High-Level Shader Language Specification

Working Draft

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Contents

1 Introduction [Intro]

1 The High Level Shader Language (HLSL) is the GPU programming language provided in conjunction with the DirectX runtime. Over many years its use has expanded to cover every major rendering API across all major development platforms. Despite its popularity and long history HLSL has never had a formal language specification. This document seeks to change that.

2 HLSL draws heavy inspiration originally from ISO C standard (2011) and later from ISO C++ standard (2011) with additions specific to graphics and parallel computation programming. The language is also influenced to a lesser degree by other popular graphics and parallel programming languages.

3 HLSL has two reference implementations which this specification draws heavily from. The original reference implementation Legacy DirectX Shader Compiler (FXC) has been in use since DirectX 9. The more recent reference implementation DirectX Shader Compiler (DXC) has been the primary shader compiler since DirectX 12.

4 In writing this specification bias is leaned toward the language behavior of DXC rather than the behavior of FXC, although that can vary by context.

5 In very rare instances this spec will be aspirational, and may diverge from both reference implementation behaviors. This will only be done in instances where there is an intent to alter implementation behavior in the future. Since this document and the implementations are living sources, one or the other may be ahead in different regards at any point in time.

1.1 Scope [Intro.Scope]

1 This document specifies the requirements for implementations of HLSL. The HLSL specification is based on and highly influenced by the specifications for the C Programming Language (C) and the C++ Programming Language (C++).

2 This document covers both describing the language grammar and semantics for HLSL, and (in later sections) the standard library of data types used in shader programming.

1.2 Normative References [Intro.Refs]

1 The following referenced documents provide significant influence on this document and should be used in conjunction with interpreting this standard.

- ISO C standard (2011), *Programming languages - C*
- ISO C++ standard (2011), *Programming languages - C++*
- DirectX Specifications, *https://microsoft.github.io/DirectX-Specs/*

1.3 Terms and definitions [Intro.Terms]

1 This document aims to use terms consistent with their definitions in ISO C standard (2011) and ISO C++ standard (2011). In cases where the definitions are unclear, or where this document diverges from ISO C standard (2011) and ISO C++ standard (2011), the definitions in this section, the remaining sections in this chapter, and the attached glossary (10) supersede other sources.

1.4 Common Definitions [Intro.Defs]

1 The following definitions are consistent between HLSL and the ISO C standard (2011) and ISO C++ standard (2011) specifications, however they are included here for reader convenience.

1.4.1 Correct Data [Intro.Defs.CorrectData]

1 Data is correct if it represents values that have specified or unspecified but not undefined behavior for all the operations in which it is used. Data that is the result of undefined behavior is not correct, and may be treated as undefined.

1.4.2 Diagnostic Message [Intro.Defs.Diags]

1 An implementation defined message belonging to a subset of the implementation's output messages which communicates diagnostic information to the user.

1.4.3 Ill-formed Program [Intro.Defs.IllFormed]

1 A program that is not well-formed, for which the implementation is expected to return unsuccessfully and produce one or more diagnostic messages.

1.4.4 Implementation-defined Behavior [Intro.Defs.ImpDef]

1 Behavior of a well-formed program and correct data which may vary by the implementation, and the implementation is expected to document the behavior.

1.4.5 Implementation Limits [Intro.Defs.ImpLimits]

1 Restrictions imposed upon programs by the implementation of either the compiler or runtime environment. The compiler may seek to surface runtime-imposed limits to the user for improved user experience.

1.4.6 Undefined Behavior [Intro.Defs.Undefined]

1 Behavior of invalid program constructs or incorrect data for which this standard imposes no requirements, or does not sufficiently detail.

1.4.7 Unspecified Behavior [Intro.Defs.Unspecified]

1 Behavior of a well-formed program and correct data which may vary by the implementation, and the implementation is not expected to document the behavior.

1.4.8 Well-formed Program [Intro.Defs.WellFormed]

1 An HLSL program constructed according to the syntax rules, diagnosable semantic rules, and the One Definition Rule.

1.4.9 Runtime Implementation [Intro.Defs.Runtime]

1 A runtime implementation refers to a full-stack implementation of a software runtime that can facilitate the execution of HLSL programs. This broad definition includes libraries and device driver implementations. The HLSL specification does not distinguish between the user-facing programming interfaces and the vendor-specific backing implementation.

1.5 Runtime Targeting [Intro.Runtime]

1 HLSL emerged from the evolution of DirectX to grant greater control over GPU geometry and color processing. It gained popularity because it targeted a common hardware description which all conforming drivers were required to support. This common hardware description, called a Shader Model, is an integral part of the description for HLSL . Some HLSL features require specific Shader Model features, and are only supported by compilers when targeting those Shader Model versions or later.

1.6 Single Program Multiple Data Programming Model [Intro.Model]

1 HLSL uses a Single Program Multiple Data (SPMD) programming model where a program describes operations on a single element of data, but when the program executes it executes across more than one element at a time. This programming model is useful due to GPUs largely being Single Instruction Multiple Data (SIMD) hardware architectures where each instruction natively executes across multiple data elements at the same time.

2 There are many different terms of art for describing the elements of a GPU architecture and the way they relate to the SPMD program model. In this document we will use the terms as defined in the following subsections.

1.6.1 SPMD Terminology [Intro.Model.Terms]

1.6.1.1 Host and Device [Intro.Model.Terms.HostDevice]

1 HLSL is a data-parallel programming language designed for programming auxiliary processors in a larger system. In this context the *host* refers to the primary processing unit that runs the application which in turn uses a runtime to execute HLSL programs on a supported *device*. There is no strict requirement that the host and device be different physical hardware, although they commonly are. The separation of host and device in this specification is useful for defining the execution and memory model as well as specific semantics of language constructs.

1.6.1.2 Lane [Intro.Model.Terms.Lane]

1 A Lane represents a single computed element in an SPMD program. In a traditional programming model it would be analogous to a thread of execution, however it differs in one key way. In multi-threaded programming threads advance independent of each other. In SPMD programs, a group of Lanes may execute instructions in lockstep because each instruction may be a SIMD instruction computing the results for multiple Lanes simultaneously, or synchronizing execution across multiple Lanes or Waves. A Lane has an associated *lane state* which denotes the execution status of the lane (1.6.1.7).

1.6.1.3 Wave [Intro.Model.Terms.Wave]

1 A grouping of Lanes for execution is called a Wave. The size of a Wave is defined as the maximum number of *active* Lanes the Wave supports. Wave sizes vary by hardware architecture, and are required to be powers of two. The number of *active* Lanes in a Wave can be any value between one and the Wave size.

2 Some hardware implementations support multiple Wave sizes. There is no overall minimum wave size requirement, although some language features do have minimum Lane size requirements.

3 HLSL is explicitly designed to run on hardware with arbitrary Wave sizes. Hardware architectures may implement Waves as Single Instruction Multiple Thread (SIMT) where each thread executes instructions in lockstep. This is not a requirement of the model. Some constructs in HLSL require synchronized execution. Such constructs will explicitly specify that requirement.

1.6.1.4 Quad [Intro.Model.Terms.Quad]

1 A Quad is a subdivision of four Lanes in a Wave which are computing adjacent values. In pixel shaders a Quad may represent four adjacent pixels and Quad operations allow passing data between adjacent Lanes. In compute shaders quads may be one or two dimensional depending on the workload dimensionality. Quad operations require four active Lanes.

1.6.1.5 Thread Group [Intro.Model.Terms.Group]

1 A grouping of Lanes executing the same shader to produce a combined result is called a Thread Group. Thread Groups are independent of SIMD hardware specifications. The dimensions of a Thread Group are defined in three dimensions. The maximum extent along each dimension of a Thread Group, and the total size of a Thread Group are implementation limits defined by the runtime and enforced by the compiler. If a Thread Group's size is not a whole multiple of the hardware Wave size, the unused hardware Lanes are implicitly inactive.

2 If a Thread Group size is smaller than the Wave size , or if the Thread Group size is not an even multiple of the Wave size, the remaining Lane are *inactive* Lanes.

1.6.1.6 Dispatch [Intro.Model.Terms.Dispatch]

1 A grouping of Thread Groups which represents the full execution of a HLSL program and results in a completed result for all input data elements.

1.6.1.7 Lane States [Intro.Model.Terms.LaneState]

1 Lanes may be in three primary states: *active*, *helper*, *inactive*, and *predicated off*.

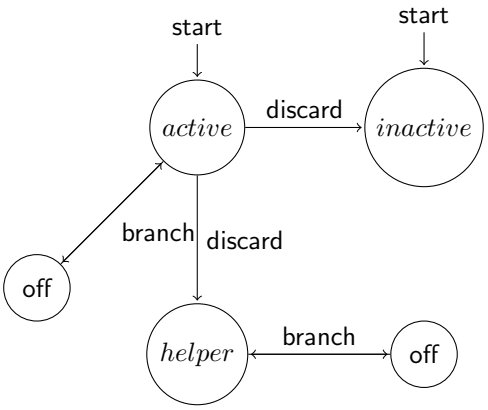
2 An *active* Lane is enabled to perform computations and produce output results based on the initial launch conditions and program control flow.

3 A *helper* Lane is a lane which would not be executed by the initial launch conditions except that its computations are required for adjacent pixel operations in pixel fragment shaders. A *helper* Lane will execute all computations but will not perform writes to buffers, and any outputs it produces are discarded. *Helper* lanes may be required for Lane-cooperative operations to execute correctly.

4 A *inactive* Lane is a lane that is not executed by the initial launch conditions. This can occur if there are insufficient inputs to fill all Lanes in the Wave, or to reduce per-thread memory requirements or register pressure.

5 A *predicated off* Lane is a lane that is not being executed due to program control flow. A Lane may be *predicated off* when control flow for the Lanes in a Wave diverge and one or more lanes are temporarily not executing.

6 The diagram blow illustrates the state transitions between Lane states:



1.6.2 SPMD Execution Model [Intro.Model.Exec]

1 A runtime implementation shall provide an implementation-defined mechanism for defining a Dispatch. A runtime shall manage hardware resources and schedule execution to conform to the behaviors defined in this specification in an implementation-defined way. A runtime implementation may sort the Thread Groups of a Dispatch into Waves in an implementation-defined way. During execution no guarantees are made that all Lanes in a Wave are actively executing.

2 Wave, Quad, and Thread Group operations require execution synchronization of applicable active and helper Lanes as defined by the individual operation.

1.6.3 Optimization Restrictions [Intro.Model.Restrictions]

1 An optimizing compiler may not optimize code generation such that it changes the behavior of a well-formed program except in the presence of *implementation-defined* or *unspecified* behavior.

2 The presence of Wave, Quad, or Thread Group operations may further limit the valid transformations of a program. Specifically, control flow operations which result in changing which Lanes, Quads, or Waves are actively executing are illegal in the presence of cooperative operations if the optimization alters the behavior of the program.

1.7 HLSL Memory Models [Intro.Memory]

1 Memory accesses for Shader Model 5.0 and earlier operate on 128-bit slots aligned on 128-bit boundaries. This optimized for the common case in early shaders where data being processed on the GPU was usually 4-element vectors of 32-bit data types.

2 On modern hardware memory access restrictions are loosened, and reads of 32-bit multiples are supported starting with Shader Model 5.1 and reads of 16-bit multiples are supported with Shader Model 6.0. Shader Model features are fully documented in the DirectX Specifications, and this document will not attempt to elaborate further.

1.7.1 Memory Spaces [Intro.Memory.Spaces]

1 HLSL programs manipulate data stored in four distinct memory spaces: thread, threadgroup, device and constant.

1.7.1.1 Thread Memory [Intro.Memory.Spaces.Thread]

1 Thread memory is local to the Lane. It is the default memory space used to store local variables. Thread memory cannot be directly read from other threads without the use of intrinsics to synchronize execution and memory.

1.7.1.2 Thread Group Memory [Intro.Memory.Spaces.Group]

1 Thread Group memory is denoted in HLSL with the `groupshared` keyword. The underlying memory for any declaration annotated with `groupshared` is shared across an entire Thread Group. Reads and writes to Thread Group Memory, may occur in any order except as restricted by synchronization intrinsics or other memory annotations.

1.7.1.3 Device Memory [Intro.Memory.Spaces.Device]

1 Device memory is memory available to all Lanes executing on the device. This memory may be read or written to by multiple Thread Groups that are executing concurrently. Reads and writes to device memory may occur in any order except as restricted by synchronization intrinsics or other memory annotations. Some device memory may be visible to the host. Device memory that is visible to the host may have additional synchronization concerns for host visibility.

1.7.1.4 Constant Memory [Intro.Memory.Spaces.Constant]

1 Constant memory is similar to device memory in that it is available to all Lanes executing on the device. Constant memory is read-only, and an implementation can assume that constant memory is immutable and cannot change during execution.

2 Lexical Conventions [Lex]

2.1 Unit of Translation [Lex.Translation]

1 The text of HLSL programs is collected in *source* and *header* files. The distinction between source and header files is social and not technical. An implementation will construct a *translation unit* from a single source file and any included source or header files referenced via the `#include` preprocessing directive conforming to the ISO C standard (2011) preprocessor specification.

2 An implementation may implicitly include additional sources as required to expose the HLSL library functionality as defined in (10).

2.2 Phases of Translation [Lex.Phases]

1 HLSL inherits the phases of translation from ISO C++ standard (2011), with minor alterations, specifically the removal of support for trigraph and digraph sequences. Below is a description of the phases.

1. Source files are characters that are mapped to the basic source character set in an implementation-defined manner.
2. Any sequence of backslash (\) immediately followed by a new line is deleted, resulting in splicing lines together.
3. Tokenization occurs and comments are isolated. If a source file ends in a partial comment or preprocessor token the program is ill-formed and a diagnostic shall be issued. Each comment block shall be treated as a single white-space character.
4. Preprocessing directives are executed, macros are expanded, `pragma` and other unary operator expressions are executed. Processing of `#include` directives results in all preceding steps being executed on the resolved file, and can continue recursively. Finally all preprocessing directives are removed from the source.
5. Character and string literal specifiers are converted into the appropriate character set for the execution environment.
6. Adjacent string literal tokens are concatenated.
7. White-space is no longer significant. Syntactic and semantic analysis occurs translating the whole translation unit into an implementation-defined representation.
8. The translation unit is processed to determine required instantiations, the definitions of the required instantiations are located, and the translation and instantiation units are merged. The program is ill-formed if any required instantiation cannot be located or fails during instantiation.
9. External references are resolved, library references linked, and all translation output is collected into a single output.

2.3 Character Sets [Lex.CharSet]

1 The *basic source character set* is a subset of the ASCII character set. The table below lists the valid characters and their ASCII values:

Hex ASCII Value	Character Name	Glyph or C Escape Sequence
0x09	Horizontal Tab	\t
0x0A	Line Feed	\n
0x0D	Carriage Return	\r
0x20	Space	
0x21	Exclamation Mark	!
0x22	Quotation Mark	"
0x23	Number Sign	#
0x25	Percent Sign	%
0x26	Ampersand	&
0x27	Apostrophe	’
0x28	Left Parenthesis	(
0x29	Right Parenthesis	)
0x2A	Asterisk	*
0x2B	Plus Sign	+
0x2C	Comma	,
0x2D	Hyphen-Minus	-
0x2E	Full Stop	.
0x2F	Solidus	/
0x30 .. 0x39	Digit Zero .. Nine	0 1 2 3 4 5 6 7 8 9
0x3A	Colon	:
0x3B	Semicolon	;
0x3C	Less-than Sign	<
0x3D	Equals Sign	=
0x3E	Greater-than Sign	>
0x3F	Question Mark	?
0x41 .. 0x5A	Latin Capital Letter A .. 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
0x5B	Left Square Bracket	[
0x5C	Reverse Solidus	\
0x5D	Right Square Bracket	[
0x5E	Circumflex Accent	^
0x5F	Underscore	_
0x61 .. 0x7A	Latin Small Letter a .. 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
0x7B	Left Curly Bracket	{
0x7C	Vertical Line	|
0x7D	Right Curly Bracket	}

2 An implementation may allow source files to be written in alternate *extended character sets* as long as that set is a superset of the *basic character set*. The *translation character set* is an *extended character set* or the *basic character set* as chosen by the implementation.

2.4 Preprocessing Tokens [Lex.PPTokens]

preprocessing-token:
header-name
identifier
pp-number
character-literal
string-literal
preprocessing-op-or-punc
each non-whitespace character from the *translation character set* that cannot be one of the above

1

[1]The preprocessor is inherited from C++ 11 with no grammar extensions. It is specified here only for completeness.

1 Each preprocessing token that is converted to a token shall have the lexical form of a keyword, an identifier, a constant, a string literal or an operator or punctuator.

2 Preprocessing tokens are the minimal lexical elements of the language during translation phases 3 through 6 (2.2). Preprocessing tokens can be separated by whitespace in the form of comments, white space characters, or both. White space may appear within a preprocessing token only as part of a header name or between the quotation characters in a character constant or string literal.

3 Header name preprocessing tokens are only recognized within `#include` preprocessing directives, `__has_include` expressions, and implementation-defined locations within `#pragma` directives. In those contexts, a sequence of characters that could be either a header name or a string literal is recognized as a header name.

2.5 Tokens [Lex.Tokens]

token:
identifier
keyword
literal
operator-or-punctuator

1 There are five kinds of tokens: identifiers, keywords, literals, and operators or punctuators. All whitespace characters and comments are ignored except as they separate tokens.

2.6 Comments [Lex.Comments]

1 The characters `/*` start a comment which terminates with the characters `*\`. The characters `//` start a comment which terminates at the next new line.

2.7 Header Names [Lex.Headers]

header-name:
< *h-char-sequence* >
" *h-char-sequence* "

h-char-sequence:
h-char
h-char-sequence h-char

h-char:
any character in the *translation character set* except newline or >

q-char-sequence:
q-char
q-char-sequence q-char

q-char:
any character in the *translation character set* except newline or "

1 Character sequences in header names are mapped to header files or external source file names in an implementation defined way.

2.8 Preprocessing numbers [Lex.PPNumber]

pp-number:

digit
. *digit*
pp-number ' *digit*
pp-number ' *non-digit*
pp-number `e` *sign*
pp-number `E` *sign*
pp-number `p` *sign*
pp-number `P` *sign*
pp-number .

1 Preprocessing numbers begin with a digit or period (`.`), and may be followed by valid identifier characters and floating point literal suffixes (`e+`, `e-`, `E+`, `E-`, `p+`, `p-`, `P+`, and `P-`). Preprocessing number tokens lexically include all *integer-literal* and *floating-literal* tokens.

2 Preprocessing numbers do not have types or values. Types and values are assigned to *integer-literal*, *floating-literal*, and *vector-literal* tokens on successful conversion from preprocessing numbers.

3 A preprocessing number cannot end in a period (`.`) if the immediate next token is a *scalar-element-sequence* (2.9.4). In this situation the *pp-number* token is truncated to end before the period[2].

2.9 Literals [Lex.Literals]

2.9.1 Literal Classifications [Lex.Literal.Kinds]

literal:
integer-literal
character-literal
floating-literal
string-literal
boolean-literal
vector-literal

2.9.2 Integer Literals [Lex.Literal.Int]

integer-literal:
decimal-literal integer-suffix$_{opt}$
octal-literal integer-suffix$_{opt}$
hexadecimal-literal integer-suffix$_{opt}$

decimal-literal:
nonzero-digit
decimal-literal digit

octal-literal: `0`
octal-literal octal-digit

hexadecimal-literal:
`0x` *hexadecimal-digit*
`0X` *hexadecimal-digit*
hexadecimal-literal hexadecimal-digit

nonzero-digit: one of
`1 2 3 4 5 6 7 8 9`

[2] This grammar formulation is not context-free and requires an LL(2) parser.

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`

integer-suffix:
unsigned-suffix long-suffix$_{opt}$
long-suffix unsigned-suffix$_{opt}$

unsigned-suffix: one of
`u U`

long-suffix: one of
`l L`

1 An *integer literal* is an optional base prefix, a sequence of digits in the appropriate base, and an optional type suffix. An integer literal shall not contain a period or exponent specifier.

2 The type of an integer literal is the first of the corresponding list in the table below in which its value can be represented[3].

Suffix	Decimal constant	Octal or hexadecimal constant

none	`int32_t`
	`int64_t`
		`int32_t`
		`uint32_t`
		`int64_t`
		`uint64_t`

`u` or `U`	`uint32_t` `uint64_t`	`uint32_t` `uint64_t`
`l` or `L`	`int64_t`	`int64_t` `uint64_t`
Both `u` or `U` and `l` or `L`	`uint64_t`	`uint64_t`

3 If the specified value of an integer literal cannot be represented by any type in the corresponding list, the integer literal has no type and the program is ill-formed.

4 An implementation may support the integer suffixes `ll` and `ull` as equivalent to `l` and `ul` respectively.

2.9.3 Floating-point Literals [Lex.Literal.Float]

floating-literal:
fractional-constant exponent-part$_{opt}$ *floating-suffix*$_{opt}$
digit-sequence exponent-part floating-suffx$_{opt}$
fractional-constant:
digit-sequence$_{opt}$ `.` *digit-sequence*
digit-sequence `.`
exponent-part:
`e` *sign*$_{opt}$ *digit-sequence*
`E` *sign*$_{opt}$ *digit-sequence*
sign: one of
`+ -` *digit-sequence*:
digit
digit-sequence digit floating-suffix: one of `h f l H F L`

[3] This behavior matches ISO C standard (2011) but is reduced in scope because HLSL has fewer data types.

1 A floating literal is written either as a *fractional-constant* with an optional *exponent-part* and optional *floating-suffix*, or as an integer *digit-sequence* with a required *exponent-part* and optional *floating-suffix*.

2 The type of a floating literal is `float`, unless explicitly specified by a suffix. The suffixes `h` and `H` specify `half`, the suffixes `f` and `F` specify `float`, and the suffixes `l` and `L` specify `double`.[4] If a value specified in the source is not in the range of representable values for its type, the program is ill-formed.

2.9.4 Vector Literals [Lex.Literal.Vector]

vector-literal:
integer-literal `.` *scalar-element-sequence*
floating-literal `.` *scalar-element-sequence*

scalar-element-sequence:
scalar-element-sequence-x
scalar-element-sequence-r

scalar-element-sequence-x:
`x`
scalar-element-sequence-x `x`

scalar-element-sequence-r:
`r`
scalar-element-sequence-r `r`

1 A *vector-literal* is an *integer-literal* or *floating-point* literal followed by a period (`.`) and a *scalar-element-sequence*.

2 A *scalar-element-sequence* is a *vector-swizzle-sequence* where only the first vector element accessor is valid (`x` or `r`). A *scalar-element-sequence* is equivalent to a vector splat conversion performed on the *integer-literal* or *floating-literal* value (4.7).

[4] This substantially deviates from the implementations in FXC and DXC, but is consistent with the official documentation and the behavior of GLSL. It is also substantially simpler to implement and more regular than the existing behaviors.

3 Basic Concepts [Basic]

3.1 Types [Basic.types]

1 The *object representation* of an object of type `T` is the sequence of *N* bytes taken up by the object of type `T`, where *N* equals `sizeof(T)`[1]. The *object representation* of an object may be different based on the *memory space* it is stored in (1.7.1).

2 The *value representation* of an object is the set of bits that hold the value of type `T`. Bits in the object representation that are not part of the value representation are *padding bits*.

3 An *object type* is a type that is not a function type, not a reference type, and not a void type.

4 A *class type* is a data type declared with either the `class` or `struct` keywords (7). A class type `T` may be declared as incomplete at one point in a translation unit via a *forward declaration*, and complete later with a full definition. The type `T` is the same type throughout the translation unit.

5 There are special implementation-defined types such as *handle types*, which fall into a category of *standard intangible types*. Intangible types are types that have no defined object representation or value representation, as such the size is unknown at compile time.

6 A class type `T` is an *intangible class type* if it contains an base classes or members of intangible class type, standard intangible type, or arrays of such types. Standard intangible types and intangible class types are collectively called *intangible types*(9).

7 An object type is an *incomplete type* if the compiler lacks sufficient information to determine the size of an object of type `T`, and it is not an intangible type. It is a *complete type* if the compiler has sufficient information to determine the size of an object of type `T`, or if the type is known to be an intangible type. An object may not be defined to have an *incomplete* type.

8 Arithmetic types (3.1.1), enumeration types, and *cv-qualified* versions of these types are collectively called *scalar types*.

9 Vectors of scalar types declared with the built-in `vector<T,N>` template are *vector types*. Vector lengths must be between 1 and 4 (i.e. $1 \leq N \leq 4$).

3.1.1 Arithmetic Types [Basic.types.arithmetic]

1 There are three *standard signed integer types*: `int16_t`, `int32_t`, and `int64_t`. Each of the signed integer types is explicitly named for the size in bits of the type's object representation. There is also the type alias `int` which is an alias of `int32_t`. There is one *minimum precision signed integer type*: `min16int`. The minimum precision signed integer type is named for the required minimum value representation size in bits. The object representation of `min16int` is `int`. The standard signed integer types and minimum precision signed integer type are collectively called *signed integer types*.

2 There are three *standard unsigned integer types*: `uint16_t`, `uint32_t`, and `uint64_t`. Each of the unsigned integer types is explicitly named for the size in bits of the type's object representation. There is also the type alias `uint` which is an alias of `uint32_t`. There is one *minimum precision unsigned integer type*: `min16uint`. The minimum precision unsigned integer type is named for the required minimum value representation size in bits. The object representation of `min16uint` is `uint`. The standard unsigned integer types and minimum precision unsigned integer type are collectively called *unsigned integer types*.

3 The minimum precision signed integer types and minimum precision unsigned integer types are collectively called *minimum precision integer types*. The standard signed integer types and standard unsigned integer types are collectively called *standard integer types*. The signed integer types and unsigned integer types are collectively called *integer types*. Integer types inherit the object representation of integers defined in ISO/IEC 9899:2023: Standard for Programming

[1] `sizeof(T)` returns the size of the object as-if it's stored in device memory, and determining the size if it's stored in another memory space is not possible.

Language C.[2]. Integer types shall satisfy the constraints defined in ISO/IEC 14882:2011: Standard for Programming Language C++., section **basic.fundamental**.

4 There are three *standard floating point types*: `half`, `float`, and `double`. The `float` type is a 32-bit floating point type. The `double` type is a 64-bit floating point type. Both the `float` and `double` types have object representations as defined in IEEE Standard 754. The `half` type may be either 16-bit or 32-bit as controlled by implementation defined compiler settings. If `half` is 32-bit it will have an object representation as defined in IEEE Standard 754, otherwise it will have an object representation matching the **binary16** format defined in IEEE Standard 754[3]. There is one *minimum precision floating point type*: `min16float`. The minimum precision floating point type is named for the required minimum value representation size in bits. The object representation of `min16float` is `float`[4]. The standard floating point types and minimum precision floating point type are collectively called *floating point types*.

5 Integer and floating point types are collectively called *arithmetic types*.

6 The `void` type is inherited from ISO C++ standard (2011), which defines it as having an empty set of values and being an incomplete type that can never be completed. The `void` type is used to signify the return type of a function that returns no value. Any expression can be explicitly converted to `void`.

3.2 Lvalues and rvalues [Basic.lval]

1 Expressions are classified by the type(s) of values they produce. The valid types of values produced by expressions are:

1. An *lvalue* represents a function or object.
2. An *rvalue* represents a temporary object.
3. An *xvalue* (expiring value) represents an object near the end of its lifetime.
4. A *cxvalue* (casted expiring value) is an *xvalue* which, on expiration, assigns its value to a bound *lvalue*.
5. A *glvalue* is an *lvalue*, *xvalue*, or *cxvalue*.
6. A *prvalue* is an *rvalue* that is not an *xvalue*.

[2] C23 adopts two's compliment as the object representation for integer types.
[3] IEEE-754 only defines a binary encoding for 16-bit floating point values, it does not fully specify the behavior of such types.
[4] This means when stored to memory objects of type `min16float` are stored as **binary32** as defined in IEEE Standard 754.

4 Standard Conversions [Conv]

1 HLSL inherits standard conversions similar to ISO C++ standard (2011). This chapter enumerates the full set of conversions. A *standard conversion sequence* is a sequence of standard conversions in the following order:

1. Zero or one conversion of either lvalue-to-rvalue, array-to-pointer or function-to-pointer.
2. Zero or one conversion of either integral conversion, floating point conversion, floating point-integral conversion, or boolean conversion, derived-to-base-lvalue, vector splat, vector truncation, or flat conversion[1].
3. Zero or one conversion of either component-wise integral conversion, component-wise floating point conversion, component-wise floating point-integral conversion, or component-wise boolean conversion[2].
4. Zero or one qualification conversion.

Standard conversion sequences are applied to expressions, if necessary, to convert it to a required destination type.

4.1 Lvalue-to-rvalue conversion [Conv.lval]

1 A glvalue of a non-function type `T` can be converted to a prvalue. The program is ill-formed if `T` is an incomplete type. If the glvalue refers to an object that is not of type `T` and is not an object of a type derived from `T`, the program is ill-formed. If the glvalue refers to an object that is uninitialized, the behavior is undefined. Otherwise the prvalue is of type `T`.

2 If the glvalue refers to an array of type `T`, the prvalue will refer to a copy of the array, not memory referred to by the glvalue.

4.2 Array-to-pointer conversion [Conv.array]

1 An lvalue or rvalue of type `T[N]` (constant-sized array), can be converted to a prvalue of type pointer to `T`. [*Note: HLSL does not support grammar for specifying pointer or reference types, however they are used in the type system and must be described in language rules.*]

4.3 Integral conversion [Conv.iconv]

1 A glvalue of an integer type can be converted to a cxvalue of any other non-enumeration integer type. A prvalue of an integer type can be converted to a prvalue of any other integer type.

2 If the destination type is unsigned, integer conversion maintains the bit pattern of the source value in the destination type truncating or extending the value to the destination type.

3 If the destination type is signed, the value is unchanged if the destination type can represent the source value. If the destination type cannot represent the source value, the result is implementation-defined.

4 If the source type is `bool`, the values `true` and `false` are converted to one and zero respectively.

4.4 Floating point conversion [Conv.fconv]

1 A glvalue of a floating point type can be converted to a cxvalue of any other floating point type. A prvalue of a floating point type can be converted to a prvalue of any other floating point type.

2 If the source value can be exactly represented in the destination type, the conversion produces the exact representation of the source value. If the source value cannot be exactly represented, the conversion to a best-approximation of the source value is implementation defined.

[1] This differs from C++ with the addition of vector splat and truncation casting and flat conversions.
[2] C++ does not support this conversion in the sequence for component-wise conversion of vector and matrix types.

4.5 Floating point-integral conversion [Conv.fpint]

1 A glvalue of floating point type can be converted to a cxvalue of integer type. A prvalue of floating point type can be converted to a prvalue of integer type. Conversion of floating point values to integer values truncates by discarding the fractional value. The behavior is undefined if the truncated value cannot be represented in the destination type.

2 A glvalue of integer type can be converted to a cxvalue of floating point type. A prvalue of integer type can be converted to a prvalue of floating point type. If the destination type can exactly represent the source value, the result is the exact value. If the destination type cannot exactly represent the source value, the conversion to a best-approximation of the source value is implementation defined.

4.6 Boolean conversion [Conv.bool]

1 A glvalue of arithmetic type can be converted to a cxvalue of boolean type. A prvalue of arithmetic or unscoped enumeration type can be converted to a prvalue of boolean type. A zero value is converted to `false`; all other values are converted to `true`.

4.7 Vector splat conversion [Conv.vsplat]

1 A glvalue of type `T` can be converted to a cxvalue of type `vector<T,x>` or a prvalue of type `T` can be converted to a prvalue of type `vector<T,x>`. The destination value is the source value replicated into each element of the destination.

2 A glvalue of type `T` can be converted to a cxvalue of type `matrix<T,x,y>` or a prvalue of type `T` can be converted to a prvalue of type `matrix<T,x,y>`. The destination value is the source value replicated into each element of the destination.

4.8 Vector and matrix truncation conversion [Conv.vtrunc]

1 A glvalue of type `vector<T,x>` can be converted to a cxvalue of type `vector<T,y>`, or a prvalue of type `vector<T,x>` can be converted to a prvalue of type `vector<T,y>` only if $y < x$. The resulting value is comprised of elements $[0..y)$, dropping elements [y+1..x).

2 A glvalue of type `matrix<T,x,y>` can be converted to a cxvalue of type `matrix<T,z,w>`, or a prvalue of type `matrix<T,x,y>` can be converted to a prvalue of type `matrix<T,z,w>` only if $x \leq z$ and $y \leq w$. Matrix truncation is performed on each row and column dimension separately. The resulting value is comprised of vectors $[0..z)$ which are each separately comprised of elements $[0..w)$. Trailing vectors and elements are dropped.

4.9 Component-wise conversions [Conv.cwise]

1 A glvalue of type `vector<T,x>` can be converted to a cxvalue of type `vector<V,x>`, or a prvalue of type `vector<T,x>` can be converted to a prvalue of type `vector<V,x>`. The source value is converted by performing the appropriate conversion of each element of type `T` to an element of type `V` following the rules for standard conversions in chapter 4.

2 A glvalue of type `matrix<T,x,y>` can be converted to a cxvalue of type `matrix<V,x,y>`, or a prvalue of type `matrix<T,x,y>` can be converted to a prvalue of type `matrix<V,x,y>`. The source value is converted by performing the appropriate conversion of each element of type `T` to an element of type `V` following the rules for standard conversions in chapter 4.

4.10 Qualification conversion [Conv.qual]

A prvalue of type "*cv1* `T`" can be converted to a prvalue of type "*cv2* `T`" if type "*cv2* `T`" is more cv-qualified than "*cv1* `T`".

4.11 Conversion Rank [Conv.rank]

1 Every integer and floating point type have defined conversion ranks. A *promotion* is any conversion of a value from a lower conversion rank to a higher conversion rank.

4.11.1 Integer Conversion Rank [Conv.rank.int]

- No two signed integer types shall have the same conversion rank even if they have the same representation.
- The rank of a signed integer type shall be greater than the rank of any signed integer type with a smaller size.
- The rank of any unsigned integer type shall equal the rank of the corresponding signed integer type.
- The rank of `bool` shall be less than the rank of all other standard integer types.
- The rank of a minimum precision integer type shall be less than the rank of any other minimum precision integer type with a larger minimum value representation size.
- The rank of a minimum precision integer type shall be less than the rank of all standard integer types.
- For all integer types `T1`, `T2`, and `T3`: if `T1` has greater rank than `T2` and `T2` has greater rank than `T3`, then `T1` shall have greater rank than `T3`.

4.11.2 Floating Point Conversion Rank [Conv.rank.float]

- The rank `half` shall be greater than the rank of `min16float`.
- The rank `float` shall be greater than the rank of `half`.
- The rank `double` shall be greater than the rank of `float`.
- For all floating point types `T1`, `T2`, and `T3`: if `T1` has greater rank than `T2` and `T2` has greater rank than `T3`, then `T1` shall have greater rank than `T3`.

5 Expressions [Expr]

1 This chapter defines the formulations of expressions and the behavior of operators when they are not overloaded. Only member operators may be overloaded[1]. Operator overloading does not alter the rules for operators defined by this standard.

2 An expression may also be an *unevaluated operand* when it appears in some contexts. An *unevaluated operand* is a expression which is not evaluated in the program[2].

3 Whenever a *glvalue* appears in an expression that expects a *prvalue*, a standard conversion sequence is applied based on the rules in 4.

5.1 Usual Arithmetic Conversions [Expr.conv]

1 Binary operators for arithmetic and enumeration type require that both operands are of a common type. When the types do not match the *usual arithmetic conversions* are applied to yield a common type. When *usual arithmetic conversions* are applied to vector operands they behave as component-wise conversions (4.9). The *usual arithmetic conversions* are:

- If either operand is of scoped enumeration type no conversion is performed, and the expression is ill-formed if the types do not match.
- If either operand is a `vector<T,X>`, vector extension is performed with the following rules:
  - If both vectors are of the same length, no extension is required.
  - If one operand is a vector and the other operand is a scalar, the scalar is extended to a vector via a Splat conversion (4.7).
  - Otherwise, if both operands are vectors of different lengths, the expression is ill-formed.
- If either operand is of type `double` or `vector<double, X>`, the other operator shall be converted to match.
- Otherwise, if either operand is of type `float` or `vector<float, X>`, the other operand shall be converted to match.
- Otherwise, if either operand is of type `half` or `vector<half, X>`, the other operand shall be converted to match.
- Otherwise, integer promotions are performed on each scalar or vector operand following the appropriate scalar or component-wise conversion (4).
  - If both operands are scalar or vector elements of signed or unsigned types, the operand of lesser integer conversion rank shall be converted to the type of the operand with greater rank.
  - Otherwise, if both the operand of unsigned scalar or vector element type is of greater rank than the operand of signed scalar or vector element type, the signed operand is converted to the type of the unsigned operand.
  - Otherwise, if the operand of signed scalar or vector element type is able to represent all values of the operand of unsigned scalar or vector element type, the unsigned operand is converted to the type of the signed operand.
  - Otherwise, both operands are converted to a scalar or vector type of the unsigned integer type corresponding to the type of the operand with signed integer scalar or vector element type.

[1] This will change in the future, but this document assumes current behavior.

[2] The operand to `sizeof(...)` is a good example of an *unevaluated operand*. In the code `sizeof(Foo())`, the call to `Foo()` is never evaluated in the program.

5.2 Primary Expressions [Expr.Primary]

primary-expression:
    literal
    `this`
    `(` *expression* `)`
    id-expression

5.2.1 Literals [Expr.Primary.Literal]

1 The type of a *literal* is determined based on the grammar forms specified in 2.9.1.

5.2.2 This [Expr.Primary.This]

1 The keyword `this` names a reference to the implicit object of non-static member functions. The `this` parameter is always a *prvalue* of non-*cv-qualified*type. [3]

2 A `this` expression shall not appear outside the declaration of a non-static member function.

5.2.3 Parenthesis [Expr.Primary.Paren]

1 An expression (E) enclosed in parenthesis has the same type, result and value category as E without the enclosing parenthesis. A parenthesized expression may be used in the same contexts with the same meaning as the same non-parenthesized expression.

5.2.4 Names [Expr.Primary.ID]

> The grammar and behaviors of this section are almost identical to C/C++ with some subtractions (notably lambdas and destructors).

id-expression:
    unqualified-id
    qualified-id

5.2.4.1 Unqualified Identifiers [Expr.Primary.ID.Unqual]

unqualified-id:
    identifier
    operator-function-id
    conversion-function-id
    template-id

5.2.4.2 Qualified Identifiers [Expr.Primary.ID.Qual]

qualified-id:
    nested-name-specifier `template`$_{opt}$ *unqualified-id*

nested-name-specifier:
    `::`
    type-name `::`
    namespace-name `::`
    nested-name-specifier identifier `::`
    nested-name-specifier `template`$_{opt}$ *simple-template-id* `::`

[3] HLSL Specs Proposal 0007 proposes adopting C++-like syntax and semantics for *cv-qualified* `this` references.

5.3 Postfix Expressions [Expr.Post]

postfix-expression:
primary-expression
postfix-expression `[` *expression* `]`
postfix-expression `[` *braced-init-list* `]`
postfix-expression `(` *expression-list*$_{opt}$ `)`
simple-type-specifier `(` *expression-list*$_{opt}$ `)`
typename-specifier `(` *expression*$_{opt}$ `)`
simple-type-specifier braced-init-list
typename-specifier braced-init-list
postfix-expression `.` `template`$_{opt}$ *id-expression*
postfix-expression `->` `template`$_{opt}$ *id-expression*
postfix-expression `++`
postfix-expression `--`

5.4 Subscript [Expr.Post.Subscript]

1 A *postfix-expression* followed by an expression in square brackets (`[ ]`) is a subscript expression. In an array subscript expression of the form `E1[E2]`, `E1` must either be a variable of array of `T[]`, or an object of type `T` where `T` provides an overloaded implementation of `operator[]` (8).[4]

5.5 Function Calls [Expr.Post.Call]

1 A function call may be an *ordinary function*, or a *member function*. In a function call to an *ordinary function*, the *postfix-expression* must be an lvalue that refers to a function. In a function call to a *member function*, the *postfix-expression* will be an implicit or explicit class member access whose *id-expression* is a member function name.

2 When a function is called, each parameter shall be initialized with its corresponding argument. The order in which parameters are initialized is unspecified. [5]

3 If the function is a non-static member function the `this` argument shall be initialized to a reference to the object of the call as if casted by an explicit cast expression to an lvalue reference of the type that the function is declared as a member of.

4 Parameters are either *input parameters*, *output parameters*, or *input/output parameters* as denoted in the called function's declaration (6.1).

5 *Input parameters* are passed by-value into a function. If an argument to an *input parameter* is of constant-sized array type, the array is copied to a temporary and the temporary value is converted to an address via array-to-pointer decay. If an argument is an unsized array type, the array lvalue directly decays via array-to-pointer decay. [6]

6 Arguments to *output* and *input/output parameters* must be lvalues. *Output parameters* are not initialized prior to the call; they are passed as an uninitialized cxvalue (3.2). An *output parameter* is only initialized explicitly inside the called function. It is undefined behavior to not explicitly initialize an *output parameter* before returning from the function in which it is defined. The cxvalue created from an argument to an *input/output parameter* is initialized through copy-initialization from the lvalue argument expression. In both cases, the cxvalue shall have the type of the parameter and the argument can be converted to that type through implicit or explicit conversion.

7 If an argument to an *output* or *input/output parameter* is a constant sized array, the array is copied to a temporary cxvalue following the same rules for any other data type. If an argument to an *output* or *input/output parameter* is an unsized array type, the array lvalue directly decays via array-to-pointer decay. An argument of a constant sized array of

[4] HLSL does not support the base address of a subscript operator being the expression inside the braces, which is valid in C and C++.
[5] Today in DXC targeting DXIL matches the Microsoft C++ ABI and evaluates argument expressions right-to-left, while SPIR-V generation matches the Itanium ABI evaluating parameters left-to-right. There are good arguments for unifying these behaviors, and arguments for keeping them different.
[6] This results in *input* parameters of unsized arrays being modifiable by a function.

type `T[N]` can be converted to a cxvalue of an unsized array of type `T[]` through array to pointer decay. An unsized array of type `T[]`, cannot be implicitly converted to a a constant sized array of type `T[N]`.

8 On expiration of the cxvalue, the value is assigned back to the argument lvalue expression following an inverted conversion if applicable. The argument expression must be of a type or able to convert to a type that has defined copy-initialization to and from the parameter type. The lifetime of the cxvalue begins at argument expression evaluation, and ends after the function returns. A cxvalue argument is passed by-address to the caller.

9 If the lvalue passed to an *output* or *input/output parameter* does not alias any other parameter passed to that function, an implementation may avoid the creation of excess temporaries by passing the address of the lvalue instead of creating the cxvalue.

10 When a function is called, any parameter of object type must have completely defined type, and any parameter of array of object type must have completely defined element type.[7] The lifetime of a parameter ends on return of the function in which it is defined.[8] Initialization and destruction of each parameter occurs within the context of the calling function.

11 The value of a function call is the value returned by the called function.

12 A function call is an lvalue if the result type is an lvalue reference type; otherwise it is a prvalue.

13 If a function call is a prvalue of object type, the type of the prvalue must be complete.

[7] HLSL *output* and *input/output parameters* are passed by value, so they must also have complete type.

[8] As stated above cxvalue parameters are passed-by-address, so the expiring parameter is the reference to the address, not the cxvalue. The cxvalue expires in the caller.

6 Declarations [Decl]

6.1 Function Definitions [Decl.Function]

6.2 Attributes [Decl.Attr]

6.2.1 Entry Attributes [Decl.Attr.Entry]

7 Classes [Classes]

8 Overloading [Overload]

9 Intangible Types [Intangible]

10 Runtime [Runtime]

Acronyms

API Application Programming Interface. 29

C C Programming Language. 3

C++ C++ Programming Language. 3

DXC DirectX Shader Compiler. 3, 13

FXC Legacy DirectX Shader Compiler. 3, 13

HLSL High Level Shader Language. 1, 3–8, 16

SIMD Single Instruction Multiple Data. 5

SIMT Single Instruction Multiple Thread. 5

SPMD Single Program Multiple Data. 1, 5, 6, 29

Glossary

DirectX DirectX is the multimedia API introduced with Windows 95.. 3, 4, 7

Dispatch A group of one or more Thread Groups which comprise the largest unit of a shader execution. Also called: grid, compute space or index space.. 6

IEEE Standard 754 IEEE Standard For Floating Point Arithmetic. 15

ISO C standard (2011) ISO/IEC 9899:2011: Standard for Programming Language C.. 3, 8, 12

ISO C standard (2023) ISO/IEC 9899:2023: Standard for Programming Language C.. 14

ISO C++ standard (2011) ISO/IEC 14882:2011: Standard for Programming Language C++.. 3, 8, 15, 16

Lane The computation performed on a single element as described in the SPMD program. Also called: thread.. 5–7, 29

Quad A group of four Lanes which form a cluster of adjacent computations in the data topology. Also called: quad-group or quad-wave. . 5, 6

Shader Model Versioned hardware description included as part of the DirectX specification, which is used for code generation to a common set of features across a range of vendors.. 4, 7

Thread Group A group of Lanes which may be subdivided into one or more Waves and comprise a larger computation. Also known as: group, workgroup, block or thread block.. 5–7, 29

Wave A group of Lanes which execute together. The number of Lanes in a Wave varies by hardware implementation. Also called: warp, SIMD-group, subgroup, or wavefront.. 5, 6, 29