of a primitive. If a shader statically assigns a value to *gl_Layer*, layered rendering mode is enabled. See section 11.3.4.5 "Geometry Shader Outputs" and section 9.4.9 "Layered Framebuffers" of the OpenGL Graphics System Specification for more information. If a shader statically assigns a value to *gl_Layer*, and there is an execution path through the shader that does not set *gl_Layer*, then the value of *gl_Layer* is undefined for executions of the shader that take that path.

The output variable *gl_Layer* takes on a special value when used with an array of cube map textures. Instead of only referring to the layer, it is used to select a cube map face and a layer. Setting *gl_Layer* to the value $layer*6+face$ will render to face *face* of the cube defined in layer *layer*. The face values are defined in Table 9.3 of section 9.4.9 “Layered Framebuffers” of the OpenGL Graphics System Specification, but repeated below for clarity.

Face Value	Resulting Target
0	TEXTURE_CUBE_MAP_POSITIVE_X
1	TEXTURE_CUBE_MAP_NEGATIVE_X
2	TEXTURE_CUBE_MAP_POSITIVE_Y
3	TEXTURE_CUBE_MAP_NEGATIVE_Y
4	TEXTURE_CUBE_MAP_POSITIVE_Z
5	TEXTURE_CUBE_MAP_NEGATIVE_Z

For example, to render to the positive *y* cube map face located in the 5th layer of the cube map array, *gl_Layer* should be set to $5*6+2$.

The input variable *gl_Layer* in the fragment language will have the same value that was written to the output variable *gl_Layer* in the geometry language. If the geometry stage does not dynamically assign a value to *gl_Layer*, the value of *gl_Layer* in the fragment stage will be undefined. If the geometry stage makes no static assignment to *gl_Layer*, the input value in the fragment stage will be zero. Otherwise, the fragment stage will read the same value written by the geometry stage, even if that value is out of range. If a fragment shader contains a static access to *gl_Layer*, it will count against the implementation defined limit for the maximum number of inputs to the fragment stage.

The variable *gl_ViewportIndex* is available as an output variable in the geometry language and an input variable in the fragment language. In the geometry language, it provides the index of the viewport to which the next primitive emitted from the geometry shader should be drawn. Primitives generated by the geometry shader will undergo viewport transformation and scissor testing using the viewport transformation and scissor rectangle selected by the value of *gl_ViewportIndex*. The viewport index used will come from one of the vertices in the primitive being shaded. However, which vertex the viewport index comes from is implementation-dependent, so it is best to use the same viewport index for all vertices of the primitive. If a geometry shader does not assign a value to *gl_ViewportIndex*, viewport transform and scissor rectangle zero will be used. If a geometry shader statically assigns a value to *gl_ViewportIndex* and there is a path through the shader that does not assign a value to *gl_ViewportIndex*, the value of *gl_ViewportIndex* is undefined for executions of the shader that take that path. See section 11.3.4.6 “Layer and Viewport Selection” of the OpenGL Graphics System Specification (Core Profile) for more information.

The input variable *gl_ViewportIndex* in the fragment stage will have the same value that was written to the output variable *gl_ViewportIndex* in the geometry stage. If the geometry stage does not dynamically assign to *gl_ViewportIndex*, the value of *gl_ViewportIndex* in the fragment shader will be undefined. If the geometry stage makes no static assignment to *gl_ViewportIndex*, the fragment stage will read zero. Otherwise, the fragment stage will read the same value written by the geometry stage, even if that value is

out of range. If a fragment shader contains a static access to *gl_ViewportIndex*, it will count against the implementation defined limit for the maximum number of inputs to the fragment stage.

The variable *gl_PatchVerticesIn* is available only in the tessellation control and evaluation languages. It is an integer specifying the number of vertices in the input patch being processed by the shader. A single tessellation control or evaluation shader can read patches of differing sizes, so the value of *gl_PatchVerticesIn* may differ between patches.

The output variables *gl_TessLevelOuter[]* and *gl_TessLevelInner[]* are available only in the tessellation control language. The values written to these variables are assigned to the corresponding outer and inner tessellation levels of the output patch. They are used by the tessellation primitive generator to control primitive tessellation and may be read by tessellation evaluation shaders.

The variable *gl_TessCoord* is available only in the tessellation evaluation language. It specifies a three-component (u,v,w) vector identifying the position of the vertex being processed by the shader relative to the primitive being tessellated. Its values will obey the properties

```
gl_TessCoord.x == 1.0 - (1.0 - gl_TessCoord.x) // two operations performed
gl_TessCoord.y == 1.0 - (1.0 - gl_TessCoord.y) // two operations performed
gl_TessCoord.z == 1.0 - (1.0 - gl_TessCoord.z) // two operations performed
```

to aid in replicating subdivision computations.

The input variables *gl_TessLevelOuter[]* and *gl_TessLevelInner[]* are available only in the tessellation evaluation shader. If a tessellation control shader is active, these variables are filled with corresponding outputs written by the tessellation control shader. Otherwise, they are assigned with default tessellation levels specified in section 11.2.3.3 “Tessellation Evaluation Shader Inputs” in the OpenGL Graphics System Specification.

Fragment shaders output values to the OpenGL pipeline using declared **out** variables, the built-in variables *gl_FragDepth* and *gl_SampleMask*, unless the **discard** statement is executed.

The fixed functionality computed depth for a fragment may be obtained by reading *gl_FragCoord.z*, described below.

Writing to *gl_FragDepth* will establish the depth value for the fragment being processed. If depth buffering is enabled, and no shader writes *gl_FragDepth*, then the fixed function value for depth will be used as the fragment’s depth value. If a shader statically assigns a value to *gl_FragDepth*, and there is an execution path through the shader that does not set *gl_FragDepth*, then the value of the fragment’s depth may be undefined for executions of the shader that take that path. That is, if the set of linked fragment shaders statically contain a write to *gl_FragDepth*, then it is responsible for always writing it.

If a shader executes the **discard** keyword, the fragment is discarded, and the values of any user-defined fragment outputs, *gl_FragDepth*, and *gl_SampleMask* become irrelevant.

The variable *gl_FragCoord* is available as an input variable from within fragment shaders and it holds the window relative coordinates $(x, y, z, 1/w)$ values for the fragment. If multi-sampling, this value can be for any location within the pixel, or one of the fragment samples. The use of **centroid** does not further restrict this value to be inside the current primitive. This value is the result of the fixed functionality that interpolates primitives after vertex processing to generate fragments. The z component is the depth value that would be used for the fragment’s depth if no shader contained any writes to *gl_FragDepth*. This is

useful for invariance if a shader conditionally computes *gl_FragDepth* but otherwise wants the fixed functionality fragment depth.

Fragment shaders have access to the input built-in variable *gl_FrontFacing*, whose value is **true** if the fragment belongs to a front-facing primitive. One use of this is to emulate two-sided lighting by selecting one of two colors calculated by a vertex or geometry shader.

The values in *gl_PointCoord* are two-dimensional coordinates indicating where within a point primitive the current fragment is located, when point sprites are enabled. They range from 0.0 to 1.0 across the point. If the current primitive is not a point, or if point sprites are not enabled, then the values read from *gl_PointCoord* are undefined.

For both the input array *gl_SampleMaskIn[]* and the output array *gl_SampleMask[]*, bit *B* of mask *M* (*gl_SampleMaskIn[M]* or *gl_SampleMask[M]*) corresponds to sample $32*M+B$. These arrays have $\text{ceil}(s/32)$ elements, where *s* is the maximum number of color samples supported by the implementation.

The input variable *gl_SampleMaskIn* indicates the set of samples covered by the primitive generating the fragment during multisample rasterization. It has a sample bit set if and only if the sample is considered covered for this fragment shader invocation.

The output array *gl_SampleMask[]* sets the sample mask for the fragment being processed. Coverage for the current fragment will become the logical AND of the coverage mask and the output *gl_SampleMask*. This array must be sized in the fragment shader either implicitly or explicitly, to be no larger than the implementation-dependent maximum sample-mask (as an array of 32bit elements), determined by the maximum number of samples. If the fragment shader statically assigns a value to *gl_SampleMask*, the sample mask will be undefined for any array elements of any fragment shader invocations that fail to assign a value. If a shader does not statically assign a value to *gl_SampleMask*, the sample mask has no effect on the processing of a fragment.

The input variable *gl_SampleID* is filled with the sample number of the sample currently being processed. This variable is in the range 0 to *gl_NumSamples-1*, where *gl_NumSamples* is the total number of samples in the framebuffer, or 1 if rendering to a non-multisample framebuffer. Any static use of this variable in a fragment shader causes the entire shader to be evaluated per-sample.

The input variable *gl_SamplePosition* contains the position of the current sample within the multi-sample draw buffer. The *x* and *y* components of *gl_SamplePosition* contain the sub-pixel coordinate of the current sample and will have values in the range 0.0 to 1.0. Any static use of this variable in a fragment shader causes the entire shader to be evaluated per sample.

The value *gl_HelperInvocation* is **true** if the fragment shader invocation is considered a *helper invocation* and is **false** otherwise. A *helper invocation* is a fragment-shader invocation that is created solely for the purposes of evaluating derivatives for use in non-helper fragment-shader invocations. Such derivatives are computed implicitly in the built-in function **texture()** (see section 8.9 “Texture Functions”), and explicitly in the derivative functions in section 8.13.1 “Derivative Functions”, for example **dFdx()** and **dFdy()**.

Fragment shader helper invocations execute the same shader code as non-helper invocations, but will not have side effects that modify the framebuffer or other shader-accessible memory. In particular:

- Fragments corresponding to helper invocations are discarded when shader execution is complete, without updating the framebuffer.

- Stores to image and buffer variables performed by helper invocations have no effect on the underlying image or buffer memory.
- Atomic operations to image, buffer, or atomic counter variables performed by helper invocations have no effect on the underlying image or buffer memory. The values returned by such atomic operations are undefined.

Helper invocations may be generated for pixels not covered by a primitive being rendered. While fragment shader inputs qualified with **centroid** are normally required to be sampled in the intersection of the pixel and the primitive, the requirement is ignored for such pixels since there is no intersection between the pixel and primitive.

Helper invocations may also be generated for fragments that are covered by a primitive being rendered when the fragment is killed by early fragment tests (using the *early_fragment_tests* qualifier) or where the implementation is able to determine that executing the fragment shader would have no effect other than assisting in computing derivatives for other fragment shader invocations.

The set of helper invocations generated when processing any set of primitives is implementation dependent.

The *gl_PerVertex* block can be redeclared in a shader to explicitly indicate what subset of the fixed pipeline interface will be used. This is necessary to establish the interface between multiple programs. For example:

```
out gl_PerVertex {
    vec4 gl_Position;    // will use gl_Position
    float gl_PointSize; // will use gl_PointSize
    vec4 t;              // error, only gl_PerVertex members allowed
}; // no other members of gl_PerVertex will be used
```

This establishes the output interface the shader will use with the subsequent pipeline stage. It must be a subset of the built-in members of *gl_PerVertex*. Such a redeclaration can also add the **invariant** qualifier, interpolation qualifiers, and the layout qualifiers **xfb_offset**, **xfb_buffer**, and **xfb_stride**. It can also add an array size for unsized arrays. For example:

```
out layout(xfb_buffer = 1, xfb_stride = 16) gl_PerVertex {
    vec4 gl_Position;
    layout(xfb_offset = 0) float gl_ClipDistance[4];
};
```

Other layout qualifiers, like **location**, cannot be added to such a redeclaration, unless specifically stated.

If a built-in interface block is redeclared, it must appear in the shader before any use of any member included in the built-in declaration, or a compile-time error will result. It is also a compile-time error to redeclare the block more than once or to redeclare a built-in block and then use a member from that built-in block that was not included in the redeclaration. Also, if a built-in interface block is redeclared, no member of the built-in declaration can be redeclared outside the block redeclaration. If multiple shaders using members of a built-in block belonging to the same interface are linked together in the same program, they must all redeclare the built-in block in the same way, as described in section 4.3.9 “Interface Blocks” for interface-block matching, or a link-time error will result. It will also be a link-time error if some shaders in a program redeclare a specific built-in interface block while another shader in that

program does not redeclare that interface block yet still uses a member of that interface block. If a built-in block interface is formed across shaders in different programs, the shaders must all redeclare the built-in block in the same way (as described for a single program), or the values passed along the interface are undefined.

7.1.1 Compatibility Profile Built-In Language Variables

When using the compatibility profile, the GL can provide fixed functionality behavior for the vertex and fragment programmable pipeline stages. For example, mixing a fixed functionality vertex stage with a programmable fragment stage.

The following built-in vertex, tessellation control, tessellation evaluation, and geometry output variables are available to specify inputs for the subsequent programmable shader stage or the fixed functionality fragment stage. A particular one should be written to if any functionality in a corresponding fragment shader or fixed pipeline uses it or state derived from it. Otherwise, behavior is undefined. The following members are added to the output *gl_PerVertex* block in these languages:

```
out gl_PerVertex {          // part of the gl_PerVertex block described in 7.1
    // in addition to other gl_PerVertex members...
    vec4  gl_ClipVertex;
    vec4  gl_FrontColor;
    vec4  gl_BackColor;
    vec4  gl_FrontSecondaryColor;
    vec4  gl_BackSecondaryColor;
    vec4  gl_TexCoord[];
    float gl_FogFragCoord;
};
```

The output variable *gl_ClipVertex* provides a place for vertex and geometry shaders to write the coordinate to be used with the user clipping planes. Writing to *gl_ClipDistance* is the preferred method for user clipping. It is a compile-time or link-time error for the set of shaders forming a program to statically read or write both *gl_ClipVertex* and either *gl_ClipDistance* or *gl_CullDistance*. If neither *gl_ClipVertex* nor *gl_ClipDistance* is written, their values are undefined and any clipping against user clip planes is also undefined.

Similarly to what was previously described for the core profile, the *gl_PerVertex* block can be redeclared in a shader to explicitly include these additional members. For example:

```
out gl_PerVertex {
    vec4 gl_Position;      // will use gl_Position
    vec4 gl_FrontColor;    // will consume gl_color in the fragment shader
    vec4 gl_BackColor;
    vec4 gl_TexCoord[3];  // 3 elements of gl_TexCoord will be used
}; // no other aspects of the fixed interface will be used
```

The user must ensure the clip vertex and user clipping planes are defined in the same coordinate space. User clip planes work properly only under linear transform. It is undefined what happens under non-linear transform.

The output variables *gl_FrontColor*, *glFrontSecondaryColor*, *gl_BackColor*, and *glBackSecondaryColor* assign primary and secondary colors for front and back faces of primitives containing the vertex being processed. The output variable *gl_TexCoord* assigns texture coordinates for the vertex being processed.

For *gl_FogFragCoord*, the value written will be used as the “c” value in section 16.4 “Fog” of the compatibility profile of the OpenGL Graphics System Specification, by the fixed functionality pipeline. For example, if the z-coordinate of the fragment in eye space is desired as “c”, then that’s what the vertex shader executable should write into *gl_FogFragCoord*.

As with all arrays, indices used to subscript *gl_TexCoord* must either be an integral constant expressions, or this array must be redeclared by the shader with a size. The size can be at most *gl_MaxTextureCoords*. Using indexes close to 0 may aid the implementation in preserving varying resources. The redeclaration of *gl_TexCoord* can also be done at global scope as, for example:

```
in vec4 gl_TexCoord[3];
out vec4 gl_TexCoord[4];
```

(This treatment is a special case for *gl_TexCoord[]*, not a general method for redeclaring members of blocks.) It is a compile-time error to redeclare *gl_TexCoord[]* at global scope if there is a redeclaration of the corresponding built-in block; only one form of redeclaration is allowed within a shader (and hence within a stage, as block redeclarations must match across all shaders using it).

In the tessellation control, evaluation, and geometry shaders, the outputs of the previous stage described above are also available in the input *gl_PerVertex* block in these languages.

```
in gl_PerVertex {          // part of the gl_PerVertex block described in 7.1
    // in addition to other gl_PerVertex members...
    vec4  gl_ClipVertex;
    vec4  gl_FrontColor;
    vec4  gl_BackColor;
    vec4  gl_FrontSecondaryColor;
    vec4  gl_BackSecondaryColor;
    vec4  gl_TexCoord[];
    float gl_FogFragCoord;
} gl_in[];
```

These can be redeclared to establish an explicit pipeline interface, the same way as described above for the output block *gl_PerVertex*, and the input redeclaration must match the output redeclaration of the previous stage. However, when a built-in interface block with an instance name is redeclared (e.g., *gl_in*), the instance name must be included in the redeclaration. It is a compile-time error to not include the built-in instance name or to change its name. For example,

```
in gl_PerVertex {
    vec4  gl_ClipVertex;
    vec4  gl_FrontColor;
} gl_in[]; // must be present and must be “gl_in[]”
```

Treatment of *gl_TexCoord[]* redeclaration is also identical to that described for the output block *gl_TexCoord[]* redeclaration.

The following fragment input block is also available in a fragment shader when using the compatibility profile:

```
in gl_PerFragment {
    in float gl_FogFragCoord;
    in vec4  gl_TexCoord[];
    in vec4  gl_Color;
    in vec4  gl_SecondaryColor;
};
```

The values in *gl_Color* and *gl_SecondaryColor* will be derived automatically by the system from *gl_FrontColor*, *gl_BackColor*, *gl_FrontSecondaryColor*, and *gl_BackSecondaryColor* based on which face is visible in the primitive producing the fragment. If fixed functionality is used for vertex processing, then *gl_FogFragCoord* will either be the z-coordinate of the fragment in eye space, or the interpolation of the fog coordinate, as described in section 16.4 “Fog” of the compatibility profile of the OpenGL Graphics System Specification. The *gl_TexCoord[]* values are the interpolated *gl_TexCoord[]* values from a vertex shader or the texture coordinates of any fixed pipeline based vertex functionality.

Indices to the fragment shader *gl_TexCoord* array are as described above in the vertex shader text.

As described above for the input and output *gl_PerVertex* blocks, the *gl_PerFragment* block can be redeclared to create an explicit interface to another program. When matching these interfaces between separate programs, members in the *gl_PerVertex* output block must be declared if and only if the corresponding fragment-shader members generated from them are present in the *gl_PerFragment* input block. These matches are described in detail in section 7.4.1 “Shader Interface Matching” of the OpenGL Graphics System Specification. If they don't match within a program, a link-time error will result. If the mismatch is between two programs, values passed between programs are undefined. Unlike with all other block matching, the order of declaration within *gl_PerFragment* does not have to match across shaders and does not have to correspond with order of declaration in a matching *gl_PerVertex* redeclaration.

The following fragment output variables are available in a fragment shader when using the compatibility profile:

```
out vec4 gl_FragColor;
out vec4 gl_FragData[gl_MaxDrawBuffers];
```

Writing to *gl_FragColor* specifies the fragment color that will be used by the subsequent fixed functionality pipeline. If subsequent fixed functionality consumes fragment color and an execution of the fragment shader executable does not write a value to *gl_FragColor* then the fragment color consumed is undefined.

The variable *gl_FragData* is an array. Writing to *gl_FragData[n]* specifies the fragment data that will be used by the subsequent fixed functionality pipeline for data *n*. If subsequent fixed functionality consumes fragment data and an execution of a fragment shader executable does not write a value to it, then the fragment data consumed is undefined.

If a shader statically assigns a value to *gl_FragColor*, it may not assign a value to any element of *gl_FragData*. If a shader statically writes a value to any element of *gl_FragData*, it may not assign a value to *gl_FragColor*. That is, a shader may assign values to either *gl_FragColor* or *gl_FragData*, but not both. Multiple shaders linked together must also consistently write just one of these variables. Similarly, if user-declared output variables are in use (statically assigned to), then the built-in variables

gl_FragColor and *gl_FragData* may not be assigned to. These incorrect usages all generate compile-time or link-time errors.

If a shader executes the **discard** keyword, the fragment is discarded, and the values of *gl_FragDepth* and *gl_FragColor* become irrelevant.

7.2 Compatibility Profile Vertex Shader Built-In Inputs

The following predeclared input names can be used from within a vertex shader to access the current values of OpenGL state when using the compatibility profile.

```
in vec4  gl_Color;
in vec4  gl_SecondaryColor;
in vec3  gl_Normal;
in vec4  gl_Vertex;
in vec4  gl_MultiTexCoord0;
in vec4  gl_MultiTexCoord1;
in vec4  gl_MultiTexCoord2;
in vec4  gl_MultiTexCoord3;
in vec4  gl_MultiTexCoord4;
in vec4  gl_MultiTexCoord5;
in vec4  gl_MultiTexCoord6;
in vec4  gl_MultiTexCoord7;
in float gl_FogCoord;
```

7.3 Built-In Constants

The following built-in constants are provided to all shaders. The actual values used are implementation dependent, but must be at least the value shown.

```
//
// Implementation-dependent constants. The example values below
// are the minimum values allowed for these maximums.
//

const ivec3 gl_MaxComputeWorkGroupCount = { 65535, 65535, 65535 };
const ivec3 gl_MaxComputeWorkGroupSize = { 1024, 1024, 64 };
const int  gl_MaxComputeUniformComponents = 1024;
const int  gl_MaxComputeTextureImageUnits = 16;
const int  gl_MaxComputeImageUniforms = 8;
const int  gl_MaxComputeAtomicCounters = 8;
const int  gl_MaxComputeAtomicCounterBuffers = 8;

const int  gl_MaxVertexAttribs = 16;
const int  gl_MaxVertexUniformComponents = 1024;
```

7 Built-in Variables

```
const int gl_MaxVaryingComponents = 60;
const int gl_MaxVertexOutputComponents = 64;
const int gl_MaxGeometryInputComponents = 64;
const int gl_MaxGeometryOutputComponents = 128;
const int gl_MaxFragmentInputComponents = 128;
const int gl_MaxVertexTextureImageUnits = 16;
const int gl_MaxCombinedTextureImageUnits = 96;
const int gl_MaxTextureImageUnits = 16;
const int gl_MaxImageUnits = 8;
const int gl_MaxCombinedImageUnitsAndFragmentOutputs = 8; // deprecated
const int gl_MaxCombinedShaderOutputResources = 8;
const int gl_MaxImageSamples = 0;
const int gl_MaxVertexImageUniforms = 0;
const int gl_MaxTessControlImageUniforms = 0;
const int gl_MaxTessEvaluationImageUniforms = 0;
const int gl_MaxGeometryImageUniforms = 0;
const int gl_MaxFragmentImageUniforms = 8;
const int gl_MaxCombinedImageUniforms = 8;
const int gl_MaxFragmentUniformComponents = 1024;
const int gl_MaxDrawBuffers = 8;
const int gl_MaxClipDistances = 8;
const int gl_MaxGeometryTextureImageUnits = 16;

const int gl_MaxGeometryOutputVertices = 256;
const int gl_MaxGeometryTotalOutputComponents = 1024;
const int gl_MaxGeometryUniformComponents = 1024;
const int gl_MaxGeometryVaryingComponents = 64; // deprecated

const int gl_MaxTessControlInputComponents = 128;
const int gl_MaxTessControlOutputComponents = 128;
const int gl_MaxTessControlTextureImageUnits = 16;
const int gl_MaxTessControlUniformComponents = 1024;
const int gl_MaxTessControlTotalOutputComponents = 4096;

const int gl_MaxTessEvaluationInputComponents = 128;
const int gl_MaxTessEvaluationOutputComponents = 128;
const int gl_MaxTessEvaluationTextureImageUnits = 16;
const int gl_MaxTessEvaluationUniformComponents = 1024;

const int gl_MaxTessPatchComponents = 120;
const int gl_MaxPatchVertices = 32;
const int gl_MaxTessGenLevel = 64;

const int gl_MaxViewports = 16;

const int gl_MaxVertexUniformVectors = 256;
const int gl_MaxFragmentUniformVectors = 256;
const int gl_MaxVaryingVectors = 15;
```

```

const int gl_MaxVertexAtomicCounters = 0;
const int gl_MaxTessControlAtomicCounters = 0;
const int gl_MaxTessEvaluationAtomicCounters = 0;
const int gl_MaxGeometryAtomicCounters = 0;
const int gl_MaxFragmentAtomicCounters = 8;
const int gl_MaxCombinedAtomicCounters = 8;
const int gl_MaxAtomicCounterBindings = 1;
const int gl_MaxVertexAtomicCounterBuffers = 0;
const int gl_MaxTessControlAtomicCounterBuffers = 0;
const int gl_MaxTessEvaluationAtomicCounterBuffers = 0;
const int gl_MaxGeometryAtomicCounterBuffers = 0;
const int gl_MaxFragmentAtomicCounterBuffers = 1;
const int gl_MaxCombinedAtomicCounterBuffers = 1;
const int gl_MaxAtomicCounterBufferSize = 32;

const int gl_MinProgramTexelOffset = -8;
const int gl_MaxProgramTexelOffset = 7;

const int gl_MaxTransformFeedbackBuffers = 4;
const int gl_MaxTransformFeedbackInterleavedComponents = 64;

const int gl_MaxCullDistances = 8;
const int gl_MaxCombinedClipAndCullDistances = 8;
const int gl_MaxSamples = 4;

const int gl_MaxVertexImageUniforms = 0;
const int gl_MaxFragmentImageUniforms = 8;
const int gl_MaxComputeImageUniforms = 8;
const int gl_MaxCombinedImageUniforms = 48;
const int gl_MaxCombinedShaderOutputResources = 16;

```

The constant *gl_MaxVaryingFloats* is removed in the core profile, use *gl_MaxVaryingComponents* instead.

7.3.1 Compatibility Profile Built-In Constants

```

const int gl_MaxTextureUnits = 2;
const int gl_MaxTextureCoords = 8;
const int gl_MaxClipPlanes = 8;
const int gl_MaxVaryingFloats = 60;

```

7.4 Built-In Uniform State

Built-in uniform state is not available when generating SPIR-V.

Otherwise, as an aid to accessing OpenGL processing state, the following uniform variables are built into the OpenGL Shading Language.

```
//
// Depth range in window coordinates,
// section 13.6.1 "Controlling the Viewport" in the
// OpenGL Graphics System Specification.
//
// Note: Depth-range state is only for viewport 0.
//
struct gl_DepthRangeParameters {
    float near;        // n
    float far;         // f
    float diff;        // f - n
};
uniform gl_DepthRangeParameters gl_DepthRange;

uniform int gl_NumSamples;
```

7.4.1 Compatibility Profile State

These variables are present only in the compatibility profile. They are not available to compute shaders, but are available to all other shaders.

```
//
// compatibility profile only
//
uniform mat4  gl_ModelViewMatrix;
uniform mat4  gl_ProjectionMatrix;
uniform mat4  gl_ModelViewProjectionMatrix;
uniform mat4  gl_TextureMatrix[gl_MaxTextureCoords];

//
// compatibility profile only
//
uniform mat3  gl_NormalMatrix; // transpose of the inverse of the
                                // upper leftmost 3x3 of gl_ModelViewMatrix

uniform mat4  gl_ModelViewMatrixInverse;
uniform mat4  gl_ProjectionMatrixInverse;
uniform mat4  gl_ModelViewProjectionMatrixInverse;
uniform mat4  gl_TextureMatrixInverse[gl_MaxTextureCoords];

uniform mat4  gl_ModelViewMatrixTranspose;
uniform mat4  gl_ProjectionMatrixTranspose;
uniform mat4  gl_ModelViewProjectionMatrixTranspose;
```


7 Built-in Variables

```
uniform mat4  gl_TextureMatrixTranspose[gl_MaxTextureCoords];

uniform mat4  gl_ModelViewMatrixInverseTranspose;
uniform mat4  gl_ProjectionMatrixInverseTranspose;
uniform mat4  gl_ModelViewProjectionMatrixInverseTranspose;
uniform mat4  gl_TextureMatrixInverseTranspose[gl_MaxTextureCoords];

//
// compatibility profile only
//
uniform float  gl_NormalScale;

//
// compatibility profile only
//
uniform vec4   gl_ClipPlane[gl_MaxClipPlanes];

//
// compatibility profile only
//
struct gl_PointParameters {
    float size;
    float sizeMin;
    float sizeMax;
    float fadeThresholdSize;
    float distanceConstantAttenuation;
    float distanceLinearAttenuation;
    float distanceQuadraticAttenuation;
};

uniform gl_PointParameters gl_Point;

//
// compatibility profile only
//
struct gl_MaterialParameters {
    vec4  emission;    // Ecm
    vec4  ambient;     // Acm
    vec4  diffuse;     // Dcm
    vec4  specular;    // Scm
    float shininess;   // Srm
};

uniform gl_MaterialParameters  gl_FrontMaterial;
uniform gl_MaterialParameters  gl_BackMaterial;
```

7 Built-in Variables

```
//
// compatibility profile only
//

struct gl_LightSourceParameters {
    vec4  ambient;          // Acli
    vec4  diffuse;         // Dcli
    vec4  specular;        // Scli
    vec4  position;        // Ppli
    vec4  halfVector;      // Derived: Hi
    vec3  spotDirection;   // Sdli
    float spotExponent;    // Srli
    float spotCutoff;      // Crli
                          // (range: [0.0,90.0], 180.0)
    float spotCosCutoff;   // Derived: cos(Crli)
                          // (range: [1.0,0.0],-1.0)
    float constantAttenuation; // K0
    float linearAttenuation;  // K1
    float quadraticAttenuation; // K2
};

uniform gl_LightSourceParameters  gl_LightSource[gl_MaxLights];

struct gl_LightModelParameters {
    vec4  ambient;        // Acs
};

uniform gl_LightModelParameters  gl_LightModel;

//
// compatibility profile only
//
// Derived state from products of light and material.
//

struct gl_LightModelProducts {
    vec4  sceneColor;     // Derived. Ecm + Acn * Acs
};

uniform gl_LightModelProducts  gl_FrontLightModelProduct;
uniform gl_LightModelProducts  gl_BackLightModelProduct;

struct gl_LightProducts {
    vec4  ambient;       // Acn * Acli
    vec4  diffuse;       // Dcn * Dcli
    vec4  specular;      // Scn * Scli
};

uniform gl_LightProducts  gl_FrontLightProduct[gl_MaxLights];
uniform gl_LightProducts  gl_BackLightProduct[gl_MaxLights];
```

```

//
// compatibility profile only
//
uniform vec4  gl_TextureEnvColor[gl_MaxTextureUnits];
uniform vec4  gl_EyePlaneS[gl_MaxTextureCoords];
uniform vec4  gl_EyePlaneT[gl_MaxTextureCoords];
uniform vec4  gl_EyePlaneR[gl_MaxTextureCoords];
uniform vec4  gl_EyePlaneQ[gl_MaxTextureCoords];
uniform vec4  gl_ObjectPlaneS[gl_MaxTextureCoords];
uniform vec4  gl_ObjectPlaneT[gl_MaxTextureCoords];
uniform vec4  gl_ObjectPlaneR[gl_MaxTextureCoords];
uniform vec4  gl_ObjectPlaneQ[gl_MaxTextureCoords];

//
// compatibility profile only
//
struct gl_FogParameters {
    vec4 color;
    float density;
    float start;
    float end;
    float scale;    // Derived:  1.0 / (end - start)
};

uniform gl_FogParameters gl_Fog;

```

8 Built-in Functions

The OpenGL Shading Language defines an assortment of built-in convenience functions for scalar and vector operations. Many of these built-in functions can be used in more than one type of shader, but some are intended to provide a direct mapping to hardware and so are available only for a specific type of shader.

The built-in functions basically fall into three categories:

- They expose some necessary hardware functionality in a convenient way such as accessing a texture map. There is no way in the language for these functions to be emulated by a shader.
- They represent a trivial operation (clamp, mix, etc.) that is very simple for the user to write, but they are very common and may have direct hardware support. It is a very hard problem for the compiler to map expressions to complex assembler instructions.
- They represent an operation graphics hardware is likely to accelerate at some point. The trigonometry functions fall into this category.

Many of the functions are similar to the same named ones in common C libraries, but they support vector input as well as the more traditional scalar input.

Applications should be encouraged to use the built-in functions rather than do the equivalent computations in their own shader code since the built-in functions are assumed to be optimal (e.g., perhaps supported directly in hardware).

User code can replace built-in functions with their own if they choose, by simply redeclaring and defining the same name and argument list. Because built-in functions are in a more outer scope than user built-in functions, doing this will hide all built-in functions with the same name as the redeclared function.

When the built-in functions are specified below, where the input arguments (and corresponding output) can be **float**, **vec2**, **vec3**, or **vec4**, *genType* is used as the argument. Where the input arguments (and corresponding output) can be **int**, **ivec2**, **ivec3**, or **ivec4**, *genIType* is used as the argument. Where the input arguments (and corresponding output) can be **uint**, **uvec2**, **uvec3**, or **uvec4**, *genUType* is used as the argument. Where the input arguments (or corresponding output) can be **bool**, **bvec2**, **bvec3**, or **bvec4**, *genBType* is used as the argument. Where the input arguments (and corresponding output) can be **double**, **dvec2**, **dvec3**, **dvec4**, *genDType* is used as the argument. For any specific use of a function, the actual types substituted for *genType*, *genIType*, *genUType*, or *genBType* have to have the same number of components for all arguments and for the return type. Similarly, *mat* is used for any matrix basic type with single-precision components and *dmat* is used for any matrix basic type with double-precision components.

8.1 Angle and Trigonometry Functions

Function parameters specified as *angle* are assumed to be in units of radians. In no case will any of these functions result in a divide by zero error. If the divisor of a ratio is 0, then results will be undefined.

These all operate component-wise. The description is per component.

Syntax	Description
genType radians (genType <i>degrees</i>)	Converts <i>degrees</i> to radians, i.e., $\frac{\pi}{180} \cdot \text{degrees}$
genType degrees (genType <i>radians</i>)	Converts <i>radians</i> to degrees, i.e., $\frac{180}{\pi} \cdot \text{radians}$
genType sin (genType <i>angle</i>)	The standard trigonometric sine function.
genType cos (genType <i>angle</i>)	The standard trigonometric cosine function.
genType tan (genType <i>angle</i>)	The standard trigonometric tangent.
genType asin (genType <i>x</i>)	Arc sine. Returns an angle whose sine is <i>x</i> . The range of values returned by this function is $\left[-\frac{\pi}{2}, \frac{\pi}{2}\right]$. Results are undefined if $ x > 1$.
genType acos (genType <i>x</i>)	Arc cosine. Returns an angle whose cosine is <i>x</i> . The range of values returned by this function is $[0, \pi]$. Results are undefined if $ x > 1$.
genType atan (genType <i>y</i> , genType <i>x</i>)	Arc tangent. Returns an angle whose tangent is <i>y/x</i> . The signs of <i>x</i> and <i>y</i> are used to determine what quadrant the angle is in. The range of values returned by this function is $[-\pi, \pi]$. Results are undefined if <i>x</i> and <i>y</i> are both 0.
genType atan (genType <i>y_over_x</i>)	Arc tangent. Returns an angle whose tangent is <i>y_over_x</i> . The range of values returned by this function is $\left[-\frac{\pi}{2}, \frac{\pi}{2}\right]$.

Syntax	Description
genType sinh (genType <i>x</i>)	Returns the hyperbolic sine function $\frac{e^x - e^{-x}}{2}$
genType cosh (genType <i>x</i>)	Returns the hyperbolic cosine function $\frac{e^x + e^{-x}}{2}$
genType tanh (genType <i>x</i>)	Returns the hyperbolic tangent function $\frac{\sinh(x)}{\cosh(x)}$
genType asinh (genType <i>x</i>)	Arc hyperbolic sine; returns the inverse of sinh .
genType acosh (genType <i>x</i>)	Arc hyperbolic cosine; returns the non-negative inverse of cosh . Results are undefined if $x < 1$.
genType atanh (genType <i>x</i>)	Arc hyperbolic tangent; returns the inverse of tanh . Results are undefined if $ x \geq 1$.

8.2 Exponential Functions

These all operate component-wise. The description is per component.

Syntax	Description
genType pow (genType x , genType y)	Returns x raised to the y power, i.e., x^y Results are undefined if $x < 0$. Results are undefined if $x = 0$ and $y <= 0$.
genType exp (genType x)	Returns the natural exponentiation of x , i.e., e^x .
genType log (genType x)	Returns the natural logarithm of x , i.e., returns the value y which satisfies the equation $x = e^y$. Results are undefined if $x <= 0$.
genType exp2 (genType x)	Returns 2 raised to the x power, i.e., 2^x
genType log2 (genType x)	Returns the base 2 logarithm of x , i.e., returns the value y which satisfies the equation $x = 2^y$ Results are undefined if $x <= 0$.
genType sqrt (genType x) genDType sqrt (genDType x)	Returns \sqrt{x} . Results are undefined if $x < 0$.
genType inversesqrt (genType x) genDType inversesqrt (genDType x)	Returns $\frac{1}{\sqrt{x}}$. Results are undefined if $x <= 0$.

8.3 Common Functions

These all operate component-wise. The description is per component.

Syntax	Description
genType abs (genType x) genIType abs (genIType x) genDType abs (genDType x)	Returns x if $x \geq 0$; otherwise it returns $-x$.
genType sign (genType x) genIType sign (genIType x) genDType sign (genDType x)	Returns 1.0 if $x > 0$, 0.0 if $x = 0$, or -1.0 if $x < 0$.
genType floor (genType x) genDType floor (genDType x)	Returns a value equal to the nearest integer that is less than or equal to x .
genType trunc (genType x) genDType trunc (genDType x)	Returns a value equal to the nearest integer to x whose absolute value is not larger than the absolute value of x .
genType round (genType x) genDType round (genDType x)	Returns a value equal to the nearest integer to x . The fraction 0.5 will round in a direction chosen by the implementation, presumably the direction that is fastest. This includes the possibility that round (x) returns the same value as roundEven (x) for all values of x .
genType roundEven (genType x) genDType roundEven (genDType x)	Returns a value equal to the nearest integer to x . A fractional part of 0.5 will round toward the nearest even integer. (Both 3.5 and 4.5 for x will return 4.0.)
genType ceil (genType x) genDType ceil (genDType x)	Returns a value equal to the nearest integer that is greater than or equal to x .
genType fract (genType x) genDType fract (genDType x)	Returns $x - \mathbf{floor}(x)$.
genType mod (genType x , float y) genType mod (genType x , genType y) genDType mod (genDType x , double y) genDType mod (genDType x , genDType y)	Modulus. Returns $x - y * \mathbf{floor}(x/y)$.

Syntax	Description
genType modf (genType <i>x</i> , out genType <i>i</i>) genDType modf (genDType <i>x</i> , out genDType <i>i</i>)	Returns the fractional part of <i>x</i> and sets <i>i</i> to the integer part (as a whole number floating-point value). Both the return value and the output parameter will have the same sign as <i>x</i> .
genType min (genType <i>x</i> , genType <i>y</i>) genType min (genType <i>x</i> , float <i>y</i>) genDType min (genDType <i>x</i> , genDType <i>y</i>) genDType min (genDType <i>x</i> , double <i>y</i>) genIType min (genIType <i>x</i> , genIType <i>y</i>) genIType min (genIType <i>x</i> , int <i>y</i>) genUType min (genUType <i>x</i> , genUType <i>y</i>) genUType min (genUType <i>x</i> , uint <i>y</i>)	Returns <i>y</i> if $y < x$; otherwise it returns <i>x</i> .
genType max (genType <i>x</i> , genType <i>y</i>) genType max (genType <i>x</i> , float <i>y</i>) genDType max (genDType <i>x</i> , genDType <i>y</i>) genDType max (genDType <i>x</i> , double <i>y</i>) genIType max (genIType <i>x</i> , genIType <i>y</i>) genIType max (genIType <i>x</i> , int <i>y</i>) genUType max (genUType <i>x</i> , genUType <i>y</i>) genUType max (genUType <i>x</i> , uint <i>y</i>)	Returns <i>y</i> if $x < y$; otherwise it returns <i>x</i> .

Syntax	Description
<p>genType clamp (genType <i>x</i>, genType <i>minVal</i>, genType <i>maxVal</i>)</p> <p>genType clamp (genType <i>x</i>, float <i>minVal</i>, float <i>maxVal</i>)</p> <p>genDType clamp (genDType <i>x</i>, genDType <i>minVal</i>, genDType <i>maxVal</i>)</p> <p>genDType clamp (genDType <i>x</i>, double <i>minVal</i>, double <i>maxVal</i>)</p> <p>genIType clamp (genIType <i>x</i>, genIType <i>minVal</i>, genIType <i>maxVal</i>)</p> <p>genIType clamp (genIType <i>x</i>, int <i>minVal</i>, int <i>maxVal</i>)</p> <p>genUType clamp (genUType <i>x</i>, genUType <i>minVal</i>, genUType <i>maxVal</i>)</p> <p>genUType clamp (genUType <i>x</i>, uint <i>minVal</i>, uint <i>maxVal</i>)</p>	<p>Returns min (max (<i>x</i>, <i>minVal</i>), <i>maxVal</i>).</p> <p>Results are undefined if <i>minVal</i> > <i>maxVal</i>.</p>
<p>genType mix (genType <i>x</i>, genType <i>y</i>, genType <i>a</i>)</p> <p>genType mix (genType <i>x</i>, genType <i>y</i>, float <i>a</i>)</p> <p>genDType mix (genDType <i>x</i>, genDType <i>y</i>, genDType <i>a</i>)</p> <p>genDType mix (genDType <i>x</i>, genDType <i>y</i>, double <i>a</i>)</p>	<p>Returns the linear blend of <i>x</i> and <i>y</i>, i.e., $x \cdot (1 - a) + y \cdot a$</p>

Syntax	Description
genType mix (genType <i>x</i> , genType <i>y</i> , genBType <i>a</i>) genDType mix (genDType <i>x</i> , genDType <i>y</i> , genBType <i>a</i>) genType mix (genType <i>x</i> , genType <i>y</i> , genBType <i>a</i>) genUType mix (genUType <i>x</i> , genUType <i>y</i> , genBType <i>a</i>) genBType mix (genBType <i>x</i> , genBType <i>y</i> , genBType <i>a</i>)	Selects which vector each returned component comes from. For a component of <i>a</i> that is false , the corresponding component of <i>x</i> is returned. For a component of <i>a</i> that is true , the corresponding component of <i>y</i> is returned. Components of <i>x</i> and <i>y</i> that are not selected are allowed to be invalid floating-point values and will have no effect on the results. Thus, this provides different functionality than, for example, <pre>genType mix(genType x, genType y, genType(a))</pre> where <i>a</i> is a Boolean vector.
genType step (genType <i>edge</i> , genType <i>x</i>) genType step (float <i>edge</i> , genType <i>x</i>) genDType step (genDType <i>edge</i> , genDType <i>x</i>) genDType step (double <i>edge</i> , genDType <i>x</i>)	Returns 0.0 if $x < edge$; otherwise it returns 1.0.
genType smoothstep (genType <i>edge0</i> , genType <i>edge1</i> , genType <i>x</i>) genType smoothstep (float <i>edge0</i> , float <i>edge1</i> , genType <i>x</i>) genDType smoothstep (genDType <i>edge0</i> , genDType <i>edge1</i> , genDType <i>x</i>) genDType smoothstep (double <i>edge0</i> , double <i>edge1</i> , genDType <i>x</i>)	Returns 0.0 if $x \leq edge0$ and 1.0 if $x \geq edge1$ and performs smooth Hermite interpolation between 0 and 1 when $edge0 < x < edge1$. This is useful in cases where you would want a threshold function with a smooth transition. This is equivalent to: <pre>genType t; t = clamp((x - edge0) / (edge1 - edge0), 0, 1); return t * t * (3 - 2 * t);</pre> (And similarly for doubles.) Results are undefined if $edge0 \geq edge1$.
genBType isnan (genType <i>x</i>) genBType isnan (genDType <i>x</i>)	Returns true if <i>x</i> holds a NaN. Returns false otherwise. Always returns false if NaNs are not implemented.
genBType isinf (genType <i>x</i>) genBType isinf (genDType <i>x</i>)	Returns true if <i>x</i> holds a positive infinity or negative infinity. Returns false otherwise.

Syntax	Description
genType floatBitsToInt (genType <i>value</i>) genUType floatBitsToUint (genType <i>value</i>)	Returns a signed or unsigned integer value representing the encoding of a float . The float value's bit-level representation is preserved.
genType intBitsToFloat (genIType <i>value</i>) genType uintBitsToFloat (genUType <i>value</i>)	Returns a float value corresponding to a signed or unsigned integer encoding of a float . If a NaN is passed in, it will not signal, and the resulting value is unspecified. If an Inf is passed in, the resulting value is the corresponding Inf.
genType fma (genType <i>a</i> , genType <i>b</i> , genType <i>c</i>) genDType fma (genDType <i>a</i> , genDType <i>b</i> , genDType <i>c</i>)	<p>Computes and returns $a*b + c$.</p> <p>In uses where the return value is eventually consumed by a variable declared as precise:</p> <ul style="list-style-type: none"> • fma() is considered a single operation, whereas the expression "$a*b + c$" consumed by a variable declared precise is considered two operations. • The precision of fma() can differ from the precision of the expression "$a*b + c$". • fma() will be computed with the same precision as any other fma() consumed by a precise variable, giving invariant results for the same input values of <i>a</i>, <i>b</i>, and <i>c</i>. <p>Otherwise, in the absence of precise consumption, there are no special constraints on the number of operations or difference in precision between fma() and the expression "$a*b + c$".</p>
genType frexp (genType <i>x</i> , out genIType <i>exp</i>) genDType frexp (genDType <i>x</i> , out genIType <i>exp</i>)	<p>Splits <i>x</i> into a floating-point significand in the range [0.5, 1.0) and an integral exponent of two, such that:</p> $x = \text{significand} \cdot 2^{\text{exponent}}$ <p>The significand is returned by the function and the exponent is returned in the parameter <i>exp</i>. For a floating-point value of zero, the significand and exponent are both zero. For a floating-point value that is an infinity or is not a number, the results are undefined.</p> <p>If an implementation supports negative 0, frexp(-0) should return -0; otherwise it will return 0.</p>

Syntax	Description
genType ldexp (genType x , genIType exp) genDType ldexp (genDType x , genIType exp)	<p>Builds a floating-point number from x and the corresponding integral exponent of two in exp, returning:</p> $\text{significand} \cdot 2^{\text{exponent}}$ <p>If this product is too large to be represented in the floating-point type, the result is undefined.</p> <p>If exp is greater than +128 (single-precision) or +1024 (double-precision), the value returned is undefined. If exp is less than -126 (single-precision) or -1022 (double-precision), the value returned 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-denormized values.</p>

8.4 Floating-Point Pack and Unpack Functions

These functions do not operate component-wise, rather, as described in each case.

Syntax	Description
uint packUnorm2x16 (vec2 v) uint packSnorm2x16 (vec2 v) uint packUnorm4x8 (vec4 v) uint packSnorm4x8 (vec4 v)	<p>First, converts each component of the normalized floating-point value v into 8- or 16-bit integer values. Then, the results are packed into the returned 32-bit unsigned integer.</p> <p>The conversion for component c of v to fixed point is done as follows:</p> <ul style="list-style-type: none"> packUnorm2x16: $\text{round}(\text{clamp}(c, 0, +1) * 65535.0)$ packSnorm2x16: $\text{round}(\text{clamp}(c, -1, +1) * 32767.0)$ packUnorm4x8: $\text{round}(\text{clamp}(c, 0, +1) * 255.0)$ packSnorm4x8: $\text{round}(\text{clamp}(c, -1, +1) * 127.0)$ <p>The first component of the vector will be written to the least significant bits of the output; the last component will be written to the most significant bits.</p>

Syntax	Description
vec2 unpackUnorm2x16 (uint p) vec2 unpackSnorm2x16 (uint p) vec4 unpackUnorm4x8 (uint p) vec4 unpackSnorm4x8 (uint p)	<p>First, unpacks a single 32-bit unsigned integer p into a pair of 16-bit unsigned integers, a pair of 16-bit signed integers, four 8-bit unsigned integers, or four 8-bit signed integers. Then, each component is converted to a normalized floating-point value to generate the returned two- or four-component vector.</p> <p>The conversion for unpacked fixed-point value f to floating point is done as follows:</p> <p>unpackUnorm2x16: $f / 65535.0$ unpackSnorm2x16: $\text{clamp}(f / 32767.0, -1, +1)$ unpackUnorm4x8: $f / 255.0$ unpackSnorm4x8: $\text{clamp}(f / 127.0, -1, +1)$</p> <p>The first component of the returned vector will be extracted from the least significant bits of the input; the last component will be extracted from the most significant bits.</p>
double packDouble2x32 (uvec2 v)	<p>Returns a 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.</p>
uvec2 unpackDouble2x32 (double v)	<p>Returns a two-component unsigned integer 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.</p>
uint packHalf2x16 (vec2 v)	<p>Returns an unsigned integer obtained by converting the components of a two-component floating-point vector to the 16-bit floating-point representation found in the OpenGL Specification, and then packing these two 16-bit integers into a 32-bit unsigned integer.</p> <p>The first vector component specifies the 16 least-significant bits of the result; the second component specifies the 16 most-significant bits.</p>

Syntax	Description
vec2 unpackHalf2x16 (uint <i>v</i>)	<p>Returns a 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.</p> <p>The first component of the vector is obtained from the 16 least-significant bits of <i>v</i>; the second component is obtained from the 16 most-significant bits of <i>v</i>.</p> <p>It is preferred that when denormalized values are unpacked that their values are preserved, however it is allowed that they can also be flushed to zero.</p>

8.5 Geometric Functions

These operate on vectors as vectors, not component-wise.

Syntax	Description
float length (genType <i>x</i>) double length (genDType <i>x</i>)	Returns the length of vector <i>x</i> , i.e., $\sqrt{x[0]^2 + x[1]^2 + \dots}$
float distance (genType <i>p0</i> , genType <i>p1</i>) double distance (genDType <i>p0</i> , genDType <i>p1</i>)	Returns the distance between <i>p0</i> and <i>p1</i> , i.e., length (<i>p0</i> - <i>p1</i>)
float dot (genType <i>x</i> , genType <i>y</i>) double dot (genDType <i>x</i> , genDType <i>y</i>)	Returns the dot product of <i>x</i> and <i>y</i> , i.e., $x[0] \cdot y[0] + x[1] \cdot y[1] + \dots$
vec3 cross (vec3 <i>x</i> , vec3 <i>y</i>) dvec3 cross (dvec3 <i>x</i> , dvec3 <i>y</i>)	Returns the cross product of <i>x</i> and <i>y</i> , i.e., $\begin{bmatrix} x[1] \cdot y[2] - y[1] \cdot x[2] \\ x[2] \cdot y[0] - y[2] \cdot x[0] \\ x[0] \cdot y[1] - y[0] \cdot x[1] \end{bmatrix}$
genType normalize (genType <i>x</i>) genDType normalize (genDType <i>x</i>)	Returns a vector in the same direction as <i>x</i> but with a length of 1.
<i>compatibility profile only</i> vec4 ftransform ()	Available only when using the compatibility profile. For core OpenGL, use invariant . For vertex shaders only. This function will ensure that the incoming vertex value will be transformed in a way that produces exactly the same result as would be produced by OpenGL's fixed functionality transform. It is intended to be used to compute <i>gl_Position</i> , e.g., $\text{gl_Position} = \mathbf{ftransform}()$ This function should be used, for example, when an application is rendering the same geometry in separate passes, and one pass uses the fixed functionality path to render and another pass uses programmable shaders.

Syntax	Description
genType faceforward (genType N , genType I , genType $Nref$) genDType faceforward (genDType N , genDType I , genDType $Nref$)	If $\mathbf{dot}(Nref, I) < 0$ return N , otherwise return $-N$.
genType reflect (genType I , genType N) genDType reflect (genDType I , genDType N)	For the incident vector I and surface orientation N , returns the reflection direction: $I - 2 * \mathbf{dot}(N, I) * N$ N must already be normalized in order to achieve the desired result.
genType refract (genType I , genType N , float eta) genDType refract (genDType I , genDType N , float eta)	For the incident vector I and surface normal N , and the ratio of indices of refraction eta , return the refraction vector. The result is computed by $k = 1.0 - eta * eta * (1.0 - \mathbf{dot}(N, I) * \mathbf{dot}(N, I))$ if ($k < 0.0$) return genType(0.0) // or genDType(0.0) else return $eta * I - (eta * \mathbf{dot}(N, I) + \mathbf{sqrt}(k)) * N$ The input parameters for the incident vector I and the surface normal N must already be normalized to get the desired results.

8.6 Matrix Functions

For each of the following built-in matrix functions, there is both a single-precision floating-point version, where all arguments and return values are single precision, and a double-precision floating-point version, where all arguments and return values are double precision. Only the single-precision floating-point version is shown.

Syntax	Description
mat matrixCompMult (mat x , mat y)	Multiply matrix x by matrix y component-wise, i.e., $\text{result}[i][j]$ is the scalar product of $x[i][j]$ and $y[i][j]$. Note: to get linear algebraic matrix multiplication, use the multiply operator (*).
mat2 outerProduct (vec2 c , vec2 r) mat3 outerProduct (vec3 c , vec3 r) mat4 outerProduct (vec4 c , vec4 r) mat2x3 outerProduct (vec3 c , vec2 r) mat3x2 outerProduct (vec2 c , vec3 r) mat2x4 outerProduct (vec4 c , vec2 r) mat4x2 outerProduct (vec2 c , vec4 r) mat3x4 outerProduct (vec4 c , vec3 r) mat4x3 outerProduct (vec3 c , vec4 r)	Treats the first parameter c as a column vector (matrix with one column) and the second parameter r as a row vector (matrix with one row) and does a linear algebraic matrix multiply $c * r$, yielding a matrix whose number of rows is the number of components in c and whose number of columns is the number of components in r .
mat2 transpose (mat2 m) mat3 transpose (mat3 m) mat4 transpose (mat4 m) mat2x3 transpose (mat3x2 m) mat3x2 transpose (mat2x3 m) mat2x4 transpose (mat4x2 m) mat4x2 transpose (mat2x4 m) mat3x4 transpose (mat4x3 m) mat4x3 transpose (mat3x4 m)	Returns a matrix that is the transpose of m . The input matrix m is not modified.
float determinant (mat2 m) float determinant (mat3 m) float determinant (mat4 m)	Returns the determinant of m .

Syntax	Description
mat2 inverse (mat2 <i>m</i>) mat3 inverse (mat3 <i>m</i>) mat4 inverse (mat4 <i>m</i>)	Returns a matrix that is the inverse of <i>m</i> . The input matrix <i>m</i> is not modified. The values in the returned matrix are undefined if <i>m</i> is singular or poorly-conditioned (nearly singular).

8.7 Vector Relational Functions

Relational and equality operators (<, <=, >, >=, ==, !=) are defined to operate on scalars and produce scalar Boolean results. For vector results, use the following built-in functions. Below, the following placeholders are used for the listed specific types:

Placeholder	Specific Types Allowed
bvec	bvec2, bvec3, bvec4
ivec	ivec2, ivec3, ivec4
uvec	uvec2, uvec3, uvec4
vec	vec2, vec3, vec4, dvec2, dvec3, dvec4

In all cases, the sizes of all the input and return vectors for any particular call must match.

Syntax	Description
bvec lessThan (vec x, vec y) bvec lessThan (ivec x, ivec y) bvec lessThan (uvec x, uvec y)	Returns the component-wise compare of $x < y$.
bvec lessThanEqual (vec x, vec y) bvec lessThanEqual (ivec x, ivec y) bvec lessThanEqual (uvec x, uvec y)	Returns the component-wise compare of $x \leq y$.
bvec greaterThan (vec x, vec y) bvec greaterThan (ivec x, ivec y) bvec greaterThan (uvec x, uvec y)	Returns the component-wise compare of $x > y$.
bvec greaterThanEqual (vec x, vec y) bvec greaterThanEqual (ivec x, ivec y) bvec greaterThanEqual (uvec x, uvec y)	Returns the component-wise compare of $x \geq y$.
bvec equal (vec x, vec y) bvec equal (ivec x, ivec y) bvec equal (uvec x, uvec y) bvec equal (bvec x, bvec y)	Returns the component-wise compare of $x == y$.
bvec notEqual (vec x, vec y) bvec notEqual (ivec x, ivec y) bvec notEqual (uvec x, uvec y) bvec notEqual (bvec x, bvec y)	Returns the component-wise compare of $x != y$.

8 Built-in Functions

Syntax	Description
bool any (bvec x)	Returns true if any component of x is true .
bool all (bvec x)	Returns true only if all components of x are true .
bvec not (bvec x)	Returns the component-wise logical complement of x .

8.8 Integer Functions

These all operate component-wise. The description is per component. The notation $[a, b]$ means the set of bits from bit-number a through bit-number b , inclusive. The lowest-order bit is bit 0. “Bit number” will always refer to counting up from the lowest-order bit as bit 0.

Syntax	Description
genUType uaddCarry (genUType x , genUType y , out genUType $carry$)	Adds 32-bit unsigned integer x and y , returning the sum modulo 2^{32} . The value $carry$ is set to 0 if the sum was less than 2^{32} , or to 1 otherwise.
genUType usubBorrow (genUType x , genUType y , out genUType $borrow$)	Subtracts the 32-bit unsigned integer y from x , returning the difference if non-negative, or 2^{32} plus the difference otherwise. The value $borrow$ is set to 0 if $x \geq y$, or to 1 otherwise.
void umulExtended (genUType x , genUType y , out genUType msb , out genUType lsb) void imulExtended (genIType x , genIType y , out genIType msb , out genIType lsb)	Multiplies 32-bit integers x and y , producing a 64-bit result. The 32 least-significant bits are returned in lsb . The 32 most-significant bits are returned in msb .
genIType bitfieldExtract (genIType $value$, int $offset$, int $bits$) genUType bitfieldExtract (genUType $value$, int $offset$, int $bits$)	Extracts bits $[offset, offset + bits - 1]$ from $value$, returning them in the least significant bits of the result. For unsigned data types, the most significant bits of the result will be set to zero. For signed data types, the most significant bits will be set to the value of bit $offset + bits - 1$. If $bits$ is zero, the result will be zero. The result will be undefined if $offset$ or $bits$ is negative, or if the sum of $offset$ and $bits$ is greater than the number of bits used to store the operand.

Syntax	Description
<p>genIType bitfieldInsert (genIType <i>base</i>, genIType <i>insert</i>, int <i>offset</i>, int <i>bits</i>)</p> <p>genUType bitfieldInsert (genUType <i>base</i>, genUType <i>insert</i>, int <i>offset</i>, int <i>bits</i>)</p>	<p>Returns the insertion of the <i>bits</i> least-significant bits of <i>insert</i> into <i>base</i>.</p> <p>The result will have bits [<i>offset</i>, <i>offset</i> + <i>bits</i> - 1] taken from bits [0, <i>bits</i> - 1] of <i>insert</i>, and all other bits taken directly from the corresponding bits of <i>base</i>. If <i>bits</i> is zero, the result will simply be <i>base</i>. The result will be undefined if <i>offset</i> or <i>bits</i> is negative, or if the sum of <i>offset</i> and <i>bits</i> is greater than the number of bits used to store the operand.</p>
<p>genIType bitfieldReverse (genIType <i>value</i>) genUType bitfieldReverse (genUType <i>value</i>)</p>	<p>Returns the reversal of the bits of <i>value</i>. The bit numbered <i>n</i> of the result will be taken from bit (<i>bits</i> - 1) - <i>n</i> of <i>value</i>, where <i>bits</i> is the total number of bits used to represent <i>value</i>.</p>
<p>genIType bitCount (genIType <i>value</i>) genIType bitCount (genUType <i>value</i>)</p>	<p>Returns the number of bits set to 1 in the binary representation of <i>value</i>.</p>
<p>genIType findLSB (genIType <i>value</i>) genIType findLSB (genUType <i>value</i>)</p>	<p>Returns the bit number of the least significant bit set to 1 in the binary representation of <i>value</i>. If <i>value</i> is zero, -1 will be returned.</p>
<p>genIType findMSB (genIType <i>value</i>) genIType findMSB (genUType <i>value</i>)</p>	<p>Returns the bit number of the most significant bit in the binary representation of <i>value</i>.</p> <p>For positive integers, the result will be the bit number of the most significant bit set to 1. For negative integers, the result will be the bit number of the most significant bit set to 0. For a <i>value</i> of zero or negative one, -1 will be returned.</p>

8.9 Texture Functions

Texture lookup functions are available in all shading stages. However, automatic level of detail is computed only for fragment shaders. Other shaders operate as though the base level of detail were computed as zero. The functions in the table below provide access to textures through samplers, as set up through the OpenGL API. Texture properties such as size, pixel format, number of dimensions, filtering method, number of mipmap levels, depth comparison, and so on are also defined by OpenGL API calls. Such properties are taken into account as the texture is accessed via the built-in functions defined below.

Texture data can be stored by the GL as single-precision floating point, unsigned normalized integer, unsigned integer or signed integer data. This is determined by the type of the internal format of the texture.

Texture lookup functions are provided that can return their result as floating point, unsigned integer or signed integer, depending on the sampler type passed to the lookup function. Care must be taken to use the right sampler type for texture access. The following table lists the supported combinations of sampler types and texture internal formats. Blank entries are unsupported. Doing a texture lookup will return undefined values for unsupported combinations.

Internal Texture Format	Floating-Point Sampler Types	Signed Integer Sampler Types	Unsigned Integer Sampler Types
Floating point	Supported		
Normalized Integer	Supported		
Signed Integer		Supported	
Unsigned Integer			Supported

If an integer sampler type is used, the result of a texture lookup is an **ivec4**. If an unsigned integer sampler type is used, the result of a texture lookup is a **uvec4**. If a floating-point sampler type is used, the result of a texture lookup is a **vec4**.

In the prototypes below, the “g” in the return type “*gvec4*” is used as a placeholder for nothing, “i”, or “u” making a return type of **vec4**, **ivec4**, or **uvec4**. In these cases, the sampler argument type also starts with “g”, indicating the same substitution done on the return type; it is either a single-precision floating point, signed integer, or unsigned integer sampler, matching the basic type of the return type, as described above.

For shadow forms (the sampler parameter is a shadow-type), a depth comparison lookup on the depth texture bound to *sampler* is done as described in section 8.22 “Texture Comparison Modes” of the OpenGL Graphics System Specification. See the table below for which component specifies D_{ref} . The texture bound to *sampler* must be a depth texture, or results are undefined. If a non-shadow texture call is made to a sampler that represents a depth texture with depth comparisons turned on, then results are undefined. If a shadow texture call is made to a sampler that represents a depth texture with depth comparisons turned off, then results are undefined. If a shadow texture call is made to a sampler that does not represent a depth texture, then results are undefined.

In all functions below, the *bias* parameter is optional for fragment shaders. The *bias* parameter is not accepted in any other shader stage. For a fragment shader, if *bias* is present, it is added to the implicit level of detail prior to performing the texture access operation. No *bias* or *lod* parameters for rectangle textures, multi-sample textures, or texture buffers are supported because mipmaps are not allowed for these types of textures.

The implicit level of detail is selected as follows: For a texture that is not mipmapped, the texture is used directly. If it is mipmapped and running in a fragment shader, the LOD computed by the implementation is used to do the texture lookup. If it is mipmapped and running on the vertex shader, then the base texture is used.

Some texture functions (non-“**Lod**” and non-“**Grad**” versions) may require implicit derivatives. Implicit derivatives are undefined within non-uniform control flow and for non-fragment-shader texture fetches.

For **Cube** forms, the direction of *P* is used to select which face to do a 2-dimensional texture lookup in, as described in section 8.13 “Cube Map Texture Selection” in the OpenGL Graphics System Specification.

For **Array** forms, the array layer used will be

$$\max(0, \min(d - 1, \text{floor}(\text{layer} + 0.5)))$$

where *d* is the depth of the texture array and *layer* comes from the component indicated in the tables below.

For depth/stencil textures, the sampler type should match the component being accessed as set through the OpenGL API. When the depth/stencil texture mode is set to DEPTH_COMPONENT, a floating-point sampler type should be used. When the depth/stencil texture mode is set to STENCIL_INDEX, an unsigned integer sampler type should be used. Doing a texture lookup with an unsupported combination will return undefined values.

8.9.1 Texture Query Functions

The **textureSize** functions query the dimensions of a specific texture level for a sampler.

The **textureQueryLod** functions are available only in a fragment shader. They take the components of *P* and compute the level of detail information that the texture pipe would use to access that texture through a normal texture lookup. The level of detail λ' (equation 3.18 in the OpenGL Graphics System Specification) is obtained after any LOD bias, but prior to clamping to [TEXTURE_MIN_LOD, TEXTURE_MAX_LOD]. The mipmap array(s) that would be accessed are also computed. If a single level of detail would be accessed, the level-of-detail number relative to the base level is returned. If multiple levels of detail would be accessed, a floating-point number between the two levels is returned, with the fractional part equal to the fractional part of the computed and clamped level of detail.

The algorithm used is given by the following pseudo-code:

```
float ComputeAccessedLod(float computedLod)
{
    // Clamp the computed LOD according to the texture LOD clamps.
    if (computedLod < TEXTURE_MIN_LOD) computedLod = TEXTURE_MIN_LOD;
    if (computedLod > TEXTURE_MAX_LOD) computedLod = TEXTURE_MAX_LOD;

    // Clamp the computed LOD to the range of accessible levels.
    if (computedLod < 0.0)
        computedLod = 0.0;
    if (computedLod > (float)
        maxAccessibleLevel) computedLod = (float) maxAccessibleLevel;

    // Return a value according to the min filter.
    if (TEXTURE_MIN_FILTER is LINEAR or NEAREST) {
        return 0.0;
    } else if (TEXTURE_MIN_FILTER is NEAREST_MIPMAP_NEAREST
        or LINEAR_MIPMAP_NEAREST) {
        return ceil(computedLod + 0.5) - 1.0;
    } else {
        return computedLod;
    }
}
```

The value *maxAccessibleLevel* is the level number of the smallest accessible level of the mipmap array (the value *q* in section 8.14.3 “Mipmapping” of the OpenGL Graphics System Specification) minus the base level.

Syntax	Description
int textureSize (gsampler1D <i>sampler</i> , int <i>lod</i>) ivec2 textureSize (gsampler2D <i>sampler</i> , int <i>lod</i>) ivec3 textureSize (gsampler3D <i>sampler</i> , int <i>lod</i>) ivec2 textureSize (gsamplerCube <i>sampler</i> , int <i>lod</i>) int textureSize (sampler1DShadow <i>sampler</i> , int <i>lod</i>) ivec2 textureSize (sampler2DShadow <i>sampler</i> , int <i>lod</i>) ivec2 textureSize (samplerCubeShadow <i>sampler</i> , int <i>lod</i>) ivec3 textureSize (gsamplerCubeArray <i>sampler</i> , int <i>lod</i>) ivec3 textureSize (samplerCubeArrayShadow <i>sampler</i> , int <i>lod</i>) ivec2 textureSize (gsampler2DRect <i>sampler</i>) ivec2 textureSize (sampler2DRectShadow <i>sampler</i>) ivec2 textureSize (gsampler1DArray <i>sampler</i> , int <i>lod</i>) ivec3 textureSize (gsampler2DArray <i>sampler</i> , int <i>lod</i>) ivec2 textureSize (sampler1DArrayShadow <i>sampler</i> , int <i>lod</i>) ivec3 textureSize (sampler2DArrayShadow <i>sampler</i> , int <i>lod</i>) int textureSize (gsamplerBuffer <i>sampler</i>) ivec2 textureSize (gsampler2DMS <i>sampler</i>) ivec3 textureSize (gsampler2DMSArray <i>sampler</i>)	Returns the dimensions of level <i>lod</i> (if present) for the texture bound to <i>sampler</i> , as described in section 11.1.3.4 “Texture Queries” of the OpenGL Graphics System Specification. The components in the return value are filled in, in order, with the width, height, and depth of the texture. For the array forms, the last component of the return value is the number of layers in the texture array, or the number of cubes in the texture cube map array.

Syntax	Description
vec2 textureQueryLod (gsampler1D <i>sampler</i> , float <i>P</i>) vec2 textureQueryLod (gsampler2D <i>sampler</i> , vec2 <i>P</i>) vec2 textureQueryLod (gsampler3D <i>sampler</i> , vec3 <i>P</i>) vec2 textureQueryLod (gsamplerCube <i>sampler</i> , vec3 <i>P</i>) vec2 textureQueryLod (gsampler1DArray <i>sampler</i> , float <i>P</i>) vec2 textureQueryLod (gsampler2DArray <i>sampler</i> , vec2 <i>P</i>) vec2 textureQueryLod (gsamplerCubeArray <i>sampler</i> , vec3 <i>P</i>) vec2 textureQueryLod (sampler1DShadow <i>sampler</i> , float <i>P</i>) vec2 textureQueryLod (sampler2DShadow <i>sampler</i> , vec2 <i>P</i>) vec2 textureQueryLod (samplerCubeShadow <i>sampler</i> , vec3 <i>P</i>) vec2 textureQueryLod (sampler1DArrayShadow <i>sampler</i> , float <i>P</i>) vec2 textureQueryLod (sampler2DArrayShadow <i>sampler</i> , vec2 <i>P</i>) vec2 textureQueryLod (samplerCubeArrayShadow <i>sampler</i> , vec3 <i>P</i>)	Returns the mipmap array(s) that would be accessed in the <i>x</i> component of the return value. Returns the computed level of detail relative to the base level in the <i>y</i> component of the return value. If called on an incomplete texture, the results are undefined.
int textureQueryLevels (gsampler1D <i>sampler</i>) int textureQueryLevels (gsampler2D <i>sampler</i>) int textureQueryLevels (gsampler3D <i>sampler</i>) int textureQueryLevels (gsamplerCube <i>sampler</i>) int textureQueryLevels (gsampler1DArray <i>sampler</i>) int textureQueryLevels (gsampler2DArray <i>sampler</i>) int textureQueryLevels (gsamplerCubeArray <i>sampler</i>) int textureQueryLevels (sampler1DShadow <i>sampler</i>) int textureQueryLevels (sampler2DShadow <i>sampler</i>) int textureQueryLevels (samplerCubeShadow <i>sampler</i>) int textureQueryLevels (sampler1DArrayShadow <i>sampler</i>) int textureQueryLevels (sampler2DArrayShadow <i>sampler</i>) int textureQueryLevels (samplerCubeArrayShadow <i>sampler</i>)	Returns the number of mipmap levels accessible in the texture associated with <i>sampler</i> , as defined in the OpenGL Specification. The value zero will be returned if no texture or an incomplete texture is associated with <i>sampler</i> . Available in all shader stages.
int textureSamples (gsampler2DMS <i>sampler</i>) int textureSamples (gsampler2DMSArray <i>sampler</i>)	Returns the number of samples of the texture or textures bound to <i>sampler</i> .

8.9.2 Texel Lookup Functions

Syntax	Description
<p>gvec4 texture (gsampler1D <i>sampler</i>, float <i>P</i> [, float <i>bias</i>]) gvec4 texture (gsampler2D <i>sampler</i>, vec2 <i>P</i> [, float <i>bias</i>]) gvec4 texture (gsampler3D <i>sampler</i>, vec3 <i>P</i> [, float <i>bias</i>]) gvec4 texture (gsamplerCube <i>sampler</i>, vec3 <i>P</i> [, float <i>bias</i>]) float texture (sampler1DShadow <i>sampler</i>, vec3 <i>P</i> [, float <i>bias</i>]) float texture (sampler2DShadow <i>sampler</i>, vec3 <i>P</i> [, float <i>bias</i>]) float texture (samplerCubeShadow <i>sampler</i>, vec4 <i>P</i> [, float <i>bias</i>]) gvec4 texture (gsampler1DArray <i>sampler</i>, vec2 <i>P</i> [, float <i>bias</i>]) gvec4 texture (gsampler2DArray <i>sampler</i>, vec3 <i>P</i> [, float <i>bias</i>]) gvec4 texture (gsamplerCubeArray <i>sampler</i>, vec4 <i>P</i> [, float <i>bias</i>]) float texture (sampler1DArrayShadow <i>sampler</i>, vec3 <i>P</i> [, float <i>bias</i>]) float texture (sampler2DArrayShadow <i>sampler</i>, vec4 <i>P</i>) gvec4 texture (gsampler2DRect <i>sampler</i>, vec2 <i>P</i>) float texture (sampler2DRectShadow <i>sampler</i>, vec3 <i>P</i>) float texture (gsamplerCubeArrayShadow <i>sampler</i>, vec4 <i>P</i>, float <i>compare</i>)</p>	<p>Use the texture coordinate <i>P</i> to do a texture lookup in the texture currently bound to <i>sampler</i>.</p> <p>For shadow forms: When <i>compare</i> is present, it is used as D_{ref} and the array layer comes from $P.w$. When <i>compare</i> is not present, the last component of <i>P</i> is used as D_{ref} and the array layer comes from the second to last component of <i>P</i>. (The second component of <i>P</i> is unused for 1D shadow lookups.)</p> <p>For non-shadow forms: the array layer comes from the last component of <i>P</i>.</p>
<p>gvec4 textureProj (gsampler1D <i>sampler</i>, vec2 <i>P</i> [, float <i>bias</i>]) gvec4 textureProj (gsampler1D <i>sampler</i>, vec4 <i>P</i> [, float <i>bias</i>]) gvec4 textureProj (gsampler2D <i>sampler</i>, vec3 <i>P</i> [, float <i>bias</i>]) gvec4 textureProj (gsampler2D <i>sampler</i>, vec4 <i>P</i> [, float <i>bias</i>]) gvec4 textureProj (gsampler3D <i>sampler</i>, vec4 <i>P</i> [, float <i>bias</i>]) float textureProj (sampler1DShadow <i>sampler</i>, vec4 <i>P</i> [, float <i>bias</i>]) float textureProj (sampler2DShadow <i>sampler</i>, vec4 <i>P</i> [, float <i>bias</i>]) gvec4 textureProj (gsampler2DRect <i>sampler</i>, vec3 <i>P</i>) gvec4 textureProj (gsampler2DRect <i>sampler</i>, vec4 <i>P</i>) float textureProj (sampler2DRectShadow <i>sampler</i>, vec4 <i>P</i>)</p>	<p>Do a texture lookup with projection. The texture coordinates consumed from <i>P</i>, not including the last component of <i>P</i>, are divided by the last component of <i>P</i>. The resulting 3rd component of <i>P</i> in the shadow forms is used as D_{ref}. After these values are computed, texture lookup proceeds as in texture.</p>
<p>gvec4 textureLod (gsampler1D <i>sampler</i>, float <i>P</i>, float <i>lod</i>) gvec4 textureLod (gsampler2D <i>sampler</i>, vec2 <i>P</i>, float <i>lod</i>) gvec4 textureLod (gsampler3D <i>sampler</i>, vec3 <i>P</i>, float <i>lod</i>) gvec4 textureLod (gsamplerCube <i>sampler</i>, vec3 <i>P</i>, float <i>lod</i>) float textureLod (sampler1DShadow <i>sampler</i>, vec3 <i>P</i>, float <i>lod</i>) float textureLod (sampler2DShadow <i>sampler</i>, vec3 <i>P</i>, float <i>lod</i>) gvec4 textureLod (gsampler1DArray <i>sampler</i>, vec2 <i>P</i>, float <i>lod</i>) gvec4 textureLod (gsampler2DArray <i>sampler</i>, vec3 <i>P</i>, float <i>lod</i>) float textureLod (sampler1DArrayShadow <i>sampler</i>, vec3 <i>P</i>, float <i>lod</i>) gvec4 textureLod (gsamplerCubeArray <i>sampler</i>, vec4 <i>P</i>, float <i>lod</i>)</p>	<p>Do a texture lookup as in texture but with explicit LOD; <i>lod</i> specifies λ_{base} and sets the partial derivatives as follows. (See section 8.14 “Texture Minification” and equations 8.4-8.6 in the OpenGL Graphics System Specification.)</p> $\frac{\partial u}{\partial x} = 0 \quad \frac{\partial v}{\partial x} = 0 \quad \frac{\partial w}{\partial x} = 0$ $\frac{\partial u}{\partial y} = 0 \quad \frac{\partial v}{\partial y} = 0 \quad \frac{\partial w}{\partial y} = 0$

Syntax	Description
<p><code>gvec4 textureOffset</code> (gsampler1D <i>sampler</i>, float <i>P</i>, int <i>offset</i> [, float <i>bias</i>])</p> <p><code>gvec4 textureOffset</code> (gsampler2D <i>sampler</i>, vec2 <i>P</i>, ivec2 <i>offset</i> [, float <i>bias</i>])</p> <p><code>gvec4 textureOffset</code> (gsampler3D <i>sampler</i>, vec3 <i>P</i>, ivec3 <i>offset</i> [, float <i>bias</i>])</p> <p><code>gvec4 textureOffset</code> (gsampler2DRect <i>sampler</i>, vec2 <i>P</i>, ivec2 <i>offset</i>)</p> <p>float <code>textureOffset</code> (sampler2DRectShadow <i>sampler</i>, vec3 <i>P</i>, ivec2 <i>offset</i>)</p> <p>float <code>textureOffset</code> (sampler1DShadow <i>sampler</i>, vec3 <i>P</i>, int <i>offset</i> [, float <i>bias</i>])</p> <p>float <code>textureOffset</code> (sampler2DShadow <i>sampler</i>, vec3 <i>P</i>, ivec2 <i>offset</i> [, float <i>bias</i>])</p> <p><code>gvec4 textureOffset</code> (gsampler1DArray <i>sampler</i>, vec2 <i>P</i>, int <i>offset</i> [, float <i>bias</i>])</p> <p><code>gvec4 textureOffset</code> (gsampler2DArray <i>sampler</i>, vec3 <i>P</i>, ivec2 <i>offset</i> [, float <i>bias</i>])</p> <p>float <code>textureOffset</code> (sampler1DArrayShadow <i>sampler</i>, vec3 <i>P</i>, int <i>offset</i> [, float <i>bias</i>])</p> <p>float <code>textureOffset</code> (sampler2DArrayShadow <i>sampler</i>, vec4 <i>P</i>, ivec2 <i>offset</i>)</p>	<p>Do a texture lookup as in texture but with <i>offset</i> added to the (u,v,w) texel coordinates before looking up each texel. The offset value must be a constant expression. A limited range of offset values are supported; the minimum and maximum offset values are implementation-dependent and given by <code>gl_MinProgramTexelOffset</code> and <code>gl_MaxProgramTexelOffset</code>, respectively.</p> <p>Note that <i>offset</i> does not apply to the layer coordinate for texture arrays. This is explained in detail in section 8.14.2 “Coordinate Wrapping and Texel Selection” of the OpenGL Graphics System Specification, where <i>offset</i> is $(\delta_u, \delta_v, \delta_w)$. Note that texel offsets are also not supported for cube maps.</p>
<p><code>gvec4 texelFetch</code> (gsampler1D <i>sampler</i>, int <i>P</i>, int <i>lod</i>)</p> <p><code>gvec4 texelFetch</code> (gsampler2D <i>sampler</i>, ivec2 <i>P</i>, int <i>lod</i>)</p> <p><code>gvec4 texelFetch</code> (gsampler3D <i>sampler</i>, ivec3 <i>P</i>, int <i>lod</i>)</p> <p><code>gvec4 texelFetch</code> (gsampler2DRect <i>sampler</i>, ivec2 <i>P</i>)</p> <p><code>gvec4 texelFetch</code> (gsampler1DArray <i>sampler</i>, ivec2 <i>P</i>, int <i>lod</i>)</p> <p><code>gvec4 texelFetch</code> (gsampler2DArray <i>sampler</i>, ivec3 <i>P</i>, int <i>lod</i>)</p> <p><code>gvec4 texelFetch</code> (gsamplerBuffer <i>sampler</i>, int <i>P</i>)</p> <p><code>gvec4 texelFetch</code> (gsampler2DMS <i>sampler</i>, ivec2 <i>P</i>, int <i>sample</i>)</p> <p><code>gvec4 texelFetch</code> (gsampler2DMSArray <i>sampler</i>, ivec3 <i>P</i>, int <i>sample</i>)</p>	<p>Use integer texture coordinate <i>P</i> to lookup a single texel from <i>sampler</i>. The array layer comes from the last component of <i>P</i> for the array forms. The level-of-detail <i>lod</i> (if present) is as described in sections 11.1.3.2 “Texel Fetches” and 8.14.1 “Scale Factor and Level of Detail” of the OpenGL Graphics System Specification.</p>

Syntax	Description
<p><code>gvec4 texelFetchOffset</code> (<code>gsampler1D sampler</code>, <code>int P</code>, <code>int lod</code>, <code>int offset</code>)</p> <p><code>gvec4 texelFetchOffset</code> (<code>gsampler2D sampler</code>, <code>ivec2 P</code>, <code>int lod</code>, <code>ivec2 offset</code>)</p> <p><code>gvec4 texelFetchOffset</code> (<code>gsampler3D sampler</code>, <code>ivec3 P</code>, <code>int lod</code>, <code>ivec3 offset</code>)</p> <p><code>gvec4 texelFetchOffset</code> (<code>gsampler2DRect sampler</code>, <code>ivec2 P</code>, <code>ivec2 offset</code>)</p> <p><code>gvec4 texelFetchOffset</code> (<code>gsampler1DArray sampler</code>, <code>ivec2 P</code>, <code>int lod</code>, <code>int offset</code>)</p> <p><code>gvec4 texelFetchOffset</code> (<code>gsampler2DArray sampler</code>, <code>ivec3 P</code>, <code>int lod</code>, <code>ivec2 offset</code>)</p>	Fetch a single texel as in texelFetch offset by <i>offset</i> as described in textureOffset .
<p><code>gvec4 textureProjOffset</code> (<code>gsampler1D sampler</code>, <code>vec2 P</code>, <code>int offset</code> [, <code>float bias</code>])</p> <p><code>gvec4 textureProjOffset</code> (<code>gsampler1D sampler</code>, <code>vec4 P</code>, <code>int offset</code> [, <code>float bias</code>])</p> <p><code>gvec4 textureProjOffset</code> (<code>gsampler2D sampler</code>, <code>vec3 P</code>, <code>ivec2 offset</code> [, <code>float bias</code>])</p> <p><code>gvec4 textureProjOffset</code> (<code>gsampler2D sampler</code>, <code>vec4 P</code>, <code>ivec2 offset</code> [, <code>float bias</code>])</p> <p><code>gvec4 textureProjOffset</code> (<code>gsampler3D sampler</code>, <code>vec4 P</code>, <code>ivec3 offset</code> [, <code>float bias</code>])</p> <p><code>gvec4 textureProjOffset</code> (<code>gsampler2DRect sampler</code>, <code>vec3 P</code>, <code>ivec2 offset</code>)</p> <p><code>gvec4 textureProjOffset</code> (<code>gsampler2DRect sampler</code>, <code>vec4 P</code>, <code>ivec2 offset</code>)</p> <p><code>float textureProjOffset</code> (<code>sampler2DRectShadow sampler</code>, <code>vec4 P</code>, <code>ivec2 offset</code>)</p> <p><code>float textureProjOffset</code> (<code>sampler1DShadow sampler</code>, <code>vec4 P</code>, <code>int offset</code> [, <code>float bias</code>])</p> <p><code>float textureProjOffset</code> (<code>sampler2DShadow sampler</code>, <code>vec4 P</code>, <code>ivec2 offset</code> [, <code>float bias</code>])</p>	Do a projective texture lookup as described in textureProj offset by <i>offset</i> as described in textureOffset .

Syntax	Description
<p><code>gvec4 textureLodOffset</code> (<i>gsampler1D sampler</i>, <i>float P</i>, <i>float lod</i>, <i>int offset</i>)</p> <p><code>gvec4 textureLodOffset</code> (<i>gsampler2D sampler</i>, <i>vec2 P</i>, <i>float lod</i>, <i>ivec2 offset</i>)</p> <p><code>gvec4 textureLodOffset</code> (<i>gsampler3D sampler</i>, <i>vec3 P</i>, <i>float lod</i>, <i>ivec3 offset</i>)</p> <p><code>float textureLodOffset</code> (<i>sampler1DShadow sampler</i>, <i>vec3 P</i>, <i>float lod</i>, <i>int offset</i>)</p> <p><code>float textureLodOffset</code> (<i>sampler2DShadow sampler</i>, <i>vec3 P</i>, <i>float lod</i>, <i>ivec2 offset</i>)</p> <p><code>gvec4 textureLodOffset</code> (<i>gsampler1DArray sampler</i>, <i>vec2 P</i>, <i>float lod</i>, <i>int offset</i>)</p> <p><code>gvec4 textureLodOffset</code> (<i>gsampler2DArray sampler</i>, <i>vec3 P</i>, <i>float lod</i>, <i>ivec2 offset</i>)</p> <p><code>float textureLodOffset</code> (<i>sampler1DArrayShadow sampler</i>, <i>vec3 P</i>, <i>float lod</i>, <i>int offset</i>)</p>	<p>Do an offset texture lookup with explicit LOD. See textureLod and textureOffset.</p>
<p><code>gvec4 textureProjLod</code> (<i>gsampler1D sampler</i>, <i>vec2 P</i>, <i>float lod</i>)</p> <p><code>gvec4 textureProjLod</code> (<i>gsampler1D sampler</i>, <i>vec4 P</i>, <i>float lod</i>)</p> <p><code>gvec4 textureProjLod</code> (<i>gsampler2D sampler</i>, <i>vec3 P</i>, <i>float lod</i>)</p> <p><code>gvec4 textureProjLod</code> (<i>gsampler2D sampler</i>, <i>vec4 P</i>, <i>float lod</i>)</p> <p><code>gvec4 textureProjLod</code> (<i>gsampler3D sampler</i>, <i>vec4 P</i>, <i>float lod</i>)</p> <p><code>float textureProjLod</code> (<i>sampler1DShadow sampler</i>, <i>vec4 P</i>, <i>float lod</i>)</p> <p><code>float textureProjLod</code> (<i>sampler2DShadow sampler</i>, <i>vec4 P</i>, <i>float lod</i>)</p>	<p>Do a projective texture lookup with explicit LOD. See textureProj and textureLod.</p>
<p><code>gvec4 textureProjLodOffset</code> (<i>gsampler1D sampler</i>, <i>vec2 P</i>, <i>float lod</i>, <i>int offset</i>)</p> <p><code>gvec4 textureProjLodOffset</code> (<i>gsampler1D sampler</i>, <i>vec4 P</i>, <i>float lod</i>, <i>int offset</i>)</p> <p><code>gvec4 textureProjLodOffset</code> (<i>gsampler2D sampler</i>, <i>vec3 P</i>, <i>float lod</i>, <i>ivec2 offset</i>)</p> <p><code>gvec4 textureProjLodOffset</code> (<i>gsampler2D sampler</i>, <i>vec4 P</i>, <i>float lod</i>, <i>ivec2 offset</i>)</p> <p><code>gvec4 textureProjLodOffset</code> (<i>gsampler3D sampler</i>, <i>vec4 P</i>, <i>float lod</i>, <i>ivec3 offset</i>)</p> <p><code>float textureProjLodOffset</code> (<i>sampler1DShadow sampler</i>, <i>vec4 P</i>, <i>float lod</i>, <i>int offset</i>)</p> <p><code>float textureProjLodOffset</code> (<i>sampler2DShadow sampler</i>, <i>vec4 P</i>, <i>float lod</i>, <i>ivec2 offset</i>)</p>	<p>Do an offset projective texture lookup with explicit LOD. See textureProj, textureLod, and textureOffset.</p>

Syntax	Description
<p>gvec4 textureGrad (gsampler1D <i>sampler</i>, float <i>P</i>, float <i>dPdx</i>, float <i>dPdy</i>)</p> <p>gvec4 textureGrad (gsampler2D <i>sampler</i>, vec2 <i>P</i>, vec2 <i>dPdx</i>, vec2 <i>dPdy</i>)</p> <p>gvec4 textureGrad (gsampler3D <i>sampler</i>, vec3 <i>P</i>, vec3 <i>dPdx</i>, vec3 <i>dPdy</i>)</p> <p>gvec4 textureGrad (gsamplerCube <i>sampler</i>, vec3 <i>P</i>, vec3 <i>dPdx</i>, vec3 <i>dPdy</i>)</p> <p>gvec4 textureGrad (gsampler2DRect <i>sampler</i>, vec2 <i>P</i>, vec2 <i>dPdx</i>, vec2 <i>dPdy</i>)</p> <p>float textureGrad (sampler2DRectShadow <i>sampler</i>, vec3 <i>P</i>, vec2 <i>dPdx</i>, vec2 <i>dPdy</i>)</p> <p>float textureGrad (sampler1DShadow <i>sampler</i>, vec3 <i>P</i>, float <i>dPdx</i>, float <i>dPdy</i>)</p> <p>float textureGrad (sampler2DShadow <i>sampler</i>, vec3 <i>P</i>, vec2 <i>dPdx</i>, vec2 <i>dPdy</i>)</p> <p>float textureGrad (samplerCubeShadow <i>sampler</i>, vec4 <i>P</i>, vec3 <i>dPdx</i>, vec3 <i>dPdy</i>)</p> <p>gvec4 textureGrad (gsampler1DArray <i>sampler</i>, vec2 <i>P</i>, float <i>dPdx</i>, float <i>dPdy</i>)</p> <p>gvec4 textureGrad (gsampler2DArray <i>sampler</i>, vec3 <i>P</i>, vec2 <i>dPdx</i>, vec2 <i>dPdy</i>)</p> <p>float textureGrad (sampler1DArrayShadow <i>sampler</i>, vec3 <i>P</i>, float <i>dPdx</i>, float <i>dPdy</i>)</p> <p>float textureGrad (sampler2DArrayShadow <i>sampler</i>, vec4 <i>P</i>, vec2 <i>dPdx</i>, vec2 <i>dPdy</i>)</p> <p>gvec4 textureGrad (gsamplerCubeArray <i>sampler</i>, vec4 <i>P</i>, vec3 <i>dPdx</i>, vec3 <i>dPdy</i>)</p>	<p>Do a texture lookup as in texture but with explicit gradients. The partial derivatives of <i>P</i> are with respect to window x and window y. Set</p> $\frac{\partial s}{\partial x} = \begin{cases} \frac{\partial P}{\partial x} & \text{for a 1D texture} \\ \frac{\partial P.s}{\partial x} & \text{otherwise} \end{cases}$ $\frac{\partial s}{\partial y} = \begin{cases} \frac{\partial P}{\partial y} & \text{for a 1D texture} \\ \frac{\partial P.s}{\partial y} & \text{otherwise} \end{cases}$ $\frac{\partial t}{\partial x} = \begin{cases} 0.0 & \text{for a 1D texture} \\ \frac{\partial P.t}{\partial x} & \text{otherwise} \end{cases}$ $\frac{\partial t}{\partial y} = \begin{cases} 0.0 & \text{for a 1D texture} \\ \frac{\partial P.t}{\partial y} & \text{otherwise} \end{cases}$ $\frac{\partial r}{\partial x} = \begin{cases} 0.0 & \text{for 1D or 2D} \\ \frac{\partial P.p}{\partial x} & \text{cube, other} \end{cases}$ $\frac{\partial r}{\partial y} = \begin{cases} 0.0 & \text{for 1D or 2D} \\ \frac{\partial P.p}{\partial y} & \text{cube, other} \end{cases}$ <p>For the cube version, the partial derivatives of <i>P</i> are assumed to be in the coordinate system used before texture coordinates are projected onto the appropriate cube face.</p>

Syntax	Description
<p><code>gvec4 textureGradOffset</code> (<code>gsampler1D sampler</code>, <code>float P</code>, <code>float dPdx</code>, <code>float dPdy</code>, <code>int offset</code>)</p> <p><code>gvec4 textureGradOffset</code> (<code>gsampler2D sampler</code>, <code>vec2 P</code>, <code>vec2 dPdx</code>, <code>vec2 dPdy</code>, <code>ivec2 offset</code>)</p> <p><code>gvec4 textureGradOffset</code> (<code>gsampler3D sampler</code>, <code>vec3 P</code>, <code>vec3 dPdx</code>, <code>vec3 dPdy</code>, <code>ivec3 offset</code>)</p> <p><code>gvec4 textureGradOffset</code> (<code>gsampler2DRect sampler</code>, <code>vec2 P</code>, <code>vec2 dPdx</code>, <code>vec2 dPdy</code>, <code>ivec2 offset</code>)</p> <p><code>float textureGradOffset</code> (<code>sampler2DRectShadow sampler</code>, <code>vec3 P</code>, <code>vec2 dPdx</code>, <code>vec2 dPdy</code>, <code>ivec2 offset</code>)</p> <p><code>float textureGradOffset</code> (<code>sampler1DShadow sampler</code>, <code>vec3 P</code>, <code>float dPdx</code>, <code>float dPdy</code>, <code>int offset</code>)</p> <p><code>float textureGradOffset</code> (<code>sampler2DShadow sampler</code>, <code>vec3 P</code>, <code>vec2 dPdx</code>, <code>vec2 dPdy</code>, <code>ivec2 offset</code>)</p> <p><code>gvec4 textureGradOffset</code> (<code>gsampler1DArray sampler</code>, <code>vec2 P</code>, <code>float dPdx</code>, <code>float dPdy</code>, <code>int offset</code>)</p> <p><code>gvec4 textureGradOffset</code> (<code>gsampler2DArray sampler</code>, <code>vec3 P</code>, <code>vec2 dPdx</code>, <code>vec2 dPdy</code>, <code>ivec2 offset</code>)</p> <p><code>float textureGradOffset</code> (<code>sampler1DArrayShadow sampler</code>, <code>vec3 P</code>, <code>float dPdx</code>, <code>float dPdy</code>, <code>int offset</code>)</p> <p><code>float textureGradOffset</code> (<code>sampler2DArrayShadow sampler</code>, <code>vec4 P</code>, <code>vec2 dPdx</code>, <code>vec2 dPdy</code>, <code>ivec2 offset</code>)</p>	<p>Do a texture lookup with both explicit gradient and offset, as described in textureGrad and textureOffset.</p>
<p><code>gvec4 textureProjGrad</code> (<code>gsampler1D sampler</code>, <code>vec2 P</code>, <code>float dPdx</code>, <code>float dPdy</code>)</p> <p><code>gvec4 textureProjGrad</code> (<code>gsampler1D sampler</code>, <code>vec4 P</code>, <code>float dPdx</code>, <code>float dPdy</code>)</p> <p><code>gvec4 textureProjGrad</code> (<code>gsampler2D sampler</code>, <code>vec3 P</code>, <code>vec2 dPdx</code>, <code>vec2 dPdy</code>)</p> <p><code>gvec4 textureProjGrad</code> (<code>gsampler2D sampler</code>, <code>vec4 P</code>, <code>vec2 dPdx</code>, <code>vec2 dPdy</code>)</p> <p><code>gvec4 textureProjGrad</code> (<code>gsampler3D sampler</code>, <code>vec4 P</code>, <code>vec3 dPdx</code>, <code>vec3 dPdy</code>)</p> <p><code>gvec4 textureProjGrad</code> (<code>gsampler2DRect sampler</code>, <code>vec3 P</code>, <code>vec2 dPdx</code>, <code>vec2 dPdy</code>)</p> <p><code>gvec4 textureProjGrad</code> (<code>gsampler2DRect sampler</code>, <code>vec4 P</code>, <code>vec2 dPdx</code>, <code>vec2 dPdy</code>)</p> <p><code>float textureProjGrad</code> (<code>sampler2DRectShadow sampler</code>, <code>vec4 P</code>, <code>vec2 dPdx</code>, <code>vec2 dPdy</code>)</p> <p><code>float textureProjGrad</code> (<code>sampler1DShadow sampler</code>, <code>vec4 P</code>, <code>float dPdx</code>, <code>float dPdy</code>)</p> <p><code>float textureProjGrad</code> (<code>sampler2DShadow sampler</code>, <code>vec4 P</code>, <code>vec2 dPdx</code>, <code>vec2 dPdy</code>)</p>	<p>Do a texture lookup both projectively, as described in textureProj, and with explicit gradient as described in textureGrad. The partial derivatives <code>dPdx</code> and <code>dPdy</code> are assumed to be already projected.</p>

Syntax	Description
<code>gvec4 textureProjGradOffset (gsampler1D <i>sampler</i>, vec2 <i>P</i>, float <i>dPdx</i>, float <i>dPdy</i>, int <i>offset</i>)</code>	Do a texture lookup projectively and with explicit gradient as described in textureProjGrad , as well as with offset, as described in textureOffset .
<code>gvec4 textureProjGradOffset (gsampler1D <i>sampler</i>, vec4 <i>P</i>, float <i>dPdx</i>, float <i>dPdy</i>, int <i>offset</i>)</code>	
<code>gvec4 textureProjGradOffset (gsampler2D <i>sampler</i>, vec3 <i>P</i>, vec2 <i>dPdx</i>, vec2 <i>dPdy</i>, ivec2 <i>offset</i>)</code>	
<code>gvec4 textureProjGradOffset (gsampler2D <i>sampler</i>, vec4 <i>P</i>, vec2 <i>dPdx</i>, vec2 <i>dPdy</i>, ivec2 <i>offset</i>)</code>	
<code>gvec4 textureProjGradOffset (gsampler2DRect <i>sampler</i>, vec3 <i>P</i>, vec2 <i>dPdx</i>, vec2 <i>dPdy</i>, ivec2 <i>offset</i>)</code>	
<code>gvec4 textureProjGradOffset (gsampler2DRect <i>sampler</i>, vec4 <i>P</i>, vec2 <i>dPdx</i>, vec2 <i>dPdy</i>, ivec2 <i>offset</i>)</code>	
<code>float textureProjGradOffset (sampler2DRectShadow <i>sampler</i>, vec4 <i>P</i>, vec2 <i>dPdx</i>, vec2 <i>dPdy</i>, ivec2 <i>offset</i>)</code>	
<code>gvec4 textureProjGradOffset (gsampler3D <i>sampler</i>, vec4 <i>P</i>, vec3 <i>dPdx</i>, vec3 <i>dPdy</i>, ivec3 <i>offset</i>)</code>	
<code>float textureProjGradOffset (sampler1DShadow <i>sampler</i>, vec4 <i>P</i>, float <i>dPdx</i>, float <i>dPdy</i>, int <i>offset</i>)</code>	
<code>float textureProjGradOffset (sampler2DShadow <i>sampler</i>, vec4 <i>P</i>, vec2 <i>dPdx</i>, vec2 <i>dPdy</i>, ivec2 <i>offset</i>)</code>	

8.9.3 Texture Gather Functions

The texture gather functions take components of a single floating-point vector operand as a texture coordinate, determine a set of four texels to sample from the base level of detail of the specified texture image, and return one component from each texel in a four-component result vector.

When performing a texture gather operation, the minification and magnification filters are ignored, and the rules for LINEAR filtering in the OpenGL Specification are applied to the base level of the texture image to identify the four texels i_{j1} , i_{j2} , i_{j3} , and i_{j4} . The texels are then converted to texture base colors (R_s, G_s, B_s, A_s) according to table 15.1, followed by application of the texture swizzle as described in section 15.2.1 “Texture Access” of the OpenGL Graphics System Specification. A four-component vector is assembled by taking the selected component from each of the post-swizzled texture source colors in the order $(i_{j1}, i_{j2}, i_{j3}, i_{j4})$.

For texture gather functions using a shadow sampler type, each of the four texel lookups perform a depth comparison against the depth reference value passed in (*refZ*), and returns the result of that comparison in the appropriate component of the result vector.

As with other texture lookup functions, the results of a texture gather are undefined for shadow samplers if the texture referenced is not a depth texture or has depth comparisons disabled; or for non-shadow samplers if the texture referenced is a depth texture with depth comparisons enabled.

Syntax	Description
<p><code>gvec4 textureGather (gsampler2D <i>sampler</i>, vec2 <i>P</i> [, int <i>comp</i>])</code></p> <p><code>gvec4 textureGather (gsampler2DArray <i>sampler</i>, vec3 <i>P</i> [, int <i>comp</i>])</code></p> <p><code>gvec4 textureGather (gsamplerCube <i>sampler</i>, vec3 <i>P</i> [, int <i>comp</i>])</code></p> <p><code>gvec4 textureGather (gsamplerCubeArray <i>sampler</i>, vec4 <i>P</i> [, int <i>comp</i>])</code></p> <p><code>gvec4 textureGather (gsampler2DRect <i>sampler</i>, vec2 <i>P</i> [, int <i>comp</i>])</code></p> <p><code>vec4 textureGather (sampler2DShadow <i>sampler</i>, vec2 <i>P</i>, float <i>refZ</i>)</code></p> <p><code>vec4 textureGather (sampler2DArrayShadow <i>sampler</i>, vec3 <i>P</i>, float <i>refZ</i>)</code></p> <p><code>vec4 textureGather (samplerCubeShadow <i>sampler</i>, vec3 <i>P</i>, float <i>refZ</i>)</code></p> <p><code>vec4 textureGather (samplerCubeArrayShadow <i>sampler</i>, vec4 <i>P</i>, float <i>refZ</i>)</code></p> <p><code>vec4 textureGather (sampler2DRectShadow <i>sampler</i>, vec2 <i>P</i>, float <i>refZ</i>)</code></p>	<p>Returns the value</p> <p><code>vec4(Sample_i0_j1(<i>P</i>, base).<i>comp</i>, Sample_i1_j1(<i>P</i>, base).<i>comp</i>, Sample_i1_j0(<i>P</i>, base).<i>comp</i>, Sample_i0_j0(<i>P</i>, base).<i>comp</i>)</code></p> <p>If specified, the value of <i>comp</i> must be a constant integer expression with a value of 0, 1, 2, or 3, identifying the <i>x</i>, <i>y</i>, <i>z</i>, or <i>w</i> post-swizzled component of the four-component vector lookup result for each texel, respectively. If <i>comp</i> is not specified, it is treated as 0, selecting the <i>x</i> component of each texel to generate the result.</p>
<p><code>gvec4 textureGatherOffset (gsampler2D <i>sampler</i>, vec2 <i>P</i>, ivec2 <i>offset</i> [, int <i>comp</i>])</code></p> <p><code>gvec4 textureGatherOffset (gsampler2DArray <i>sampler</i>, vec3 <i>P</i>, ivec2 <i>offset</i> [, int <i>comp</i>])</code></p> <p><code>gvec4 textureGatherOffset (gsampler2DRect <i>sampler</i>, vec2 <i>P</i>, ivec2 <i>offset</i> [, int <i>comp</i>])</code></p> <p><code>vec4 textureGatherOffset (sampler2DShadow <i>sampler</i>, vec2 <i>P</i>, float <i>refZ</i>, ivec2 <i>offset</i>)</code></p> <p><code>vec4 textureGatherOffset (sampler2DArrayShadow <i>sampler</i>, vec3 <i>P</i>, float <i>refZ</i>, ivec2 <i>offset</i>)</code></p> <p><code>vec4 textureGatherOffset (sampler2DRectShadow <i>sampler</i>, vec2 <i>P</i>, float <i>refZ</i>, ivec2 <i>offset</i>)</code></p>	<p>Perform a texture gather operation as in textureGather by <i>offset</i> as described in textureOffset except that the <i>offset</i> can be variable (non constant) and the implementation-dependent minimum and maximum offset values are given by <code>MIN_PROGRAM_TEXTURE_GATHER_OFFSET</code> and <code>MAX_PROGRAM_TEXTURE_GATHER_OFFSET</code>, respectively.</p>

Syntax	Description
<pre> gvec4 textureGatherOffsets (gsampler2D sampler, vec2 P, ivec2 offsets[4] [, int comp]) gvec4 textureGatherOffsets (gsampler2DArray sampler, vec3 P, ivec2 offsets[4] [, int comp]) gvec4 textureGatherOffsets (gsampler2DRect sampler, vec2 P, ivec2 offsets[4] [, int comp]) vec4 textureGatherOffsets (sampler2DShadow sampler, vec2 P, float refZ, ivec2 offsets[4]) vec4 textureGatherOffsets (sampler2DArrayShadow sampler, vec3 P, float refZ, ivec2 offsets[4]) vec4 textureGatherOffsets (sampler2DRectShadow sampler, vec2 P, float refZ, ivec2 offsets[4]) </pre>	<p>Operate identically to textureGatherOffset except that <i>offsets</i> is used to determine the location of the four texels to sample. Each of the four texels is obtained by applying the corresponding offset in <i>offsets</i> as a (u, v) coordinate offset to <i>P</i>, identifying the four-texel LINEAR footprint, and then selecting the texel i_{ij_0} of that footprint. The specified values in <i>offsets</i> must be constant expressions.</p>

8.9.4 Compatibility Profile Texture Functions

The following texture functions are only in the compatibility profile.

Syntax (deprecated)	Description (deprecated)
vec4 texture1D (sampler1D <i>sampler</i> , float <i>coord</i> [, float <i>bias</i>]) vec4 texture1DProj (sampler1D <i>sampler</i> , vec2 <i>coord</i> [, float <i>bias</i>]) vec4 texture1DProj (sampler1D <i>sampler</i> , vec4 <i>coord</i> [, float <i>bias</i>]) vec4 texture1DLod (sampler1D <i>sampler</i> , float <i>coord</i> , float <i>lod</i>) vec4 texture1DProjLod (sampler1D <i>sampler</i> , vec2 <i>coord</i> , float <i>lod</i>) vec4 texture1DProjLod (sampler1D <i>sampler</i> , vec4 <i>coord</i> , float <i>lod</i>)	See corresponding signature above without “1D” in the name.
vec4 texture2D (sampler2D <i>sampler</i> , vec2 <i>coord</i> [, float <i>bias</i>]) vec4 texture2DProj (sampler2D <i>sampler</i> , vec3 <i>coord</i> [, float <i>bias</i>]) vec4 texture2DProj (sampler2D <i>sampler</i> , vec4 <i>coord</i> [, float <i>bias</i>]) vec4 texture2DLod (sampler2D <i>sampler</i> , vec2 <i>coord</i> , float <i>lod</i>) vec4 texture2DProjLod (sampler2D <i>sampler</i> , vec3 <i>coord</i> , float <i>lod</i>) vec4 texture2DProjLod (sampler2D <i>sampler</i> , vec4 <i>coord</i> , float <i>lod</i>)	See corresponding signature above without “2D” in the name.
vec4 texture3D (sampler3D <i>sampler</i> , vec3 <i>coord</i> [, float <i>bias</i>]) vec4 texture3DProj (sampler3D <i>sampler</i> , vec4 <i>coord</i> [, float <i>bias</i>]) vec4 texture3DLod (sampler3D <i>sampler</i> , vec3 <i>coord</i> , float <i>lod</i>) vec4 texture3DProjLod (sampler3D <i>sampler</i> , vec4 <i>coord</i> , float <i>lod</i>)	See corresponding signature above without “3D” in the name. Use the texture coordinate <i>coord</i> to do a texture lookup in the 3D texture currently bound to <i>sampler</i> . For the projective (“ Proj ”) versions, the texture coordinate is divided by <i>coord.q</i> .
vec4 textureCube (samplerCube <i>sampler</i> , vec3 <i>coord</i> [, float <i>bias</i>]) vec4 textureCubeLod (samplerCube <i>sampler</i> , vec3 <i>coord</i> , float <i>lod</i>)	See corresponding signature above without “Cube” in the name.

Syntax (deprecated)	Description (deprecated)
vec4 shadow1D (sampler1DShadow <i>sampler</i> ; vec3 <i>coord</i> [, float <i>bias</i>]) vec4 shadow2D (sampler2DShadow <i>sampler</i> ; vec3 <i>coord</i> [, float <i>bias</i>]) vec4 shadow1DProj (sampler1DShadow <i>sampler</i> ; vec4 <i>coord</i> [, float <i>bias</i>]) vec4 shadow2DProj (sampler2DShadow <i>sampler</i> ; vec4 <i>coord</i> [, float <i>bias</i>]) vec4 shadow1DLod (sampler1DShadow <i>sampler</i> ; vec3 <i>coord</i> , float <i>lod</i>) vec4 shadow2DLod (sampler2DShadow <i>sampler</i> ; vec3 <i>coord</i> , float <i>lod</i>) vec4 shadow1DProjLod (sampler1DShadow <i>sampler</i> ; vec4 <i>coord</i> , float <i>lod</i>) vec4 shadow2DProjLod (sampler2DShadow <i>sampler</i> ; vec4 <i>coord</i> , float <i>lod</i>)	Same functionality as the “ texture ” based names above with the same signature.

8.10 Atomic-Counter Functions

The atomic-counter operations in this section operate atomically with respect to each other. They are atomic for any single counter, meaning any of these operations on a specific counter in one shader instantiation will be indivisible by any of these operations on the same counter from another shader instantiation. There is no guarantee that these operations are atomic with respect to other forms of access to the counter or that they are serialized when applied to separate counters. Such cases would require additional use of fences, barriers, or other forms of synchronization, if atomicity or serialization is desired.

The underlying counter is a 32-bit unsigned integer. The result of operations will wrap to $[0, 2^{32}-1]$.

Syntax	Description
<code>uint atomicCounterIncrement (atomic_uint c)</code>	Atomically <ol style="list-style-type: none"> 1. increments the counter for <i>c</i>, and 2. returns its value prior to the increment operation. These two steps are done atomically with respect to the atomic counter functions in this table.
<code>uint atomicCounterDecrement (atomic_uint c)</code>	Atomically <ol style="list-style-type: none"> 1. decrements the counter for <i>c</i>, and 2. returns the value resulting from the decrement operation. These two steps are done atomically with respect to the atomic counter functions in this table.
<code>uint atomicCounter (atomic_uint c)</code>	Returns the counter value for <i>c</i> .
<code>uint atomicCounterAdd (atomic_uint c, uint data)</code>	Atomically <ol style="list-style-type: none"> 1. adds the value of <i>data</i> to the counter for <i>c</i>, and 2. returns its value prior to the operation. These two steps are done atomically with respect to the atomic counter functions in this table.
<code>uint atomicCounterSubtract (atomic_uint c, uint data)</code>	Atomically <ol style="list-style-type: none"> 1. subtracts the value of <i>data</i> from the counter for <i>c</i>, and 2. returns its value prior to the operation. These two steps are done atomically with respect to the atomic counter functions in this table.

Syntax	Description
uint atomicCounterMin (atomic_uint <i>c</i> , uint <i>data</i>)	Atomically <ol style="list-style-type: none"> sets the counter for <i>c</i> to the minimum of the value of the counter and the value of <i>data</i>, and returns the value prior to the operation. These two steps are done atomically with respect to the atomic counter functions in this table.
uint atomicCounterMax (atomic_uint <i>c</i> , uint <i>data</i>)	Atomically <ol style="list-style-type: none"> sets the counter for <i>c</i> to the maximum of the value of the counter and the value of <i>data</i>, and returns the value prior to the operation. These two steps are done atomically with respect to the atomic counter functions in this table.
uint atomicCounterAnd (atomic_uint <i>c</i> , uint <i>data</i>)	Atomically <ol style="list-style-type: none"> sets the counter for <i>c</i> to the bitwise AND of the value of the counter and the value of <i>data</i>, and returns the value prior to the operation. These two steps are done atomically with respect to the atomic counter functions in this table.
uint atomicCounterOr (atomic_uint <i>c</i> , uint <i>data</i>)	Atomically <ol style="list-style-type: none"> sets the counter for <i>c</i> to the bitwise OR of the value of the counter and the value of <i>data</i>, and returns the value prior to the operation. These two steps are done atomically with respect to the atomic counter functions in this table.
uint atomicCounterXor (atomic_uint <i>c</i> , uint <i>data</i>)	Atomically <ol style="list-style-type: none"> sets the counter for <i>c</i> to the bitwise XOR of the value of the counter and the value of <i>data</i>, and returns the value prior to the operation. These two steps are done atomically with respect to the atomic counter functions in this table.
uint atomicCounterExchange (atomic_uint <i>c</i> , uint <i>data</i>)	Atomically <ol style="list-style-type: none"> sets the counter value for <i>c</i> to the value of <i>data</i>, and returns its value prior to the operation. These two steps are done atomically with respect to the atomic counter functions in this table.

Syntax	Description
uint atomicCounterCompSwap (atomic_uint <i>c</i> , uint <i>compare</i> , uint <i>data</i>)	Atomically <ol style="list-style-type: none"> 1. compares the value of <i>compare</i> and the counter value for <i>c</i> 2. if the values are equal, sets the counter value for <i>c</i> to the value of <i>data</i>, and 3. returns its value prior to the operation. These three steps are done atomically with respect to the atomic counter functions in this table.

8.11 Atomic Memory Functions

Atomic memory functions perform atomic operations on an individual signed or unsigned integer stored in buffer-object or shared-variable storage. All of the atomic memory operations read a value from memory, compute a new value using one of the operations described below, write the new value to memory, and return the original value read. The contents of the memory being updated by the atomic operation are guaranteed not to be modified by any other assignment or atomic memory function in any shader invocation between the time the original value is read and the time the new value is written.

Atomic memory functions are supported only for a limited set of variables. A shader will fail to compile if the value passed to the *mem* argument of an atomic memory function does not correspond to a buffer or shared variable. It is acceptable to pass an element of an array or a single component of a vector to the *mem* argument of an atomic memory function, as long as the underlying array or vector is a buffer or shared variable.

All the built-in functions in this section accept arguments with combinations of **restrict**, **coherent**, and **volatile** memory qualification, despite not having them listed in the prototypes. The atomic operation will operate as required by the calling argument's memory qualification, not by the built-in function's formal-parameter memory qualification.

Syntax	Description
uint atomicAdd (inout uint <i>mem</i> , uint <i>data</i>) int atomicAdd (inout int <i>mem</i> , int <i>data</i>)	Computes a new value by adding the value of <i>data</i> to the contents <i>mem</i> .
uint atomicMin (inout uint <i>mem</i> , uint <i>data</i>) int atomicMin (inout int <i>mem</i> , int <i>data</i>)	Computes a new value by taking the minimum of the value of <i>data</i> and the contents of <i>mem</i> .
uint atomicMax (inout uint <i>mem</i> , uint <i>data</i>) int atomicMax (inout int <i>mem</i> , int <i>data</i>)	Computes a new value by taking the maximum of the value of <i>data</i> and the contents of <i>mem</i> .
uint atomicAnd (inout uint <i>mem</i> , uint <i>data</i>) int atomicAnd (inout int <i>mem</i> , int <i>data</i>)	Computes a new value by performing a bit-wise AND of the value of <i>data</i> and the contents of <i>mem</i> .

Syntax	Description
uint atomicOr (inout uint <i>mem</i> , uint <i>data</i>) int atomicOr (inout int <i>mem</i> , int <i>data</i>)	Computes a new value by performing a bit-wise OR of the value of <i>data</i> and the contents of <i>mem</i> .
uint atomicXor (inout uint <i>mem</i> , uint <i>data</i>) int atomicXor (inout int <i>mem</i> , int <i>data</i>)	Computes a new value by performing a bit-wise EXCLUSIVE OR of the value of <i>data</i> and the contents of <i>mem</i> .
uint atomicExchange (inout uint <i>mem</i> , uint <i>data</i>) int atomicExchange (inout int <i>mem</i> , int <i>data</i>)	Computes a new value by simply copying the value of <i>data</i> .
uint atomicCompSwap (inout uint <i>mem</i> , uint <i>compare</i> , uint <i>data</i>) int atomicCompSwap (inout int <i>mem</i> , int <i>compare</i> , int <i>data</i>)	Compares the value of <i>compare</i> and the contents of <i>mem</i> . If the values are equal, the new value is given by <i>data</i> ; otherwise, it is taken from the original contents of <i>mem</i> .

8.12 Image Functions

Variables using one of the image basic types may be used by the built-in shader image memory functions defined in this section to read and write individual texels of a texture. Each image variable references an image unit, which has a texture image attached.

When image memory functions below access memory, an individual texel in the image is identified using an (i) , (i, j) , or (i, j, k) coordinate corresponding to the values of P . For **image2DMS** and **image2DMSArray** variables (and the corresponding int/unsigned int types) corresponding to multi-sample textures, each texel may have multiple samples and an individual sample is identified using the integer *sample* parameter. The coordinates and sample number are used to select an individual texel in the manner described in section 8.25 “Texture Image Loads and Stores” of the OpenGL specification.

Loads and stores support float, integer, and unsigned integer types. The data types below starting “*gimage*” serve as placeholders meaning types starting either “**image**”, “**iimage**”, or “**uimage**” in the same way as *gvec* or *gsampler* in earlier sections.

The *IMAGE_PARAMS* in the prototypes below is a placeholder representing 33 separate functions, each for a different type of image variable. The *IMAGE_PARAMS* placeholder is replaced by one of the following parameter lists:

```

gimage1D image, int P
gimage2D image, ivec2 P
gimage3D image, ivec3 P
gimage2DRect image, ivec2 P
gimageCube image, ivec3 P
gimageBuffer image, int P
gimage1DArray image, ivec2 P

```

```

gimage2DArray image, ivec3 P
gimageCubeArray image, ivec3 P
gimage2DMS image, ivec2 P, int sample
gimage2DMSArray image, ivec3 P, int sample

```

where each of the lines represents one of three different image variable types, and *image*, *P*, and *sample* specify the individual texel to operate on. The method for identifying the individual texel operated on from *image*, *P*, and *sample*, and the method for reading and writing the texel are specified in section 8.25 “Texture Image Loads and Stores” of the OpenGL specification.

The atomic functions perform atomic operations on individual texels or samples of an image variable. Atomic memory operations read a value from the selected texel, compute a new value using one of the operations described below, write the new value to the selected texel, and return the original value read. The contents of the texel being updated by the atomic operation are guaranteed not to be modified by any other image store or atomic function between the time the original value is read and the time the new value is written.

Atomic memory operations are supported on only a subset of all image variable types; *image* must be either:

- a signed integer image variable (type starts “**iimage**”) and a format qualifier of *r32i*, used with a *data* argument of type **int**, or
- an unsigned image variable (type starts “**uimage**”) and a format qualifier of *r32ui*, used with a *data* argument of type **uint**.

All the built-in functions in this section accept arguments with combinations of **restrict**, **coherent**, and **volatile** memory qualification, despite not having them listed in the prototypes. The image operation will operate as required by the calling argument's memory qualification, not by the built-in function's formal-parameter memory qualification.

Syntax	Description
<p>int imageSize (readonly writeonly gimage1D <i>image</i>)</p> <p>ivec2 imageSize (readonly writeonly gimage2D <i>image</i>)</p> <p>ivec3 imageSize (readonly writeonly gimage3D <i>image</i>)</p> <p>ivec2 imageSize (readonly writeonly gimageCube <i>image</i>)</p> <p>ivec3 imageSize (readonly writeonly gimageCubeArray <i>image</i>)</p> <p>ivec2 imageSize (readonly writeonly gimageRect <i>image</i>)</p> <p>ivec2 imageSize (readonly writeonly gimage1DArray <i>image</i>)</p> <p>ivec3 imageSize (readonly writeonly gimage2DArray <i>image</i>)</p> <p>int imageSize (readonly writeonly gimageBuffer <i>image</i>)</p> <p>ivec2 imageSize (readonly writeonly gimage2DMS <i>image</i>)</p> <p>ivec3 imageSize (readonly writeonly gimage2DMSArray <i>image</i>)</p>	<p>Returns the dimensions of the image or images bound to <i>image</i>. For arrayed images, the last component of the return value will hold the size of the array. Cube images only return the dimensions of one face, and the number of cubes in the cube map array, if arrayed.</p> <p>Note: The qualification readonly writeonly accepts a variable qualified with readonly, writeonly, both, or neither. It means the formal argument will be used for neither reading nor writing to the underlying memory.</p>
<p>int imageSamples (readonly writeonly gimage2DMS <i>image</i>)</p> <p>int imageSamples (readonly writeonly gimage2DMSArray <i>image</i>)</p>	<p>Returns the number of samples of the image or images bound to <i>image</i>.</p>
<p>gvec4 imageLoad (readonly <i>IMAGE_PARAMS</i>)</p>	<p>Loads the texel at the coordinate <i>P</i> from the image unit <i>image</i> (in <i>IMAGE_PARAMS</i>). For multi-sample loads, the sample number is given by <i>sample</i>. When <i>image</i>, <i>P</i>, <i>sample</i> identify a valid texel, the bits used to represent the selected texel in memory are converted to a vec4, ivec4, or uvec4 in the manner described in section 8.25 “Texture Image Loads and Stores” of the OpenGL Specification and returned.</p>
<p>void imageStore (writeonly <i>IMAGE_PARAMS</i>, gvec4 <i>data</i>)</p>	<p>Stores <i>data</i> into the texel at the coordinate <i>P</i> from the image specified by <i>image</i>. For multi-sample stores, the sample number is given by <i>sample</i>. When <i>image</i>, <i>P</i>, and <i>sample</i> identify a valid texel, the bits used to represent <i>data</i> are converted to the format of the image unit in the manner described in section 8.25 “Texture Image Loads and Stores” of the OpenGL Specification and stored to the specified texel.</p>

Syntax	Description
uint imageAtomicAdd (<i>IMAGE_PARAMS</i> , uint <i>data</i>) int imageAtomicAdd (<i>IMAGE_PARAMS</i> , int <i>data</i>)	Computes a new value by adding the value of <i>data</i> to the contents of the selected texel.
uint imageAtomicMin (<i>IMAGE_PARAMS</i> , uint <i>data</i>) int imageAtomicMin (<i>IMAGE_PARAMS</i> , int <i>data</i>)	Computes a new value by taking the minimum of the value of <i>data</i> and the contents of the selected texel.
uint imageAtomicMax (<i>IMAGE_PARAMS</i> , uint <i>data</i>) int imageAtomicMax (<i>IMAGE_PARAMS</i> , int <i>data</i>)	Computes a new value by taking the maximum of the value <i>data</i> and the contents of the selected texel.
uint imageAtomicAnd (<i>IMAGE_PARAMS</i> , uint <i>data</i>) int imageAtomicAnd (<i>IMAGE_PARAMS</i> , int <i>data</i>)	Computes a new value by performing a bit-wise AND of the value of <i>data</i> and the contents of the selected texel.
uint imageAtomicOr (<i>IMAGE_PARAMS</i> , uint <i>data</i>) int imageAtomicOr (<i>IMAGE_PARAMS</i> , int <i>data</i>)	Computes a new value by performing a bit-wise OR of the value of <i>data</i> and the contents of the selected texel.
uint imageAtomicXor (<i>IMAGE_PARAMS</i> , uint <i>data</i>) int imageAtomicXor (<i>IMAGE_PARAMS</i> , int <i>data</i>)	Computes a new value by performing a bit-wise EXCLUSIVE OR of the value of <i>data</i> and the contents of the selected texel.
uint imageAtomicExchange (<i>IMAGE_PARAMS</i> , uint <i>data</i>) int imageAtomicExchange (<i>IMAGE_PARAMS</i> , int <i>data</i>) int imageAtomicExchange (<i>IMAGE_PARAMS</i> , float <i>data</i>)	Computes a new value by simply copying the value of <i>data</i> . These functions support 32-bit signed and unsigned operands, and 32-bit floating-point operands.

Syntax	Description
<pre>uint imageAtomicCompSwap (IMAGE_PARAMS, uint compare, uint data) int imageAtomicCompSwap (IMAGE_PARAMS, int compare, int data)</pre>	<p>Compares the value of <i>compare</i> and the contents of the selected texel. If the values are equal, the new value is given by <i>data</i>; otherwise, it is taken from the original value loaded from the texel.</p>

8.13 Fragment Processing Functions

Fragment processing functions are only available in fragment shaders.

8.13.1 Derivative Functions

Derivatives may be computationally expensive and/or numerically unstable. Therefore, an OpenGL implementation may approximate the true derivatives by using a fast but not entirely accurate derivative computation. Derivatives are undefined within non-uniform control flow.

The expected behavior of a derivative is specified using forward/backward differencing.

Forward differencing:

$$F(x+dx) - F(x) \sim dFdx(x) \cdot dx \quad 1a$$

$$dFdx(x) \sim \frac{F(x+dx) - F(x)}{dx} \quad 1b$$

Backward differencing:

$$F(x-dx) - F(x) \sim -dFdx(x) \cdot dx \quad 2a$$

$$dFdx(x) \sim \frac{F(x) - F(x-dx)}{dx} \quad 2b$$

With single-sample rasterization, $dx \leq 1.0$ in equations 1b and 2b. For multi-sample rasterization, $dx < 2.0$ in equations 1b and 2b.

dFdy is approximated similarly, with *y* replacing *x*.

With multi-sample rasterization, for any given fragment or sample, either neighboring fragments or samples may be considered.

It is typical to consider a 2x2 square of fragments or samples, and compute independent **dFdxFine** per row and independent **dFdyFine** per column, while computing only a single **dFdxCoarse** and a single **dFdyCoarse** for the entire 2x2 square. Thus, all second-order coarse derivatives, e.g.,

dFdxCoarse(dFdxCoarse(x)), may be 0, even for non-linear arguments. However, second-order fine derivatives, e.g., **dFdxFine(dFdyFine(x))** will properly reflect the difference between the independent fine derivatives computed within the 2x2 square.

The method may differ per fragment, subject to the constraint that the method may vary by window coordinates, not screen coordinates. The invariance requirement described in section 14.2 “Invariance” of the OpenGL Graphics System Specification, is relaxed for derivative calculations, because the method may be a function of fragment location.

In some implementations, varying degrees of derivative accuracy for **dFdx** and **dFdy** may be obtained by providing GL hints (section 21.4 “Hints” of the OpenGL Graphics System Specification), allowing a user to make an image quality versus speed trade off. These hints have no effect on **dFdxCoarse**, **dFdyCoarse**, **dFdxFine** and **dFdyFine**.

Syntax	Description
genType dFdx (genType <i>p</i>)	Returns either dFdxFine(p) or dFdxCoarse(p) , based on implementation choice, presumably whichever is the faster, or by whichever is selected in the API through quality-versus-speed hints.
genType dFdy (genType <i>p</i>)	Returns either dFdyFine(p) or dFdyCoarse(p) , based on implementation choice, presumably whichever is the faster, or by whichever is selected in the API through quality-versus-speed hints.
genType dFdxFine (genType <i>p</i>)	Returns the partial derivative of <i>p</i> with respect to the window x coordinate. Will use local differencing based on the value of <i>p</i> for the current fragment and its immediate neighbor(s).
genType dFdyFine (genType <i>p</i>)	Returns the partial derivative of <i>p</i> with respect to the window y coordinate. Will use local differencing based on the value of <i>p</i> for the current fragment and its immediate neighbor(s).
genType dFdxCoarse (genType <i>p</i>)	Returns the partial derivative of <i>p</i> with respect to the window x coordinate. Will use local differencing based on the value of <i>p</i> for the current fragment's neighbors, and will possibly, but not necessarily, include the value of <i>p</i> for the current fragment. That is, over a given area, the implementation can x compute derivatives in fewer unique locations than would be allowed for dFdxFine(p) .

Syntax	Description
genType dFdyCoarse (genType <i>p</i>)	Returns the partial derivative of <i>p</i> with respect to the window y coordinate. Will use local differencing based on the value of <i>p</i> for the current fragment's neighbors, and will possibly, but not necessarily, include the value of <i>p</i> for the current fragment. That is, over a given area, the implementation can compute y derivatives in fewer unique locations than would be allowed for dFdyFine (<i>p</i>).
genType fwidth (genType <i>p</i>)	Returns abs (dFdx (<i>p</i>)) + abs (dFdy (<i>p</i>)) .
genType fwidthFine (genType <i>p</i>)	Returns abs(dFdxFine(<i>p</i>)) + abs(dFdyFine(<i>p</i>)) .
genType fwidthCoarse (genType <i>p</i>)	Returns abs(dFdxCoarse(<i>p</i>)) + abs(dFdyCoarse(<i>p</i>)) .

8.13.2 Interpolation Functions

Built-in interpolation functions are available to compute an interpolated value of a fragment shader input variable at a shader-specified (*x*, *y*) location. A separate (*x*, *y*) location may be used for each invocation of the built-in function, and those locations may differ from the default (*x*, *y*) location used to produce the default value of the input.

For all of the interpolation functions, *interpolant* must be an l-value from an **in** declaration; this can include a variable, a block or structure member, an array element, or some combination of these. Component selection operators (e.g., *.xy*) may be used when specifying *interpolant*. Arrayed inputs can be indexed with general (nonuniform) integer expressions. If *interpolant* is declared with the **flat** qualifier, the interpolated value will have the same value everywhere for a single primitive, so the location used for interpolation has no effect and the functions just return that same value. If *interpolant* is declared with the **centroid** qualifier, the value returned by **interpolateAtSample()** and **interpolateAtOffset()** will be evaluated at the specified location, ignoring the location normally used with the **centroid** qualifier. If *interpolant* is declared with the **noperspective** qualifier, the interpolated value will be computed without perspective correction.

Syntax	Description
float interpolateAtCentroid (float <i>interpolant</i>) vec2 interpolateAtCentroid (vec2 <i>interpolant</i>) vec3 interpolateAtCentroid (vec3 <i>interpolant</i>) vec4 interpolateAtCentroid (vec4 <i>interpolant</i>)	Returns the value of the input <i>interpolant</i> sampled at a location inside both the pixel and the primitive being processed. The value obtained would be the same value assigned to the input variable if declared with the centroid qualifier.

Syntax	Description
float interpolateAtSample (float <i>interpolant</i> , int <i>sample</i>) vec2 interpolateAtSample (vec2 <i>interpolant</i> , int <i>sample</i>) vec3 interpolateAtSample (vec3 <i>interpolant</i> , int <i>sample</i>) vec4 interpolateAtSample (vec4 <i>interpolant</i> , int <i>sample</i>)	Returns the value of the input <i>interpolant</i> variable at the location of sample number <i>sample</i> . If multisample buffers are not available, the input variable will be evaluated at the center of the pixel. If sample <i>sample</i> does not exist, the position used to interpolate the input variable is undefined.
float interpolateAtOffset (float <i>interpolant</i> , vec2 <i>offset</i>) vec2 interpolateAtOffset (vec2 <i>interpolant</i> , vec2 <i>offset</i>) vec3 interpolateAtOffset (vec3 <i>interpolant</i> , vec2 <i>offset</i>) vec4 interpolateAtOffset (vec4 <i>interpolant</i> , vec2 <i>offset</i>)	Returns the value of the input <i>interpolant</i> variable sampled at an offset from the center of the pixel specified by <i>offset</i> . The two floating-point components of <i>offset</i> , give the offset in pixels in the <i>x</i> and <i>y</i> directions, respectively. An offset of (0, 0) identifies the center of the pixel. The range and granularity of offsets supported by this function is implementation-dependent.

8.14 Noise Functions

The noise functions **noise1**, **noise2**, **noise3**, and **noise4** have been deprecated starting with version 4.4 of GLSL. They are defined to return the value 0.0 or a vector whose components are all 0.0. However, as in previous releases, they are not semantically considered to be compile-time constant expressions.

Syntax (deprecated)	Description (deprecated)
float noise1 (genType <i>x</i>)	Returns a 1D noise value based on the input value <i>x</i> .
vec2 noise2 (genType <i>x</i>)	Returns a 2D noise value based on the input value <i>x</i> .
vec3 noise3 (genType <i>x</i>)	Returns a 3D noise value based on the input value <i>x</i> .
vec4 noise4 (genType <i>x</i>)	Returns a 4D noise value based on the input value <i>x</i> .

8.15 Geometry Shader Functions

These functions are only available in geometry shaders. They are described in more depth following the table.

Syntax	Description
void EmitStreamVertex (int <i>stream</i>)	Emits the current values of output variables to the current output primitive on stream <i>stream</i> . The argument to <i>stream</i> must be a constant integral expression. On return from this call, the values of all output variables are undefined. Can only be used if multiple output streams are supported.
void EndStreamPrimitive (int <i>stream</i>)	Completes the current output primitive on stream <i>stream</i> and starts a new one. The argument to <i>stream</i> must be a constant integral expression. No vertex is emitted. Can only be used if multiple output streams are supported.
void EmitVertex ()	Emits the current values of output variables to the current output primitive. On return from this call, the values of output variables are undefined. When multiple output streams are supported, this is equivalent to calling EmitStreamVertex (0).
void EndPrimitive ()	Completes the current output primitive and starts a new one. No vertex is emitted. When multiple output streams are supported, this is equivalent to calling EndStreamPrimitive (0).

The function **EmitStreamVertex**() specifies that a vertex is completed. A vertex is added to the current output primitive in vertex stream *stream* using the current values of all built-in and user-defined output variables associated with *stream*. The values of all output variables for all output streams are undefined after a call to **EmitStreamVertex**(). If a geometry shader invocation has emitted more vertices than permitted by the output layout qualifier **max_vertices**, the results of calling **EmitStreamVertex**() are undefined.

The function **EndStreamPrimitive**() specifies that the current output primitive for vertex stream *stream* is completed and a new output primitive (of the same type) will be started by any subsequent **EmitStreamVertex**(). This function does not emit a vertex. If the output layout is declared to be **points**, calling **EndStreamPrimitive**() is optional.

A geometry shader starts with an output primitive containing no vertices for each stream. When a geometry shader terminates, the current output primitive for each stream is automatically completed. It is not necessary to call **EndStreamPrimitive**() if the geometry shader writes only a single primitive.

Multiple output streams are supported only if the output primitive type is declared to be **points**. It is a compile-time or link-time error if a program contains a geometry shader calling **EmitStreamVertex()** or **EndStreamPrimitive()** if its output primitive type is not **points**.

8.16 Shader Invocation Control Functions

The shader invocation control function is available only in tessellation control shaders and compute shaders. It is used to control the relative execution order of multiple shader invocations used to process a patch (in the case of tessellation control shaders) or a local work group (in the case of compute shaders), which are otherwise executed with an undefined relative order.

Syntax	Description
void barrier ()	For any given static instance of barrier (), all tessellation control shader invocations for a single input patch must enter it before any will be allowed to continue beyond it, or all invocations for a single work group must enter it before any will continue beyond it.

The function **barrier**() provides a partially defined order of execution between shader invocations. This ensures that values written by one invocation prior to a given static instance of **barrier**() can be safely read by other invocations after their call to the same static instance **barrier**(). Because invocations may execute in undefined order between these barrier calls, the values of a per-vertex or per-patch output variable or shared variables for compute shaders will be undefined in a number of cases enumerated in section 4.3.6 “Output Variables” (for tessellation control shaders) and section 4.3.8 “Shared Variables” (for compute shaders).

For tessellation control shaders, the **barrier**() function may only be placed inside the function **main**() of the tessellation control shader and may not be called within any control flow. Barriers are also disallowed after a return statement in the function **main**(). Any such misplaced barriers result in a compile-time error.

For compute shaders, the **barrier**() function may be placed within flow control, but that flow control must be uniform flow control. That is, all the controlling expressions that lead to execution of the barrier must be dynamically uniform expressions. This ensures that if any shader invocation enters a conditional statement, then all invocations will enter it. While compilers are encouraged to give warnings if they can detect this might not happen, compilers cannot completely determine this. Hence, it is the author's responsibility to ensure **barrier**() only exists inside uniform flow control. Otherwise, some shader invocations will stall indefinitely, waiting for a barrier that is never reached by other invocations.

8.17 Shader Memory Control Functions

Shaders of all types may read and write the contents of textures and buffer objects using image variables. While the order of reads and writes within a single shader invocation is well-defined, the relative order of reads and writes to a single shared memory address from multiple separate shader invocations is largely undefined. The order of memory accesses performed by one shader invocation, as observed by other shader invocations, is also largely undefined but can be controlled through memory control functions.

Syntax	Description
void memoryBarrier ()	Control the ordering of memory transactions issued by a single shader invocation.
void memoryBarrierAtomicCounter ()	Control the ordering of accesses to atomic-counter variables issued by a single shader invocation.
void memoryBarrierBuffer ()	Control the ordering of memory transactions to buffer variables issued within a single shader invocation.
void memoryBarrierShared ()	Control the ordering of memory transactions to shared variables issued within a single shader invocation. Only available in compute shaders.
void memoryBarrierImage ()	Control the ordering of memory transactions to images issued within a single shader invocation.
void groupMemoryBarrier ()	Control the ordering of all memory transactions issued within a single shader invocation, as viewed by other invocations in the same work group. Only available in compute shaders.

The memory barrier built-in functions can be used to order reads and writes to variables stored in memory accessible to other shader invocations. When called, these functions will wait for the completion of all reads and writes previously performed by the caller that access selected variable types, and then return with no other effect. The built-in functions **memoryBarrierAtomicCounter()**, **memoryBarrierBuffer()**, **memoryBarrierImage()**, and **memoryBarrierShared()** wait for the completion of accesses to atomic counter, buffer, image, and shared variables, respectively. The built-in functions **memoryBarrier()** and **groupMemoryBarrier()** wait for the completion of accesses to all of the above variable types. The functions **memoryBarrierShared()** and **groupMemoryBarrier()** are available only in compute shaders; the other functions are available in all shader types.

When these functions return, the results of any memory stores performed using coherent variables performed prior to the call will be visible to any future coherent access to the same memory performed by any other shader invocation. In particular, the values written this way in one shader stage are guaranteed to be visible to coherent memory accesses performed by shader invocations in subsequent stages when those invocations were triggered by the execution of the original shader invocation (e.g., fragment shader invocations for a primitive resulting from a particular geometry shader invocation).

Additionally, memory barrier functions order stores performed by the calling invocation, as observed by other shader invocations. Without memory barriers, if one shader invocation performs two stores to coherent variables, a second shader invocation might see the values written by the second store prior to seeing those written by the first. However, if the first shader invocation calls a memory barrier function between the two stores, selected other shader invocations will never see the results of the second store before seeing those of the first. When using the function **groupMemoryBarrier()** or **memoryBarrierShared()**, this ordering guarantee applies only to other shader invocations in the same compute shader work group; all other memory barrier functions provide the guarantee to all other shader invocations. No memory barrier is required to guarantee the order of memory stores as observed by the invocation performing the stores; an invocation reading from a variable that it previously wrote will always see the most recently written value unless another shader invocation also wrote to the same memory.

8.18 Shader Invocation Group Functions

Implementations of the OpenGL Shading Language may optionally group multiple shader invocations for a single shader stage into a single SIMD invocation group, where invocations are assigned to groups in an undefined, implementation-dependent manner. Shader algorithms on such implementations may benefit from being able to evaluate a composite of Boolean values over all active invocations in a group.

Syntax	Description
bool anyInvocation (bool <i>value</i>)	Returns true if and only if <i>value</i> is true for at least one active invocation in the group.
bool allInvocations (bool <i>value</i>)	Returns true if and only if <i>value</i> is true for all active invocations in the group.
bool anyallInvocationsEqual (bool <i>value</i>)	Returns true if <i>value</i> is the same for all active invocations in the group.

For all of these functions, the same result is returned to all active invocations in the group.

These functions may be called within conditionally executed code. In groups where some invocations do not execute the function call, the value returned by the function is not affected by any invocation not calling the function, even when *value* is well-defined for that invocation.

Because these functions depend on the values of *value* in an undefined group of invocations, the value returned by these functions is largely undefined. However, **anyInvocation()** is guaranteed to return **true** if *value* is **true**, and **allInvocations()** is guaranteed to return **false** if *value* is **false**.

Because implementations are not required to combine invocations into groups, simply returning *value* for **anyInvocation()** and **allInvocations()** and returning **true** for **allInvocationsEqual()** is a legal implementation of these functions.

For fragment shaders, invocations in a SIMD invocation group may include invocations corresponding to pixels that are covered by a primitive being rasterized, as well as invocations corresponding to neighboring pixels not covered by the primitive. *Helper invocations* (see section 7.1 “Built-In Language Variables”) may be created and the value of *value* for such helper-invocation pixels may affect the value returned by **anyInvocation()**, **allInvocations()**, and **allInvocationsEqual()**.

9 Shading Language Grammar for Core Profile

The grammar is fed from the output of lexical analysis. The tokens returned from lexical analysis are

```

CONST BOOL FLOAT DOUBLE INT UINT
BREAK CONTINUE DO ELSE FOR IF DISCARD RETURN SWITCH CASE DEFAULT SUBROUTINE
BVEC2 BVEC3 BVEC4 IVEC2 IVEC3 IVEC4 UVEC2 UVEC3 UVEC4 VEC2 VEC3 VEC4
MAT2 MAT3 MAT4 CENTROID IN OUT INOUT
UNIFORM PATCH SAMPLE BUFFER SHARED
COHERENT VOLATILE RESTRICT READONLY WRITEONLY
DVEC2 DVEC3 DVEC4 DMAT2 DMAT3 DMAT4

NOPERSPECTIVE FLAT SMOOTH LAYOUT
MAT2X2 MAT2X3 MAT2X4
MAT3X2 MAT3X3 MAT3X4
MAT4X2 MAT4X3 MAT4X4
DMAT2X2 DMAT2X3 DMAT2X4
DMAT3X2 DMAT3X3 DMAT3X4
DMAT4X2 DMAT4X3 DMAT4X4
ATOMIC_UINT
SAMPLER1D SAMPLER2D SAMPLER3D SAMPLERCUBE SAMPLER1DSHADOW SAMPLER2DSHADOW
SAMPLERCUBESHADOW SAMPLER1DARRAY SAMPLER2DARRAY SAMPLER1DARRAYSHADOW
SAMPLER2DARRAYSHADOW ISAMPLER1D ISAMPLER2D ISAMPLER3D ISAMPLERCUBE
ISAMPLER1DARRAY ISAMPLER2DARRAY USAMPLER1D USAMPLER2D USAMPLER3D
USAMPLERCUBE USAMPLER1DARRAY USAMPLER2DARRAY
SAMPLER2DRECT SAMPLER2DRECTSHADOW ISAMPLER2DRECT USAMPLER2DRECT
SAMPLERBUFFER ISAMPLERBUFFER USAMPLERBUFFER
SAMPLERCUBEARRAY SAMPLERCUBEARRAYSHADOW
ISAMPLERCUBEARRAY USAMPLERCUBEARRAY
SAMPLER2DMS ISAMPLER2DMS USAMPLER2DMS
SAMPLER2DMSARRAY ISAMPLER2DMSARRAY USAMPLER2DMSARRAY
IMAGE1D IIMAGE1D UIMAGE1D IMAGE2D IIMAGE2D
UIMAGE2D IMAGE3D IIMAGE3D UIMAGE3D
IMAGE2DRECT IIMAGE2DRECT UIMAGE2DRECT
IMAGECUBE IIMAGECUBE UIMAGECUBE
IMAGEBUFFER IIMAGEBUFFER UIMAGEBUFFER
IMAGE1DARRAY IIMAGE1DARRAY UIMAGE1DARRAY
IMAGE2DARRAY IIMAGE2DARRAY UIMAGE2DARRAY
IMAGECUBEARRAY IIMAGECUBEARRAY UIMAGECUBEARRAY
IMAGE2DMS IIMAGE2DMS UIMAGE2DMS
IMAGE2DMSARRAY IIMAGE2DMSARRAY UIMAGE2DMSARRAY

```


9 Shading Language Grammar for Core Profile

```
STRUCT VOID WHILE

IDENTIFIER TYPE_NAME
FLOATCONSTANT DOUBLECONSTANT INTCONSTANT UINTCONSTANT BOOLCONSTANT
FIELD_SELECTION
LEFT_OP RIGHT_OP
INC_OP DEC_OP LE_OP GE_OP EQ_OP NE_OP
AND_OP OR_OP XOR_OP MUL_ASSIGN DIV_ASSIGN ADD_ASSIGN
MOD_ASSIGN LEFT_ASSIGN RIGHT_ASSIGN AND_ASSIGN XOR_ASSIGN OR_ASSIGN
SUB_ASSIGN

LEFT_PAREN RIGHT_PAREN LEFT_BRACKET RIGHT_BRACKET LEFT_BRACE RIGHT_BRACE DOT
COMMA COLON EQUAL SEMICOLON BANG DASH TILDE PLUS STAR SLASH PERCENT
LEFT_ANGLE RIGHT_ANGLE VERTICAL_BAR CARET AMPERSAND QUESTION

INVARIANT PRECISE
HIGH_PRECISION MEDIUM_PRECISION LOW_PRECISION PRECISION
```

The following describes the grammar for the OpenGL Shading Language in terms of the above tokens. The starting rule is *translation_unit*. An empty shader (one having no tokens to parse, after pre-processing) is valid, resulting in no compile-time errors, even though the grammar below does not have a rule to accept an empty token stream.

variable_identifier:

IDENTIFIER

primary_expression:

variable_identifier

INTCONSTANT

UINTCONSTANT

FLOATCONSTANT

BOOLCONSTANT

DOUBLECONSTANT

LEFT_PAREN expression RIGHT_PAREN

postfix_expression:

primary_expression

postfix_expression LEFT_BRACKET integer_expression RIGHT_BRACKET

function_call

postfix_expression DOT FIELD_SELECTION

postfix_expression INC_OP

postfix_expression DEC_OP

9 Shading Language Grammar for Core Profile

integer_expression:

expression

function_call:

function_call_or_method

function_call_or_method:

function_call_generic

function_call_generic:

function_call_header_with_parameters RIGHT_PAREN

function_call_header_no_parameters RIGHT_PAREN

function_call_header_no_parameters:

function_call_header VOID

function_call_header

function_call_header_with_parameters:

function_call_header assignment_expression

function_call_header_with_parameters COMMA assignment_expression

function_call_header:

function_identifier LEFT_PAREN

// Grammar Note: Constructors look like functions, but lexical analysis recognized most of them as

// keywords. They are now recognized through "type_specifier".

// Methods (.length), subroutine array calls, and identifiers are recognized through postfix_expression.

function_identifier:

type_specifier

postfix_expression

unary_expression:

postfix_expression

INC_OP unary_expression

DEC_OP unary_expression

unary_operator unary_expression

// Grammar Note: No traditional style type casts.

9 Shading Language Grammar for Core Profile

unary_operator:

PLUS
DASH
BANG
TILDE

// Grammar Note: No '' or '&' unary ops. Pointers are not supported.*

multiplicative_expression:

unary_expression
multiplicative_expression STAR unary_expression
multiplicative_expression SLASH unary_expression
multiplicative_expression PERCENT unary_expression

additive_expression:

multiplicative_expression
additive_expression PLUS multiplicative_expression
additive_expression DASH multiplicative_expression

shift_expression:

additive_expression
shift_expression LEFT_OP additive_expression
shift_expression RIGHT_OP additive_expression

relational_expression:

shift_expression
relational_expression LEFT_ANGLE shift_expression
relational_expression RIGHT_ANGLE shift_expression
relational_expression LE_OP shift_expression
relational_expression GE_OP shift_expression

equality_expression:

relational_expression
equality_expression EQ_OP relational_expression
equality_expression NE_OP relational_expression

and_expression:

equality_expression
and_expression AMPERSAND equality_expression

9 Shading Language Grammar for Core Profile

exclusive_or_expression:

and_expression

exclusive_or_expression CARET and_expression

inclusive_or_expression:

exclusive_or_expression

inclusive_or_expression VERTICAL_BAR exclusive_or_expression

logical_and_expression:

inclusive_or_expression

logical_and_expression AND_OP inclusive_or_expression

logical_xor_expression:

logical_and_expression

logical_xor_expression XOR_OP logical_and_expression

logical_or_expression:

logical_xor_expression

logical_or_expression OR_OP logical_xor_expression

conditional_expression:

logical_or_expression

logical_or_expression QUESTION expression COLON assignment_expression

assignment_expression:

conditional_expression

unary_expression assignment_operator assignment_expression

assignment_operator:

EQUAL

MUL_ASSIGN

DIV_ASSIGN

MOD_ASSIGN

ADD_ASSIGN

SUB_ASSIGN

LEFT_ASSIGN

RIGHT_ASSIGN

AND_ASSIGN

XOR_ASSIGN

OR_ASSIGN

expression:

assignment_expression
expression COMMA assignment_expression

constant_expression:

conditional_expression

declaration:

function_prototype SEMICOLON
init_declarator_list SEMICOLON
PRECISION precision_qualifier type_specifier SEMICOLON
type_qualifier IDENTIFIER LEFT_BRACE struct_declaration_list RIGHT_BRACE SEMICOLON
type_qualifier IDENTIFIER LEFT_BRACE struct_declaration_list RIGHT_BRACE
IDENTIFIER SEMICOLON
type_qualifier IDENTIFIER LEFT_BRACE struct_declaration_list RIGHT_BRACE
IDENTIFIER array_specifier SEMICOLON
type_qualifier SEMICOLON
type_qualifier IDENTIFIER SEMICOLON
type_qualifier IDENTIFIER identifier_list SEMICOLON

identifier_list:

COMMA IDENTIFIER
identifier_list COMMA IDENTIFIER

function_prototype:

function_declarator RIGHT_PAREN

function_declarator:

function_header
function_header_with_parameters

function_header_with_parameters:

function_header parameter_declaration
function_header_with_parameters COMMA parameter_declaration

function_header:

fully_specified_type IDENTIFIER LEFT_PAREN

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parameter_declarator:

type_specifier IDENTIFIER
type_specifier IDENTIFIER array_specifier

parameter_declaration:

type_qualifier parameter_declarator
parameter_declarator
type_qualifier parameter_type_specifier
parameter_type_specifier

parameter_type_specifier:

type_specifier

init_declarator_list:

single_declaration
init_declarator_list COMMA IDENTIFIER
init_declarator_list COMMA IDENTIFIER array_specifier
init_declarator_list COMMA IDENTIFIER array_specifier EQUAL initializer
init_declarator_list COMMA IDENTIFIER EQUAL initializer

single_declaration:

fully_specified_type
fully_specified_type IDENTIFIER
fully_specified_type IDENTIFIER array_specifier
fully_specified_type IDENTIFIER array_specifier EQUAL initializer
fully_specified_type IDENTIFIER EQUAL initializer

// Grammar Note: No 'enum', or 'typedef'.

fully_specified_type:

type_specifier
type_qualifier type_specifier

invariant_qualifier:

INVARIANT

interpolation_qualifier:

SMOOTH

FLAT

NOPERSPECTIVE

layout_qualifier:

LAYOUT LEFT_PAREN layout_qualifier_id_list RIGHT_PAREN

layout_qualifier_id_list:

layout_qualifier_id

layout_qualifier_id_list COMMA layout_qualifier_id

layout_qualifier_id:

IDENTIFIER

IDENTIFIER EQUAL constant_expression

SHARED

precise_qualifier:

PRECISE

type_qualifier:

single_type_qualifier

type_qualifier single_type_qualifier

single_type_qualifier:

storage_qualifier

layout_qualifier

precision_qualifier

interpolation_qualifier

invariant_qualifier

precise_qualifier

storage_qualifier:

CONST

INOUT

IN

OUT

CENTROID

PATCH

SAMPLE

9 Shading Language Grammar for Core Profile

UNIFORM
BUFFER
SHARED
COHERENT
VOLATILE
RESTRICT
READONLY
WRITEONLY
SUBROUTINE
SUBROUTINE LEFT_PAREN type_name_list RIGHT_PAREN

type_name_list:

TYPE_NAME
type_name_list COMMA TYPE_NAME

type_specifier:

type_specifier_nonarray
type_specifier_nonarray array_specifier

array_specifier:

LEFT_BRACKET RIGHT_BRACKET
LEFT_BRACKET conditional_expression RIGHT_BRACKET
array_specifier LEFT_BRACKET RIGHT_BRACKET
array_specifier LEFT_BRACKET conditional_expression RIGHT_BRACKET

type_specifier_nonarray:

VOID
FLOAT
DOUBLE
INT
UINT
BOOL
VEC2
VEC3
VEC4
DVEC2
DVEC3

DVEC4
BVEC2
BVEC3
BVEC4
IVEC2
IVEC3
IVEC4
UVEC2
UVEC3
UVEC4
MAT2
MAT3
MAT4
MAT2X2
MAT2X3
MAT2X4
MAT3X2
MAT3X3
MAT3X4
MAT4X2
MAT4X3
MAT4X4
DMAT2
DMAT3
DMAT4
DMAT2X2
DMAT2X3
DMAT2X4
DMAT3X2
DMAT3X3
DMAT3X4
DMAT4X2
DMAT4X3
DMAT4X4
ATOMIC_UINT
SAMPLER1D
SAMPLER2D

SAMPLER3D
SAMPLERCUBE
SAMPLER1DSHADOW
SAMPLER2DSHADOW
SAMPLERCUBESHADOW
SAMPLER1DARRAY
SAMPLER2DARRAY
SAMPLER1DARRAYSHADOW
SAMPLER2DARRAYSHADOW
SAMPLERCUBEARRAY
SAMPLERCUBEARRAYSHADOW
ISAMPLER1D
ISAMPLER2D
ISAMPLER3D
ISAMPLERCUBE
ISAMPLER1DARRAY
ISAMPLER2DARRAY
ISAMPLERCUBEARRAY
USAMPLER1D
USAMPLER2D
USAMPLER3D
USAMPLERCUBE
USAMPLER1DARRAY
USAMPLER2DARRAY
USAMPLERCUBEARRAY
SAMPLER2DRECT
SAMPLER2DRECTSHADOW
ISAMPLER2DRECT
USAMPLER2DRECT
SAMPLERBUFFER
ISAMPLERBUFFER
USAMPLERBUFFER
SAMPLER2DMS
ISAMPLER2DMS
USAMPLER2DMS
SAMPLER2DMSARRAY
ISAMPLER2DMSARRAY

USAMPLER2DMSARRAY
IMAGE1D
IIMAGE1D
UIMAGE1D
IMAGE2D
IIMAGE2D
UIMAGE2D
IMAGE3D
IIMAGE3D
UIMAGE3D
IMAGE2DRECT
IIMAGE2DRECT
UIMAGE2DRECT
IMAGECUBE
IIMAGECUBE
UIMAGECUBE
IMAGEBUFFER
IIMAGEBUFFER
UIMAGEBUFFER
IMAGE1DARRAY
IIMAGE1DARRAY
UIMAGE1DARRAY
IMAGE2DARRAY
IIMAGE2DARRAY
UIMAGE2DARRAY
IMAGECUBEARRAY
IIMAGECUBEARRAY
UIMAGECUBEARRAY
IMAGE2DMS
IIMAGE2DMS
UIMAGE2DMS
IMAGE2DMSARRAY
IIMAGE2DMSARRAY
UIMAGE2DMSARRAY
struct_specifier
TYPE_NAME
precision_qualifier:
HIGH_PRECISION

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MEDIUM_PRECISION
LOW_PRECISION

struct_specifier:

STRUCT IDENTIFIER LEFT_BRACE struct_declaration_list RIGHT_BRACE
STRUCT LEFT_BRACE struct_declaration_list RIGHT_BRACE

struct_declaration_list:

struct_declaration
struct_declaration_list struct_declaration

struct_declaration:

type_specifier struct_declarator_list SEMICOLON
type_qualifier type_specifier struct_declarator_list SEMICOLON

struct_declarator_list:

struct_declarator
struct_declarator_list COMMA struct_declarator

struct_declarator:

IDENTIFIER
IDENTIFIER array_specifier

initializer:

assignment_expression
LEFT_BRACE initializer_list RIGHT_BRACE
LEFT_BRACE initializer_list COMMA RIGHT_BRACE

initializer_list:

initializer
initializer_list COMMA initializer

declaration_statement:

declaration

statement:

compound_statement
simple_statement

// Grammar Note: labeled statements for SWITCH only; 'goto' is not supported.

simple_statement:

declaration_statement

expression_statement

selection_statement

switch_statement

case_label

iteration_statement

jump_statement

compound_statement:

LEFT_BRACE RIGHT_BRACE

LEFT_BRACE statement_list RIGHT_BRACE

statement_no_new_scope:

compound_statement_no_new_scope

simple_statement

compound_statement_no_new_scope:

LEFT_BRACE RIGHT_BRACE

LEFT_BRACE statement_list RIGHT_BRACE

statement_list:

statement

statement_list statement

expression_statement:

SEMICOLON

expression SEMICOLON

selection_statement:

IF LEFT_PAREN expression RIGHT_PAREN selection_rest_statement

selection_rest_statement:

statement ELSE statement

statement

condition:

expression

fully_specified_type IDENTIFIER EQUAL initializer

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switch_statement:
SWITCH LEFT_PAREN *expression* RIGHT_PAREN LEFT_BRACE *switch_statement_list*
RIGHT_BRACE

switch_statement_list:
/* nothing */
statement_list

case_label:
CASE *expression* COLON
DEFAULT COLON

iteration_statement:
WHILE LEFT_PAREN *condition* RIGHT_PAREN *statement_no_new_scope*
DO *statement* WHILE LEFT_PAREN *expression* RIGHT_PAREN SEMICOLON
FOR LEFT_PAREN *for_init_statement* *for_rest_statement* RIGHT_PAREN
statement_no_new_scope

for_init_statement:
expression_statement
declaration_statement

conditionopt:
condition
/* empty */

for_rest_statement:
conditionopt SEMICOLON
conditionopt SEMICOLON *expression*

jump_statement:
CONTINUE SEMICOLON
BREAK SEMICOLON
RETURN SEMICOLON
RETURN *expression* SEMICOLON
DISCARD SEMICOLON // Fragment shader only.

// Grammar Note: No 'goto'. Gotos are not supported.

translation_unit:
external_declaration
translation_unit *external_declaration*

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external_declaration:

function_definition

declaration

SEMICOLON

function_definition:

function_prototype compound_statement_no_new_scope

10 Normative References

1. International Standard ISO/IEC 14882:1998(E). Programming Languages – C++. Referenced for preprocessor only.