

# The OpenGL<sup>®</sup> Shading Language

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# 1 Introduction

This document specifies only version 1.50 of the OpenGL Shading Language. It requires `__VERSION__` to substitute 150, and requires `#version` to accept only 150. 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, Version 3.2, for details on what language versions are supported.

All OpenGL Graphics System Specification references in this specification are to version 3.2.

## 1.1 Acknowledgments

This specification is based on the work of those who contributed to past versions of the OpenGL Language Specification, the OpenGL ES 2.0 Language Specification, and the following contributors to this version:

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## 1.2 Changes

### 1.2.1 Changes from revision 9 of version 1.5

- [Clarify that `discard` control flow exits the shader.](#)
- [Explain how to redeclare `gl\_TexCoord\[\]`.](#)
- [Remove accidental inclusion of `textureGradOffset` on `samplerCubeShadow`.](#)
- [Clarify it is generally an error to redeclare variables, including built-ins.](#)

### 1.2.2 Changes from revision 6 of version 1.5

- Put `gl_MaxTextureUnits` and `gl_MaxTextureCoords` into the compatibility profile. It was an oversight to not have them there in the previous release.
- Change `ARB_compatibility` extension to compatibility profile.
- Small clarifying comments of existing specification.
- Add new minimum maximums for `gl_MaxVertexOutputComponents`, `gl_MaxGeometryInputComponents`, `gl_MaxGeometryOutputComponents`, and `gl_MaxFragmentInputComponents`, rather than relying on `gl_MaxVaryingComponents`. Also, corrected `gl_MaxVaryingComponents` to be 60 instead of 64.

### 1.2.3 Changes from revision 5 of version 1.5

- Completed full update to grammar section. Tested spec examples against it:
  - add multi-sampler sampler types
  - add unsized arrays for block members
  - allow partial qualification of block members
  - add assignments within the layout qualifier id list
  - allow instance names on blocks, no array, unsized array, and array
- Brought `ARB_compatibility` up to full 1.5 functionality.
- Corrected API transform/feedback example in section 4.3.7.
- Clarify that when redeclaring built-ins (`invariant`, `flat`, etc.) that block instance names are not used
- Clarify that **`invariant`** can be used on output variables that are then input into a subsequent shader stage and both the input and output declarations of that variable must be declared `invariant` or it is a link error.

### 1.2.4 Changes from revision 4 of version 1.5

- `gl_PrimitiveID` comes from the provoking vertex, while `gl_Layer` comes from some vertex.
- Require #extension “`GL_ARB_compatibility : enable`” to use `ARB_compatibility` features.

- Updated grammar for assignments in layout qualifiers and new texture keywords.
- Lots of editorial changes.

### 1.2.5 Summary of Functionality differences from version 1.4

- Created profiles. Turned the compatibility extension into the compatibility profile.
- Update geometry shader layouts: they must be declared, telling the system the primitive input and output types and maximum number of vertices.
- Added geometry shader constants.
- Changed *gl\_FragCoord* qualifiers to use the **layout()** mechanism instead.
- Made version be 150, 1.50, etc.
- Added geometry shaders. This includes targeting layers in FBO rendering.
- Added *gl\_PrimitiveID* as an input to fragment shaders.
- Added **determinant()** built-in.
- Broaden array usage to include vertex shader inputs (vertex **in**).
- Broaden structure usage to include fragment and geometry inputs and vertex and geometry outputs.
- Broadened interface blocks from just uniforms to in and out interfaces as well.
- Added *gl\_FragCoord* qualifiers **origin\_upper\_left**, and **pixel\_center\_integer** to modify the values returned by *gl\_FragCoord* (and have no affect on any other aspect of the pipeline or language).
- Removed the ability to have statements before the first case in a switch.
- Added support for multi-sample textures through **sampler2DMS** and **sampler2DMSArray** support in **texelFetch()** and **textureSize()**.
- Deprecated *gl\_MaxVaryingComponents*;

## 1.3 Overview

This document describes *The OpenGL Shading Language, version 1.50*.

Independent compilation units written in this language are called *shaders*. A *program* is a complete set of shaders that are compiled and linked together. 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. Compilers are required to return messages regarding lexically, grammatically, or semantically incorrect shaders.

## 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

Previous versions of the OpenGL Shading Language 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 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, geometry, and fragment 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, geometry, or fragment.

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 complete set of vertex shaders are 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 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 complete set of geometry shaders are 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.

### 2.3 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 complete set of fragment shaders are compiled and linked, they result in a *fragment shader executable* that runs on the fragment processor.

## 2 Overview of OpenGL Shading

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.

# 3 Basics

## 3.1 Character Set

The source character set used for the OpenGL shading languages is a subset of ASCII. It includes the following characters:

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 (`?`).

The number sign (`#`) for preprocessor use.

White space: the space character, horizontal tab, vertical tab, form feed, carriage-return, and line-feed.

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. There is no line continuation character.

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.

## 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.

### 3.3 Preprocessor

There is a preprocessor that processes the source strings as part of the compilation process.

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.

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.

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 150.

All macro names containing two consecutive underscores ( `__` ) are reserved for future use as predefined macro names. All macro names prefixed with “GL\_” (“GL” followed by a single underscore) are also reserved.

`#if`, `#ifdef`, `#ifndef`, `#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. It is an error to use `#if` or `#elif` on expressions containing undefined macro names, other than as arguments to 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 diagnostic message into the shader object’s information log (see section 6.1.10 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 150**” is required in any shader that uses version 1.50 of the language. Any *number* representing a version of the language a compiler does not support will cause an 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 declaring version 1.4 of the shading language can be linked with shaders declaring version 1.5 in the same program. Shaders targeting earlier versions of the shading language cannot be linked with version 1.5 shaders.

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

```
core
compatibility
```

If no *profile* argument is provided, the default is **core**. 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.

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
```

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 syntactic, grammatical, and semantic 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

<b>behavior</b>	<b>Effect</b>
<b>require</b>	Behave as specified by the extension <i>extension_name</i> . Give an error on the <b>#extension</b> if the extension <i>extension_name</i> is not supported, or if <b>all</b> is specified.
<b>enable</b>	Behave as specified by the extension <i>extension_name</i> . Warn on the <b>#extension</b> if the extension <i>extension_name</i> is not supported. Give an error on the <b>#extension</b> if <b>all</b> is specified.
<b>warn</b>	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 <b>all</b> is specified, then warn on all detectable uses of any extension used. Warn on the <b>#extension</b> if the extension <i>extension_name</i> is not supported.
<b>disable</b>	Behave (including issuing errors and warnings) as if the extension <i>extension_name</i> is not part of the language definition. If <b>all</b> is specified, then behavior must revert back to that of the non-extended core version of the language being compiled to. Warn on the <b>#extension</b> 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*+1 and source string number *source-string-number*. Subsequent source strings will be numbered sequentially, until another **#line** directive overrides that numbering.

## 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. If a comment resides entirely within a single line, it is treated syntactically as a single space. New-lines are not eliminated by comments.

### 3.5 Tokens

The language is a sequence of tokens. A token can be

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

### 3.6 Keywords

The following are the keywords in the language, and cannot be used for any other purpose than that defined by this document:

**attribute const uniform varying**  
**layout**  
**centroid flat smooth noperspective**  
**break continue do for while switch case default**  
**if else**  
**in out inout**  
**float int void bool true false**  
**invariant**  
**discard return**  
**mat2 mat3 mat4**  
**mat2x2 mat2x3 mat2x4**  
**mat3x2 mat3x3 mat3x4**  
**mat4x2 mat4x3 mat4x4**  
**vec2 vec3 vec4 ivec2 ivec3 ivec4 bvec2 bvec3 bvec4**  
**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**  
**struct**

The following are the keywords reserved for future use. Using them will result in an error:

**common partition active**  
**asm**  
**class union enum typedef template this packed**  
**goto**  
**inline noline volatile public static extern external interface**  
**long short double half fixed unsigned superp**  
**input output**  
**hvec2 hvec3 hvec4 dvec2 dvec3 dvec4 fvec2 fvec3 fvec4**  
**sampler3DRect**  
**filter**  
**image1D image2D image3D imageCube**  
**iimage1D iimage2D iimage3D iimageCube**  
**uimage1D uimage2D uimage3D uimageCube**  
**image1DArray image2DArray**  
**iimage1DArray iimage2DArray uimage1DArray uimage2DArray**  
**image1DShadow image2DShadow**  
**image1DArrayShadow image2DArrayShadow**  
**imageBuffer iimageBuffer uimageBuffer**  
**sizeof cast**  
**namespace using**  
**row\_major**

In addition, all identifiers containing two consecutive underscores (\_\_) are reserved as possible future keywords.

### 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 fields, as discussed in Section 5.5 “Vector 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 as either a variable or a function. However, as noted in the specification, there are some cases where previously declared variables can be redeclared to change [or add](#) some property, and predeclared “gl\_” names are allowed to be redeclared in a shader: [only for these specific purposes. More generally, it is an error to redeclare a variable, including those starting “gl\\_”](#).

### 3.8 Static Use

Some language rules described below depend on whether something is *statically* written or used.

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 run-time flow of control will cause that statement to be executed.

# 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 (=). The grammar near the end of this document provides a full reference for the syntax of declaring variables.

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 no implicit conversions between types, with the exception that an integer value may appear where a floating-point type is expected, and be converted to a floating-point value. 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
<b>void</b>	for functions that do not return a value
<b>bool</b>	a conditional type, taking on values of true or false
<b>int</b>	a signed integer
<b>uint</b>	an unsigned integer
<b>float</b>	a single floating-point scalar
<b>vec2</b>	a two-component floating-point vector
<b>vec3</b>	a three-component floating-point vector
<b>vec4</b>	a four-component floating-point vector
<b>bvec2</b>	a two-component Boolean vector
<b>bvec3</b>	a three-component Boolean vector
<b>bvec4</b>	a four-component Boolean vector
<b>ivec2</b>	a two-component signed integer vector
<b>ivec3</b>	a three-component signed integer vector
<b>ivec4</b>	a four-component signed integer vector

Type	Meaning
<b>uvec2</b>	a two-component unsigned integer vector
<b>uvec3</b>	a three-component unsigned integer vector
<b>uvec4</b>	a four-component unsigned integer vector
<b>mat2</b>	a 2×2 floating-point matrix
<b>mat3</b>	a 3×3 floating-point matrix
<b>mat4</b>	a 4×4 floating-point matrix
<b>mat2x2</b>	same as a <b>mat2</b>
<b>mat2x3</b>	a floating-point matrix with 2 columns and 3 rows
<b>mat2x4</b>	a floating-point matrix with 2 columns and 4 rows
<b>mat3x2</b>	a floating-point matrix with 3 columns and 2 rows
<b>mat3x3</b>	same as a <b>mat3</b>
<b>mat3x4</b>	a floating-point matrix with 3 columns and 4 rows
<b>mat4x2</b>	a floating-point matrix with 4 columns and 2 rows
<b>mat4x3</b>	a floating-point matrix with 4 columns and 3 rows
<b>mat4x4</b>	same as a <b>mat4</b>

## Floating Point Sampler Types (opaque)

Type	Meaning
<b>sampler1D</b>	a handle for accessing a 1D texture
<b>sampler2D</b>	a handle for accessing a 2D texture
<b>sampler3D</b>	a handle for accessing a 3D texture
<b>samplerCube</b>	a handle for accessing a cube mapped texture
<b>sampler2DRect</b>	a handle for accessing a rectangular texture
<b>sampler1DShadow</b>	a handle for accessing a 1D depth texture with comparison
<b>sampler2DShadow</b>	a handle for accessing a 2D depth texture with comparison
<b>sampler2DRectShadow</b>	a handle for accessing a rectangular texture with comparison
<b>sampler1DArray</b>	a handle for accessing a 1D array texture
<b>sampler2DArray</b>	a handle for accessing a 2D array texture
<b>sampler1DArrayShadow</b>	a handle for accessing a 1D array depth texture with comparison
<b>sampler2DArrayShadow</b>	a handle for accessing a 2D array depth texture with comparison
<b>samplerBuffer</b>	a handle for accessing a buffer texture
<b>sampler2DMS</b>	a handle for accessing a 2D multi-sample texture

Type	Meaning
<b>sampler2DMSArray</b>	a handle for accessing a 2D multi-sample array texture

Signed Integer Sampler Types (opaque)

Type	Meaning
<b>isampler1D</b>	a handle for accessing an integer 1D texture
<b>isampler2D</b>	a handle for accessing an integer 2D texture
<b>isampler3D</b>	a handle for accessing an integer 3D texture
<b>isamplerCube</b>	a handle for accessing an integer cube mapped texture
<b>isampler2DRect</b>	a handle for accessing an integer 2D rectangular texture
<b>isampler1DArray</b>	a handle for accessing an integer 1D array texture
<b>isampler2DArray</b>	a handle for accessing an integer 2D array texture
<b>isamplerBuffer</b>	a handle for accessing an integer buffer texture
<b>isampler2DMS</b>	a handle for accessing an integer 2D multi-sample texture
<b>isampler2DMSArray</b>	a handle for accessing an integer 2D multi-sample array texture

Unsigned Integer Sampler Types (opaque)

Type	Meaning
<b>usampler1D</b>	a handle for accessing an unsigned integer 1D texture
<b>usampler2D</b>	a handle for accessing an unsigned integer 2D texture
<b>usampler3D</b>	a handle for accessing an unsigned integer 3D texture
<b>usamplerCube</b>	a handle for accessing an unsigned integer cube mapped texture
<b>usampler2DRect</b>	a handle for accessing an unsigned integer rectangular texture
<b>usampler1DArray</b>	a handle for accessing an unsigned integer 1D array texture
<b>usampler2DArray</b>	a handle for accessing an unsigned integer 2D array texture
<b>usamplerBuffer</b>	a handle for accessing an unsigned integer buffer texture
<b>usampler2DMS</b>	a handle for accessing an unsigned integer 2D multi-sample texture
<b>usampler2DMSArray</b>	a handle for accessing an unsigned integer 2D multi-sample texture array

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

There are no pointer types.

### 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).

### 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. 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.

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<sub>opt</sub>*

*octal-constant integer-suffix<sub>opt</sub>*

*hexadecimal-constant integer-suffix<sub>opt</sub>*

*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 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.

It is an error to provide a literal integer whose magnitude is too large to store in a variable of matching signed or unsigned type.

#### 4.1.4 Floats

Floats are available for use in a variety of scalar calculations. Floating-point variables are defined as in the following example:

```
float a, b = 1.5;
```

As an input value to one of the processing units, a floating-point variable is expected to match the IEEE single precision floating-point definition for precision and dynamic range. It is not required that the precision of internal processing match the IEEE floating-point specification for floating-point operations, but the guidelines for precision established by the OpenGL 1.4 specification must be met. Similarly, treatment of conditions such as divide by 0 may lead to an unspecified result, but in no case should such a condition lead to the interruption or termination of processing.

Floating-point constants are defined as follows.

*floating-constant* :

*fractional-constant* *exponent-part*<sub>opt</sub> *floating-suffix*<sub>opt</sub>

*digit-sequence* *exponent-part* *floating-suffix*<sub>opt</sub>

*fractional-constant* :

*digit-sequence* . *digit-sequence*

*digit-sequence* .

. *digit-sequence*

*exponent-part* :

*e* *sign*<sub>opt</sub> *digit-sequence*

*E* *sign*<sub>opt</sub> *digit-sequence*

*sign* : one of

+ -

*digit-sequence* :

*digit*

*digit-sequence* *digit*

*floating-suffix*: one of

**f F**

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. 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  $2 \times 2$ ,  $2 \times 3$ ,  $2 \times 4$ ,  $3 \times 2$ ,  $3 \times 3$ ,  $3 \times 4$ ,  $4 \times 2$ ,  $4 \times 3$ , and  $4 \times 4$  matrices of floating-point numbers. The first number in the type is the number of columns, the second is the number of rows. 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
```

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

### 4.1.7 Samplers

Sampler types (e.g., **sampler2D**) are effectively opaque handles to textures and their filters. They are used with the built-in texture functions (described in Section 8.7 “Texture Lookup Functions”) to specify which texture to access and how it is to be filtered. They can only be declared as function parameters or **uniform** variables (see Section 4.3.5 “Uniform”). Except for array indexing, structure field selection, and parentheses, samplers are not allowed to be operands in expressions. Samplers aggregated into arrays within a shader (using square brackets [ ]) can only be indexed with integral constant expressions (see Section 4.3.3 “Constant Expressions”). Samplers cannot be treated as l-values; hence cannot be used as **out** or **inout** function parameters, nor can they be assigned into. As uniforms, they are initialized only with the OpenGL API; they cannot be declared with an initializer in a shader. As function parameters, only samplers may be passed to samplers of matching type. This enables consistency checking between shader texture accesses and OpenGL texture state before a shader is run.

### 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* :

$$\textit{qualifier}_{opt} \mathbf{struct} \textit{name}_{opt} \{ \textit{member-list} \} \textit{declarators}_{opt};$$

*member-list* :

$$\textit{member-declaration};$$

$$\textit{member-declaration} \textit{member-list};$$

*member-declaration* :

$$\textit{basic-type} \textit{declarators};$$

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 may not contain any other qualifiers. Bit fields are not supported. Member types must be already defined (there are no forward references). Member declarations cannot contain initializers. 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.

```
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”.

### 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. If an array is indexed with an expression that is not an integral constant expression, or if an array is passed as an argument to a function, then its size must be declared before any such use. It is legal to declare an array without a size and then later re-declare the same name as an array of the same type and specify a size. It is illegal 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 also illegal 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. Only one-dimensional arrays may be declared. All basic types and structures can be formed into arrays. Some examples are:

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

An array type can be formed by specifying a type followed by square brackets ( [ ] ) and including a size:

```
float[5]
```

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;
```

It is an error to declare arrays of arrays:

```
float a[5][3]; // illegal
float[5] a[3]; // illegal
```

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
```

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
```

However, implicitly sized arrays cannot be assigned to. Note, this is a rare case that initializers and assignments appear to have different semantics.

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

```
a.length(); // returns 5 for the above declarations
```

The length method cannot be called on an array that has not been explicitly sized.

### 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
<b>int</b> <b>uint</b>	<b>float</b>
<b>ivec2</b> <b>uvec2</b>	<b>vec2</b>
<b>ivec3</b> <b>uvec3</b>	<b>vec3</b>
<b>ivec4</b> <b>uvec4</b>	<b>vec4</b>

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

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 floating point mantissa will lose precision when converted to **float**.

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

## 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. 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 body has a scope nested inside the function's definition. 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.
```

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 re-declared 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 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 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.

Shared globals are global variables declared with the same name in independently compiled units (shaders) within the same language (vertex, geometry, or fragment) 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. If no shader has an explicit size for the array, the largest implicit size is used. 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 field names to be considered the same type. This rule applies recursively for nested or embedded types. All initializers for a shared global must have the same value, or a link error will result.

### 4.3 Storage Qualifiers

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

Qualifier	Meaning
< none: default >	local read/write memory, or an input parameter to a function
<b>const</b>	a compile-time constant, or a function parameter that is read-only
<b>in</b> <b>centroid in</b>	linkage into a shader from a previous stage, variable is copied in linkage with centroid based interpolation
<b>out</b> <b>centroid out</b>	linkage out of a shader to a subsequent stage, variable is copied out linkage with centroid based interpolation
<b>attribute</b>	deprecated; linkage between a vertex shader and OpenGL for per-vertex data
<b>uniform</b>	value does not change across the primitive being processed, uniforms form the linkage between a shader, OpenGL, and the application
<b>varying</b> <b>centroid varying</b>	deprecated; linkage between a vertex shader and a fragment shader for interpolated data

Outputs from shader (**out**) and inputs to a shader (**in**) can be further qualified with one of these interpolation qualifiers

Qualifier	Meaning
<b>smooth</b>	perspective correct interpolation
<b>flat</b>	no interpolation
<b>noperspective</b>	linear interpolation

These interpolation qualifiers may only precede the qualifiers **in**, **centroid in**, **out**, or **centroid out** in a declaration. They do not apply to the deprecated storage qualifiers **varying** or **centroid varying**. They also do not apply to inputs into a vertex shader or outputs from a fragment shader.

Local variables can only use the **const** 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 fields do not use storage qualifiers.

Data types for communication from one run of a shader executable to its next run (to communicate between fragments or between vertices) do not exist. This would prevent parallel execution of the same shader executable on multiple vertices or fragments.

Initializers may only be used in declarations of globals 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.

### 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 can be declared using the **const** qualifier. Any variables qualified as constant are read-only variables for that shader. Declaring variables as constant allows more descriptive shaders than using hard-wired numerical constants. The **const** qualifier can be used with any of the basic data types. It is an 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);
```

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

Initializers for const declarations must be constant expressions, as defined in Section 4.3.3 “Constant Expressions.”

### 4.3.3 Constant Expressions

A *constant expression* is one of

- a literal value (e.g., **5** or **true**)
- a global or local variable qualified as **const** (i.e., not including function parameters)
- an expression formed by an operator on operands that are all constant expressions, including getting an element or length of a constant array, or a field of a constant structure, or components of a constant vector.
- a constructor whose arguments are all constant expressions
- a built-in function call whose arguments are all constant expressions, with the exception of the texture lookup functions and the noise functions. The built-in functions **dFdx**, **dFdy**, and **fwidth** must return 0 when evaluated inside an initializer with an argument that is a constant expression.

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 be evaluated in an invariant way so as to create the same value in multiple shaders when the same constant expressions appear in those shaders. See section 4.6.1 “The Invariant Qualifier” for more details on how to create invariant expressions.

#### 4.3.4 Inputs

Shader input variables are declared with the **in** storage qualifier or the **centroid in** storage qualifier. 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. Variables declared as **in** or **centroid in** may not be written to during shader execution. Only the input variables that are actually read need to be written by the previous stage; it is allowed to have superfluous declarations of input variables.

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 or the deprecated **attribute** qualifier. It is an error to use **centroid in** or interpolation qualifiers in a vertex shader input. The values copied in are established by the OpenGL API. It is an error to use **attribute** in a non-vertex shader. Vertex shader inputs can only be **float**, floating-point vectors, matrices, signed and unsigned integers and integer vectors. Vertex shader inputs can also form arrays of these types, but not structures.

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 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.

Geometry shader input variables get the per-vertex values written out by vertex shader output variables of the same names. Since a geometry shader operates on a set of vertices, each input varying 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. 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 4.3.8.1 Input Layout Qualifiers.

For the interface between a vertex shader and a geometry shader, vertex shader output variables and geometry shader input variables of the same name must match in type and qualification, except that the vertex shader name cannot be declared as an array while the geometry shader name must be declared as an array. Otherwise, a link error will occur.

If the output of a vertex shader is itself an array to be consumed by a geometry shader, then it must appear in an output block (see interface blocks below) in the vertex shader and in an input block in the geometry shader with a block instance name declared as an array. This is required for arrays output from a vertex shader because two-dimensional arrays are not supported.

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 **centroid in** storage qualifier, or the deprecated **varying** and **centroid varying** storage qualifiers. Fragment inputs can only be signed and unsigned integers and integer vectors, **float**, floating-point vectors, matrices, or arrays or structures of these. Fragment shader inputs that are signed or unsigned integers or integer vectors 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;
```

If a geometry shader is not present in a program, but a vertex and fragment shader are present, then the output of the vertex shader and the input of the fragment shader form an interface. For this interface, vertex shader output variables and fragment shader input variables of the same name must match in type and qualification (other than **out** matching to **in**).

### 4.3.5 Uniform

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. Sampler types cannot have initializers.

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 uniform variables with the same name must match across all shaders that are linked into a single program.

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.

### 4.3.6 Outputs

Shader output variables are declared with the **out** or **centroid out** storage qualifiers. 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 at global scope for declaring a single variable name as both input and output to a shader. 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 and geometry output variables output per-vertex data and are declared using the **out** storage qualifier, the **centroid out** storage qualifier, or the deprecated **varying** storage qualifier. They can only be **float**, floating-point vectors, matrices, signed or unsigned integers or integer vectors, or arrays or structures of any these.

Individual vertex 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; // varying is deprecated
flat out vec3 myColor;
noperspective centroid out vec2 myTexCoord;
```

These can also appear in interface blocks, as described in the “Interface Blocks” section. 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.

Fragment outputs output per-fragment data and are declared using the **out** storage qualifier. It is an error to use **centroid out** in a fragment shader. Fragment outputs can only be **float**, floating-point vectors, signed or unsigned integers or integer vectors, or arrays of any these. Matrices and structures cannot be output. Fragment outputs are declared as in the following examples:

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

### 4.3.7 Interface Blocks

Input, output, and uniform 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. It is illegal 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**, or **uniform** 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 ;

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

interface-qualifier :
    in
    out
    uniform

layout-qualifier-id-list
    comma separated list of layout-qualifier-id

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

member-declaration :
    layout-qualifieropt qualifiersopt type declarators ;

instance-name :
    identifier
    identifier [ ]
    identifier [ integral-constant-expression ]

```

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, and uniform variable declarations outside blocks, with these exceptions:

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

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 variable is just **in**, **out**, or **uniform** as determined by *interface-qualifier*. If optional qualifiers are used, they can include interpolation and storage qualifiers and they must declare an input, output, or uniform variable consistent with the interface qualifier of the block: Input variables, output variables, and uniform variables can only be in **in** blocks, **out** blocks, and **uniform** blocks, respectively. Repeating the **in**, **out**, or **uniform** interface qualifier for a member's storage qualifier is optional. Declarations using the deprecated **attribute** and **varying** qualifiers are not allowed. 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 interfaces
    varying vec2 TexCoord2; //illegal, deprecated keywords don't get new uses
};
```

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

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

The block name (*block-name*) is used to match 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 an error to use a block name at global scope for anything other than as a block name. Matched block names within an 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). Furthermore, if a matching block is declared as an array, then the array sizes must also match (or follow array matching rules for the interface between a vertex and a geometry shader). Any mismatch will generate a link error. A block name is allowed to have different definitions in different interfaces.

## 4 Variables and Types

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 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.

```
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"
};
```

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;
    float     Deformation;
} transforms[4];
...
... = transforms[2].ModelViewMatrix; // shader access of instance 2
// API uses "Transform.ModelViewMatrix" to query an offset or other query
```

For uniform blocks declared an array, each individual array element corresponds to a separate buffer object backing one instance of the block. As the array size indicates the number of buffer objects needed, uniform block array declarations must specify an array size. All indexes used to index a uniform block array must be integral constant expressions.

When using OpenGL API entry points to identify the name of an individual block in an array of blocks, the name string must 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 is an implementation dependent limit on the number of uniform blocks that can be used per stage. If this limit is exceeded, it will cause a link error.

### 4.3.8 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 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, and only where indicated in the following subsections; their details are specific to what the interface qualifier is, and are discussed individually.

As shown in the previous section, *layout-qualifier* expands to

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

The tokens in any *layout-qualifier-id-list* are identifiers, not keywords. 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.

#### 4.3.8.1 Input Layout Qualifiers

Vertex shaders do not have any input layout qualifiers.

Geometry shaders allow input layout qualifiers only on the interface qualifier **in**, not on an input block, block member, or variable. The layout qualifier identifiers for geometry shader inputs are

*layout-qualifier-id*  
**points**  
**lines**  
**lines\_adjacency**  
**triangles**  
**triangles\_adjacency**

Only one argument is accepted. For example,

```
layout(triangles) in;
```

will establish that all inputs to the geometry shader are triangles.

At least one geometry shader (compilation unit) in a program must declare an input 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 layout.

All geometry shader input unsized array declarations will be sized by an earlier input 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 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 array use requiring its size be known.

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

```

// code sequence within one shader...
in vec4 Color1[];    // size unknown
...Color1.length()...// illegal, length() unknown
in vec4 Color2[2];  // size is 2
...Color1.length()...// illegal, Color1 still has no size
in vec4 Color3[3];  // illegal, input sizes are inconsistent
layout(lines) in;   // legal, input size is 2, matching
in vec4 Color4[3];  // illegal, contradicts layout
...Color1.length()...// legal, length() is 2, Color1 sized by layout()
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 the program.

Fragment shaders can have an input layout only for redeclaring the built-in variable *gl\_FragCoord* (see section 7.2 Fragment Shader Special Variables). The layout qualifier identifiers for *gl\_FragCoord* are

```

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**. Redclarations 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 *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 will be illegal.

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 affect on rasterization, transformation, or any other part of the OpenGL pipeline or language features.

### 4.3.8.2 Output Layout Qualifiers

Vertex and fragment shaders cannot have output layout qualifiers.

Geometry shaders can have output layout qualifiers only on the interface qualifier **out**, not on an output block or variable declaration.

The layout qualifier identifiers for geometry shader outputs are

```
layout-qualifier-id
points
line_strip
triangle_strip
max_vertices = integer-constant
```

One declaration can declare either a primitive type (**points**, **line\_strip**, or **triangle\_strip**), or **max\_vertices**, or both. Use **max\_vertices** to declare the maximum number of vertices this shader will ever emit in a single execution. For 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
```

these will establish that 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**.

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

### 4.3.8.3 Uniform Block Layout Qualifiers

Layout qualifiers can be used for uniform blocks, but not for non-block uniform declarations. The layout qualifier identifiers for uniform blocks are

```
layout-qualifier-id
shared
packed
std140
row_major
column_major
```

None of these have any semantic affect 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 block layout qualifiers can be declared for global scope, on a single uniform block, or on a single block member declaration.

Default layouts are established at global scope for uniform blocks as

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

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 block definitions.

The initial state of compilation is as if the following were declared:

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

Explicitly declaring this in a shader will return defaults back to their initial state.

Uniform 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* 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 they also matched in their *row\_major* and/or *column\_major* qualifications. This allows use of the same buffer to back the same block definition across different programs.

The *packed* qualifier overrides only *std140* 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. Attempts to share a packed uniform block across programs or stages will generally fail. However, implementations may aid application management of packed blocks by using canonical layouts for packed blocks.

The *std140* qualifier overrides only the *packed* and *shared* qualifiers; other qualifiers are inherited. The layout is explicitly determined by this, as described in section 2.11.4 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*, or *std140* qualifiers. These can only be used at global scope or on a block declaration.

The *row\_major* qualifier overrides only the *column\_major* qualifier; other qualifiers are inherited. It only affects the layout of matrices. Elements within a matrix row will be contiguous in memory.

The *column\_major* qualifier overrides only the *row\_major* qualifier; other qualifiers are inherited. It only affects the layout of matrices. Elements within a matrix column will be contiguous in memory.

When multiple arguments are listed in a **layout** declaration, the affect 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
};
```

### 4.3.9 Interpolation

The presence of and type of interpolation is controlled by the storage qualifiers **centroid in** and **centroid out**, and by the optional interpolation qualifiers **smooth**, **flat**, and **noperspective** as well as by default behaviors established through the OpenGL API when no interpolation qualifier is present. When an interpolation qualifier is used, it overrides settings established through the OpenGL API. It is a compile-time error to use more than one interpolation qualifier.

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 centroid**, 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 equations 3.6 in the OpenGL Graphics System Specification, section 3.5.

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.

This paragraph only applies if interpolation is being done: If single-sampling, the value is interpolated to the pixel's center, and the **centroid** qualifier, if present, is ignored. If multi-sampling and the variable is not qualified with **centroid**, then the value must be interpolated to the pixel's center, or anywhere within the pixel, or to one of the pixel's samples. If multi-sampling and the variable is qualified with **centroid**, then the value must be interpolated to a point that lies in both the pixel and in the primitive being rendered, or to one of the pixel's samples that falls within the primitive. Due to the less regular location of centroids, their derivatives may be less accurate than non-centroid interpolated variables.

The type and presence of the interpolation qualifiers and storage qualifiers and **invariant** qualifiers of variables with the same name declared in all linked shaders must match, otherwise the link command will fail.

#### 4.3.9.1 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 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
```

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

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.

## 4.4 Parameter Qualifiers

Parameters can have these qualifiers.

Qualifier	Meaning
< none: default >	same as <b>in</b>
<b>in</b>	for function parameters passed into a function
<b>out</b>	for function parameters passed back out of a function, but not initialized for use when passed in
<b>inout</b>	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”.

## 4.5 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.

### 4.5.1 Range and Precision

Section number reserved for future use.

### 4.5.2 Precision Qualifiers

Any floating point or any integer declaration can have the type preceded by one of these precision qualifiers:

Qualifier	Meaning
<b>highp</b>	None.
<b>mediump</b>	None.
<b>lowp</b>	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 effect 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.

The same object declared in different shaders that are linked together must have the same precision qualification. This applies to inputs, outputs, uniforms, and globals.

### 4.5.3 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**, and the *precision-qualifier* can be **lowp**, **mediump**, or **highp**. Any other types or qualifiers will result in an error. If *type* is **float**, the directive applies to non-precision-qualified 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 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;
```

#### 4.5.4 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, geometry, and fragment languages.

## 4.6 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*.

### 4.6.1 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;
```

The invariant qualifier must appear before any interpolation qualifiers or storage qualifiers when combined with a declaration. 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. For variables leaving one shader and coming into another shader, the **invariant** keyword has to be used in both shaders, or a link error will result.

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 at the global scope, 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. It is an error to use this pragma in a fragment shader.

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.

### 4.6.2 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.

### 4.7 Order of Qualification

When multiple qualifications are present, they must follow a strict order. This order is as follows.

*invariant-qualifier interpolation-qualifier storage-qualifier precision-qualifier  
storage-qualifier parameter-qualifier precision-qualifier*

# 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, swizzler 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 field. For the other types, the arguments must provide a sufficient number of components to perform the initialization, and it is an 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(bool)      // converts a Boolean value to an int
int(float)     // converts a float value to an int
float(bool)    // converts a Boolean value to a float
float(int)     // converts a signed integer value to a float
bool(float)    // converts a float value to a Boolean
bool(int)      // converts a signed integer value to a Boolean
uint(bool)     // converts a Boolean value to an unsigned integer
uint(float)    // converts a float value to an unsigned integer
uint(int)      // converts a signed integer value to an unsigned integer
int(uint)      // converts an unsigned integer to a signed integer
bool(uint)     // converts an unsigned integer value to a Boolean value
float(uint)    // converts an unsigned integer value to a float value
```

When constructors are used to convert a **float** to an **int** or **uint**, 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 an **int**, **uint**, or a **float** 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 an **int**, **uint**, or **float**, **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 an 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 an error to have any other arguments.

If the basic type (**bool**, **int**, or **float**) 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

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

```

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 fields, in order, using one argument per field. Each argument must be the same type as the field it sets, or be a type that can be converted to the field'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.”

## 5.5 Vector Components

The names of the components of a vector 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 of a vector 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

The component names  $x$ ,  $r$ , and  $s$  are, for example, synonyms for the same (first) component in a vector.

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 vector type is an error so, for example:

```
vec2 pos;
pos.x // is legal
pos.z // is illegal
```

## 5 Operators and Expressions

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)
```

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 r-value.

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 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 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 is illegal. 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.

## 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 an error to access a matrix with a constant expression that is outside the bounds of the matrix.

## 5.7 Structure and Array Operations

The fields 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 or method selector	<code>.</code>
equality	<code>== !=</code>
assignment	<code>=</code>
indexing (arrays only)	<code>[ ]</code>

The equality operators and assignment operator are only allowed if the two operands are same size and type. 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 fields 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 an 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 fields, 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.

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**, **int**, **uint**, **float**, all vector types, and all matrix types.
- Constructors of all types.
- Variable names of all types.
- An array name 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.
- The arithmetic binary operators add (+), subtract (-), multiply (\*), and divide (/) operate on integer and floating-point scalars, vectors, and matrices. If one operand is floating-point based and the other is not, then the conversions from Section 4.1.10 “Implicit Conversions” are applied to the non-floating-point-based operand. If the operands are integer types, they must both be signed or both be unsigned. All arithmetic binary operators result in the same fundamental type (signed integer, unsigned integer, or 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 are illegal.

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 integers or integer vectors. The operand types must both be signed or both be unsigned. The operands cannot be vectors of differing size. 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 the integer operand, after which the types must match. 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. 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, fields, or elements of one operand must equal the corresponding components, fields, 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**.

## 5 Operators and Expressions

- 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. 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. The fundamental types of the operands (signed or unsigned) must match, and 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.

# 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. Each of the *typeN* must include a type and can optionally include a parameter qualifier and/or **const**.

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**. 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. 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. When argument conversions are used to find a match, it is a semantic error if there are multiple ways to apply these conversions to make the call match more than one function.

For example,

```
vec4 f(in vec4 x, out vec4 y);
vec4 f(in vec4 x, out ivec4 y); // okay, different argument type
int  f(in vec4 x, out ivec4 y); // error, only return type differs
vec4 f(in vec4 x, in ivec4 y); // error, only qualifier differs
int  f(const in vec4 x, out ivec4 y); // error, only qualifier differs
```

Calling the first two functions above with the following argument types yields

```
f(vec4, vec4) // exact match of vec4 f(in vec4 x, out vec4 y)
f(vec4, ivec4) // exact match of vec4 f(in vec4 x, out ivec4 y)
f(ivec4, vec4) // error, convertible to both
f(ivec4, ivec4) // okay, convertible only to vec4 f(in vec4 x, out ivec4 y)
```

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. 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 an 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.
- 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**.

No qualifier is allowed on the return type of a function.

*function-prototype :*

*precision-qualifier type function-name(const-qualifier parameter-qualifier precision-qualifier  
type name array-specifier, ... )*

*type :*

any basic type, array type, structure name, *or structure definition*

*const-qualifier :*

empty

**const**

*parameter-qualifier :*

empty

**in**

**out**

**inout**

*name :*

empty

identifier

*array-specifier :*

empty

[ *integral-constant-expression* ]

However, the **const** qualifier cannot be used with **out** or **inout**. The above is used 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 the program contains cycles.

## 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 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

```

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 *init-expression* in a switch statement must be a scalar integer. If a **case** label has a *constant-expression* of equal value, then execution will continue after that label. Otherwise, if there is a **default** label, execution will continue after that label. Otherwise, execution skips the rest of the switch statement. It is an error to have more than one **default** or a replicated *constant-expression*. 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, but it is an error to have no statement between a label and the end of the **switch** statement. No statements are allowed in a switch statement before the first **case** statement.

No **case** or **default** labels can be nested inside other flow control nested 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 control flow is non-uniform \(meaning different fragments within the primitive take different control paths\)](#). 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 Vertex and Geometry Shader Special Variables

Some OpenGL operations occur in fixed functionality between the vertex processor and the fragment processor. Shaders communicate with the fixed functionality of OpenGL through the use of built-in variables.

The built-in vertex shader variables for communicating with fixed functionality are intrinsically declared as follows in the vertex language:

```
in int    gl_VertexID;
in int    gl_InstanceID;

out gl_PerVertex {
    vec4    gl_Position;
    float   gl_PointSize;
    float   gl_ClipDistance[];
};
```

In the geometry language, the special variables are intrinsically declared as:

```
in gl_PerVertex {
    vec4    gl_Position;
    float   gl_PointSize;
    float   gl_ClipDistance[];
} gl_in[];

in int gl_PrimitiveIDIn;

out gl_PerVertex {
    vec4    gl_Position;
    float   gl_PointSize;
    float   gl_ClipDistance[];
};

out int gl_PrimitiveID;
out int gl_Layer;
```

Unless otherwise noted elsewhere, these variables are only available in the vertex and geometry languages as declared above.

The 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).

The 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.

The variable *gl\_VertexID* is a vertex shader input variable that holds an integer index for the vertex, as defined under Shader Inputs in section 2.11.7 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 shader input variable that holds the integer index of the current primitive in an instanced draw call (see Shader Inputs in section 2.11.7 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\_ClipDistance* provides the forward compatible mechanism for controlling user clipping. To use this, a vertex or geometry shader is responsible for maintaining a set of clip planes, computing the distance from the vertex to each clip plane, and storing distances to the plane in *gl\_ClipDistance[i]* 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 sized by the shader either redeclaring it with a size or 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.

The input variable *gl\_PrimitiveIDIn* is available only in the geometry language and is filled with the number of primitives processed by the geometry shader since the current set of rendering primitives was started.

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 2.12.4 (under Geometry Shader Outputs) and section 3.9.2 (under Shader Inputs) of the OpenGL Graphics System Specification for more information.

The output variable *gl\_Layer* is available only in the geometry language, and is used to select a specific layer of a multi-layer framebuffer attachment. The actual layer used will come from one of vertices in the primitive being shaded. Which vertex the layer comes from is 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 2.12.4 (under Geometry Shader Outputs) and section 4.4.7 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.

### 7.1.1 Compatibility Profile Vertex and Geometry Shader Special Variables

When using the compatibility profile, the following additional built-in variables are added to the output *gl\_PerVertex* block in the vertex language:

```
out gl_PerVertex {          // part of the gl_PerVertex block described in 7.1
    // in addition to other gl_PerVertex members...
    vec4 gl_ClipVertex;
};
```

When using the compatibility profile, the following additional built-in variables are added to the input *gl\_PerVertex* block in the geometry language:

```
in gl_PerVertex {          // part of the gl_PerVertex block described in 7.1
    // in addition to other gl_PerVertex members...
    vec4 gl_ClipVertex;
} gl_in[];

out vec4 gl_ClipVertex;
```

The variable *gl\_ClipVertex* is available only in the vertex and geometry languages and provides a place for vertex and geometry shaders to write the coordinate to be used with the user clipping planes. Geometry shaders can read the values written by vertex shaders.

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.

If a linked set of shaders forming a program contains no static write to *gl\_ClipVertex* or *gl\_ClipDistance*, but the application has requested clipping against user clip planes through the API, then the coordinate written to *gl\_Position* is used for comparison against the user clip planes. Writing to *gl\_ClipDistance* is the preferred method for user clipping. It is an error for the set of shaders forming a program to statically read or write both *gl\_ClipVertex* and *gl\_ClipDistance*.

## 7.2 Fragment Shader Special Variables

The built-in special variables that are accessible from a fragment shader are intrinsically declared as follows:

```

in  vec4  gl_FragCoord;
in  bool  gl_FrontFacing;
in  float  gl_ClipDistance[];
out vec4  gl_FragColor;           // deprecated
out vec4  gl_FragData[gl_MaxDrawBuffers]; // deprecated
out float  gl_FragDepth;
in  vec2  gl_PointCoord;
in  int   gl_PrimitiveID;

```

Except as noted below, they behave as other input and output variables.

The output of the fragment shader executable is processed by the fixed function operations at the back end of the OpenGL pipeline.

Fragment shaders output values to the OpenGL pipeline using the built-in variables *gl\_FragColor*, *gl\_FragData*, and *gl\_FragDepth*, unless the **discard** statement is executed. Both *gl\_FragColor* and *gl\_FragData* are deprecated; the preferred usage is to explicitly declare these outputs in the fragment shader using the **out** storage qualifier.

The fixed functionality computed depth for a fragment may be obtained by reading *gl\_FragCoord.z*, described below.

Deprecated: 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.

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.

Deprecated: 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 errors.

If a shader executes the **discard** keyword, the fragment is discarded, and the values of any user-defined fragment outputs, *gl\_FragDepth*, *gl\_FragColor*, and *gl\_FragData* 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 in** 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 built-in input variable *gl\_ClipDistance* array contains linearly interpolated values for the vertex values written by a shader to the *gl\_ClipDistance* vertex output variable. This array must be sized either implicitly or explicitly to be the same size in all shaders. Only elements in this array that have clipping enabled will have defined values.

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.

The input variable *gl\_PrimitiveID* holds the ID of the currently processed primitive. If no geometry shader is present, it is filled with the number of primitives processed by the vertex shader since the current set of rendering primitives was started. If a geometry shader is present, it is taken from the *gl\_PrimitiveID* geometry shader output, as described in section 7.1 Vertex and Geometry Shader Special Variables.

### 7.3 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;
```

### 7.4 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. Some are deprecated, as indicated in comments.

```
//
// Implementation dependent constants. The example values below
// are the minimum values allowed for these maximums.
//

const int  gl_MaxVertexAttribs = 16;
const int  gl_MaxVertexUniformComponents = 1024;
const int  gl_MaxVaryingFloats = 60;           // Deprecated
const int  gl_MaxVaryingComponents = 60;       // Deprecated
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 = 48;
const int  gl_MaxTextureImageUnits = 16;
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;
```

The constant *gl\_MaxVaryingFloats* is deprecated, use *gl\_MaxVaryingComponents* instead.

### 7.4.1 Compatibility Profile Built-In Constants

```
const int gl_MaxTextureUnits = 2;
const int gl_MaxTextureCoords = 8;
const int gl_MaxClipPlanes = 8;
```

## 7.5 Built-In Uniform State

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 2.13.1 in the OpenGL Graphics System Specification.
//
struct gl_DepthRangeParameters {
    float near;        // n
    float far;         // f
    float diff;        // f - n
};
uniform gl_DepthRangeParameters gl_DepthRange;
```

### 7.5.1 Compatibility Profile State

These variables are present only in the compatibility profile.

```
//
// 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;
uniform mat4 gl_TextureMatrixTranspose[gl_MaxTextureCoords];
```

## 7 Built-in Variables

```
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;

```

## 7.6 Compatibility Profile Vertex and Fragment Interface

When using the compatibility profile, the GL can provide fixed functionality behavior for any programmable pipeline stage. For example, mixing a fixed functionality vertex stage with a programmable fragment stage.

The following built-in vertex and geometry input and output variables are available to effect the inputs to a fragment shader or 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. These are added to the output *gl\_PerVertex* block in the vertex language:

```
out gl_PerVertex {
    // in addition to other gl_PerVertex members...
    vec4  gl_FrontColor;
    vec4  gl_BackColor;
    vec4  gl_FrontSecondaryColor;
    vec4  gl_BackSecondaryColor;
    vec4  gl_TexCoord[];
    float gl_FogFragCoord;
};
```

and similarly to the input of the geometry language:

```
in gl_PerVertex {
    // in addition to other gl_PerVertex members...
    vec4  gl_FrontColor;
    vec4  gl_BackColor;
    vec4  gl_FrontSecondaryColor;
    vec4  gl_BackSecondaryColor;
    vec4  gl_TexCoord[];
    float gl_FogFragCoord;
} gl_in[];
```

For *gl\_FogFragCoord*, the value written will be used as the “c” value in section 3.11 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 re-declared 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\* is done at global scope as, for example,](#)

```
in vec4 gl\_TexCoord\[3\];
out vec4 gl\_TexCoord\[4\];
```

[which is the same way it was done in previous releases. This treatment is a special case for \*gl\\_TexCoord\[\]\*, not a general method for redeclaring members of blocks.](#)

The following fragment inputs are also available in a fragment shader when using the compatibility profile:

## 7 Built-in Variables

```
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. 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 3.11 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.

## 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 re-declaring 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 re-declared 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. 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 for *mat*, which can be any matrix basic type.

## 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 <b>radians</b> (genType <i>degrees</i> )	Converts <i>degrees</i> to radians, i.e., $\frac{\pi}{180} \cdot \text{degrees}$
genType <b>degrees</b> (genType <i>radians</i> )	Converts <i>radians</i> to degrees, i.e., $\frac{180}{\pi} \cdot \text{radians}$
genType <b>sin</b> (genType <i>angle</i> )	The standard trigonometric sine function.
genType <b>cos</b> (genType <i>angle</i> )	The standard trigonometric cosine function.
genType <b>tan</b> (genType <i>angle</i> )	The standard trigonometric tangent.
genType <b>asin</b> (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 <b>acos</b> (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 <b>atan</b> (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 <b>atan</b> (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 <b>sinh</b> (genType $x$ )	Returns the hyperbolic sine function $\frac{e^x - e^{-x}}{2}$
genType <b>cosh</b> (genType $x$ )	Returns the hyperbolic cosine function $\frac{e^x + e^{-x}}{2}$
genType <b>tanh</b> (genType $x$ )	Returns the hyperbolic tangent function $\frac{\sinh(x)}{\cosh(x)}$
genType <b>asinh</b> (genType $x$ )	Arc hyperbolic sine; returns the inverse of <b>sinh</b> .
genType <b>acosh</b> (genType $x$ )	Arc hyperbolic cosine; returns the non-negative inverse of <b>cosh</b> . Results are undefined if $x < 1$ .
genType <b>atanh</b> (genType $x$ )	Arc hyperbolic tangent; returns the inverse of <b>tanh</b> . Results are undefined if $ x  \geq 1$ .

## 8.2 Exponential Functions

These all operate component-wise. The description is per component.

Syntax	Description
genType <b>pow</b> (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 <b>exp</b> (genType $x$ )	Returns the natural exponentiation of $x$ , i.e., $e^x$ .
genType <b>log</b> (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 <b>exp2</b> (genType $x$ )	Returns 2 raised to the $x$ power, i.e., $2^x$
genType <b>log2</b> (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 $x <= 0$ .

Syntax	Description
genType <b>sqrt</b> (genType $x$ )	Returns $\sqrt{x}$ . Results are undefined if $x < 0$ .
genType <b>inversesqrt</b> (genType $x$ )	Returns $\frac{1}{\sqrt{x}}$ . Results are undefined if $x \leq 0$ .

### 8.3 Common Functions

These all operate component-wise. The description is per component.

Syntax	Description
genType <b>abs</b> (genType $x$ ) genType <b>abs</b> (genType $x$ )	Returns $x$ if $x \geq 0$ , otherwise it returns $-x$ .
genType <b>sign</b> (genType $x$ ) genType <b>sign</b> (genType $x$ )	Returns 1.0 if $x > 0$ , 0.0 if $x = 0$ , or $-1.0$ if $x < 0$ .
genType <b>floor</b> (genType $x$ )	Returns a value equal to the nearest integer that is less than or equal to $x$ .
genType <b>trunc</b> (genType $x$ )	Returns a value equal to the nearest integer to $x$ whose absolute value is not larger than the absolute value of $x$ .
genType <b>round</b> (genType $x$ )	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 <b>round</b> ( $x$ ) returns the same value as <b>roundEven</b> ( $x$ ) for all values of $x$ .
genType <b>roundEven</b> (genType $x$ )	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 <b>ceil</b> (genType $x$ )	Returns a value equal to the nearest integer that is greater than or equal to $x$ .
genType <b>fract</b> (genType $x$ )	Returns $x - \mathbf{floor}(x)$ .

Syntax	Description
genType <b>mod</b> (genType <i>x</i> , float <i>y</i> ) genType <b>mod</b> (genType <i>x</i> , genType <i>y</i> )	Modulus. Returns $x - y * \mathbf{floor}(x/y)$ .
genType <b>modf</b> (genType <i>x</i> , out genType <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 <b>min</b> (genType <i>x</i> , genType <i>y</i> ) genType <b>min</b> (genType <i>x</i> , float <i>y</i> ) genIType <b>min</b> (genIType <i>x</i> , genIType <i>y</i> ) genIType <b>min</b> (genIType <i>x</i> , int <i>y</i> ) genUType <b>min</b> (genUType <i>x</i> , genUType <i>y</i> ) genUType <b>min</b> (genUType <i>x</i> , uint <i>y</i> )	Returns <i>y</i> if $y < x$ , otherwise it returns <i>x</i> .
genType <b>max</b> (genType <i>x</i> , genType <i>y</i> ) genType <b>max</b> (genType <i>x</i> , float <i>y</i> ) genIType <b>max</b> (genIType <i>x</i> , genIType <i>y</i> ) genIType <b>max</b> (genIType <i>x</i> , int <i>y</i> ) genUType <b>max</b> (genUType <i>x</i> , genUType <i>y</i> ) genUType <b>max</b> (genUType <i>x</i> , uint <i>y</i> )	Returns <i>y</i> if $x < y$ , otherwise it returns <i>x</i> .
genType <b>clamp</b> (genType <i>x</i> , genType <i>minVal</i> , genType <i>maxVal</i> ) genType <b>clamp</b> (genType <i>x</i> , float <i>minVal</i> , float <i>maxVal</i> ) genIType <b>clamp</b> (genIType <i>x</i> , genIType <i>minVal</i> , genIType <i>maxVal</i> ) genIType <b>clamp</b> (genIType <i>x</i> , int <i>minVal</i> , int <i>maxVal</i> ) genUType <b>clamp</b> (genUType <i>x</i> , genUType <i>minVal</i> , genUType <i>maxVal</i> ) genUType <b>clamp</b> (genUType <i>x</i> , uint <i>minVal</i> , uint <i>maxVal</i> )	Returns <b>min</b> ( <b>max</b> ( <i>x</i> , <i>minVal</i> ), <i>maxVal</i> ). Results are undefined if $minVal > maxVal$ .

Syntax	Description
genType <b>mix</b> (genType <i>x</i> , genType <i>y</i> , genType <i>a</i> ) genType <b>mix</b> (genType <i>x</i> , genType <i>y</i> , float <i>a</i> )	Returns the linear blend of <i>x</i> and <i>y</i> , i.e., $x \cdot (1 - a) + y \cdot a$
genType <b>mix</b> (genType <i>x</i> , genType <i>y</i> , genBType <i>a</i> )	Selects which vector each returned component comes from. For a component of <i>a</i> that is <b>false</b> , the corresponding component of <i>x</i> is returned. For a component of <i>a</i> that is <b>true</b> , 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 $\text{genType } \mathbf{mix}(\text{genType } x, \text{genType } y, \text{genType}(a))$ where <i>a</i> is a Boolean vector.
genType <b>step</b> (genType <i>edge</i> , genType <i>x</i> ) genType <b>step</b> (float <i>edge</i> , genType <i>x</i> )	Returns 0.0 if $x < \textit{edge}$ , otherwise it returns 1.0.
genType <b>smoothstep</b> (genType <i>edge0</i> , genType <i>edge1</i> , genType <i>x</i> ) genType <b>smoothstep</b> (float <i>edge0</i> , float <i>edge1</i> , genType <i>x</i> )	Returns 0.0 if $x \leq \textit{edge0}$ and 1.0 if $x \geq \textit{edge1}$ and performs smooth Hermite interpolation between 0 and 1 when $\textit{edge0} < x < \textit{edge1}$ . 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> <i>Results are undefined if <math>\textit{edge0} \geq \textit{edge1}</math>.</i>
genBType <b>isnan</b> (genType <i>x</i> )	Returns <b>true</b> if <i>x</i> holds a NaN (not a number) representation in the underlying implementation's set of floating point representations. Returns <b>false</b> otherwise, including for implementations with no NaN representations.
genBType <b>isinf</b> (genType <i>x</i> )	Returns <b>true</b> if <i>x</i> holds a positive infinity or negative infinity representation in the underlying implementation's set of floating point representations. Returns <b>false</b> otherwise, including for implementations with no infinity representations.

## 8.4 Geometric Functions

These operate on vectors as vectors, not component-wise.

Syntax	Description
float <b>length</b> (genType <i>x</i> )	Returns the length of vector <i>x</i> , i.e., $\sqrt{x[0]^2 + x[1]^2 + \dots}$
float <b>distance</b> (genType <i>p0</i> , genType <i>p1</i> )	Returns the distance between <i>p0</i> and <i>p1</i> , i.e., <b>length</b> ( <i>p0</i> - <i>p1</i> )
float <b>dot</b> (genType <i>x</i> , genType <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 <b>cross</b> (vec3 <i>x</i> , vec3 <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 <b>normalize</b> (genType <i>x</i> )	Returns a vector in the same direction as <i>x</i> but with a length of 1.
compatibility profile only vec4 <b>ftransform</b> ()	Available only when using the compatibility profile. For core OpenGL, use <b>invariant</b> .  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.
genType <b>faceforward</b> (genType <i>N</i> , genType <i>I</i> , genType <i>Nref</i> )	If <b>dot</b> ( <i>Nref</i> , <i>I</i> ) < 0 return <i>N</i> , otherwise return $-N$ .

Syntax	Description
genType <b>reflect</b> (genType $I$ , genType $N$ )	<p>For the incident vector <math>I</math> and surface orientation <math>N</math>, returns the reflection direction:</p> $I - 2 * \mathbf{dot}(N, I) * N$ <p><math>N</math> must already be normalized in order to achieve the desired result.</p>
genType <b>refract</b> (genType $I$ , genType $N$ , float $eta$ )	<p>For the incident vector <math>I</math> and surface normal <math>N</math>, and the ratio of indices of refraction <math>eta</math>, return the refraction vector. The result is computed by</p> $k = 1.0 - eta * eta * (1.0 - \mathbf{dot}(N, I) * \mathbf{dot}(N, I))$ <p>if (<math>k &lt; 0.0</math>)  return genType(0.0)  else  return <math>eta * I - (eta * \mathbf{dot}(N, I) + \mathbf{sqrt}(k)) * N</math></p> <p>The input parameters for the incident vector <math>I</math> and the surface normal <math>N</math> must already be normalized to get the desired results.</p>

## 8.5 Matrix Functions

Syntax	Description
mat <b>matrixCompMult</b> (mat <i>x</i> , mat <i>y</i> )	Multiply matrix <i>x</i> by matrix <i>y</i> component-wise, i.e., result[ <i>i</i> ][ <i>j</i> ] is the scalar product of <i>x</i> [ <i>i</i> ][ <i>j</i> ] and <i>y</i> [ <i>i</i> ][ <i>j</i> ].  Note: to get linear algebraic matrix multiplication, use the multiply operator (*).
mat2 <b>outerProduct</b> (vec2 <i>c</i> , vec2 <i>r</i> ) mat3 <b>outerProduct</b> (vec3 <i>c</i> , vec3 <i>r</i> ) mat4 <b>outerProduct</b> (vec4 <i>c</i> , vec4 <i>r</i> )  mat2x3 <b>outerProduct</b> (vec3 <i>c</i> , vec2 <i>r</i> ) mat3x2 <b>outerProduct</b> (vec2 <i>c</i> , vec3 <i>r</i> )  mat2x4 <b>outerProduct</b> (vec4 <i>c</i> , vec2 <i>r</i> ) mat4x2 <b>outerProduct</b> (vec2 <i>c</i> , vec4 <i>r</i> )  mat3x4 <b>outerProduct</b> (vec4 <i>c</i> , vec3 <i>r</i> ) mat4x3 <b>outerProduct</b> (vec3 <i>c</i> , vec4 <i>r</i> )	Treats the first parameter <i>c</i> as a column vector (matrix with one column) and the second parameter <i>r</i> as a row vector (matrix with one row) and does a linear algebraic matrix multiply <i>c</i> * <i>r</i> , yielding a matrix whose number of rows is the number of components in <i>c</i> and whose number of columns is the number of components in <i>r</i> .
mat2 <b>transpose</b> (mat2 <i>m</i> ) mat3 <b>transpose</b> (mat3 <i>m</i> ) mat4 <b>transpose</b> (mat4 <i>m</i> )  mat2x3 <b>transpose</b> (mat3x2 <i>m</i> ) mat3x2 <b>transpose</b> (mat2x3 <i>m</i> )  mat2x4 <b>transpose</b> (mat4x2 <i>m</i> ) mat4x2 <b>transpose</b> (mat2x4 <i>m</i> )  mat3x4 <b>transpose</b> (mat4x3 <i>m</i> ) mat4x3 <b>transpose</b> (mat3x4 <i>m</i> )	Returns a matrix that is the transpose of <i>m</i> . The input matrix <i>m</i> is not modified.
float <b>determinant</b> (mat2 <i>m</i> ) float <b>determinant</b> (mat3 <i>m</i> ) float <b>determinant</b> (mat4 <i>m</i> )	Returns the determinant of <i>m</i> .
mat2 <b>inverse</b> (mat2 <i>m</i> ) mat3 <b>inverse</b> (mat3 <i>m</i> ) mat4 <b>inverse</b> (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).

## 8.6 Vector Relational Functions

Relational and equality operators (<, <=, >, >=, ==, !=) are defined to produce scalar Boolean results. For vector results, use the following built-in functions. Below, “bvec” is a placeholder for one of **bvec2**, **bvec3**, or **bvec4**, “ivec” is a placeholder for one of **ivec2**, **ivec3**, or **ivec4**, “uvec” is a placeholder for **uvec2**, **uvec3**, or **uvec4**, and “vec” is a placeholder for **vec2**, **vec3**, or **vec4**. In all cases, the sizes of the input and return vectors for any particular call must match.

Syntax	Description
bvec <b>lessThan</b> (vec x, vec y) bvec <b>lessThan</b> (ivec x, ivec y) bvec <b>lessThan</b> (uvec x, uvec y)	Returns the component-wise compare of $x < y$ .
bvec <b>lessThanEqual</b> (vec x, vec y) bvec <b>lessThanEqual</b> (ivec x, ivec y) bvec <b>lessThanEqual</b> (uvec x, uvec y)	Returns the component-wise compare of $x \leq y$ .
bvec <b>greaterThan</b> (vec x, vec y) bvec <b>greaterThan</b> (ivec x, ivec y) bvec <b>greaterThan</b> (uvec x, uvec y)	Returns the component-wise compare of $x > y$ .
bvec <b>greaterThanEqual</b> (vec x, vec y) bvec <b>greaterThanEqual</b> (ivec x, ivec y) bvec <b>greaterThanEqual</b> (uvec x, uvec y)	Returns the component-wise compare of $x \geq y$ .
bvec <b>equal</b> (vec x, vec y) bvec <b>equal</b> (ivec x, ivec y) bvec <b>equal</b> (uvec x, uvec y) bvec <b>equal</b> (bvec x, bvec y)  bvec <b>notEqual</b> (vec x, vec y) bvec <b>notEqual</b> (ivec x, ivec y) bvec <b>notEqual</b> (uvec x, uvec y) bvec <b>notEqual</b> (bvec x, bvec y)	Returns the component-wise compare of $x == y$ .  Returns the component-wise compare of $x != y$ .
bool <b>any</b> (bvec x)	Returns true if any component of $x$ is <b>true</b> .
bool <b>all</b> (bvec x)	Returns true only if all components of $x$ are <b>true</b> .
bvec <b>not</b> (bvec x)	Returns the component-wise logical complement of $x$ .

## 8.7 Texture Lookup Functions

Texture lookup functions are available to vertex, geometry, and fragment shaders. However, level of detail is not implicitly computed for vertex or geometry shaders. 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 mip-map 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 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 lookups on unsigned normalized integer and floating point data return floating point values in the range [0, 1].

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**, where each component is in the range [0, 1].

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 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 3.8.15 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 a vertex or geometry shader. 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 rectangular textures, multi-sample textures, or texture buffers are supported because mip-maps are not allowed for these types of textures.

The implicit level of detail is selected as follows: For a texture that is not mip-mapped, the texture is used directly. If it is mip-mapped and running in a fragment shader, the LOD computed by the implementation is used to do the texture lookup. If it is mip-mapped 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 vertex and geometry 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 3.8.8 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.

Syntax	Description
<p>int <b>textureSize</b> (gsampler1D <i>sampler</i>, int <i>lod</i>)  ivec2 <b>textureSize</b> (gsampler2D <i>sampler</i>, int <i>lod</i>)  ivec3 <b>textureSize</b> (gsampler3D <i>sampler</i>, int <i>lod</i>)  ivec2 <b>textureSize</b> (gsamplerCube <i>sampler</i>, int <i>lod</i>)  int <b>textureSize</b> (sampler1DShadow <i>sampler</i>, int <i>lod</i>)  ivec2 <b>textureSize</b> (sampler2DShadow <i>sampler</i>, int <i>lod</i>)  ivec2 <b>textureSize</b> (samplerCubeShadow <i>sampler</i>, int <i>lod</i>)  ivec2 <b>textureSize</b> (gsampler2DRect <i>sampler</i>)  ivec2 <b>textureSize</b> (sampler2DRectShadow <i>sampler</i>)  ivec2 <b>textureSize</b> (gsampler1DArray <i>sampler</i>, int <i>lod</i>)  ivec3 <b>textureSize</b> (gsampler2DArray <i>sampler</i>, int <i>lod</i>)  ivec2 <b>textureSize</b> (sampler1DArrayShadow <i>sampler</i>, int <i>lod</i>)  ivec3 <b>textureSize</b> (sampler2DArrayShadow <i>sampler</i>, int <i>lod</i>)  int <b>textureSize</b> (gsamplerBuffer <i>sampler</i>)  ivec2 <b>textureSize</b> (gsampler2DMS <i>sampler</i>)  ivec2 <b>textureSize</b> (gsampler2DMSArray <i>sampler</i>)</p>	<p>Returns the dimensions of level <i>lod</i> (if present) for the texture bound to <i>sampler</i>, as described in section 2.11.7 of the OpenGL Graphics System Specification, under Texture Size Query.</p> <p>The components in the return value are filled in, in order, with the width, height, depth of the texture.</p> <p>For the array forms, the last component of the return value is the number of layers in the texture array.</p>
<p>gvec4 <b>texture</b> (gsampler1D <i>sampler</i>, float <i>P</i> [, float <i>bias</i> ] )  gvec4 <b>texture</b> (gsampler2D <i>sampler</i>, vec2 <i>P</i> [, float <i>bias</i> ] )  gvec4 <b>texture</b> (gsampler3D <i>sampler</i>, vec3 <i>P</i> [, float <i>bias</i> ] )  gvec4 <b>texture</b> (gsamplerCube <i>sampler</i>, vec3 <i>P</i> [, float <i>bias</i> ] )  float <b>texture</b> (sampler1DShadow <i>sampler</i>, vec3 <i>P</i> [, float <i>bias</i> ] )  float <b>texture</b> (sampler2DShadow <i>sampler</i>, vec3 <i>P</i> [, float <i>bias</i> ] )  float <b>texture</b> (samplerCubeShadow <i>sampler</i>, vec4 <i>P</i> [, float <i>bias</i> ] )  gvec4 <b>texture</b> (gsampler1DArray <i>sampler</i>, vec2 <i>P</i> [, float <i>bias</i> ] )  gvec4 <b>texture</b> (gsampler2DArray <i>sampler</i>, vec3 <i>P</i> [, float <i>bias</i> ] )  float <b>texture</b> (sampler1DArrayShadow <i>sampler</i>, vec3 <i>P</i> [, float <i>bias</i> ] )  float <b>texture</b> (sampler2DArrayShadow <i>sampler</i>, vec4 <i>P</i>)  gvec4 <b>texture</b> (gsampler2DRect <i>sampler</i>, vec2 <i>P</i>)  float <b>texture</b> (sampler2DRectShadow <i>sampler</i>, vec3 <i>P</i>)</p>	<p>Use the texture coordinate <i>P</i> to do a texture lookup in the texture currently bound to <i>sampler</i>. The last component of <i>P</i> is used as <math>D_{ref}</math> for the shadow forms. For array forms, the array layer comes from the last component of <i>P</i> in the non-shadow forms, and the second to last component of <i>P</i> in the shadow forms.</p>
<p>gvec4 <b>textureProj</b> (gsampler1D <i>sampler</i>, vec2 <i>P</i> [, float <i>bias</i> ] )  gvec4 <b>textureProj</b> (gsampler1D <i>sampler</i>, vec4 <i>P</i> [, float <i>bias</i> ] )  gvec4 <b>textureProj</b> (gsampler2D <i>sampler</i>, vec3 <i>P</i> [, float <i>bias</i> ] )  gvec4 <b>textureProj</b> (gsampler2D <i>sampler</i>, vec4 <i>P</i> [, float <i>bias</i> ] )  gvec4 <b>textureProj</b> (gsampler3D <i>sampler</i>, vec4 <i>P</i> [, float <i>bias</i> ] )  float <b>textureProj</b> (sampler1DShadow <i>sampler</i>, vec4 <i>P</i> [, float <i>bias</i> ] )  float <b>textureProj</b> (sampler2DShadow <i>sampler</i>, vec4 <i>P</i> [, float <i>bias</i> ] )  gvec4 <b>textureProj</b> (gsampler2DRect <i>sampler</i>, vec3 <i>P</i>)  gvec4 <b>textureProj</b> (gsampler2DRect <i>sampler</i>, vec4 <i>P</i>)  float <b>textureProj</b> (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 3<sup>rd</sup> component of <i>P</i> in the shadow forms is used as <math>D_{ref}</math>. After these values are computed, texture lookup proceeds as in <b>texture</b>.</p>

Syntax	Description
<p>gvec4 <b>textureLod</b> (gsampler1D <i>sampler</i>, float <i>P</i>, float <i>lod</i>)  gvec4 <b>textureLod</b> (gsampler2D <i>sampler</i>, vec2 <i>P</i>, float <i>lod</i>)  gvec4 <b>textureLod</b> (gsampler3D <i>sampler</i>, vec3 <i>P</i>, float <i>lod</i>)  gvec4 <b>textureLod</b> (gsamplerCube <i>sampler</i>, vec3 <i>P</i>, float <i>lod</i>)  float <b>textureLod</b> (sampler1DShadow <i>sampler</i>, vec3 <i>P</i>, float <i>lod</i>)  float <b>textureLod</b> (sampler2DShadow <i>sampler</i>, vec3 <i>P</i>, float <i>lod</i>)  gvec4 <b>textureLod</b> (gsampler1DArray <i>sampler</i>, vec2 <i>P</i>, float <i>lod</i>)  gvec4 <b>textureLod</b> (gsampler2DArray <i>sampler</i>, vec3 <i>P</i>, float <i>lod</i>)  float <b>textureLod</b> (sampler1DArrayShadow <i>sampler</i>, vec3 <i>P</i>, float <i>lod</i>)</p>	<p>Do a texture lookup as in <b>texture</b> but with explicit LOD; <i>lod</i> specifies <math>\lambda_{base}</math> (see equation 3.18 in OpenGL Graphics System Specification) and set the partial derivatives in section 3.8.9 as follows.</p> $\frac{\partial u}{\partial x} = 0 \quad \frac{\partial v}{\partial x} = 0 \quad \frac{\partial w}{\partial x} = 0$ $\frac{\partial u}{\partial y} = 0 \quad \frac{\partial v}{\partial y} = 0 \quad \frac{\partial w}{\partial y} = 0$
<p>gvec4 <b>textureOffset</b> (gsampler1D <i>sampler</i>, float <i>P</i>, int <i>offset</i> [, float <i>bias</i>])  gvec4 <b>textureOffset</b> (gsampler2D <i>sampler</i>, vec2 <i>P</i>, ivec2 <i>offset</i> [, float <i>bias</i>])  gvec4 <b>textureOffset</b> (gsampler3D <i>sampler</i>, vec3 <i>P</i>, ivec3 <i>offset</i> [, float <i>bias</i>])  gvec4 <b>textureOffset</b> (gsampler2DRect <i>sampler</i>, vec2 <i>P</i>, ivec2 <i>offset</i>)  float <b>textureOffset</b> (sampler2DRectShadow <i>sampler</i>, vec3 <i>P</i>, ivec2 <i>offset</i>)  float <b>textureOffset</b> (sampler1DShadow <i>sampler</i>, vec3 <i>P</i>, int <i>offset</i> [, float <i>bias</i>])  float <b>textureOffset</b> (sampler2DShadow <i>sampler</i>, vec3 <i>P</i>, ivec2 <i>offset</i> [, float <i>bias</i>])  gvec4 <b>textureOffset</b> (gsampler1DArray <i>sampler</i>, vec2 <i>P</i>, int <i>offset</i> [, float <i>bias</i>])  gvec4 <b>textureOffset</b> (gsampler2DArray <i>sampler</i>, vec3 <i>P</i>, ivec2 <i>offset</i> [, float <i>bias</i>])  float <b>textureOffset</b> (sampler1DArrayShadow <i>sampler</i>, vec3 <i>P</i>, int <i>offset</i> [, float <i>bias</i>])</p>	<p>Do a texture lookup as in <b>texture</b> but with <i>offset</i> added to the <math>(u,v,w)</math> 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 MIN_PROGRAM_TEXEL_OFFSET and MAX_PROGRAM_TEXEL_OFFSET, 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 3.8.9 of the OpenGL Graphics System Specification, where <i>offset</i> is <math>(\delta_u, \delta_v, \delta_w)</math>. Note that texel offsets are also not supported for cube maps.</p>

Syntax	Description
<p>gvec4 <b>texelFetch</b> (gsampler1D <i>sampler</i>, int <i>P</i>, int <i>lod</i>)  gvec4 <b>texelFetch</b> (gsampler2D <i>sampler</i>, ivec2 <i>P</i>, int <i>lod</i>)  gvec4 <b>texelFetch</b> (gsampler3D <i>sampler</i>, ivec3 <i>P</i>, int <i>lod</i>)  gvec4 <b>texelFetch</b> (gsampler2DRect <i>sampler</i>, ivec2 <i>P</i>)  gvec4 <b>texelFetch</b> (gsampler1DArray <i>sampler</i>, ivec2 <i>P</i>, int <i>lod</i>)  gvec4 <b>texelFetch</b> (gsampler2DArray <i>sampler</i>, ivec3 <i>P</i>, int <i>lod</i>)  gvec4 <b>texelFetch</b> (gsamplerBuffer <i>sampler</i>, int <i>P</i>)  gvec4 <b>texelFetch</b> (gsampler2DMS <i>sampler</i>, ivec2 <i>P</i>, int <i>sample</i>)  gvec4 <b>texelFetch</b> (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 2.11.7 under Texel Fetches and section 3.8 Texturing of the OpenGL Graphics System Specification.</p>
<p>gvec4 <b>texelFetchOffset</b> (gsampler1D <i>sampler</i>, int <i>P</i>, int <i>lod</i>, int <i>offset</i>)  gvec4 <b>texelFetchOffset</b> (gsampler2D <i>sampler</i>, ivec2 <i>P</i>, int <i>lod</i>, ivec2 <i>offset</i>)  gvec4 <b>texelFetchOffset</b> (gsampler3D <i>sampler</i>, ivec3 <i>P</i>, int <i>lod</i>, ivec3 <i>offset</i>)  gvec4 <b>texelFetchOffset</b> (gsampler2DRect <i>sampler</i>, ivec2 <i>P</i>, ivec2 <i>offset</i>)  gvec4 <b>texelFetchOffset</b> (gsampler1DArray <i>sampler</i>, ivec2 <i>P</i>, int <i>lod</i>, int <i>offset</i>)  gvec4 <b>texelFetchOffset</b> (gsampler2DArray <i>sampler</i>, ivec3 <i>P</i>, int <i>lod</i>, ivec2 <i>offset</i>)</p>	<p>Fetch a single texel as in <b>texelFetch</b> offset by <i>offset</i> as described in <b>textureOffset</b>.</p>
<p>gvec4 <b>textureProjOffset</b> (gsampler1D <i>sampler</i>, vec2 <i>P</i>, int <i>offset</i> [, float <i>bias</i> ] )  gvec4 <b>textureProjOffset</b> (gsampler1D <i>sampler</i>, vec4 <i>P</i>, int <i>offset</i> [, float <i>bias</i> ] )  gvec4 <b>textureProjOffset</b> (gsampler2D <i>sampler</i>, vec3 <i>P</i>, ivec2 <i>offset</i> [, float <i>bias</i> ] )  gvec4 <b>textureProjOffset</b> (gsampler2D <i>sampler</i>, vec4 <i>P</i>, ivec2 <i>offset</i> [, float <i>bias</i> ] )  gvec4 <b>textureProjOffset</b> (gsampler3D <i>sampler</i>, vec4 <i>P</i>, ivec3 <i>offset</i> [, float <i>bias</i> ] )  gvec4 <b>textureProjOffset</b> (gsampler2DRect <i>sampler</i>, vec3 <i>P</i>, ivec2 <i>offset</i> )  gvec4 <b>textureProjOffset</b> (gsampler2DRect <i>sampler</i>, vec4 <i>P</i>, ivec2 <i>offset</i> )  float <b>textureProjOffset</b> (sampler2DRectShadow <i>sampler</i>, vec4 <i>P</i>, ivec2 <i>offset</i> )  float <b>textureProjOffset</b> (sampler1DShadow <i>sampler</i>, vec4 <i>P</i>, int <i>offset</i> [, float <i>bias</i> ] )  float <b>textureProjOffset</b> (sampler2DShadow <i>sampler</i>, vec4 <i>P</i>, ivec2 <i>offset</i> [, float <i>bias</i> ] )</p>	<p>Do a projective texture lookup as described in <b>textureProj</b> offset by <i>offset</i> as described in <b>textureOffset</b>.</p>

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 <b>textureLod</b> and <b>textureOffset</b>.</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 <b>textureProj</b> and <b>textureLod</b>.</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 <b>textureProj</b>, <b>textureLod</b>, and <b>textureOffset</b>.</p>

Syntax	Description
<p><code>gvec4 textureGrad</code> (<code>gsampler1D sampler</code>, float <math>P</math>, float <math>dPdx</math>, float <math>dPdy</math>)</p> <p><code>gvec4 textureGrad</code> (<code>gsampler2D sampler</code>, <code>vec2 P</code>, <code>vec2 dPdx</code>, <code>vec2 dPdy</code>)</p> <p><code>gvec4 textureGrad</code> (<code>gsampler3D sampler</code>, <code>vec3 P</code>, <code>vec3 dPdx</code>, <code>vec3 dPdy</code>)</p> <p><code>gvec4 textureGrad</code> (<code>gsamplerCube sampler</code>, <code>vec3 P</code>, <code>vec3 dPdx</code>, <code>vec3 dPdy</code>)</p> <p><code>gvec4 textureGrad</code> (<code>gsampler2DRect sampler</code>, <code>vec2 P</code>, <code>vec2 dPdx</code>, <code>vec2 dPdy</code>)</p> <p><code>float textureGrad</code> (<code>sampler2DRectShadow sampler</code>, <code>vec3 P</code>, <code>vec2 dPdx</code>, <code>vec2 dPdy</code>)</p> <p><code>float textureGrad</code> (<code>sampler1DShadow sampler</code>, <code>vec3 P</code>, float <math>dPdx</math>, float <math>dPdy</math>)</p> <p><code>float textureGrad</code> (<code>sampler2DShadow sampler</code>, <code>vec3 P</code>, <code>vec2 dPdx</code>, <code>vec2 dPdy</code>)</p> <p><code>float textureGrad</code> (<code>samplerCubeShadow sampler</code>, <code>vec4 P</code>, <code>vec3 dPdx</code>, <code>vec3 dPdy</code>)</p> <p><code>gvec4 textureGrad</code> (<code>gsampler1DArray sampler</code>, <code>vec2 P</code>, float <math>dPdx</math>, float <math>dPdy</math>)</p> <p><code>gvec4 textureGrad</code> (<code>gsampler2DArray sampler</code>, <code>vec3 P</code>, <code>vec2 dPdx</code>, <code>vec2 dPdy</code>)</p> <p><code>float textureGrad</code> (<code>sampler1DArrayShadow sampler</code>, <code>vec3 P</code>, float <math>dPdx</math>, float <math>dPdy</math>)</p> <p><code>float textureGrad</code> (<code>sampler2DArrayShadow sampler</code>, <code>vec4 P</code>, <code>vec2 dPdx</code>, <code>vec2 dPdy</code>)</p>	<p>Do a texture lookup as in <b>texture</b> but with explicit gradients. The partial derivatives of <math>P</math> are with respect to window <math>x</math> and window <math>y</math>. 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 <math>P</math> are assumed to be in the coordinate system used before texture coordinates are projected onto the appropriate cube face.</p>

Syntax	Description
<p>gvec4 <b>textureGradOffset</b> (gsampler1D <i>sampler</i>, float <i>P</i>, float <i>dPdx</i>, float <i>dPdy</i>, int <i>offset</i>)</p> <p>gvec4 <b>textureGradOffset</b> (gsampler2D <i>sampler</i>, vec2 <i>P</i>, vec2 <i>dPdx</i>, vec2 <i>dPdy</i>, ivec2 <i>offset</i>)</p> <p>gvec4 <b>textureGradOffset</b> (gsampler3D <i>sampler</i>, vec3 <i>P</i>, vec3 <i>dPdx</i>, vec3 <i>dPdy</i>, ivec3 <i>offset</i>)</p> <p>gvec4 <b>textureGradOffset</b> (gsampler2DRect <i>sampler</i>, vec2 <i>P</i>, vec2 <i>dPdx</i>, vec2 <i>dPdy</i>, ivec2 <i>offset</i>)</p> <p>float <b>textureGradOffset</b> (sampler2DRectShadow <i>sampler</i>, vec3 <i>P</i>, vec2 <i>dPdx</i>, vec2 <i>dPdy</i>, ivec2 <i>offset</i>)</p> <p>float <b>textureGradOffset</b> (sampler1DShadow <i>sampler</i>, vec3 <i>P</i>, float <i>dPdx</i>, float <i>dPdy</i>, int <i>offset</i>)</p> <p>float <b>textureGradOffset</b> (sampler2DShadow <i>sampler</i>, vec3 <i>P</i>, vec2 <i>dPdx</i>, vec2 <i>dPdy</i>, ivec2 <i>offset</i>)</p> <p><del>float <b>textureGradOffset</b> (samplerCubeShadow <i>sampler</i>, vec4 <i>P</i>, vec3 <i>dPdx</i>, vec3 <i>dPdy</i>, ivec2 <i>offset</i>)</del></p> <p>gvec4 <b>textureGradOffset</b> (gsampler1DArray <i>sampler</i>, vec2 <i>P</i>, float <i>dPdx</i>, float <i>dPdy</i>, int <i>offset</i>)</p> <p>gvec4 <b>textureGradOffset</b> (gsampler2DArray <i>sampler</i>, vec3 <i>P</i>, vec2 <i>dPdx</i>, vec2 <i>dPdy</i>, ivec2 <i>offset</i>)</p> <p>float <b>textureGradOffset</b> (sampler1DArrayShadow <i>sampler</i>, vec3 <i>P</i>, float <i>dPdx</i>, float <i>dPdy</i>, int <i>offset</i>)</p> <p>float <b>textureGradOffset</b> (sampler2DArrayShadow <i>sampler</i>, vec4 <i>P</i>, vec2 <i>dPdx</i>, vec2 <i>dPdy</i>, ivec2 <i>offset</i>)</p>	<p>Do a texture lookup with both explicit gradient and offset, as described in <b>textureGrad</b> and <b>textureOffset</b>.</p>
<p>gvec4 <b>textureProjGrad</b> (gsampler1D <i>sampler</i>, vec2 <i>P</i>, float <i>dPdx</i>, float <i>dPdy</i>)</p> <p>gvec4 <b>textureProjGrad</b> (gsampler1D <i>sampler</i>, vec4 <i>P</i>, float <i>dPdx</i>, float <i>dPdy</i>)</p> <p>gvec4 <b>textureProjGrad</b> (gsampler2D <i>sampler</i>, vec3 <i>P</i>, vec2 <i>dPdx</i>, vec2 <i>dPdy</i>)</p> <p>gvec4 <b>textureProjGrad</b> (gsampler2D <i>sampler</i>, vec4 <i>P</i>, vec2 <i>dPdx</i>, vec2 <i>dPdy</i>)</p> <p>gvec4 <b>textureProjGrad</b> (gsampler3D <i>sampler</i>, vec4 <i>P</i>, vec3 <i>dPdx</i>, vec3 <i>dPdy</i>)</p> <p>gvec4 <b>textureProjGrad</b> (gsampler2DRect <i>sampler</i>, vec3 <i>P</i>, vec2 <i>dPdx</i>, vec2 <i>dPdy</i>)</p> <p>gvec4 <b>textureProjGrad</b> (gsampler2DRect <i>sampler</i>, vec4 <i>P</i>, vec2 <i>dPdx</i>, vec2 <i>dPdy</i>)</p> <p>float <b>textureProjGrad</b> (sampler2DRectShadow <i>sampler</i>, vec4 <i>P</i>, vec2 <i>dPdx</i>, vec2 <i>dPdy</i>)</p> <p>float <b>textureProjGrad</b> (sampler1DShadow <i>sampler</i>, vec4 <i>P</i>, float <i>dPdx</i>, float <i>dPdy</i>)</p> <p>float <b>textureProjGrad</b> (sampler2DShadow <i>sampler</i>, vec4 <i>P</i>, vec2 <i>dPdx</i>, vec2 <i>dPdy</i>)</p>	<p>Do a texture lookup both projectively, as described in <b>textureProj</b>, and with explicit gradient as described in <b>textureGrad</b>. The partial derivatives <i>dPdx</i> and <i>dPdy</i> are assumed to be already projected.</p>

Syntax	Description
gvec4 <b>textureProjGradOffset</b> (gsampler1D <i>sampler</i> , vec2 <i>P</i> , float <i>dPdx</i> , float <i>dPdy</i> , int <i>offset</i> )	Do a texture lookup projectively and with explicit gradient as described in <b>textureProjGrad</b> , as well as with offset, as described in <b>textureOffset</b> .
gvec4 <b>textureProjGradOffset</b> (gsampler1D <i>sampler</i> , vec4 <i>P</i> , float <i>dPdx</i> , float <i>dPdy</i> , int <i>offset</i> )	
gvec4 <b>textureProjGradOffset</b> (gsampler2D <i>sampler</i> , vec3 <i>P</i> , vec2 <i>dPdx</i> , vec2 <i>dPdy</i> , vec2 <i>offset</i> )	
gvec4 <b>textureProjGradOffset</b> (gsampler2D <i>sampler</i> , vec4 <i>P</i> , vec2 <i>dPdx</i> , vec2 <i>dPdy</i> , vec2 <i>offset</i> )	
gvec4 <b>textureProjGradOffset</b> (gsampler2DRect <i>sampler</i> , vec3 <i>P</i> , vec2 <i>dPdx</i> , vec2 <i>dPdy</i> , ivec2 <i>offset</i> )	
gvec4 <b>textureProjGradOffset</b> (gsampler2DRect <i>sampler</i> , vec4 <i>P</i> , vec2 <i>dPdx</i> , vec2 <i>dPdy</i> , ivec2 <i>offset</i> )	
float <b>textureProjGradOffset</b> (sampler2DRectShadow <i>sampler</i> , vec4 <i>P</i> , vec2 <i>dPdx</i> , vec2 <i>dPdy</i> , ivec2 <i>offset</i> )	
gvec4 <b>textureProjGradOffset</b> (gsampler3D <i>sampler</i> , vec4 <i>P</i> , vec3 <i>dPdx</i> , vec3 <i>dPdy</i> , vec3 <i>offset</i> )	
float <b>textureProjGradOffset</b> (sampler1DShadow <i>sampler</i> , vec4 <i>P</i> , float <i>dPdx</i> , float <i>dPdy</i> , int <i>offset</i> )	
float <b>textureProjGradOffset</b> (sampler2DShadow <i>sampler</i> , vec4 <i>P</i> , vec2 <i>dPdx</i> , vec2 <i>dPdy</i> , vec2 <i>offset</i> )	

The following texture functions are deprecated.

Syntax	Description
vec4 <b>texture1D</b> (sampler1D <i>sampler</i> , float <i>coord</i> [, float <i>bias</i> ] ) vec4 <b>texture1DProj</b> (sampler1D <i>sampler</i> , vec2 <i>coord</i> [, float <i>bias</i> ] ) vec4 <b>texture1DProj</b> (sampler1D <i>sampler</i> , vec4 <i>coord</i> [, float <i>bias</i> ] ) vec4 <b>texture1DLod</b> (sampler1D <i>sampler</i> , float <i>coord</i> , float <i>lod</i> ) vec4 <b>texture1DProjLod</b> (sampler1D <i>sampler</i> , vec2 <i>coord</i> , float <i>lod</i> ) vec4 <b>texture1DProjLod</b> (sampler1D <i>sampler</i> , vec4 <i>coord</i> , float <i>lod</i> )	Deprecated. See corresponding signature above without “1D” in the name.
vec4 <b>texture2D</b> (sampler2D <i>sampler</i> , vec2 <i>coord</i> [, float <i>bias</i> ] ) vec4 <b>texture2DProj</b> (sampler2D <i>sampler</i> , vec3 <i>coord</i> [, float <i>bias</i> ] ) vec4 <b>texture2DProj</b> (sampler2D <i>sampler</i> , vec4 <i>coord</i> [, float <i>bias</i> ] ) vec4 <b>texture2DLod</b> (sampler2D <i>sampler</i> , vec2 <i>coord</i> , float <i>lod</i> ) vec4 <b>texture2DProjLod</b> (sampler2D <i>sampler</i> , vec3 <i>coord</i> , float <i>lod</i> ) vec4 <b>texture2DProjLod</b> (sampler2D <i>sampler</i> , vec4 <i>coord</i> , float <i>lod</i> )	Deprecated. See corresponding signature above without “2D” in the name.
vec4 <b>texture3D</b> (sampler3D <i>sampler</i> , vec3 <i>coord</i> [, float <i>bias</i> ] ) vec4 <b>texture3DProj</b> (sampler3D <i>sampler</i> , vec4 <i>coord</i> [, float <i>bias</i> ] ) vec4 <b>texture3DLod</b> (sampler3D <i>sampler</i> , vec3 <i>coord</i> , float <i>lod</i> ) vec4 <b>texture3DProjLod</b> (sampler3D <i>sampler</i> , vec4 <i>coord</i> , float <i>lod</i> )	Deprecated. 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 <b>textureCube</b> (samplerCube <i>sampler</i> , vec3 <i>coord</i> [, float <i>bias</i> ] ) vec4 <b>textureCubeLod</b> (samplerCube <i>sampler</i> , vec3 <i>coord</i> , float <i>lod</i> )	Deprecated. See corresponding signature above without “Cube” in the name.

Syntax	Description
vec4 <b>shadow1D</b> (sampler1DShadow <i>sampler</i> , vec3 <i>coord</i> [, float <i>bias</i> ] )	Deprecated. Same functionality as the “ <b>texture</b> ” based names above with the same signature.
vec4 <b>shadow2D</b> (sampler2DShadow <i>sampler</i> , vec3 <i>coord</i> [, float <i>bias</i> ] )	
vec4 <b>shadow1DProj</b> (sampler1DShadow <i>sampler</i> , vec4 <i>coord</i> [, float <i>bias</i> ] )	
vec4 <b>shadow2DProj</b> (sampler2DShadow <i>sampler</i> , vec4 <i>coord</i> [, float <i>bias</i> ] )	
vec4 <b>shadow1DLod</b> (sampler1DShadow <i>sampler</i> , vec3 <i>coord</i> , float <i>lod</i> )	
vec4 <b>shadow2DLod</b> (sampler2DShadow <i>sampler</i> , vec3 <i>coord</i> , float <i>lod</i> )	
vec4 <b>shadow1DProjLod</b> (sampler1DShadow <i>sampler</i> , vec4 <i>coord</i> , float <i>lod</i> )	
vec4 <b>shadow2DProjLod</b> (sampler2DShadow <i>sampler</i> , vec4 <i>coord</i> , float <i>lod</i> )	

## 8.8 Fragment Processing Functions

Fragment processing functions are only available in fragment shaders.

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  $x$ .

A GL implementation may use the above or other methods to perform the calculation, subject to the following conditions:

1. The method may use piecewise linear approximations. Such linear approximations imply that higher order derivatives,  $\mathbf{dFdx}(\mathbf{dFdx}(x))$  and above, are undefined.
2. The method may assume that the function evaluated is continuous. Therefore derivatives within the body of a non-uniform conditional are undefined.
3. 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 3.2 of the OpenGL Graphics System Specification, is relaxed for derivative calculations, because the method may be a function of fragment location.

Other properties that are desirable, but not required, are:

4. Functions should be evaluated within the interior of a primitive (interpolated, not extrapolated).
5. Functions for  $\mathbf{dFdx}$  should be evaluated while holding  $y$  constant. Functions for  $\mathbf{dFdy}$  should be evaluated while holding  $x$  constant. However, mixed higher order derivatives, like  $\mathbf{dFdx}(\mathbf{dFdy}(y))$  and  $\mathbf{dFdy}(\mathbf{dFdx}(x))$  are undefined.
6. Derivatives of constant arguments should be 0.

In some implementations, varying degrees of derivative accuracy may be obtained by providing GL hints (section 5.3 of the OpenGL Graphics System Specification), allowing a user to make an image quality versus speed trade off.

Syntax	Description
<code>genType <b>dFdx</b> (genType <math>p</math>)</code>	Returns the derivative in $x$ using local differencing for the input argument $p$ .
<code>genType <b>dFdy</b> (genType <math>p</math>)</code>	Returns the derivative in $y$ using local differencing for the input argument $p$ .  These two functions are commonly used to estimate the filter width used to anti-alias procedural textures. We are assuming that the expression is being evaluated in parallel on a SIMD array so that at any given point in time the value of the function is known at the grid points represented by the SIMD array. Local differencing between SIMD array elements can therefore be used to derive $\mathbf{dFdx}$ , $\mathbf{dFdy}$ , etc.
<code>genType <b>fwidth</b> (genType <math>p</math>)</code>	Returns the sum of the absolute derivative in $x$ and $y$ using local differencing for the input argument $p$ , i.e., $\mathbf{abs}(\mathbf{dFdx}(p)) + \mathbf{abs}(\mathbf{dFdy}(p))$ ;

## 8.9 Noise Functions

Noise functions are available to fragment, geometry, and vertex shaders. They are stochastic functions that can be used to increase visual complexity. Values returned by the following noise functions give the appearance of randomness, but are not truly random. The noise functions below are defined to have the following characteristics:

- The return value(s) are always in the range  $[-1.0, 1.0]$ , and cover at least the range  $[-0.6, 0.6]$ , with a Gaussian-like distribution.
- The return value(s) have an overall average of 0.0
- They are repeatable, in that a particular input value will always produce the same return value
- They are statistically invariant under rotation (i.e., no matter how the domain is rotated, it has the same statistical character)
- They have a statistical invariance under translation (i.e., no matter how the domain is translated, it has the same statistical character)
- They typically give different results under translation.
- The spatial frequency is narrowly concentrated, centered somewhere between 0.5 to 1.0.
- They are  $C^1$  continuous everywhere (i.e., the first derivative is continuous)

Syntax	Description
float <b>noise1</b> (genType $x$ )	Returns a 1D noise value based on the input value $x$ .
vec2 <b>noise2</b> (genType $x$ )	Returns a 2D noise value based on the input value $x$ .
vec3 <b>noise3</b> (genType $x$ )	Returns a 3D noise value based on the input value $x$ .
vec4 <b>noise4</b> (genType $x$ )	Returns a 4D noise value based on the input value $x$ .

## 8.10 Geometry Shader Functions

These functions are only available in geometry shaders.

Syntax	Description
void <b>EmitVertex</b> ()	Emit the current values of output variables to the current output primitive. On return from this call, the values of output variables are undefined. See below for more discussion.
void <b>EndPrimitive</b> ()	Completes the current output primitive and starts a new one. No vertex is emitted. See below for more discussion.

The function **EmitVertex**() specifies that a vertex is completed. A vertex is added to the current output primitive using the current values of the geometry shader's output variables, including *gl\_PointSize*, *gl\_ClipDistance*, *gl\_Layer*, *gl\_Position* and *gl\_PrimitiveID*. The values of all these output variables are undefined after a call to **EmitVertex**(). If a geometry shader invocation has emitted more vertices than permitted by the output layout qualifier **max\_vertices**, the results of calling **EmitVertex**() are undefined.

The function **EndPrimitive**() specifies that the current output primitive is completed and a new output primitive (of the same type) will be started by any subsequent **EmitVertex**(). This function does not emit a vertex. If the output layout is declared to be “points”, calling **EndPrimitive**() is optional.

A geometry shader starts with an output primitive containing no vertices. When a geometry shader terminates, the current output primitive is automatically completed. It is not necessary to call **EndPrimitive**() if the geometry shader writes only a single primitive.

# 9 Shading Language Grammar

The grammar is fed from the output of lexical analysis. The tokens returned from lexical analysis are

```
ATTRIBUTE CONST BOOL FLOAT INT UINT
BREAK CONTINUE DO ELSE FOR IF DISCARD RETURN SWITCH CASE DEFAULT
BVEC2 BVEC3 BVEC4 IVEC2 IVEC3 IVEC4 UVEC2 UVEC3 UVEC4 VEC2 VEC3 VEC4
MAT2 MAT3 MAT4 CENTROID IN OUT INOUT UNIFORM VARYING

NOPERSPECTIVE FLAT SMOOTH LAYOUT
MAT2X2 MAT2X3 MAT2X4
MAT3X2 MAT3X3 MAT3X4
MAT4X2 MAT4X3 MAT4X4
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

STRUCT VOID WHILE

IDENTIFIER TYPE_NAME FLOATCONSTANT 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
HIGH_PRECISION MEDIUM_PRECISION LOW_PRECISION PRECISION
```

The following describes the grammar for the OpenGL Shading Language in terms of the above tokens.

*variable identifier:*  
*IDENTIFIER*

*primary\_expression:*

*variable\_identifier*  
*INTCONSTANT*  
*UINTCONSTANT*  
*FLOATCONSTANT*  
*BOOLCONSTANT*  
*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*

*integer\_expression:*

*expression*

*function\_call:*

*function\_call\_or\_method*

*function\_call\_or\_method:*

*function\_call\_generic*  
*postfix\_expression DOT 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”.*

*function\_identifier:*

*type\_specifier*  
*IDENTIFIER*  
*FIELD\_SELECTION*

*unary\_expression:*

*postfix\_expression*  
*INC\_OP unary\_expression*  
*DEC\_OP unary\_expression*  
*unary\_operator unary\_expression*

*// Grammar Note: No traditional style type casts.*

*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*

*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\_no\_prec 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 LEFT\_BRACKET RIGHT\_BRACKET SEMICOLON*

*type\_qualifier IDENTIFIER LEFT\_BRACE struct\_declaration\_list RIGHT\_BRACE  
IDENTIFIER LEFT\_BRACKET constant\_expression RIGHT\_BRACKET SEMICOLON*

*type\_qualifier SEMICOLON*

*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

*parameter\_declarator*:

*type\_specifier* IDENTIFIER

*type\_specifier* IDENTIFIER LEFT\_BRACKET *constant\_expression* RIGHT\_BRACKET

*parameter\_declaration*:

*parameter\_type\_qualifier* *parameter\_qualifier* *parameter\_declarator*

*parameter\_qualifier* *parameter\_declarator*

*parameter\_type\_qualifier* *parameter\_qualifier* *parameter\_type\_specifier*

*parameter\_qualifier* *parameter\_type\_specifier*

*parameter\_qualifier*:

*/\* empty \*/*

IN

OUT

INOUT

*parameter\_type\_specifier*:

*type\_specifier*

*init\_declarator\_list*:

*single\_declaration*

*init\_declarator\_list* COMMA IDENTIFIER

*init\_declarator\_list* COMMA IDENTIFIER LEFT\_BRACKET RIGHT\_BRACKET

*init\_declarator\_list* COMMA IDENTIFIER LEFT\_BRACKET *constant\_expression*  
RIGHT\_BRACKET

*init\_declarator\_list* COMMA IDENTIFIER LEFT\_BRACKET  
RIGHT\_BRACKET EQUAL *initializer*

## 9 Shading Language Grammar

*init\_declarator\_list* COMMA IDENTIFIER LEFT\_BRACKET *constant\_expression*  
RIGHT\_BRACKET EQUAL *initializer*  
*init\_declarator\_list* COMMA IDENTIFIER EQUAL *initializer*

*single\_declaration*:

*fully\_specified\_type*  
*fully\_specified\_type* IDENTIFIER  
*fully\_specified\_type* IDENTIFIER LEFT\_BRACKET RIGHT\_BRACKET  
*fully\_specified\_type* IDENTIFIER LEFT\_BRACKET *constant\_expression* RIGHT\_BRACKET  
*fully\_specified\_type* IDENTIFIER LEFT\_BRACKET RIGHT\_BRACKET EQUAL *initializer*  
*fully\_specified\_type* IDENTIFIER LEFT\_BRACKET *constant\_expression*  
RIGHT\_BRACKET EQUAL *initializer*  
*fully\_specified\_type* IDENTIFIER EQUAL *initializer*  
INVARIANT IDENTIFIER

// 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 INTCONSTANT

*parameter\_type\_qualifier:*

*CONST*

*type\_qualifier:*

*storage\_qualifier*

*layout\_qualifier*

*layout\_qualifier storage\_qualifier*

*interpolation\_qualifier storage\_qualifier*

*interpolation\_qualifier*

*invariant\_qualifier storage\_qualifier*

*invariant\_qualifier interpolation\_qualifier storage\_qualifier*

*invariant*

*storage\_qualifier:*

*CONST*

*ATTRIBUTE // Vertex only.*

*VARYING*

*CENTROID VARYING*

*IN*

*OUT*

*CENTROID IN*

*CENTROID OUT*

*UNIFORM*

*type\_specifier:*

*type\_specifier\_no\_prec*

*precision\_qualifier type\_specifier\_no\_prec*

*type\_specifier\_no\_prec:*

*type\_specifier\_nonarray*

*type\_specifier\_nonarray LEFT\_BRACKET RIGHT\_BRACKET*

*type\_specifier\_nonarray LEFT\_BRACKET constant\_expression RIGHT\_BRACKET*

*type\_specifier\_nonarray:*

*VOID*

*FLOAT*

*INT*

*UINT*  
*BOOL*  
*VEC2*  
*VEC3*  
*VEC4*  
*BVEC2*  
*BVEC3*  
*BVEC4*  
*IVEC2*  
*IVEC3*  
*IVEC4*  
*UVEC2*  
*UVEC3*  
*UVEC4*  
*MAT2*  
*MAT3*  
*MAT4*  
*MAT2X2*  
*MAT2X3*  
*MAT2X4*  
*MAT3X2*  
*MAT3X3*  
*MAT3X4*  
*MAT4X2*  
*MAT4X3*  
*MAT4X4*  
*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*  
*struct\_specifier*  
*TYPE\_NAME*  
*precision\_qualifier:*  
*HIGH\_PRECISION*  
*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 LEFT\_BRACKET RIGHT\_BRACKET*  
*IDENTIFIER LEFT\_BRACKET constant\_expression RIGHT\_BRACKET*

*initializer:*

*assignment\_expression*

*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*

*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*

*external\_declaration:*

*function\_definition*  
*declaration*

*function\_definition:*

*function\_prototype compound\_statement\_no\_new\_scope*

## 10 Issues

**Issue 1:** Is it okay to reserve vertex input blocks and fragment output blocks for future use?

Resolution: Yes, leave these reserved for now.

**Issue 2:** Do we allow partial qualifications on block members, with part explicit and part inherited? For example,

```
in foo {
    smooth vec2 t;
};
```

Resolution: Yes, if the current method of doing the grammar can support it. Otherwise: No, until Issue 3 is resolved, keep this simple: Need full qualification on members (or no qualification).

**Issue 3:** Follow-on to issue 2: Should we unhook ‘centroid’ from ‘in’ to make order of qualification not matter, thus assuring no grammar issues WRT inheriting qualification from the qualifier of the interface?

Resolution: Unless we have time, no, this is a creeping feature.

**Issue 4:** Should we allow block names to be used as other things?

Resolution: No.

**Issue 5:** Do we really want to call interface blocks ‘interface’?

Resolution: Yes, until someone suggests a better name.

**Issue 6:** How does the API refer to block members?

Resolution: You express it the way you would in the shader, but in the API, use block name where instance name is used in the shader.

**Issue 7:** Do multi-sample textures have LOD? Will they? If so, can we have lod arguments?

Resolution: No LODs now or future, treat like texture rectangle.

**Issue 8:** `gl_Vertices`, the number of vertices input to the geometry shader, is a compile time constant set by the linker: The linker cannot set a compile time constant, it is too late for that. It does not support a model of compiling at compile time.

Possible Resolution A: Leave all arrays as unsized and use a uniform for `gl_Vertices`.

Possible Resolution B: The coder makes their own `const int` declaration in shaders to match their intended purpose. The linker verifies the input array's size match the primitive type.

Possible Resolution C: The shader object on the API side has a new parameter saying the size used at compile time and the linker sees if they all match.

Resolution D: Add directive to say what the input type is, and that ends up setting the constant at compile time. The constant is not intrinsically declared unless the input type is declared. Also allow declaring output type and a max vertices output count. Error to have input array sized to an inconsistent size of that declared. Say that `.length()` works because inputs declared after an input primitive type explicitly sizes those arrays. At least one shader is required to say the primitive type for input and for output and for the max size.

**Issue 9:** Where is the fragment read of `gl_PrimitiveID`? This is currently missing in the language specification.

Resolution: Put it in. See `gpu_shader4`.

**Issue 10:** Do we have consistent support for gl\_Layer?

Resolution: Yes, ARB\_geometry\_shader fully describes gl\_Layer.