



The OpenCL[™] Specification

Khronos[®] OpenCL Working Group

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Chapter 1. Introduction

Modern processor architectures have embraced parallelism as an important pathway to increased performance. Facing technical challenges with higher clock speeds in a fixed power envelope, Central Processing Units (CPUs) now improve performance by adding multiple cores. Graphics Processing Units (GPUs) have also evolved from fixed function rendering devices into programmable parallel processors. As today's computer systems often include highly parallel CPUs, GPUs and other types of processors, it is important to enable software developers to take full advantage of these heterogeneous processing platforms.

Creating applications for heterogeneous parallel processing platforms is challenging as traditional programming approaches for multi-core CPUs and GPUs are very different. CPU-based parallel programming models are typically based on standards but usually assume a shared address space and do not encompass vector operations. General purpose GPU programming models address complex memory hierarchies and vector operations but are traditionally platform-, vendor- or hardware-specific. These limitations make it difficult for a developer to access the compute power of heterogeneous CPUs, GPUs and other types of processors from a single, multi-platform source code base. More than ever, there is a need to enable software developers to effectively take full advantage of heterogeneous processing platforms from high performance compute servers, through desktop computer systems to handheld devices - that include a diverse mix of parallel CPUs, GPUs and other processors such as DSPs and the Cell/B.E. processor.

OpenCL (Open Computing Language) is an open royalty-free standard for general purpose parallel programming across CPUs, GPUs and other processors, giving software developers portable and efficient access to the power of these heterogeneous processing platforms.

OpenCL supports a wide range of applications, ranging from embedded and consumer software to HPC solutions, through a low-level, high-performance, portable abstraction. By creating an efficient, close-to-the-metal programming interface, OpenCL will form the foundation layer of a parallel computing ecosystem of platform-independent tools, middleware and applications. OpenCL is particularly suited to play an increasingly significant role in emerging interactive graphics applications that combine general parallel compute algorithms with graphics rendering pipelines.

OpenCL consists of an API for coordinating parallel computation across heterogeneous processors, a cross-platform programming language, and a cross-platform intermediate language with a well-specified computation environment. The OpenCL standard:

- Supports both data- and task-based parallel programming models
- Supports kernels written using a subset of ISO C99 with extensions for parallel execution
- Supports kernels represented by a portable and self-contained intermediate language (e.g. SPIR-V) with support for parallel execution
- Defines consistent numerical requirements based on IEEE 754
- Defines a configuration profile for handheld and embedded devices
- Supports efficient interop with OpenGL, OpenGL ES and other APIs

This document begins with an overview of basic concepts and the architecture of OpenCL, followed by a detailed description of its execution model, memory model and synchronization support. It

then discusses the OpenCL platform and runtime API. Some examples are given that describe sample compute use-cases and how they would be written in OpenCL. The specification is divided into a core specification that any OpenCL compliant implementation must support; a handheld/embedded profile which relaxes the OpenCL compliance requirements for handheld and embedded devices; and a set of optional extensions that are likely to move into the core specification in later revisions of the OpenCL specification.

1.1. Normative References

Normative references are references to external documents or resources to which implementers of OpenCL must comply with all, or specified portions of, as described in this specification.

ISO/IEC 9899:2011 - *Information technology - Programming languages - C*, <https://www.iso.org/standard/57853.html> (final specification), <http://www.open-std.org/jtc1/sc22/WG14/www/docs/n1570.pdf> (last public draft).

1.2. Version Numbers

The OpenCL version number follows a *major.minor-revision* scheme. When this version number is used within the API it generally only includes the *major.minor* components of the version number.

A difference in the *major* or *minor* version number indicates that some amount of new functionality has been added to the specification, and may also include behavior changes and bug fixes. Functionality may also be deprecated or removed when the *major* or *minor* version changes.

A difference in the *revision* number indicates small changes to the specification, typically to fix a bug or to clarify language. When the *revision* number changes there may be an impact on the behavior of existing functionality, but this should not affect backwards compatibility. Functionality should not be added or removed when the *revision* number changes.

1.3. Unified Specification

This document specifies all versions of the OpenCL API.

There are three ways that an OpenCL feature may be described in terms of what versions of OpenCL support that feature.

- Missing before *major.minor*: Features that were introduced in version *major.minor*. Implementations of an earlier version of OpenCL will not provide these features.
- Deprecated by *major.minor*: Features that were deprecated in version *major.minor*, see the definition of deprecation in the glossary.
- Universal: Features that have no mention of what version they are missing before or deprecated by are available in all versions of OpenCL.

Chapter 2. Glossary

Application

The combination of the program running on the host and OpenCL devices.

Acquire semantics

One of the memory order semantics defined for synchronization operations. Acquire semantics apply to atomic operations that load from memory. Given two units of execution, **A** and **B**, acting on a shared atomic object **M**, if **A** uses an atomic load of **M** with acquire semantics to synchronize-with an atomic store to **M** by **B** that used release semantics, then **A**'s atomic load will occur before any subsequent operations by **A**. Note that the memory orders *release*, *sequentially consistent*, and *acquire_release* all include *release semantics* and effectively pair with a load using acquire semantics.

Acquire release semantics

A memory order semantics for synchronization operations (such as atomic operations) that has the properties of both acquire and release memory orders. It is used with read-modify-write operations.

Atomic operations

Operations that at any point, and from any perspective, have either occurred completely, or not at all. Memory orders associated with atomic operations may constrain the visibility of loads and stores with respect to the atomic operations (see *relaxed semantics*, *acquire semantics*, *release semantics* or *acquire release semantics*).

Blocking and Non-Blocking Enqueue API calls

A *non-blocking enqueue API call* places a *command* on a *command-queue* and returns immediately to the host. The *blocking-mode enqueue API calls* do not return to the host until the command has completed.

Barrier

There are three types of *barriers* a *command-queue barrier*, a *work-group barrier*, and a *sub-group barrier*.

- The OpenCL API provides a function to enqueue a *command-queue barrier* command. This *barrier* command ensures that all previously enqueued commands to a *command-queue* have finished execution before any following *commands* enqueued in the *command-queue* can begin execution.
- The OpenCL kernel execution model provides built-in *work-group barrier* functionality. This *barrier* built-in function can be used by a *kernel* executing on a *device* to perform synchronization between *work-items* in a *work-group* executing the *kernel*. All the *work-items* of a *work-group* must execute the *barrier* construct before any are allowed to continue execution beyond the *barrier*.
- The OpenCL kernel execution model provides built-in *sub-group barrier* functionality. This *barrier* built-in function can be used by a *kernel* executing on a *device* to perform synchronization between *work-items* in a *sub-group* executing the *kernel*. All the *work-items* of a *sub-group* must execute the *barrier* construct before any are allowed to continue

execution beyond the *barrier*.

Buffer Object

A memory object that stores a linear collection of bytes. Buffer objects are accessible using a pointer in a *kernel* executing on a *device*. Buffer objects can be manipulated by the host using OpenCL API calls. A *buffer object* encapsulates the following information:

- Size in bytes.
- Properties that describe usage information and which region to allocate from.
- Buffer data.

Built-in Kernel

A *built-in kernel* is a *kernel* that is executed on an OpenCL *device* or *custom device* by fixed-function hardware or in firmware. *Applications* can query the *built-in kernels* supported by a *device* or *custom device*. A *program object* can only contain *kernels* written in OpenCL C or *built-in kernels* but not both. See also *Kernel* and *Program*.

Child kernel

See *Device-side enqueue*.

Command

The OpenCL operations that are submitted to a *command-queue* for execution. For example, OpenCL commands issue kernels for execution on a compute device, manipulate memory objects, etc.

Command-queue

An object that holds *commands* that will be executed on a specific *device*. The *command-queue* is created on a specific *device* in a *context*. *Commands* to a *command-queue* are queued in-order but may be executed in-order or out-of-order. Refer to *In-order Execution* and *Out-of-order Execution*.

Command-queue Barrier

See *Barrier*.

Command synchronization

Constraints on the order that commands are launched for execution on a device defined in terms of the synchronization points that occur between commands in host command-queues and between commands in device-side command-queues. See *synchronization points*.

Complete

The final state in the six state model for the execution of a command. The transition into this state occurs is signaled through event objects or callback functions associated with a command.

Compute Device Memory

This refers to one or more memories attached to the compute device.

Compute Unit

An OpenCL *device* has one or more *compute units*. A *work-group* executes on a single *compute unit*. A *compute unit* is composed of one or more *processing elements* and *local memory*. A

compute unit may also include dedicated texture filter units that can be accessed by its processing elements.

Concurrency

A property of a system in which a set of tasks in a system can remain active and make progress at the same time. To utilize concurrent execution when running a program, a programmer must identify the concurrency in their problem, expose it within the source code, and then exploit it using a notation that supports concurrency.

Constant Memory

A region of *global memory* that remains constant during the execution of a *kernel*. The *host* allocates and initializes memory objects placed into *constant memory*.

Context

The environment within which the kernels execute and the domain in which synchronization and memory management is defined. The *context* includes a set of *devices*, the memory accessible to those *devices*, the corresponding memory properties and one or more *command-queues* used to schedule execution of a *kernel(s)* or operations on *memory objects*.

Control flow

The flow of instructions executed by a work-item. Multiple logically related work-items may or may not execute the same control flow. The control flow is said to be *converged* if all the work-items in the set execution the same stream of instructions. In a *diverged* control flow, the work-items in the set execute different instructions. At a later point, if a diverged control flow becomes converged, it is said to be a re-converged control flow.

Converged control flow

See *Control flow*.

Custom Device

An OpenCL *device* that fully implements the OpenCL Runtime but does not support *programs* written in OpenCL C. A custom device may be specialized non-programmable hardware that is very power efficient and performant for directed tasks or hardware with limited programmable capabilities such as specialized DSPs. Custom devices are not OpenCL conformant. Custom devices may support an online compiler. Programs for custom devices can be created using the OpenCL runtime APIs that allow OpenCL programs to be created from source (if an online compiler is supported) and/or binary, or from *built-in kernels* supported by the *device*. See also *Device*.

Data Parallel Programming Model

Traditionally, this term refers to a programming model where concurrency is expressed as instructions from a single program applied to multiple elements within a set of data structures. The term has been generalized in OpenCL to refer to a model wherein a set of instructions from a single program are applied concurrently to each point within an abstract domain of indices.

Data race

The execution of a program contains a data race if it contains two actions in different work-items or host threads where (1) one action modifies a memory location and the other action

reads or modifies the same memory location, and (2) at least one of these actions is not atomic, or the corresponding memory scopes are not inclusive, and (3) the actions are global actions unordered by the global-happens-before relation or are local actions unordered by the local-happens-before relation.

Deprecation

Existing features are marked as deprecated if their usage is not recommended as that feature is being de-emphasized, superseded and may be removed from a future version of the specification.

Device

A *device* is a collection of *compute units*. A *command-queue* is used to queue *commands* to a *device*. Examples of *commands* include executing *kernels*, or reading and writing *memory objects*. OpenCL devices typically correspond to a GPU, a multi-core CPU, and other processors such as DSPs and the Cell/B.E. processor.

Device-side enqueue

A mechanism whereby a kernel-instance is enqueued by a kernel-instance running on a device without direct involvement by the host program. This produces *nested parallelism*; i.e. additional levels of concurrency are nested inside a running kernel-instance. The kernel-instance executing on a device (the *parent kernel*) enqueues a kernel-instance (the *child kernel*) to a device-side command-queue. Child and parent kernels execute asynchronously though a parent kernel does not complete until all of its child-kernels have completed.

Diverged control flow

See *Control flow*.

Ended

The fifth state in the six state model for the execution of a command. The transition into this state occurs when execution of a command has ended. When a Kernel-enqueue command ends, all of the work-groups associated with that command have finished their execution.

Event Object

An *event object* encapsulates the status of an operation such as a *command*. It can be used to synchronize operations in a context.

Event Wait List

An *event wait list* is a list of *event objects* that can be used to control when a particular *command* begins execution.

Fence

A memory ordering operation without an associated atomic object. A fence can use the *acquire semantics*, *release semantics*, or *acquire release semantics*.

Framework

A software system that contains the set of components to support software development and execution. A *framework* typically includes libraries, APIs, runtime systems, compilers, etc.

Generic address space

An address space that include the *private*, *local*, and *global* address spaces available to a device. The generic address space supports conversion of pointers to and from private, local and global address spaces, and hence lets a programmer write a single function that at compile time can take arguments from any of the three named address spaces.

Global-happens-before

See *Happens-before*.

Global ID

A *global ID* is used to uniquely identify a *work-item* and is derived from the number of *global work-items* specified when executing a *kernel*. The *global ID* is a N-dimensional value that starts at (0, 0, ... 0). See also *Local ID*.

Global Memory

A memory region accessible to all *work-items* executing in a *context*. It is accessible to the *host* using *commands* such as read, write and map. *Global memory* is included within the *generic address space* that includes the private and local address spaces.

GL share group

A *GL share group* object manages shared OpenGL or OpenGL ES resources such as textures, buffers, framebuffers, and renderbuffers and is associated with one or more GL context objects. The *GL share group* is typically an opaque object and not directly accessible.

Handle

An opaque type that references an *object* allocated by OpenCL. Any operation on an *object* occurs by reference to that object's handle. Each object must have a unique handle value during the course of its lifetime. Handle values may be, but are not required to be, re-used by an implementation.

Happens-before

An ordering relationship between operations that execute on multiple units of execution. If an operation A happens-before operation B then A must occur before B; in particular, any value written by A will be visible to B. We define two separate happens-before relations: *global-happens-before* and *local-happens-before*. These are defined in [Memory Ordering Rules](#).

Host

The *host* interacts with the *context* using the OpenCL API.

Host-thread

The unit of execution that executes the statements in the host program.

Host pointer

A pointer to memory that is in the virtual address space on the *host*.

Illegal

Behavior of a system that is explicitly not allowed and will be reported as an error when encountered by OpenCL.

Image Object

A *memory object* that stores a two- or three-dimensional structured array. Image data can only be accessed with read and write functions. The read functions use a *sampler*.

The *image object* encapsulates the following information:

- Dimensions of the image.
- Description of each element in the image.
- Properties that describe usage information and which region to allocate from.
- Image data.

The elements of an image are selected from a list of predefined image formats.

Implementation-Defined

Behavior that is explicitly allowed to vary between conforming implementations of OpenCL. An OpenCL implementor is required to document the implementation-defined behavior.

Independent Forward Progress

If an entity supports independent forward progress, then if it is otherwise not dependent on any actions due to be performed by any other entity (for example it does not wait on a lock held by, and thus that must be released by, any other entity), then its execution cannot be blocked by the execution of any other entity in the system (it will not be starved). Work-items in a sub-group, for example, typically do not support independent forward progress, so one work-item in a sub-group may be completely blocked (starved) if a different work-item in the same sub-group enters a spin loop.

In-order Execution

A model of execution in OpenCL where the *commands* in a *command-queue* are executed in order of submission with each *command* running to completion before the next one begins. See *Out-of-order Execution*.

Intermediate Language

A lower-level language that may be used to create programs. SPIR-V is a required intermediate language (IL) for OpenCL 2.1 and 2.2 devices. Other OpenCL devices may optionally support SPIR-V or other ILs.

Kernel

A *kernel* is a function declared in a *program* and executed on an OpenCL *device*. A *kernel* is identified by the `__kernel` or `kernel` qualifier applied to any function defined in a *program*.

Kernel-instance

The work carried out by an OpenCL program occurs through the execution of kernel-instances on devices. The kernel instance is the *kernel object*, the values associated with the arguments to the kernel, and the parameters that define the *ND-range* index space.

Kernel Object

A *kernel object* encapsulates a specific *kernel* function declared in a *program* and the argument

values to be used when executing this *kernel* function.

Kernel Language

A language that is used to represent source code for kernel. Kernels may be directly created from OpenCL C kernel language source strings. Other kernel languages may be supported by compiling to SPIR-V, another supported Intermediate Language, or to a device-specific program binary format.

Launch

The transition of a command from the *submitted* state to the *ready* state. See *Ready*.

Local ID

A *local ID* specifies a unique *work-item ID* within a given *work-group* that is executing a *kernel*. The *local ID* is a N-dimensional value that starts at (0, 0, ... 0). See also *Global ID*.

Local Memory

A memory region associated with a *work-group* and accessible only by *work-items* in that *work-group*. *Local memory* is included within the *generic address space* that includes the private and global address spaces.

Marker

A *command* queued in a *command-queue* that can be used to tag all *commands* queued before the *marker* in the *command-queue*. The *marker* command returns an *event* which can be used by the *application* to queue a wait on the marker event i.e. wait for all commands queued before the *marker* command to complete.

Memory Consistency Model

Rules that define which values are observed when multiple units of execution load data from any shared memory plus the synchronization operations that constrain the order of memory operations and define synchronization relationships. The memory consistency model in OpenCL is based on the memory model from the ISO C11 programming language.

Memory Objects

A *memory object* is a handle to a reference counted region of *Global Memory*. Also see *Buffer Object* and *Image Object*.

Memory Regions (or Pools)

A distinct address space in OpenCL. *Memory regions* may overlap in physical memory though OpenCL will treat them as logically distinct. The *memory regions* are denoted as *private*, *local*, *constant*, and *global*.

Memory Scopes

These memory scopes define a hierarchy of visibilities when analyzing the ordering constraints of memory operations. They are defined by the values of the **memory_scope** enumeration constant. Current values are **memory_scope_work_item** (memory constraints only apply to a single work-item and in practice apply only to image operations), **memory_scope_sub_group** (memory-ordering constraints only apply to work-items executing in a sub-group), **memory_scope_work_group** (memory-ordering constraints only apply to work-items executing

in a work-group), **memory_scope_device** (memory-ordering constraints only apply to work-items executing on a single device) and **memory_scope_all_svm_devices** or equivalently **memory_scope_all_devices** (memory-ordering constraints only apply to work-items executing across multiple devices and when using shared virtual memory).

Modification Order

All modifications to a particular atomic object M occur in some particular *total order*, called the *modification order* of M. If A and B are modifications of an atomic object M, and A happens-before B, then A shall precede B in the modification order of M. Note that the modification order of an atomic object M is independent of whether M is in local or global memory.

Nested Parallelism

See *device-side enqueue*.

Object

Objects are abstract representation of the resources that can be manipulated by the OpenCL API. Examples include *program objects*, *kernel objects*, and *memory objects*.

Out-of-order Execution

A model of execution in which *commands* placed in the *work queue* may begin and complete execution in any order consistent with constraints imposed by *event wait lists_and_command-queue barrier*. See *In-order Execution*.

Parent device

The OpenCL *device* which is partitioned to create *sub-devices*. Not all *parent devices* are *root devices*. A *root device* might be partitioned and the *sub-devices* partitioned again. In this case, the first set of *sub-devices* would be *parent devices* of the second set, but not the *root devices*. Also see *Device*, *parent device* and *root device*.

Parent kernel

see *Device-side enqueue*.

Pipe

The *pipe* memory object conceptually is an ordered sequence of data items. A pipe has two endpoints: a write endpoint into which data items are inserted, and a read endpoint from which data items are removed. At any one time, only one kernel instance may write into a pipe, and only one kernel instance may read from a pipe. To support the producer consumer design pattern, one kernel instance connects to the write endpoint (the producer) while another kernel instance connects to the reading endpoint (the consumer).

Platform

The *host* plus a collection of *devices* managed by the OpenCL *framework* that allow an application to share *resources* and execute *kernels* on *devices* in the *platform*.

Private Memory

A region of memory private to a *work-item*. Variables defined in one *work-items private memory* are not visible to another *work-item*.

Processing Element

A virtual scalar processor. A work-item may execute on one or more processing elements.

Program

An OpenCL *program* consists of a set of *kernels*. *Programs* may also contain auxiliary functions called by the *kernel* functions and constant data.

Program Object

A *program object* encapsulates the following information:

- A reference to an associated *context*.
- A *program* source or binary.
- The latest successfully built program executable, the list of *devices* for which the program executable is built, the build options used and a build log.
- The number of *kernel objects* currently attached.

Queued

The first state in the six state model for the execution of a command. The transition into this state occurs when the command is enqueued into a command-queue.

Ready

The third state in the six state model for the execution of a command. The transition into this state occurs when pre-requisites constraining execution of a command have been met; i.e. the command has been launched. When a kernel-enqueue command is launched, work-groups associated with the command are placed in a devices work-pool from which they are scheduled for execution.

Re-converged Control Flow

see *Control flow*.

Reference Count

The life span of an OpenCL object is determined by its *reference count*, an internal count of the number of references to the object. When you create an object in OpenCL, its *reference count* is set to one. Subsequent calls to the appropriate *retain* API (such as [clRetainContext](#), [clRetainCommandQueue](#)) increment the *reference count*. Calls to the appropriate *release* API (such as [clReleaseContext](#), [clReleaseCommandQueue](#)) decrement the *reference count*. Implementations may also modify the *reference count*, e.g. to track attached objects or to ensure correct operation of in-progress or scheduled activities. The object becomes inaccessible to host code when the number of *release* operations performed matches the number of *retain* operations plus the allocation of the object. At this point the reference count may be zero but this is not guaranteed.

Relaxed Consistency

A memory consistency model in which the contents of memory visible to different *work-items* or *commands* may be different except at a *barrier* or other explicit synchronization points.

Relaxed Semantics

A memory order semantics for atomic operations that implies no order constraints. The operation is *atomic* but it has no impact on the order of memory operations.

Release Semantics

One of the memory order semantics defined for synchronization operations. Release semantics apply to atomic operations that store to memory. Given two units of execution, **A** and **B**, acting on a shared atomic object **M**, if **A** uses an atomic store of **M** with release semantics to synchronize-with an atomic load to **M** by **B** that used acquire semantics, then **A**'s atomic store will occur *after* any prior operations by **A**. Note that the memory orders *acquire*, *sequentially consistent*, and *acquire_release* all include *acquire semantics* and effectively pair with a store using release semantics.

Remainder work-groups

When the work-groups associated with a kernel-instance are defined, the sizes of a work-group in each dimension may not evenly divide the size of the ND-range in the corresponding dimensions. The result is a collection of work-groups on the boundaries of the ND-range that are smaller than the base work-group size. These are known as *remainder work-groups*.

Running

The fourth state in the six state model for the execution of a command. The transition into this state occurs when the execution of the command starts. When a Kernel-enqueue command starts, one or more work-groups associated with the command start to execute.

Root device

A *root device* is an OpenCL *device* that has not been partitioned. Also see *Device*, *Parent device* and *Root device*.

Resource

A class of *objects* defined by OpenCL. An instance of a *resource* is an *object*. The most common *resources* are the *context*, *command-queue*, *program objects*, *kernel objects*, and *memory objects*. Computational resources are hardware elements that participate in the action of advancing a program counter. Examples include the *host*, *devices*, *compute units* and *processing elements*.

Retain, Release

The action of incrementing (retain) and decrementing (release) the reference count using an OpenCL *object*. This is a book keeping functionality to make sure the system doesn't remove an *object* before all instances that use this *object* have finished. Refer to *Reference Count*.

Sampler

An *object* that describes how to sample an image when the image is read in the *kernel*. The image read functions take a *sampler* as an argument. The *sampler* specifies the image addressing-mode i.e. how out-of-range image coordinates are handled, the filter mode, and whether the input image coordinate is a normalized or unnormalized value.

Scope inclusion

Two actions **A** and **B** are defined to have an inclusive scope if they have the same scope **P** such that: (1) if **P** is **memory_scope_sub_group**, and **A** and **B** are executed by work-items within the

same sub-group, or (2) if **P** is **memory_scope_work_group**, and **A** and **B** are executed by work-items within the same work-group, or (3) if **P** is **memory_scope_device**, and **A** and **B** are executed by work-items on the same device, or (4) if **P** is **memory_scope_all_svm_devices** or **memory_scope_all_devices**, if **A** and **B** are executed by host threads or by work-items on one or more devices that can share SVM memory with each other and the host process.

Sequenced before

A relation between evaluations executed by a single unit of execution. Sequenced-before is an asymmetric, transitive, pair-wise relation that induces a partial order between evaluations. Given any two evaluations **A** and **B**, if **A** is sequenced-before **B**, then the execution of **A** shall precede the execution of **B**.

Sequential consistency

Sequential consistency interleaves the steps executed by each unit of execution. Each access to a memory location sees the last assignment to that location in that interleaving.

Sequentially consistent semantics

One of the memory order semantics defined for synchronization operations. When using sequentially-consistent synchronization operations, the loads and stores within one unit of execution appear to execute in program order (i.e., the sequenced-before order), and loads and stores from different units of execution appear to be simply interleaved.

Shared Virtual Memory (SVM)

An address space exposed to both the host and the devices within a context. SVM causes addresses to be meaningful between the host and all of the devices within a context and therefore supports the use of pointer based data structures in OpenCL kernels. It logically extends a portion of the global memory into the host address space therefore giving work-items access to the host address space. There are three types of SVM in OpenCL:

Coarse-Grained buffer SVM

Sharing occurs at the granularity of regions of OpenCL buffer memory objects.

Fine-Grained buffer SVM

Sharing occurs at the granularity of individual loads/stores into bytes within OpenCL buffer memory objects.

Fine-Grained system SVM

Sharing occurs at the granularity of individual loads/stores into bytes occurring anywhere within the host memory.

SIMD

Single Instruction Multiple Data. A programming model where a *kernel* is executed concurrently on multiple *processing elements* each with its own data and a shared program counter. All *processing elements* execute a strictly identical set of instructions.

Specialization constants

Specialization constants are special constant objects that do not have known constant values in an intermediate language (e.g. SPIR-V). Applications may provide updated values for the

specialization constants before a program is built. Specialization constants that do not receive a value from an application shall use the default specialization constant value.

SPMD

Single Program Multiple Data. A programming model where a *kernel* is executed concurrently on multiple *processing elements* each with its own data and its own program counter. Hence, while all computational resources run the same *kernel* they maintain their own instruction counter and due to branches in a *kernel*, the actual sequence of instructions can be quite different across the set of *processing elements*.

Sub-device

An OpenCL *device* can be partitioned into multiple *sub-devices*. The new *sub-devices* alias specific collections of compute units within the parent *device*, according to a partition scheme. The *sub-devices* may be used in any situation that their parent *device* may be used. Partitioning a *device* does not destroy the parent *device*, which may continue to be used along side and intermingled with its child *sub-devices*. Also see *Device*, *Parent device* and *Root device*.

Sub-group

Sub-groups are an implementation-dependent grouping of work-items within a work-group. The size and number of sub-groups is implementation-defined.

Sub-group Barrier

See *Barrier*.

Submitted

The second state in the six state model for the execution of a command. The transition into this state occurs when the command is flushed from the command-queue and submitted for execution on the device. Once submitted, a programmer can assume a command will execute once its prerequisites have been met.

SVM Buffer

A memory allocation enabled to work with *Shared Virtual Memory (SVM)*. Depending on how the SVM buffer is created, it can be a coarse-grained or fine-grained SVM buffer. Optionally it may be wrapped by a *Buffer Object*. See *Shared Virtual Memory (SVM)*.

Synchronization

Synchronization refers to mechanisms that constrain the order of execution and the visibility of memory operations between two or more units of execution.

Synchronization operations

Operations that define memory order constraints in a program. They play a special role in controlling how memory operations in one unit of execution (such as work-items or, when using SVM a host thread) are made visible to another. Synchronization operations in OpenCL include *atomic operations* and *fences*.

Synchronization point

A synchronization point between a pair of commands (A and B) assures that results of command A happens-before command B is launched (i.e. enters the ready state) .

Synchronizes with

A relation between operations in two different units of execution that defines a memory order constraint in global memory (*global-synchronizes-with*) or local memory (*local-synchronizes-with*).

Task Parallel Programming Model

A programming model in which computations are expressed in terms of multiple concurrent tasks executing in one or more *command-queues*. The concurrent tasks can be running different *kernels*.

Thread-safe

An OpenCL API call is considered to be *thread-safe* if the internal state as managed by OpenCL remains consistent when called simultaneously by multiple *host* threads. OpenCL API calls that are *thread-safe* allow an application to call these functions in multiple *host* threads without having to implement mutual exclusion across these *host* threads i.e. they are also re-entrant-safe.

Undefined

The behavior of an OpenCL API call, built-in function used inside a *kernel* or execution of a *kernel* that is explicitly not defined by OpenCL. A conforming implementation is not required to specify what occurs when an undefined construct is encountered in OpenCL.

Unit of execution

A generic term for a process, OS managed thread running on the host (a host-thread), kernel-instance, host program, work-item or any other executable agent that advances the work associated with a program.

Valid Object

An OpenCL object is considered valid if it meets all of the following criteria:

- The object was created by a successful call to an OpenCL API function.
- The object has a strictly positive application-owned reference count.
- The object has not had its backing memory changed outside of normal usage by the OpenCL implementation (e.g. corrupted by the application, a library it uses, the implementation itself, or any other agent that can access the object's backing memory).

An object is only valid in the platform where it was created.

An OpenCL implementation must check for a **NULL** object to determine if an object is valid. The behavior for all other invalid objects is implementation-defined.

Work-group

A collection of related *work-items* that execute on a single *compute unit*. The *work-items* in the group execute the same *kernel-instance* and share *local memory* and *work-group functions*.

Work-group Barrier

See *Barrier*.

Work-group Function

A function that carries out collective operations across all the work-items in a work-group. Available collective operations are a barrier, reduction, broadcast, prefix sum, and evaluation of a predicate. A work-group function must occur within a *converged control flow*; i.e. all work-items in the work-group must encounter precisely the same work-group function.

Work-group Synchronization

Constraints on the order of execution for work-items in a single work-group.

Work-pool

A logical pool associated with a device that holds commands and work-groups from kernel-instances that are ready to execute. OpenCL does not constrain the order that commands and work-groups are scheduled for execution from the work-pool; i.e. a programmer must assume that they could be interleaved. There is one work-pool per device used by all command-queues associated with that device. The work-pool may be implemented in any manner as long as it assures that work-groups placed in the pool will eventually execute.

Work-item

One of a collection of parallel executions of a *kernel* invoked on a *device* by a *command*. A *work-item* is executed by one or more *processing elements* as part of a *work-group* executing on a *compute unit*. A *work-item* is distinguished from other work-items by its *global ID* or the combination of its *work-group ID* and its *local ID* within a *work-group*.

Chapter 3. The OpenCL Architecture

OpenCL is an open industry standard for programming a heterogeneous collection of CPUs, GPUs and other discrete computing devices organized into a single platform. It is more than a language. OpenCL is a framework for parallel programming and includes a language, API, libraries and a runtime system to support software development. Using OpenCL, for example, a programmer can write general purpose programs that execute on GPUs without the need to map their algorithms onto a 3D graphics API such as OpenGL or DirectX.

The target of OpenCL is expert programmers wanting to write portable yet efficient code. This includes library writers, middleware vendors, and performance oriented application programmers. Therefore OpenCL provides a low-level hardware abstraction plus a framework to support programming and many details of the underlying hardware are exposed.

To describe the core ideas behind OpenCL, we will use a hierarchy of models:

- Platform Model
- Memory Model
- Execution Model
- Programming Model

3.1. Platform Model

The [Platform model](#) for OpenCL is defined below. The model consists of a **host** connected to one or more **OpenCL devices**. An OpenCL device is divided into one or more **compute units** (CUs) which are further divided into one or more **processing elements** (PEs). Computations on a device occur within the processing elements.

An OpenCL application is implemented as both host code and device kernel code. The host code portion of an OpenCL application runs on a host processor according to the models native to the host platform. The OpenCL application host code submits the kernel code as commands from the host to OpenCL devices. An OpenCL device executes the commands computation on the processing elements within the device.

An OpenCL device has considerable latitude on how computations are mapped onto the devices processing elements. When processing elements within a compute unit execute the same sequence of statements across the processing elements, the control flow is said to be *converged*. Hardware optimized for executing a single stream of instructions over multiple processing elements is well suited to converged control flows. When the control flow varies from one processing element to another, it is said to be *diverged*. While a kernel always begins execution with a converged control flow, due to branching statements within a kernel, converged and diverged control flows may occur within a single kernel. This provides a great deal of flexibility in the algorithms that can be implemented with OpenCL.

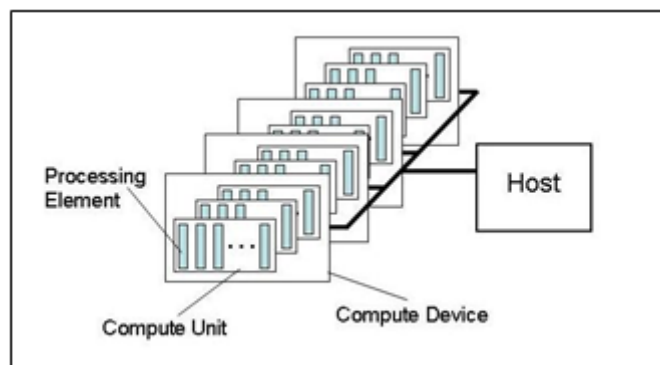


Figure 1. Platform Model ... one host plus one or more compute devices each with one or more compute units composed of one or more processing elements.

Programmers may provide programs in the form of OpenCL C source strings, the SPIR-V intermediate language, or as implementation-defined binary objects. An OpenCL platform provides a compiler to translate programs of these forms into executable program objects. The device code compiler may be *online* or *offline*. An *online compiler* is available during host program execution using standard APIs. An *offline compiler* is invoked outside of host program control, using platform-specific methods. The OpenCL runtime allows developers to get a previously compiled device program executable and be able to load and execute a previously compiled device program executable.

OpenCL defines two kinds of platform profiles: a *full profile* and a reduced-functionality *embedded profile*. A full profile platform must provide an online compiler for all its devices. An embedded platform may provide an online compiler, but is not required to do so.

A device may expose special purpose functionality as a *built-in kernel*. The platform provides APIs for enumerating and invoking the built-in kernels offered by a device, but otherwise does not define their construction or semantics. A *custom device* supports only built-in kernels, and cannot be programmed via a kernel language.



Built-in kernels and custom devices are [missing before](#) version 1.2.

All device types support the OpenCL execution model, the OpenCL memory model, and the APIs used in OpenCL to manage devices.

The platform model is an abstraction describing how OpenCL views the hardware. The relationship between the elements of the platform model and the hardware in a system may be a fixed property of a device or it may be a dynamic feature of a program dependent on how a compiler optimizes code to best utilize physical hardware.

3.2. Execution Model

The OpenCL execution model is defined in terms of two distinct units of execution: **kernels** that execute on one or more OpenCL devices and a **host program** that executes on the host. With regard to OpenCL, the kernels are where the "work" associated with a computation occurs. This work occurs through **work-items** that execute in groups (**work-groups**).

A kernel executes within a well-defined context managed by the host. The context defines the

environment within which kernels execute. It includes the following resources:

- **Devices:** One or more devices exposed by the OpenCL platform.
- **Kernel Objects:** The OpenCL functions with their associated argument values that run on OpenCL devices.
- **Program Objects:** The program source and executable that implement the kernels.
- **Memory Objects:** Variables visible to the host and the OpenCL devices. Instances of kernels operate on these objects as they execute.

The host program uses the OpenCL API to create and manage the context. Functions from the OpenCL API enable the host to interact with a device through a *command-queue*. Each command-queue is associated with a single device. The commands placed into the command-queue fall into one of three types:

- **Kernel-enqueue commands:** Enqueue a kernel for execution on a device.
- **Memory commands:** Transfer data between the host and device memory, between memory objects, or map and unmap memory objects from the host address space.
- **Synchronization commands:** Explicit synchronization points that define order constraints between commands.

In addition to commands submitted from the host command-queue, a kernel running on a device can enqueue commands to a device-side command-queue. This results in *child kernels* enqueued by a kernel executing on a device (the *parent kernel*). Regardless of whether the command-queue resides on the host or a device, each command passes through six states.

1. **Queued:** The command is enqueued to a command-queue. A command may reside in the queue until it is flushed either explicitly (a call to `clFlush`) or implicitly by some other command.
2. **Submitted:** The command is flushed from the command-queue and submitted for execution on the device. Once flushed from the command-queue, a command will execute after any prerequisites for execution are met.
3. **Ready:** All prerequisites constraining execution of a command have been met. The command, or for a kernel-enqueue command the collection of work-groups associated with a command, is placed in a device work-pool from which it is scheduled for execution.
4. **Running:** Execution of the command starts. For the case of a kernel-enqueue command, one or more work-groups associated with the command start to execute.
5. **Ended:** Execution of a command ends. When a Kernel-enqueue command ends, all of the work-groups associated with that command have finished their execution. *Immediate side effects*, i.e. those associated with the kernel but not necessarily with its child kernels, are visible to other units of execution. These side effects include updates to values in global memory.
6. **Complete:** The command and its child commands have finished execution and the status of the event object, if any, associated with the command is set to `CL_COMPLETE`.

The [execution states and the transitions between them](#) are summarized below. These states and the concept of a device work-pool are conceptual elements of the execution model. An implementation of OpenCL has considerable freedom in how these are exposed to a program. Five of the transitions,

however, are directly observable through a profiling interface. These [profiled states](#) are shown below.

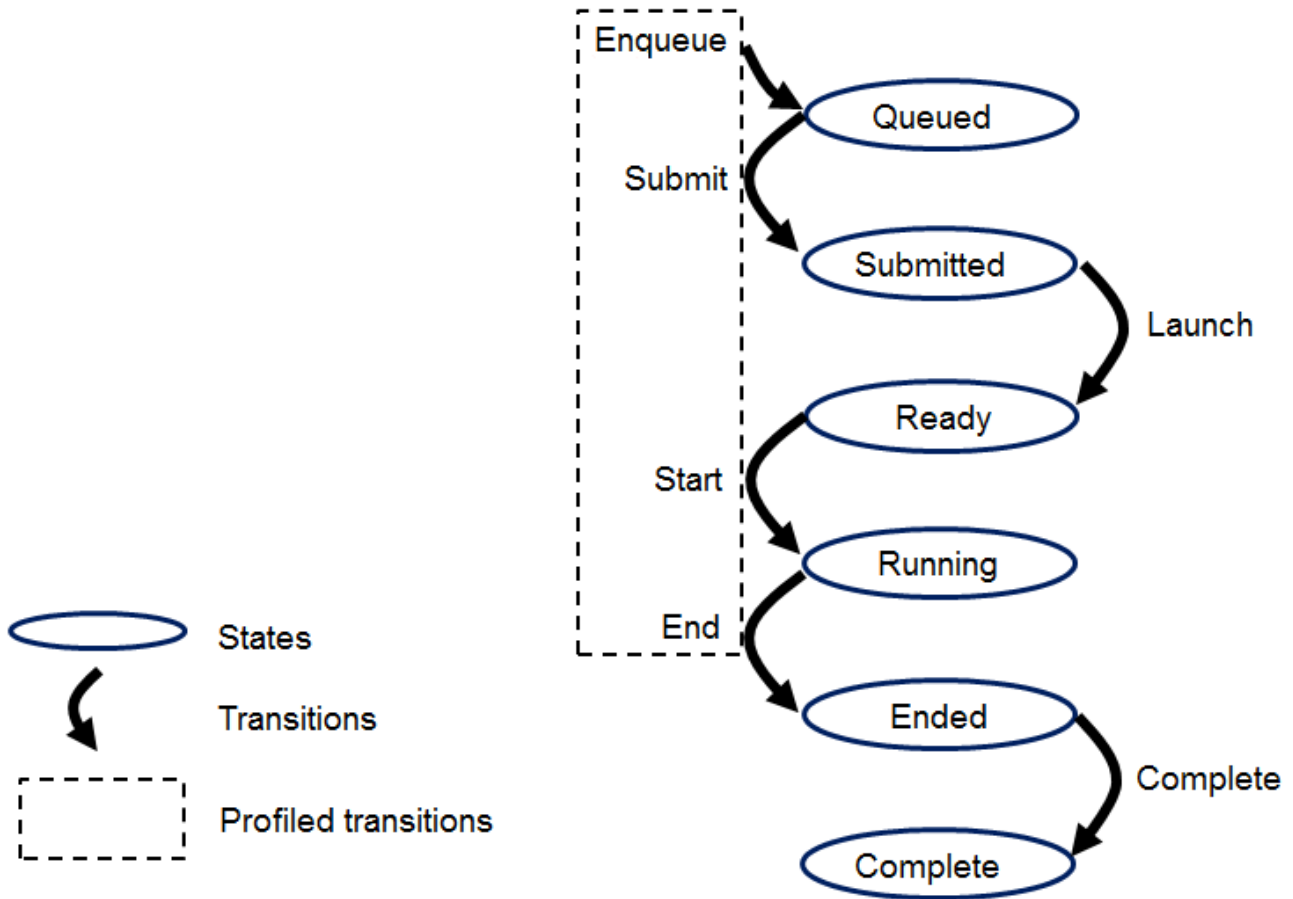


Figure 2. The states and transitions between states defined in the OpenCL execution model. A subset of these transitions is exposed through the [profiling interface](#).

Commands communicate their status through *Event objects*. Successful completion is indicated by setting the event status associated with a command to **CL_COMPLETE**. Unsuccessful completion results in abnormal termination of the command which is indicated by setting the event status to a negative value. In this case, the command-queue associated with the abnormally terminated command and all other command-queues in the same context may no longer be available and their behavior is implementation-defined.

A command submitted to a device will not launch until prerequisites that constrain the order of commands have been resolved. These prerequisites have three sources:

- They may arise from commands submitted to a command-queue that constrain the order in which commands are launched. For example, commands that follow a command-queue barrier will not launch until all commands prior to the barrier are complete.
- The second source of prerequisites is dependencies between commands expressed through events. A command may include an optional list of events. The command will wait and not launch until all the events in the list are in the state **CL_COMPLETE**. By this mechanism, event objects define order constraints between commands and coordinate execution between the host and one or more devices.
- The third source of prerequisites can be the presence of non-trivial C initializers or C++ constructors for program scope global variables. In this case, OpenCL C/C++ compiler shall

generate program initialization kernels that perform C initialization or C++ construction. These kernels must be executed by OpenCL runtime on a device before any kernel from the same program can be executed on the same device. The ND-range for any program initialization kernel is (1,1,1). When multiple programs are linked together, the order of execution of program initialization kernels that belong to different programs is undefined.

Program clean up may result in the execution of one or more program clean up kernels by the OpenCL runtime. This is due to the presence of non-trivial C++ destructors for program scope variables. The ND-range for executing any program clean up kernel is (1,1,1). The order of execution of clean up kernels from different programs (that are linked together) is undefined.



Program initialization and clean-up kernels are [missing before](#) version 2.2.

Note that C initializers, C++ constructors, or C++ destructors for program scope variables cannot use pointers to coarse grain and fine grain SVM allocations.

A command may be submitted to a device and yet have no visible side effects outside of waiting on and satisfying event dependences. Examples include markers, kernels executed over ranges of no work-items or copy operations with zero sizes. Such commands may pass directly from the *ready* state to the *ended* state.

Command execution can be blocking or non-blocking. Consider a sequence of OpenCL commands. For blocking commands, the OpenCL API functions that enqueue commands don't return until the command has completed. Alternatively, OpenCL functions that enqueue non-blocking commands return immediately and require that a programmer defines dependencies between enqueued commands to ensure that enqueued commands are not launched before needed resources are available. In both cases, the actual execution of the command may occur asynchronously with execution of the host program.

Commands within a single command-queue execute relative to each other in one of two modes:

- **In-order Execution:** Commands and any side effects associated with commands appear to the OpenCL application as if they execute in the same order they are enqueued to a command-queue.
- **Out-of-order Execution:** Commands execute in any order constrained only by explicit synchronization points (e.g. through command-queue barriers) or explicit dependencies on events.

Multiple command-queues can be present within a single context. Multiple command-queues execute commands independently. Event objects visible to the host program can be used to define synchronization points between commands in multiple command-queues. If such synchronization points are established between commands in multiple command-queues, an implementation must assure that the command-queues progress concurrently and correctly account for the dependencies established by the synchronization points. For a detailed explanation of synchronization points, see the execution model [Synchronization](#) section.

The core of the OpenCL execution model is defined by how the kernels execute. When a kernel-enqueue command submits a kernel for execution, an index space is defined. The kernel, the argument values associated with the arguments to the kernel, and the parameters that define the

index space define a *kernel-instance*. When a kernel-instance executes on a device, the kernel function executes for each point in the defined index space. Each of these executing kernel functions is called a *work-item*. The work-items associated with a given kernel-instance are managed by the device in groups called *work-groups*. These work-groups define a coarse grained decomposition of the Index space. Work-groups are further divided into *sub-groups*, which provide an additional level of control over execution.



Sub-groups are [missing before](#) version 2.1.

Work-items have a global ID based on their coordinates within the Index space. They can also be defined in terms of their work-group and the local ID within a work-group. The details of this mapping are described in the following section.

3.2.1. Mapping work-items onto an ND-range

The index space supported by OpenCL is called an ND-range. An ND-range is an N-dimensional index space, where N is one, two or three. The ND-range is decomposed into work-groups forming blocks that cover the Index space. An ND-range is defined by three integer arrays of length N:

- The extent of the index space (or global size) in each dimension.
- An offset index F indicating the initial value of the indices in each dimension (zero by default).
- The size of a work-group (local size) in each dimension.

Each work-items global ID is an N-dimensional tuple. The global ID components are values in the range from F, to F plus the number of elements in that dimension minus one.

Unless a kernel comes from a source that disallows it, e.g. OpenCL C 1.x or using `-cl-uniform-work-group-size`, the size of work-groups in an ND-range (the local size) need not be the same for all work-groups. In this case, any single dimension for which the global size is not divisible by the local size will be partitioned into two regions. One region will have work-groups that have the same number of work-items as was specified for that dimension by the programmer (the local size). The other region will have work-groups with less than the number of work items specified by the local size parameter in that dimension (the *remainder work-groups*). Work-group sizes could be non-uniform in multiple dimensions, potentially producing work-groups of up to 4 different sizes in a 2D range and 8 different sizes in a 3D range.



Non-uniform work-group sizes are [missing before](#) version 2.0.

Each work-item is assigned to a work-group and given a local ID to represent its position within the work-group. A work-item's local ID is an N-dimensional tuple with components in the range from zero to the size of the work-group in that dimension minus one.

Work-groups are assigned IDs similarly. The number of work-groups in each dimension is not directly defined but is inferred from the local and global ND-ranges provided when a kernel-instance is enqueued. A work-group's ID is an N-dimensional tuple with components in the range 0 to the ceiling of the global size in that dimension divided by the local size in the same dimension. As a result, the combination of a work-group ID and the local-ID within a work-group uniquely defines a work-item. Each work-item is identifiable in two ways; in terms of a global index, and in terms of

a work-group index plus a local index within a work-group.

For example, consider the **2-dimensional index space** shown below. We input the index space for the work-items (G_x, G_y), the size of each work-group (S_x, S_y) and the global ID offset (F_x, F_y). The global indices define an G_x by G_y index space where the total number of work-items is the product of G_x and G_y . The local indices define an S_x by S_y index space where the number of work-items in a single work-group is the product of S_x and S_y . Given the size of each work-group and the total number of work-items we can compute the number of work-groups. A 2-dimensional index space is used to uniquely identify a work-group. Each work-item is identified by its global ID (g_x, g_y) or by the combination of the work-group ID (w_x, w_y), the size of each work-group (S_x, S_y) and the local ID (s_x, s_y) inside the work-group such that

$$(g_x, g_y) = (w_x \times S_x + s_x + F_x, w_y \times S_y + s_y + F_y)$$

The number of work-groups can be computed as:

$$(W_x, W_y) = (\text{ceil}(G_x / S_x), \text{ceil}(G_y / S_y))$$

Given a global ID and the work-group size, the work-group ID for a work-item is computed as:

$$(w_x, w_y) = ((g_x - s_x - F_x) / S_x, (g_y - s_y - F_y) / S_y)$$

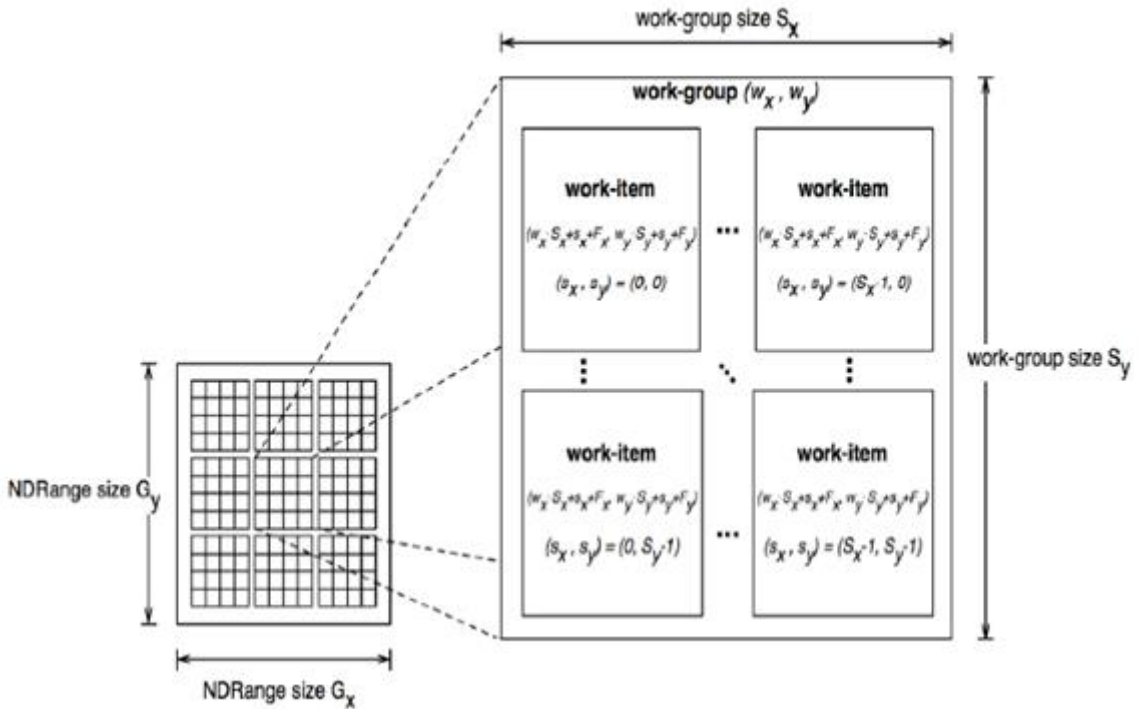


Figure 3. An example of an ND-range index space showing work-items, their global IDs and their mapping onto the pair of work-group and local IDs. In this case, we assume that in each dimension, the size of the work-group evenly divides the global ND-range size (i.e. all work-groups have the same size) and that the offset is equal to zero.

Within a work-group work-items may be divided into sub-groups. The mapping of work-items to sub-groups is implementation-defined and may be queried at runtime. While sub-groups may be used in multi-dimensional work-groups, each sub-group is 1-dimensional and any given work-item may query which sub-group it is a member of.



Sub-groups are [missing before](#) version 2.1.

Work-items are mapped into sub-groups through a combination of compile-time decisions and the parameters of the dispatch. The mapping to sub-groups is invariant for the duration of a kernels execution, across dispatches of a given kernel with the same work-group dimensions, between dispatches and query operations consistent with the dispatch parameterization, and from one work-group to another within the dispatch (excluding the trailing edge work-groups in the presence of non-uniform work-group sizes). In addition, all sub-groups within a work-group will be the same size, apart from the sub-group with the maximum index which may be smaller if the size of the work-group is not evenly divisible by the size of the sub-groups.

In the degenerate case, a single sub-group must be supported for each work-group. In this situation all sub-group scope functions are equivalent to their work-group level equivalents.

3.2.2. Execution of kernel-instances

The work carried out by an OpenCL program occurs through the execution of kernel-instances on compute devices. To understand the details of OpenCL's execution model, we need to consider how a kernel object moves from the kernel-enqueue command, into a command-queue, executes on a device, and completes.

A kernel object is defined as a function within the program object and a collection of arguments connecting the kernel to a set of argument values. The host program enqueues a kernel object to the command-queue along with the ND-range and the work-group decomposition. These define a *kernel-instance*. In addition, an optional set of events may be defined when the kernel is enqueued. The events associated with a particular kernel-instance are used to constrain when the kernel-instance is launched with respect to other commands in the queue or to commands in other queues within the same context.

A kernel-instance is submitted to a device. For an in-order command-queue, the kernel instances appear to launch and then execute in that same order; where we use the term appear to emphasize that when there are no dependencies between commands and hence differences in the order that commands execute cannot be observed in a program, an implementation can reorder commands even in an in-order command-queue. For an out-of-order command-queue, kernel-instances wait to be launched until:

- Synchronization commands enqueued prior to the kernel-instance are satisfied.
- Each of the events in an optional event list defined when the kernel-instance was enqueued are set to `CL_COMPLETE`.

Once these conditions are met, the kernel-instance is launched and the work-groups associated with the kernel-instance are placed into a pool of ready to execute work-groups. This pool is called a *work-pool*. The work-pool may be implemented in any manner as long as it assures that work-groups placed in the pool will eventually execute. The device schedules work-groups from the work-pool for execution on the compute units of the device. The kernel-enqueue command is complete when all work-groups associated with the kernel-instance end their execution, updates to global memory associated with a command are visible globally, and the device signals successful completion by setting the event associated with the kernel-enqueue command to `CL_COMPLETE`.

While a command-queue is associated with only one device, a single device may be associated with multiple command-queues all feeding into the single work-pool. A device may also be associated with command-queues associated with different contexts within the same platform, again all feeding into the single work-pool. The device will pull work-groups from the work-pool and execute them on one or several compute units in any order; possibly interleaving execution of work-groups from multiple commands. A conforming implementation may choose to serialize the work-groups so a correct algorithm cannot assume that work-groups will execute in parallel. There is no safe and portable way to synchronize across the independent execution of work-groups since once in the work-pool, they can execute in any order.

The work-items within a single sub-group execute concurrently but not necessarily in parallel (i.e. they are not guaranteed to make independent forward progress). Therefore, only high-level synchronization constructs (e.g. sub-group functions such as barriers) that apply to all the work-items in a sub-group are well defined and included in OpenCL.



Sub-groups are [missing before](#) version 2.1.

Sub-groups execute concurrently within a given work-group and with appropriate device support (see [Querying Devices](#)), may make independent forward progress with respect to each other, with respect to host threads and with respect to any entities external to the OpenCL system but running on an OpenCL device, even in the absence of work-group barrier operations. In this situation, sub-groups are able to internally synchronize using barrier operations without synchronizing with each other and may perform operations that rely on runtime dependencies on operations other sub-groups perform.

The work-items within a single work-group execute concurrently but are only guaranteed to make independent progress in the presence of sub-groups and device support. In the absence of this capability, only high-level synchronization constructs (e.g. work-group functions such as barriers) that apply to all the work-items in a work-group are well defined and included in OpenCL for synchronization within the work-group.

In the absence of synchronization functions (e.g. a barrier), work-items within a sub-group may be serialized. In the presence of sub-group functions, work-items within a sub-group may be serialized before any given sub-group function, between dynamically encountered pairs of sub-group functions and between a work-group function and the end of the kernel.

In the absence of independent forward progress of constituent sub-groups, work-items within a work-group may be serialized before, after or between work-group synchronization functions.

3.2.3. Device-side enqueue



Device-side enqueue is [missing before](#) version 2.0.

Algorithms may need to generate additional work as they execute. In many cases, this additional work cannot be determined statically; so the work associated with a kernel only emerges at runtime as the kernel-instance executes. This capability could be implemented in logic running within the host program, but involvement of the host may add significant overhead and/or complexity to the application control flow. A more efficient approach would be to nest kernel-

enqueue commands from inside other kernels. This **nested parallelism** can be realized by supporting the enqueueing of kernels on a device without direct involvement by the host program; so-called **device-side enqueue**.

Device-side kernel-enqueue commands are similar to host-side kernel-enqueue commands. The kernel executing on a device (the **parent kernel**) enqueues a kernel-instance (the **child kernel**) to a device-side command-queue. This is an out-of-order command-queue and follows the same behavior as the out-of-order command-queues exposed to the host program. Commands enqueued to a device-side command-queue generate and use events to enforce order constraints just as for the command-queue on the host. These events, however, are only visible to the parent kernel running on the device. When these prerequisite events take on the value **CL_COMPLETE**, the work-groups associated with the child kernel are launched into the devices work pool. The device then schedules them for execution on the compute units of the device. Child and parent kernels execute asynchronously. However, a parent will not indicate that it is complete by setting its event to **CL_COMPLETE** until all child kernels have ended execution and have signaled completion by setting any associated events to the value **CL_COMPLETE**. Should any child kernel complete with an event status set to a negative value (i.e. abnormally terminate), the parent kernel will abnormally terminate and propagate the childs negative event value as the value of the parents event. If there are multiple children that have an event status set to a negative value, the selection of which childs negative event value is propagated is implementation-defined.

3.2.4. Synchronization

Synchronization refers to mechanisms that constrain the order of execution between two or more units of execution. Consider the following three domains of synchronization in OpenCL:

- Work-group synchronization: Constraints on the order of execution for work-items in a single work-group
- Sub-group synchronization: Constraints on the order of execution for work-items in a single sub-group. Note: Sub-groups are **missing before** version 2.1
- Command synchronization: Constraints on the order of commands launched for execution

Synchronization across all work-items within a single work-group is carried out using a *work-group function*. These functions carry out collective operations across all the work-items in a work-group. Available collective operations are: barrier, reduction, broadcast, prefix sum, and evaluation of a predicate. A work-group function must occur within a converged control flow; i.e. all work-items in the work-group must encounter precisely the same work-group function. For example, if a work-group function occurs within a loop, the work-items must encounter the same work-group function in the same loop iterations. All the work-items of a work-group must execute the work-group function and complete reads and writes to memory before any are allowed to continue execution beyond the work-group function. Work-group functions that apply between work-groups are not provided in OpenCL since OpenCL does not define forward-progress or ordering relations between work-groups, hence collective synchronization operations are not well defined.

Synchronization across all work-items within a single sub-group is carried out using a *sub-group function*. These functions carry out collective operations across all the work-items in a sub-group. Available collective operations are: barrier, reduction, broadcast, prefix sum, and evaluation of a predicate. A sub-group function must occur within a converged control flow; i.e. all work-items in

the sub-group must encounter precisely the same sub-group function. For example, if a work-group function occurs within a loop, the work-items must encounter the same sub-group function in the same loop iterations. All the work-items of a sub-group must execute the sub-group function and complete reads and writes to memory before any are allowed to continue execution beyond the sub-group function. Synchronization between sub-groups must either be performed using work-group functions, or through memory operations. Using memory operations for sub-group synchronization should be used carefully as forward progress of sub-groups relative to each other is only supported optionally by OpenCL implementations.

Command synchronization is defined in terms of distinct **synchronization points**. The synchronization points occur between commands in host command-queues and between commands in device-side command-queues. The synchronization points defined in OpenCL include:

- **Launching a command:** A kernel-instance is launched onto a device after all events that kernel is waiting-on have been set to **CL_COMPLETE**.
- **Ending a command:** Child kernels may be enqueued such that they wait for the parent kernel to reach the *end* state before they can be launched. In this case, the ending of the parent command defines a synchronization point.
- **Completion of a command:** A kernel-instance is complete after all of the work-groups in the kernel and all of its child kernels have completed. This is signaled to the host, a parent kernel or other kernels within command-queues by setting the value of the event associated with a kernel to **CL_COMPLETE**.
- **Blocking Commands:** A blocking command defines a synchronization point between the unit of execution that calls the blocking API function and the enqueued command reaching the complete state.
- **Command-queue barrier:** The command-queue barrier ensures that all previously enqueued commands have completed before subsequently enqueued commands can be launched.
- **clFinish:** This function blocks until all previously enqueued commands in the command-queue have completed after which **clFinish** defines a synchronization point and the **clFinish** function returns.

A synchronization point between a pair of commands (A and B) assures that results of command A happens-before command B is launched. This requires that any updates to memory from command A complete and are made available to other commands before the synchronization point completes. Likewise, this requires that command B waits until after the synchronization point before loading values from global memory. The concept of a synchronization point works in a similar fashion for commands such as a barrier that apply to two sets of commands. All the commands prior to the barrier must complete and make their results available to following commands. Furthermore, any commands following the barrier must wait for the commands prior to the barrier before loading values and continuing their execution.

These *happens-before* relationships are a fundamental part of the OpenCL 2.x memory model. When applied at the level of commands, they are straightforward to define at a language level in terms of ordering relationships between different commands. Ordering memory operations inside different commands, however, requires rules more complex than can be captured by the high level concept of a synchronization point. These rules are described in detail in [Memory Ordering Rules](#).

3.2.5. Categories of Kernels

The OpenCL execution model supports three types of kernels:

- **OpenCL kernels** are managed by the OpenCL API as kernel objects associated with kernel functions within program objects. OpenCL program objects are created and built using OpenCL APIs. The OpenCL API includes functions to query the kernel languages and intermediate languages that may be used to create OpenCL program objects for a device.
- **Native kernels** are accessed through a host function pointer. Native kernels are queued for execution along with OpenCL kernels on a device and share memory objects with OpenCL kernels. For example, these native kernels could be functions defined in application code or exported from a library. The ability to execute native kernels is optional within OpenCL and the semantics of native kernels are implementation-defined. The OpenCL API includes functions to query capabilities of a device to determine if this capability is supported.
- **Built-in kernels** are tied to particular device and are not built at runtime from source code in a program object. The common use of built in kernels is to expose fixed-function hardware or firmware associated with a particular OpenCL device or custom device. The semantics of a built-in kernel may be defined outside of OpenCL and hence are implementation-defined. Note: Built-in kernels are [missing before](#) version 1.2.

All three types of kernels are manipulated through the OpenCL command-queues and must conform to the synchronization points defined in the OpenCL execution model.

3.3. Memory Model

The OpenCL memory model describes the structure, contents, and behavior of the memory exposed by an OpenCL platform as an OpenCL program runs. The model allows a programmer to reason about values in memory as the host program and multiple kernel-instances execute.

An OpenCL program defines a context that includes a host, one or more devices, command-queues, and memory exposed within the context. Consider the units of execution involved with such a program. The host program runs as one or more host threads managed by the operating system running on the host (the details of which are defined outside of OpenCL). There may be multiple devices in a single context which all have access to memory objects defined by OpenCL. On a single device, multiple work-groups may execute in parallel with potentially overlapping updates to memory. Finally, within a single work-group, multiple work-items concurrently execute, once again with potentially overlapping updates to memory.

The memory model must precisely define how the values in memory as seen from each of these units of execution interact so a programmer can reason about the correctness of OpenCL programs. We define the memory model in four parts.

- **Memory regions:** The distinct memories visible to the host and the devices that share a context.
- **Memory objects:** The objects defined by the OpenCL API and their management by the host and devices.
- **Shared Virtual Memory:** A virtual address space exposed to both the host and the devices within a context. Note: SVM is [missing before](#) version 2.0.

- **Consistency Model:** Rules that define which values are observed when multiple units of execution load data from memory plus the atomic/fence operations that constrain the order of memory operations and define synchronization relationships.

3.3.1. Fundamental Memory Regions

Memory in OpenCL is divided into two parts.

- **Host Memory:** The memory directly available to the host. The detailed behavior of host memory is defined outside of OpenCL. Memory objects move between the Host and the devices through functions within the OpenCL API or through a shared virtual memory interface.
- **Device Memory:** Memory directly available to kernels executing on OpenCL devices.

Device memory consists of four named address spaces or *memory regions*:

- **Global Memory:** This memory region permits read/write access to all work-items in all work-groups running on any device within a context. Work-items can read from or write to any element of a memory object. Reads and writes to global memory may be cached depending on the capabilities of the device.
- **Constant Memory:** A region of global memory that remains constant during the execution of a kernel-instance. The host allocates and initializes memory objects placed into constant memory.
- **Local Memory:** A memory region local to a work-group. This memory region can be used to allocate variables that are shared by all work-items in that work-group.
- **Private Memory:** A region of memory private to a work-item. Variables defined in one work-items private memory are not visible to another work-item.

The [memory regions](#) and their relationship to the OpenCL Platform model are summarized below. Local and private memories are always associated with a particular device. The global and constant memories, however, are shared between all devices within a given context. An OpenCL device may include a cache to support efficient access to these shared memories.

To understand memory in OpenCL, it is important to appreciate the relationships between these named address spaces. The four named address spaces available to a device are disjoint meaning they do not overlap. This is a logical relationship, however, and an implementation may choose to let these disjoint named address spaces share physical memory.

Programmers often need functions callable from kernels where the pointers manipulated by those functions can point to multiple named address spaces. This saves a programmer from the error-prone and wasteful practice of creating multiple copies of functions; one for each named address space. Therefore the global, local and private address spaces belong to a single *generic address space*. This is closely modeled after the concept of a generic address space used in the embedded C standard (ISO/IEC 9899:1999). Since they all belong to a single generic address space, the following properties are supported for pointers to named address spaces in device memory:

- A pointer to the generic address space can be cast to a pointer to a global, local or private address space
- A pointer to a global, local or private address space can be cast to a pointer to the generic

address space.

- A pointer to a global, local or private address space can be implicitly converted to a pointer to the generic address space, but the converse is not allowed.

The constant address space is disjoint from the generic address space.



The generic address space is [missing before](#) version 2.0.

The addresses of memory associated with memory objects in Global memory are not preserved between kernel instances, between a device and the host, and between devices. In this regard global memory acts as a global pool of memory objects rather than an address space. This restriction is relaxed when shared virtual memory (SVM) is used.



Shared virtual memory is [missing before](#) version 2.0.

SVM causes addresses to be meaningful between the host and all of the devices within a context hence supporting the use of pointer based data structures in OpenCL kernels. It logically extends a portion of the global memory into the host address space giving work-items access to the host address space. On platforms with hardware support for a shared address space between the host and one or more devices, SVM may also provide a more efficient way to share data between devices and the host. Details about SVM are presented in [Shared Virtual Memory](#).

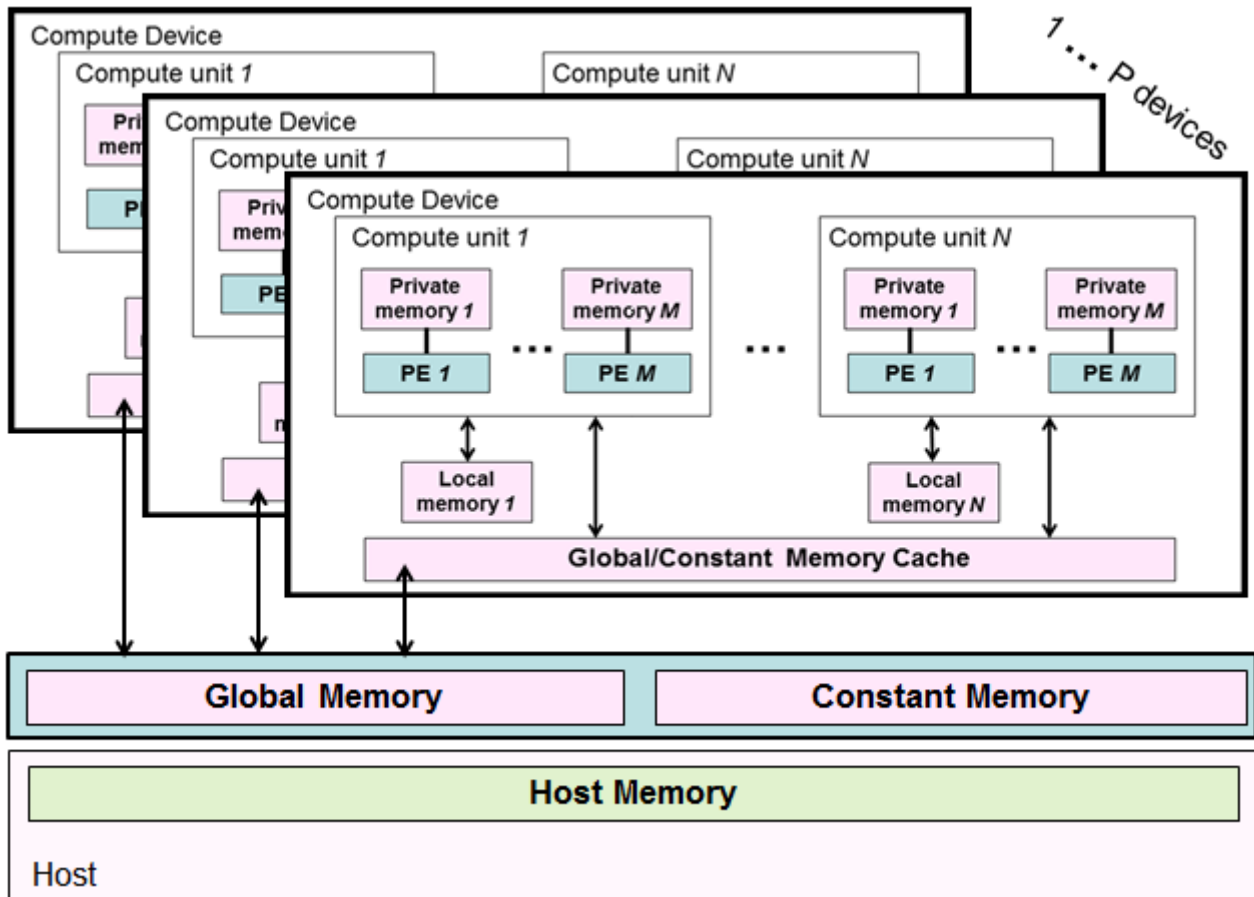


Figure 4. The named address spaces exposed in an OpenCL Platform. Global and Constant memories are shared between the one or more devices within a context, while local and private memories are associated with a single device. Each device may include an optional cache to support efficient access to their view of the global and constant address spaces.

A programmer may use the features of the [memory consistency model](#) to manage safe access to global memory from multiple work-items potentially running on one or more devices. In addition, when using shared virtual memory (SVM), the memory consistency model may also be used to ensure that host threads safely access memory locations in the shared memory region.

3.3.2. Memory Objects

The contents of global memory are *memory objects*. A memory object is a handle to a reference counted region of global memory. Memory objects use the OpenCL type `cl_mem` and fall into three distinct classes.

- **Buffer:** A memory object stored as a block of contiguous memory and used as a general purpose object to hold data used in an OpenCL program. The types of the values within a buffer may be any of the built in types (such as int, float), vector types, or user-defined structures. The buffer can be manipulated through pointers much as one would with any block of memory in C.
- **Image:** An image memory object holds one, two or three dimensional images. The formats are based on the standard image formats used in graphics applications. An image is an opaque data structure managed by functions defined in the OpenCL API. To optimize the manipulation of images stored in the texture memories found in many GPUs, OpenCL kernels have traditionally been disallowed from both reading and writing a single image. In OpenCL 2.0, however, we have relaxed this restriction by providing synchronization and fence operations that let

programmers properly synchronize their code to safely allow a kernel to read and write a single image.

- **Pipe:** The *pipe* memory object conceptually is an ordered sequence of data items. A pipe has two endpoints: a write endpoint into which data items are inserted, and a read endpoint from which data items are removed. At any one time, only one kernel instance may write into a pipe, and only one kernel instance may read from a pipe. To support the producer consumer design pattern, one kernel instance connects to the write endpoint (the producer) while another kernel instance connects to the reading endpoint (the consumer). Note: The *pipe* memory object is [missing before](#) version 2.0.

Memory objects are allocated by host APIs. The host program can provide the runtime with a pointer to a block of continuous memory to hold the memory object when the object is created (`CL_MEM_USE_HOST_PTR`). Alternatively, the physical memory can be managed by the OpenCL runtime and not be directly accessible to the host program.

Allocation and access to memory objects within the different memory regions varies between the host and work-items running on a device. This is summarized in the [Memory Regions](#) table, which describes whether the kernel or the host can allocate from a memory region, the type of allocation (static at compile time vs. dynamic at runtime) and the type of access allowed (i.e. whether the kernel or the host can read and/or write to a memory region).

Table 1. Memory Regions

		Global	Constant	Local	Private
Host	Allocation	Dynamic	Dynamic	Dynamic	None
	Access	Read/Write to Buffers and Images, but not Pipes	Read/Write	None	None
Kernel	Allocation	Static (program scope variables)	Static (program scope variables)	Static for parent kernel, Dynamic for child kernels	Static
	Access	Read/Write	Read-only	Read/Write, No access to child kernel memory	Read/Write

The [Memory Regions](#) table shows the different memory regions in OpenCL and how memory objects are allocated and accessed by the host and by an executing instance of a kernel. For kernels, we distinguish between the behavior of local memory for a parent kernel and its child kernels.

Once allocated, a memory object is made available to kernel-instances running on one or more devices. In addition to [Shared Virtual Memory](#), there are three basic ways to manage the contents of buffers between the host and devices.

- **Read/Write/Fill commands:** The data associated with a memory object is explicitly read and written between the host and global memory regions using commands enqueued to an OpenCL command-queue. Note: Fill commands are [missing before](#) version 1.2.

- **Map/Unmap commands:** Data from the memory object is mapped into a contiguous block of memory accessed through a host accessible pointer. The host program enqueues a *map* command on block of a memory object before it can be safely manipulated by the host program. When the host program is finished working with the block of memory, the host program enqueues an *unmap* command to allow a kernel-instance to safely read and/or write the buffer.
- **Copy commands:** The data associated with a memory object is copied between two buffers, each of which may reside either on the host or on the device.

With Read/Write/Map, the commands can be blocking or non-blocking operations. The OpenCL function call for a blocking memory transfer returns once the command (memory transfer) has completed. At this point the associated memory resources on the host can be safely reused, and following operations on the host are guaranteed that the transfer has already completed. For a non-blocking memory transfer, the OpenCL function call returns as soon as the command is enqueued.

Memory objects are bound to a context and hence can appear in multiple kernel-instances running on more than one physical device. The OpenCL platform must support a large range of hardware platforms including systems that do not support a single shared address space in hardware; hence the ways memory objects can be shared between kernel-instances is restricted. The basic principle is that multiple read operations on memory objects from multiple kernel-instances that overlap in time are allowed, but mixing overlapping reads and writes into the same memory objects from different kernel instances is only allowed when fine grained synchronization is used with [Shared Virtual Memory](#).

When global memory is manipulated by multiple kernel-instances running on multiple devices, the OpenCL runtime system must manage the association of memory objects with a given device. In most cases the OpenCL runtime will implicitly associate a memory object with a device. A kernel instance is naturally associated with the command-queue to which the kernel was submitted. Since a command-queue can only access a single device, the queue uniquely defines which device is involved with any given kernel-instance; hence defining a clear association between memory objects, kernel-instances and devices. Programmers may anticipate these associations in their programs and explicitly manage association of memory objects with devices in order to improve performance.

3.3.3. Shared Virtual Memory



Shared virtual memory is [missing before](#) version 2.0.

OpenCL extends the global memory region into the host memory region through a shared virtual memory (SVM) mechanism. There are three types of SVM in OpenCL

- **Coarse-Grained buffer SVM:** Sharing occurs at the granularity of regions of OpenCL buffer memory objects. Consistency is enforced at synchronization points and with map/unmap commands to drive updates between the host and the device. This form of SVM is similar to non-SVM use of memory; however, it lets kernel-instances share pointer-based data structures (such as linked-lists) with the host program. Program scope global variables are treated as per-device coarse-grained SVM for addressing and sharing purposes.
- **Fine-Grained buffer SVM:** Sharing occurs at the granularity of individual loads/stores into bytes within OpenCL buffer memory objects. Loads and stores may be cached. This means

consistency is guaranteed at synchronization points. If the optional OpenCL atomics are supported, they can be used to provide fine-grained control of memory consistency.

- **Fine-Grained system SVM:** Sharing occurs at the granularity of individual loads/stores into bytes occurring anywhere within the host memory. Loads and stores may be cached so consistency is guaranteed at synchronization points. If the optional OpenCL atomics are supported, they can be used to provide fine-grained control of memory consistency.

Table 2. A summary of shared virtual memory (SVM) options in OpenCL

	Granularity of sharing	Memory Allocation	Mechanisms to enforce Consistency	Explicit updates between host and device
Non-SVM buffers	OpenCL Memory objects(buffer)	clCreateBuffer clCreateBufferWithProperties	Host synchronization points on the same or between devices.	yes, through Map and Unmap commands.
Coarse-Grained buffer SVM	OpenCL Memory objects (buffer)	clSVMAlloc	Host synchronization points between devices	yes, through Map and Unmap commands.
Fine-Grained buffer SVM	Bytes within OpenCL Memory objects (buffer)	clSVMAlloc	Synchronization points plus atomics (if supported)	No
Fine-Grained system SVM	Bytes within Host memory (system)	Host memory allocation mechanisms (e.g. malloc)	Synchronization points plus atomics (if supported)	No

Coarse-Grained buffer SVM is a required feature for OpenCL 2.0, 2.1, or 2.2 devices and an optional feature for OpenCL 3.0 or newer devices. Fine-Grained SVM is an optional feature for all OpenCL devices. The various SVM mechanisms to access host memory from the work-items associated with a kernel instance are [summarized above](#).

3.3.4. Memory Consistency Model for OpenCL 1.x



This memory consistency model is [deprecated by](#) version 2.0.

OpenCL 1.x uses a relaxed consistency memory model; i.e. the state of memory visible to a work-item is not guaranteed to be consistent across the collection of work-items at all times.

Within a work-item memory has load / store consistency. Local memory is consistent across work-items in a single work-group at a work-group barrier. Global memory is consistent across work-items in a single work-group at a work-group barrier, but there are no guarantees of memory consistency between different work-groups executing a kernel.

Memory consistency for memory objects shared between enqueued commands is enforced at a synchronization point.

3.3.5. Memory Consistency Model for OpenCL 2.x



This memory consistency model is [missing before](#) version 2.0.

The OpenCL 2.x memory model tells programmers what they can expect from an OpenCL 2.x implementation; which memory operations are guaranteed to happen in which order and which memory values each read operation will return. The memory model tells compiler writers which restrictions they must follow when implementing compiler optimizations; which variables they can cache in registers and when they can move reads or writes around a barrier or atomic operation. The memory model also tells hardware designers about limitations on hardware optimizations; for example, when they must flush or invalidate hardware caches.

The memory consistency model in OpenCL 2.x is based on the memory model from the ISO C11 programming language. To help make the presentation more precise and self-contained, we include modified paragraphs taken verbatim from the ISO C11 international standard. When a paragraph is taken or modified from the C11 standard, it is identified as such along with its original location in the [C11 standard](#).

For programmers, the most intuitive model is the *sequential consistency* memory model. Sequential consistency interleaves the steps executed by each of the units of execution. Each access to a memory location sees the last assignment to that location in that interleaving. While sequential consistency is relatively straightforward for a programmer to reason about, implementing sequential consistency is expensive. Therefore, OpenCL 2.x implements a relaxed memory consistency model; i.e. it is possible to write programs where the loads from memory violate sequential consistency. Fortunately, if a program does not contain any races and if the program only uses atomic operations that utilize the sequentially consistent memory order (the default memory ordering for OpenCL 2.x), OpenCL programs appear to execute with sequential consistency.

Programmers can to some degree control how the memory model is relaxed by choosing the memory order for synchronization operations. The precise semantics of synchronization and the memory orders are formally defined in [Memory Ordering Rules](#). Here, we give a high level description of how these memory orders apply to atomic operations on atomic objects shared between units of execution. OpenCL 2.x memory_order choices are based on those from the ISO C11 standard memory model. They are specified in certain OpenCL functions through the following enumeration constants:

- **memory_order_relaxed**: implies no order constraints. This memory order can be used safely to increment counters that are concurrently incremented, but it doesn't guarantee anything about the ordering with respect to operations to other memory locations. It can also be used, for example, to do ticket allocation and by expert programmers implementing lock-free algorithms.
- **memory_order_acquire**: A synchronization operation (fence or atomic) that has acquire semantics "acquires" side-effects from a release operation that synchronises with it: if an acquire synchronises with a release, the acquiring unit of execution will see all side-effects preceding that release (and possibly subsequent side-effects.) As part of carefully-designed

protocols, programmers can use an "acquire" to safely observe the work of another unit of execution.

- **memory_order_release**: A synchronization operation (fence or atomic operation) that has release semantics "releases" side effects to an acquire operation that synchronises with it. All side effects that precede the release are included in the release. As part of carefully-designed protocols, programmers can use a "release" to make changes made in one unit of execution visible to other units of execution.



In general, no acquire must *always* synchronise with any particular release. However, synchronisation can be forced by certain executions. See the description of [Fence Operations](#) for detailed rules for when synchronisation must occur.

- **memory_order_acq_rel**: A synchronization operation with acquire-release semantics has the properties of both the acquire and release memory orders. It is typically used to order read-modify-write operations.
- **memory_order_seq_cst**: The loads and stores of each unit of execution appear to execute in program (i.e., sequenced-before) order, and the loads and stores from different units of execution appear to be simply interleaved.

Regardless of which `memory_order` is specified, resolving constraints on memory operations across a heterogeneous platform adds considerable overhead to the execution of a program. An OpenCL platform may be able to optimize certain operations that depend on the features of the memory consistency model by restricting the scope of the memory operations. Distinct memory scopes are defined by the values of the `memory_scope` enumeration constant:

- **memory_scope_work_item**: memory-ordering constraints only apply within the work-item ^[1].
- **memory_scope_sub_group**: memory-ordering constraints only apply within the sub-group.
- **memory_scope_work_group**: memory-ordering constraints only apply to work-items executing within a single work-group.
- **memory_scope_device**: memory-ordering constraints only apply to work-items executing on a single device
- **memory_scope_all_svm_devices**: memory-ordering constraints apply to work-items executing across multiple devices and (when using SVM) the host. A release performed with **memory_scope_all_svm_devices** to a buffer that does not have the `CL_MEM_SVM_ATOMICS` flag set will commit to at least **memory_scope_device** visibility, with full synchronization of the buffer at a queue synchronization point (e.g. an OpenCL event).
- **memory_scope_all_devices**: an alias for **memory_scope_all_svm_devices**.

These memory scopes define a hierarchy of visibilities when analyzing the ordering constraints of memory operations. For example if a programmer knows that a sequence of memory operations will only be associated with a collection of work-items from a single work-group (and hence will run on a single device), the implementation is spared the overhead of managing the memory orders across other devices within the same context. This can substantially reduce overhead in a program. All memory scopes are valid when used on global memory or local memory. For local memory, all visibility is constrained to within a given work-group and scopes wider than **memory_scope_work_group** carry no additional meaning.

In the following subsections (leading up to [OpenCL Framework](#)), we will explain the synchronization constructs and detailed rules needed to use OpenCL's 2.x relaxed memory models. It is important to appreciate, however, that many programs do not benefit from relaxed memory models. Even expert programmers have a difficult time using atomics and fences to write correct programs with relaxed memory models. A large number of OpenCL programs can be written using a simplified memory model. This is accomplished by following these guidelines.

- Write programs that manage safe sharing of global memory objects through the synchronization points defined by the command-queues.
- Restrict low level synchronization inside work-groups to the work-group functions such as `barrier`.
- If you want sequential consistency behavior with system allocations or fine-grain SVM buffers with atomics support, use only **`memory_order_seq_cst`** operations with the scope **`memory_scope_all_svm_devices`**.
- If you want sequential consistency behavior when not using system allocations or fine-grain SVM buffers with atomics support, use only **`memory_order_seq_cst`** operations with the scope **`memory_scope_device`** or **`memory_scope_all_svm_devices`**.
- Ensure your program has no races.

If these guidelines are followed in your OpenCL programs, you can skip the detailed rules behind the relaxed memory models and go directly to [OpenCL Framework](#).

3.3.6. Overview of atomic and fence operations

OpenCL 2.x has a number of *synchronization operations* that are used to define memory order constraints in a program. They play a special role in controlling how memory operations in one unit of execution (such as work-items or, when using SVM a host thread) are made visible to another. There are two types of synchronization operations in OpenCL; *atomic operations* and *fences*.

Atomic operations are indivisible. They either occur completely or not at all. These operations are used to order memory operations between units of execution and hence they are parameterized with the `memory_order` and `memory_scope` parameters defined by the OpenCL memory consistency model. The atomic operations for OpenCL kernel languages are similar to the corresponding operations defined by the C11 standard.

The OpenCL 2.x atomic operations apply to variables of an atomic type (a subset of those in the C11 standard) including atomic versions of the `int`, `uint`, `long`, `ulong`, `float`, `double`, `half`, `intptr_t`, `uintptr_t`, `size_t`, and `ptrdiff_t` types. However, support for some of these atomic types depends on support for the corresponding regular types.

An atomic operation on one or more memory locations is either an acquire operation, a release operation, or both an acquire and release operation. An atomic operation without an associated memory location is a fence and can be either an acquire fence, a release fence, or both an acquire and release fence. In addition, there are relaxed atomic operations, which do not have synchronization properties, and atomic read-modify-write operations, which have special characteristics. [\[C11 standard, Section 5.1.2.4, paragraph 5, modified.\]](#)

The orders **memory_order_acquire** (used for reads), **memory_order_release** (used for writes), and **memory_order_acq_rel** (used for read-modify-write operations) are used for simple communication between units of execution using shared variables. Informally, executing a **memory_order_release** on an atomic object A makes all previous side effects visible to any unit of execution that later executes a **memory_order_acquire** on A. The orders **memory_order_acquire**, **memory_order_release**, and **memory_order_acq_rel** do not provide sequential consistency for race-free programs because they will not ensure that atomic stores followed by atomic loads become visible to other threads in that order.

The fence operation is `atomic_work_item_fence`, which includes a `memory_order` argument as well as the `memory_scope` and `cl_mem_fence_flags` arguments. Depending on the `memory_order` argument, this operation:

- has no effects, if **memory_order_relaxed**;
- is an acquire fence, if **memory_order_acquire**;
- is a release fence, if **memory_order_release**;
- is both an acquire fence and a release fence, if **memory_order_acq_rel**;
- is a sequentially-consistent fence with both acquire and release semantics, if **memory_order_seq_cst**.

If specified, the `cl_mem_fence_flags` argument must be `CLK_IMAGE_MEM_FENCE`, `CLK_GLOBAL_MEM_FENCE`, `CLK_LOCAL_MEM_FENCE`, or `CLK_GLOBAL_MEM_FENCE | CLK_LOCAL_MEM_FENCE`.

The `atomic_work_item_fence(CLK_IMAGE_MEM_FENCE, ...)` built-in function must be used to make sure that sampler-less writes are visible to later reads by the same work-item. Without use of the `atomic_work_item_fence` function, write-read coherence on image objects is not guaranteed: if a work-item reads from an image to which it has previously written without an intervening `atomic_work_item_fence`, it is not guaranteed that those previous writes are visible to the work-item.

The synchronization operations in OpenCL 2.x can be parameterized by a `memory_scope`. Memory scopes control the extent that an atomic operation or fence is visible with respect to the memory model. These memory scopes may be used when performing atomic operations and fences on global memory and local memory. When used on global memory visibility is bounded by the capabilities of that memory. When used on a fine-grained non-atomic SVM buffer, a coarse-grained SVM buffer, or a non-SVM buffer, operations parameterized with **memory_scope_all_svm_devices** will behave as if they were parameterized with **memory_scope_device**. When used on local memory, visibility is bounded by the work-group and, as a result, `memory_scope` with wider visibility than **memory_scope_work_group** will be reduced to **memory_scope_work_group**.

Two actions **A** and **B** are defined to have an inclusive scope if they have the same scope **P** such that:

- **P** is **memory_scope_sub_group** and **A** and **B** are executed by work-items within the same sub-group.
- **P** is **memory_scope_work_group** and **A** and **B** are executed by work-items within the same work-group.
- **P** is **memory_scope_device** and **A** and **B** are executed by work-items on the same device when

A and **B** apply to an SVM allocation or **A** and **B** are executed by work-items in the same kernel or one of its children when **A** and **B** apply to a `cl_mem` buffer.

- **P** is **memory_scope_all_svm_devices** if **A** and **B** are executed by host threads or by work-items on one or more devices that can share SVM memory with each other and the host process.

3.3.7. Memory Ordering Rules

Fundamentally, the issue in a memory model is to understand the orderings in time of modifications to objects in memory. Modifying an object or calling a function that modifies an object are side effects, i.e. changes in the state of the execution environment. Evaluation of an expression in general includes both value computations and initiation of side effects. Value computation for an lvalue expression includes determining the identity of the designated object. [C11 standard, Section 5.1.2.3, paragraph 2, modified.]

We assume that the OpenCL kernel language and host programming languages have a sequenced-before relation between the evaluations executed by a single unit of execution. This sequenced-before relation is an asymmetric, transitive, pair-wise relation between those evaluations, which induces a partial order among them. Given any two evaluations **A** and **B**, if **A** is sequenced-before **B**, then the execution of **A** shall precede the execution of **B**. (Conversely, if **A** is sequenced-before **B**, then **B** is sequenced-after **A**.) If **A** is not sequenced-before or sequenced-after **B**, then **A** and **B** are unsequenced. Evaluations **A** and **B** are indeterminately sequenced when **A** is either sequenced-before or sequenced-after **B**, but it is unspecified which. [C11 standard, Section 5.1.2.3, paragraph 3, modified.]



Sequenced-before is a partial order of the operations executed by a single unit of execution (e.g. a host thread or work-item). It generally corresponds to the source program order of those operations, and is partial because of the undefined argument evaluation order of the OpenCL C kernel language.

In an OpenCL kernel language, the value of an object visible to a work-item **W** at a particular point is the initial value of the object, a value stored in the object by **W**, or a value stored in the object by another work-item or host thread, according to the rules below. Depending on details of the host programming language, the value of an object visible to a host thread may also be the value stored in that object by another work-item or host thread. [C11 standard, Section 5.1.2.4, paragraph 2, modified.]

Two expression evaluations conflict if one of them modifies a memory location and the other one reads or modifies the same memory location. [C11 standard, Section 5.1.2.4, paragraph 4.]

All modifications to a particular atomic object **M** occur in some particular total order, called the modification order of **M**. If **A** and **B** are modifications of an atomic object **M**, and **A** happens-before **B**, then **A** shall precede **B** in the modification order of **M**, which is defined below. Note that the modification order of an atomic object **M** is independent of whether **M** is in local or global memory. [C11 standard, Section 5.1.2.4, paragraph 7, modified.]

A release sequence begins with a release operation **A** on an atomic object **M** and is the maximal contiguous sub-sequence of side effects in the modification order of **M**, where the first operation is **A** and every subsequent operation either is performed by the same work-item or host thread that

performed the release or is an atomic read-modify-write operation. [C11 standard, Section 5.1.2.4, paragraph 10, modified.]

OpenCL's local and global memories are disjoint. Kernels may access both kinds of memory while host threads may only access global memory. Furthermore, the *flags* argument of OpenCL's `work_group_barrier` function specifies which memory operations the function will make visible: these memory operations can be, for example, just the ones to local memory, or the ones to global memory, or both. Since the visibility of memory operations can be specified for local memory separately from global memory, we define two related but independent relations, *global-synchronizes-with* and *local-synchronizes-with*. Certain operations on global memory may global-synchronize-with other operations performed by another work-item or host thread. An example is a release atomic operation in one work-item that global-synchronizes-with an acquire atomic operation in a second work-item. Similarly, certain atomic operations on local objects in kernels can local-synchronize-with other atomic operations on those local objects. [C11 standard, Section 5.1.2.4, paragraph 11, modified.]

We define two separate happens-before relations: global-happens-before and local-happens-before.

A global memory action **A** global-happens-before a global memory action **B** if

- **A** is sequenced before **B**, or
- **A** global-synchronizes-with **B**, or
- For some global memory action **C**, **A** global-happens-before **C** and **C** global-happens-before **B**.

A local memory action **A** local-happens-before a local memory action **B** if

- **A** is sequenced before **B**, or
- **A** local-synchronizes-with **B**, or
- For some local memory action **C**, **A** local-happens-before **C** and **C** local-happens-before **B**.

An OpenCL 2.x implementation shall ensure that no program execution demonstrates a cycle in either the local-happens-before relation or the global-happens-before relation.



The global- and local-happens-before relations are critical to defining what values are read and when data races occur. The global-happens-before relation, for example, defines what global memory operations definitely happen before what other global memory operations. If an operation **A** global-happens-before operation **B** then **A** must occur before **B**; in particular, any write done by **A** will be visible to **B**. The local-happens-before relation has similar properties for local memory. Programmers can use the local- and global-happens-before relations to reason about the order of program actions.

A visible side effect **A** on a global object **M** with respect to a value computation **B** of **M** satisfies the conditions:

- **A** global-happens-before **B**, and
- there is no other side effect **X** to **M** such that **A** global-happens-before **X** and **X** global-happens-before **B**.

We define visible side effects for local objects **M** similarly. The value of a non-atomic scalar object **M**, as determined by evaluation **B**, shall be the value stored by the visible side effect **A**. [C11 standard, Section 5.1.2.4, paragraph 19, modified.]

The execution of a program contains a data race if it contains two conflicting actions **A** and **B** in different units of execution, and

- (1) at least one of **A** or **B** is not atomic, or **A** and **B** do not have inclusive memory scope, and
- (2) the actions are global actions unordered by the global-happens-before relation or are local actions unordered by the local-happens-before relation.

Any such data race results in undefined behavior. [C11 standard, Section 5.1.2.4, paragraph 25, modified.]

We also define the visible sequence of side effects on local and global atomic objects. The remaining paragraphs of this subsection define this sequence for a global atomic object **M**; the visible sequence of side effects for a local atomic object is defined similarly by using the local-happens-before relation.

The visible sequence of side effects on a global atomic object **M**, with respect to a value computation **B** of **M**, is a maximal contiguous sub-sequence of side effects in the modification order of **M**, where the first side effect is visible with respect to **B**, and for every side effect, it is not the case that **B** global-happens-before it. The value of **M**, as determined by evaluation **B**, shall be the value stored by some operation in the visible sequence of **M** with respect to **B**. [C11 standard, Section 5.1.2.4, paragraph 22, modified.]

If an operation **A** that modifies an atomic object **M** global-happens-before an operation **B** that modifies **M**, then **A** shall be earlier than **B** in the modification order of **M**. This requirement is known as write-write coherence.

If a value computation **A** of an atomic object **M** global-happens-before a value computation **B** of **M**, and **A** takes its value from a side effect **X** on **M**, then the value computed by **B** shall either equal the value stored by **X**, or be the value stored by a side effect **Y** on **M**, where **Y** follows **X** in the modification order of **M**. This requirement is known as read-read coherence. [C11 standard, Section 5.1.2.4, paragraph 22, modified.]

If a value computation **A** of an atomic object **M** global-happens-before an operation **B** on **M**, then **A** shall take its value from a side effect **X** on **M**, where **X** precedes **B** in the modification order of **M**. This requirement is known as read-write coherence.

If a side effect **X** on an atomic object **M** global-happens-before a value computation **B** of **M**, then the evaluation **B** shall take its value from **X** or from a side effect **Y** that follows **X** in the modification order of **M**. This requirement is known as write-read coherence.

3.3.7.1. Atomic Operations

This and following sections describe how different program actions in kernel C code and the host program contribute to the local- and global-happens-before relations. This section discusses ordering rules for OpenCL 2.x atomic operations.

Device-side `enqueue` defines the enumerated type `memory_order`.

- For **`memory_order_relaxed`**, no operation orders memory.
- For **`memory_order_release`**, **`memory_order_acq_rel`**, and **`memory_order_seq_cst`**, a store operation performs a release operation on the affected memory location.
- For **`memory_order_acquire`**, **`memory_order_acq_rel`**, and **`memory_order_seq_cst`**, a load operation performs an acquire operation on the affected memory location. [C11 standard, Section 7.17.3, paragraphs 2-4, modified.]

Certain built-in functions synchronize with other built-in functions performed by another unit of execution. This is true for pairs of release and acquire operations under specific circumstances. An atomic operation **A** that performs a release operation on a global object **M** global-synchronizes-with an atomic operation **B** that performs an acquire operation on **M** and reads a value written by any side effect in the release sequence headed by **A**. A similar rule holds for atomic operations on objects in local memory: an atomic operation **A** that performs a release operation on a local object **M** local-synchronizes-with an atomic operation **B** that performs an acquire operation on **M** and reads a value written by any side effect in the release sequence headed by **A**. [C11 standard, Section 5.1.2.4, paragraph 11, modified.]



Atomic operations specifying **`memory_order_relaxed`** are relaxed only with respect to memory ordering. Implementations must still guarantee that any given atomic access to a particular atomic object be indivisible with respect to all other atomic accesses to that object.

There shall exist a single total order **S** for all **`memory_order_seq_cst`** operations that is consistent with the modification orders for all affected locations, as well as the appropriate global-happens-before and local-happens-before orders for those locations, such that each **`memory_order_seq_cst`** operation **B** that loads a value from an atomic object **M** in global or local memory observes one of the following values:

- the result of the last modification **A** of **M** that precedes **B** in **S**, if it exists, or
- if **A** exists, the result of some modification of **M** in the visible sequence of side effects with respect to **B** that is not **`memory_order_seq_cst`** and that does not happen before **A**, or
- if **A** does not exist, the result of some modification of **M** in the visible sequence of side effects with respect to **B** that is not **`memory_order_seq_cst`**. [C11 standard, Section 7.17.3, paragraph 6, modified.]

Let **X** and **Y** be two **`memory_order_seq_cst`** operations. If **X** local-synchronizes-with or global-synchronizes-with **Y** then **X** both local-synchronizes-with **Y** and global-synchronizes-with **Y**.

If the total order **S** exists, the following rules hold:

- For an atomic operation **B** that reads the value of an atomic object **M**, if there is a **`memory_order_seq_cst`** fence **X** sequenced-before **B**, then **B** observes either the last **`memory_order_seq_cst`** modification of **M** preceding **X** in the total order **S** or a later modification of **M** in its modification order. [C11 standard, Section 7.17.3, paragraph 9.]
- For atomic operations **A** and **B** on an atomic object **M**, where **A** modifies **M** and **B** takes its value,

if there is a **memory_order_seq_cst** fence **X** such that **A** is sequenced-before **X** and **B** follows **X** in **S**, then **B** observes either the effects of **A** or a later modification of **M** in its modification order. [C11 standard, Section 7.17.3, paragraph 10.]

- For atomic operations **A** and **B** on an atomic object **M**, where **A** modifies **M** and **B** takes its value, if there are **memory_order_seq_cst** fences **X** and **Y** such that **A** is sequenced-before **X**, **Y** is sequenced-before **B**, and **X** precedes **Y** in **S**, then **B** observes either the effects of **A** or a later modification of **M** in its modification order. [C11 standard, Section 7.17.3, paragraph 11.]
- For atomic operations **A** and **B** on an atomic object **M**, if there are **memory_order_seq_cst** fences **X** and **Y** such that **A** is sequenced-before **X**, **Y** is sequenced-before **B**, and **X** precedes **Y** in **S**, then **B** occurs later than **A** in the modification order of **M**.



memory_order_seq_cst ensures sequential consistency only for a program that is (1) free of data races, and (2) exclusively uses **memory_order_seq_cst** synchronization operations. Any use of weaker ordering will invalidate this guarantee unless extreme care is used. In particular, **memory_order_seq_cst** fences ensure a total order only for the fences themselves. Fences cannot, in general, be used to restore sequential consistency for atomic operations with weaker ordering specifications.

Atomic read-modify-write operations should always read the last value (in the modification order) stored before the write associated with the read-modify-write operation. [C11 standard, Section 7.17.3, paragraph 12.]

Implementations should ensure that no "out-of-thin-air" values are computed that circularly depend on their own computation.

Note: Under the rules described above, and independent to the previously footnoted C++ issue, it is known that `x == y == 42` is a valid final state in the following problematic example:

```
global atomic_int x = ATOMIC_VAR_INIT(0);
local atomic_int y = ATOMIC_VAR_INIT(0);

unit_of_execution_1:
... [execution not reading or writing x or y, leading up to:]
int t = atomic_load_explicit(&y, memory_order_acquire);
atomic_store_explicit(&x, t, memory_order_release);

unit_of_execution_2:
... [execution not reading or writing x or y, leading up to:]
int t = atomic_load_explicit(&x, memory_order_acquire);
atomic_store_explicit(&y, t, memory_order_release);
```

This is not useful behavior and implementations should not exploit this phenomenon. It should be expected that in the future this may be disallowed by appropriate updates to the memory model description by the OpenCL committee.

Implementations should make atomic stores visible to atomic loads within a reasonable amount of

time. [\[C11 standard, Section 7.17.3, paragraph 16.\]](#)

As long as the following conditions are met, a host program sharing SVM memory with a kernel executing on one or more OpenCL 2.x devices may use atomic and synchronization operations to ensure that its assignments, and those of the kernel, are visible to each other:

1. Either fine-grained buffer or fine-grained system SVM must be used to share memory. While coarse-grained buffer SVM allocations may support atomic operations, visibility on these allocations is not guaranteed except at map and unmap operations.
2. The optional OpenCL 2.x SVM atomic-controlled visibility specified by provision of the `CL_MEM_SVM_ATOMICS` flag must be supported by the device and the flag provided to the SVM buffer on allocation.
3. The host atomic and synchronization operations must be compatible with those of an OpenCL kernel language. This requires that the size and representation of the data types that the host atomic operations act on be consistent with the OpenCL kernel language atomic types.

If these conditions are met, the host operations will apply at `all_svm_devices` scope.

3.3.7.2. Fence Operations

This section describes how the OpenCL 2.x fence operations contribute to the local- and global-happens-before relations.

Earlier, we introduced synchronization primitives called fences. Fences can utilize the `acquire memory_order`, `release memory_order`, or both. A fence with acquire semantics is called an acquire fence; a fence with release semantics is called a release fence. The [overview of atomic and fence operations](#) section describes the memory orders that result in acquire and release fences.

A global release fence **A** global-synchronizes-with a global acquire fence **B** if there exist atomic operations **X** and **Y**, both operating on some global atomic object **M**, such that **A** is sequenced-before **X**, **X** modifies **M**, **Y** is sequenced-before **B**, **Y** reads the value written by **X** or a value written by any side effect in the hypothetical release sequence **X** would head if it were a release operation, and that the scopes of **A**, **B** are inclusive. [\[C11 standard, Section 7.17.4, paragraph 2, modified.\]](#)

A global release fence **A** global-synchronizes-with an atomic operation **B** that performs an acquire operation on a global atomic object **M** if there exists an atomic operation **X** such that **A** is sequenced-before **X**, **X** modifies **M**, **B** reads the value written by **X** or a value written by any side effect in the hypothetical release sequence **X** would head if it were a release operation, and the scopes of **A** and **B** are inclusive. [\[C11 standard, Section 7.17.4, paragraph 3, modified.\]](#)

An atomic operation **A** that is a release operation on a global atomic object **M** global-synchronizes-with a global acquire fence **B** if there exists some atomic operation **X** on **M** such that **X** is sequenced-before **B** and reads the value written by **A** or a value written by any side effect in the release sequence headed by **A**, and the scopes of **A** and **B** are inclusive. [\[C11 standard, Section 7.17.4, paragraph 4, modified.\]](#)

A local release fence **A** local-synchronizes-with a local acquire fence **B** if there exist atomic operations **X** and **Y**, both operating on some local atomic object **M**, such that **A** is sequenced-before **X**, **X** modifies **M**, **Y** is sequenced-before **B**, and **Y** reads the value written by **X** or a value written by

any side effect in the hypothetical release sequence **X** would head if it were a release operation, and the scopes of **A** and **B** are inclusive. [C11 standard, Section 7.17.4, paragraph 2, modified.]

A local release fence **A** local-synchronizes-with an atomic operation **B** that performs an acquire operation on a local atomic object **M** if there exists an atomic operation **X** such that **A** is sequenced-before **X**, **X** modifies **M**, and **B** reads the value written by **X** or a value written by any side effect in the hypothetical release sequence **X** would head if it were a release operation, and the scopes of **A** and **B** are inclusive. [C11 standard, Section 7.17.4, paragraph 3, modified.]

An atomic operation **A** that is a release operation on a local atomic object **M** local-synchronizes-with a local acquire fence **B** if there exists some atomic operation **X** on **M** such that **X** is sequenced-before **B** and reads the value written by **A** or a value written by any side effect in the release sequence headed by **A**, and the scopes of **A** and **B** are inclusive. [C11 standard, Section 7.17.4, paragraph 4, modified.]

Let **X** and **Y** be two work-item fences that each have both the `CLK_GLOBAL_MEM_FENCE` and `CLK_LOCAL_MEM_FENCE` flags set. **X** global-synchronizes-with **Y** and **X** local synchronizes with **Y** if the conditions required for **X** to global-synchronize with **Y** are met, the conditions required for **X** to local-synchronize-with **Y** are met, or both sets of conditions are met.

3.3.7.3. Work-group Functions

The OpenCL kernel execution model includes collective operations across the work-items within a single work-group. These are called work-group functions, and include functions such as barriers, scans, reductions, and broadcasts. We will first discuss the work-group barrier function. Other work-group functions are discussed afterwards.

The barrier function provides a mechanism for a kernel to synchronize the work-items within a single work-group: informally, each work-item of the work-group must execute the barrier before any are allowed to proceed. It also orders memory operations to a specified combination of one or more address spaces such as local memory or global memory, in a similar manner to a fence.

To precisely specify the memory ordering semantics for barrier, we need to distinguish between a dynamic and a static instance of the call to a barrier. A call to a barrier can appear in a loop, for example, and each execution of the same static barrier call results in a new dynamic instance of the barrier that will independently synchronize a work-groups work-items.

A work-item executing a dynamic instance of a barrier results in two operations, both fences, that are called the entry and exit fences. These fences obey all the rules for fences specified elsewhere in this chapter as well as the following:

- The entry fence is a release fence with the same flags and scope as requested for the barrier.
- The exit fence is an acquire fence with the same flags and scope as requested for the barrier.
- For each work-item the entry fence is sequenced before the exit fence.
- If the flags have `CLK_GLOBAL_MEM_FENCE` set then for each work-item the entry fence global-synchronizes-with the exit fence of all other work-items in the same work-group.
- If the flags have `CLK_LOCAL_MEM_FENCE` set then for each work-item the entry fence local-synchronizes-with the exit fence of all other work-items in the same work-group.

Other work-group functions include such functions as scans, reductions, and broadcasts, and are described in the kernel language and IL specifications. The use of these work-group functions implies sequenced-before relationships between statements within the execution of a single work-item in order to satisfy data dependencies. For example, a work-item that provides a value to a work-group function must behave as if it generates that value before beginning execution of that work-group function. Furthermore, the programmer must ensure that all work-items in a work-group must execute the same work-group function call site, or dynamic work-group function instance.

3.3.7.4. Sub-group Functions



Sub-group functions are [missing before](#) version 2.1. Also see extension `cl_khr_subgroups`.

The OpenCL kernel execution model includes collective operations across the work-items within a single sub-group. These are called sub-group functions. We will first discuss the sub-group barrier. Other sub-group functions are discussed afterwards.

The barrier function provides a mechanism for a kernel to synchronize the work-items within a single sub-group: informally, each work-item of the sub-group must execute the barrier before any are allowed to proceed. It also orders memory operations to a specified combination of one or more address spaces such as local memory or global memory, in a similar manner to a fence.

To precisely specify the memory ordering semantics for barrier, we need to distinguish between a dynamic and a static instance of the call to a barrier. A call to a barrier can appear in a loop, for example, and each execution of the same static barrier call results in a new dynamic instance of the barrier that will independently synchronize the work-items in a sub-group.

A work-item executing a dynamic instance of a barrier results in two operations, both fences, that are called the entry and exit fences. These fences obey all the rules for fences specified elsewhere in this chapter as well as the following:

- The entry fence is a release fence with the same flags and scope as requested for the barrier.
- The exit fence is an acquire fence with the same flags and scope as requested for the barrier.
- For each work-item the entry fence is sequenced before the exit fence.
- If the flags have `CLK_GLOBAL_MEM_FENCE` set then for each work-item the entry fence global-synchronizes-with the exit fence of all other work-items in the same sub-group.
- If the flags have `CLK_LOCAL_MEM_FENCE` set then for each work-item the entry fence local-synchronizes-with the exit fence of all other work-items in the same sub-group.

Other sub-group functions include such functions as scans, reductions, and broadcasts, and are described in the kernel languages and IL specifications. The use of these sub-group functions implies sequenced-before relationships between statements within the execution of a single work-item in order to satisfy data dependencies. For example, a work-item that provides a value to a sub-group function must behave as if it generates that value before beginning execution of that sub-group function. Furthermore, the programmer must ensure that all work-items in a sub-group must execute the same sub-group function call site, or dynamic sub-group function instance.

3.3.7.5. Host-side and Device-side Commands

This section describes how the OpenCL API functions associated with command-queues contribute to happens-before relations. There are two types of command-queues and associated API functions in OpenCL 2.x; *host command-queues* and *device command-queues*. The interaction of these command-queues with the memory model are for the most part equivalent. In a few cases, the rules only applies to the host command-queue. We will indicate these special cases by specifically denoting the host command-queue in the memory ordering rule. SVM memory consistency in such instances is implied only with respect to synchronizing host commands.

Memory ordering rules in this section apply to all memory objects (buffers, images and pipes) as well as to SVM allocations where no earlier, and more fine-grained, rules apply.

In the remainder of this section, we assume that each command **C** enqueued onto a command-queue has an associated event object **E** that signals its execution status, regardless of whether **E** was returned to the unit of execution that enqueued **C**. We also distinguish between the API function call that enqueues a command **C** and creates an event **E**, the execution of **C**, and the completion of **C**(which marks the event **E** as complete).

The ordering and synchronization rules for API commands are defined as following:

1. If an API function call **X** enqueues a command **C**, then **X** global-synchronizes-with **C**. For example, a host API function to enqueue a kernel global-synchronizes-with the start of that kernel-instances execution, so that memory updates sequenced-before the enqueue kernel function call will global-happen-before any kernel reads or writes to those same memory locations. For a device-side enqueue, global memory updates sequenced before **X** happens-before **C** reads or writes to those memory locations only in the case of fine-grained SVM.
2. If **E** is an event upon which a command **C** waits, then **E** global-synchronizes-with **C**. In particular, if **C** waits on an event **E** that is tracking the execution status of the command **C1**, then memory operations done by **C1** will global-happen-before memory operations done by **C**. As an example, assume we have an OpenCL program using coarse-grain SVM sharing that enqueues a kernel to a host command-queue to manipulate the contents of a region of a buffer that the host thread then accesses after the kernel completes. To do this, the host thread can call [clEnqueueMapBuffer](#) to enqueue a blocking-mode map command to map that buffer region, specifying that the map command must wait on an event signaling the kernels completion. When [clEnqueueMapBuffer](#) returns, any memory operations performed by the kernel to that buffer region will global- happen-before subsequent memory operations made by the host thread.
3. If a command **C** has an event **E** that signals its completion, then **C** global- synchronizes-with **E**.
4. For a command **C** enqueued to a host-side command-queue, if **C** has an event **E** that signals its completion, then **E** global-synchronizes-with an API call **X** that waits on **E**. For example, if a host thread or kernel-instance calls the wait-for-events function on **E** (e.g. the [clWaitForEvents](#) function called from a host thread), then **E** global-synchronizes-with that wait-for-events function call.
5. If commands **C** and **C1** are enqueued in that sequence onto an in-order command-queue, then the event (including the event implied between **C** and **C1** due to the in-order queue) signaling **C**'s completion global-synchronizes-with **C1**. Note that in OpenCL 2.x, only a host command-

queue can be configured as an in-order queue.

6. If an API call enqueues a marker command **C** with an empty list of events upon which **C** should wait, then the events of all commands enqueued prior to **C** in the command-queue global-synchronize-with **C**.
7. If a host API call enqueues a command-queue barrier command **C** with an empty list of events on which **C** should wait, then the events of all commands enqueued prior to **C** in the command-queue global-synchronize-with **C**. In addition, the event signaling the completion of **C** global-synchronizes-with all commands enqueued after **C** in the command-queue.
8. If a host thread executes a **clFinish** call **X**, then the events of all commands enqueued prior to **X** in the command-queue global-synchronizes-with **X**.
9. The start of a kernel-instance **K** global-synchronizes-with all operations in the work-items of **K**. Note that this includes the execution of any atomic operations by the work-items in a program using fine-grain SVM.
10. All operations of all work-items of a kernel-instance **K** global-synchronizes-with the event signaling the completion of **K**. Note that this also includes the execution of any atomic operations by the work-items in a program using fine-grain SVM.
11. If a callback procedure **P** is registered on an event **E**, then **E** global-synchronizes-with all operations of **P**. Note that callback procedures are only defined for commands within host command-queues.
12. If **C** is a command that waits for an event **E**'s completion, and API function call **X** sets the status of a user event **E**'s status to **CL_COMPLETE** (for example, from a host thread using a **clSetUserEventStatus** function), then **X** global-synchronizes-with **C**.
13. If a device enqueues a command **C** with the **CLK_ENQUEUE_FLAGS_WAIT_KERNEL** flag, then the end state of the parent kernel instance global-synchronizes with **C**.
14. If a work-group enqueues a command **C** with the **CLK_ENQUEUE_FLAGS_WAIT_WORK_GROUP** flag, then the end state of the work-group global-synchronizes with **C**.

When using an out-of-order command-queue, a wait on an event or a marker or command-queue barrier command can be used to ensure the correct ordering of dependent commands. In those cases, the wait for the event or the marker or barrier command will provide the necessary global-synchronizes-with relation.

In this situation:

- access to shared locations or disjoint locations in a single **cl_mem** object when using atomic operations from different kernel instances enqueued from the host such that one or more of the atomic operations is a write is implementation-defined and correct behavior is not guaranteed except at synchronization points.
- access to shared locations or disjoint locations in a single **cl_mem** object when using atomic operations from different kernel instances consisting of a parent kernel and any number of child kernels enqueued by that kernel is guaranteed under the memory ordering rules described earlier in this section.
- access to shared locations or disjoint locations in a single program scope global variable, coarse-grained SVM allocation or fine-grained SVM allocation when using atomic operations from

different kernel instances enqueued from the host to a single device is guaranteed under the memory ordering rules described earlier in this section.

If fine-grain SVM is used but without support for the OpenCL 2.x atomic operations, then the host and devices can concurrently read the same memory locations and can concurrently update non-overlapping memory regions, but attempts to update the same memory locations are undefined. Memory consistency is guaranteed at the OpenCL synchronization points without the need for calls to `clEnqueueMapBuffer` and `clEnqueueUnmapMemObject`. For fine-grained SVM buffers it is guaranteed that at synchronization points only values written by the kernel will be updated. No writes to fine-grained SVM buffers can be introduced that were not in the original program.

In the remainder of this section, we discuss a few points regarding the ordering rules for commands with a host command-queue.



In an OpenCL 1.x implementation a synchronization point is a kernel-instance or host program location where the contents of memory visible to different work-items or command-queue commands are the same. It also says that waiting on an event and a command-queue barrier are synchronization points between commands in command-queues. Four of the rules listed above (2, 4, 7, and 8) cover these OpenCL synchronization points.

A map operation (`clEnqueueMapBuffer` or `clEnqueueMapImage`) performed on a non-SVM buffer or a coarse-grained SVM buffer is allowed to overwrite the entire target region with the latest runtime view of the data as seen by the command with which the map operation synchronizes, whether the values were written by the executing kernels or not. Any values that were changed within this region by another kernel or host thread while the kernel synchronizing with the map operation was executing may be overwritten by the map operation.

Access to non-SVM `cl_mem` buffers and coarse-grained SVM allocations is ordered at synchronization points between host commands. In the presence of an out-of-order command-queue or a set of command-queues mapped to the same device, multiple kernel instances may execute concurrently on the same device.

3.4. The OpenCL Framework

The OpenCL framework allows applications to use a host and one or more OpenCL devices as a single heterogeneous parallel computer system. The framework contains the following components:

- **OpenCL Platform layer:** The platform layer allows the host program to discover OpenCL devices and their capabilities and to create contexts.
- **OpenCL Runtime:** The runtime allows the host program to manipulate contexts once they have been created.
- **OpenCL Compiler:** The OpenCL compiler creates program executables that contain OpenCL kernels. The OpenCL compiler may build program executables from OpenCL C source strings, the SPIR-V intermediate language, or device-specific program binary objects, depending on the capabilities of a device. Other kernel languages or intermediate languages may be supported by

some implementations.

3.4.1. Mixed Version Support



Mixed version support [missing before](#) version 1.1.

OpenCL supports devices with different capabilities under a single platform. This includes devices which conform to different versions of the OpenCL specification. There are three version identifiers to consider for an OpenCL system: the platform version, the version of a device, and the version(s) of the kernel language or IL supported on a device.

The platform version indicates the version of the OpenCL runtime that is supported. This includes all of the APIs that the host can use to interact with resources exposed by the OpenCL runtime; including contexts, memory objects, devices, and command-queues.

The device version is an indication of the device's capabilities separate from the runtime and compiler as represented by the device info returned by `clGetDeviceInfo`. Examples of attributes associated with the device version are resource limits (e.g., minimum size of local memory per compute unit) and extended functionality (e.g., list of supported KHR extensions). The version returned corresponds to the highest version of the OpenCL specification for which the device is conformant, but is not higher than the platform version.

The language version for a device represents the OpenCL programming language features a developer can assume are supported on a given device. The version reported is the highest version of the language supported.

3.4.2. Backwards Compatibility

Backwards compatibility is an important goal for the OpenCL standard. Backwards compatibility is expected such that a device will consume earlier versions of the OpenCL C programming languages and the SPIR-V intermediate language with the following minimum requirements:

- An OpenCL 1.x device must support at least one 1.x version of the OpenCL C programming language.
- An OpenCL 2.0 device must support all the requirements of an OpenCL 1.2 device in addition to the OpenCL C 2.0 programming language. If multiple language versions are supported, the compiler defaults to using the OpenCL C 1.2 language version. To utilize the OpenCL 2.0 Kernel programming language, a programmer must specifically pass the appropriate compiler build option (`-cl-std=CL2.0`). The language version must not be higher than the platform version, but may exceed the [device version](#).
- An OpenCL 2.1 device must support all the requirements of an OpenCL 2.0 device in addition to the SPIR-V intermediate language at version 1.0 or above. Intermediate language versioning is encoded as part of the binary object and no flags are required to be passed to the compiler.
- An OpenCL 2.2 device must support all the requirements of an OpenCL 2.0 device in addition to the SPIR-V intermediate language at version 1.2 or above. Intermediate language versioning is encoded as a part of the binary object and no flags are required to be passed to the compiler.
- OpenCL 3.0 is designed to enable any OpenCL implementation supporting OpenCL 1.2 or newer

to easily support and transition to OpenCL 3.0, by making many features in OpenCL 2.0, 2.1, or 2.2 optional. This means that OpenCL 3.0 is backwards compatible with OpenCL 1.2, but is not necessarily backwards compatible with OpenCL 2.0, 2.1, or 2.2.

An OpenCL 3.0 platform must implement all OpenCL 3.0 APIs, but some APIs may return an error code unconditionally when a feature is not supported by any devices in the platform. Whenever a feature is optional, it will be paired with a query to determine whether the feature is supported. The queries will enable correctly written applications to selectively use all optional features without generating any OpenCL errors, if desired.

OpenCL 3.0 also adds a new version of the OpenCL C programming language, which makes many features in OpenCL C 2.0 optional. The new version of OpenCL C is backwards compatible with OpenCL C 1.2, but is not backwards compatible with OpenCL C 2.0. The new version of OpenCL C must be explicitly requested via the `-cl-std=` build option, otherwise a program will continue to be compiled using the highest OpenCL C 1.x language version supported for the device.

Whenever an OpenCL C feature is optional in the new version of the OpenCL C programming language, it will be paired with a feature macro, such as `__opencl_c_feature_name`, and a corresponding API query. If a feature macro is defined then the feature is supported by the OpenCL C compiler, otherwise the optional feature is not supported.

In order to allow future versions of OpenCL to support new types of devices, minor releases of OpenCL may add new profiles where some features that are currently required for all OpenCL devices become optional. All features that are required for an OpenCL profile will also be required for that profile in subsequent minor releases of OpenCL, thereby guaranteeing backwards compatibility for applications targeting specific profiles. It is therefore strongly recommended that applications [query the profile](#) supported by the OpenCL device they are running on in order to remain robust to future changes.

3.4.3. Versioning

The OpenCL specification is regularly updated with bug fixes and clarifications. Occasionally new functionality is added to the core and extensions. In order to indicate to developers how and when these changes are made to the specification, and to provide a way to identify each set of changes, the OpenCL API, C language, intermediate languages and extensions maintain a version number. Built-in kernels are also versioned.

3.4.3.1. Versions

A version number comprises three logical fields:

- The *major* version indicates a significant change. Backwards compatibility may break across major versions.
- The *minor* version indicates the addition of new functionality with backwards compatibility for any existing profiles.
- The *patch* version indicates bug fixes, clarifications and general improvements.

Version numbers are represented using the `cl_version` type that is an alias for a 32-bit integer. The

fields are packed as follows:

- The *major* version is a 10-bit integer packed into bits 31-22.
- The *minor* version is a 10-bit integer packed into bits 21-12.
- The *patch* version is a 12-bit integer packed into bits 11-0.

This enables versions to be ordered using standard C/C++ operators.

A number of convenience macros are provided by the OpenCL Headers to make working with version numbers easier.

`CL_VERSION_MAJOR` extracts the *major* version from a packed `cl_version`.

`CL_VERSION_MINOR` extracts the *minor* version from a packed `cl_version`.

`CL_VERSION_PATCH` extracts the *patch* version from a packed `cl_version`.

`CL_MAKE_VERSION` returns a packed `cl_version` from a *major*, *minor* and *patch* version.

These are defined as follows:

```
typedef cl_uint cl_version;

#define CL_VERSION_MAJOR_BITS (10)
#define CL_VERSION_MINOR_BITS (10)
#define CL_VERSION_PATCH_BITS (12)

#define CL_VERSION_MAJOR_MASK ((1 << CL_VERSION_MAJOR_BITS) - 1)
#define CL_VERSION_MINOR_MASK ((1 << CL_VERSION_MINOR_BITS) - 1)
#define CL_VERSION_PATCH_MASK ((1 << CL_VERSION_PATCH_BITS) - 1)

#define CL_VERSION_MAJOR(version) \
    ((version) >> (CL_VERSION_MINOR_BITS + CL_VERSION_PATCH_BITS))

#define CL_VERSION_MINOR(version) \
    (((version) >> CL_VERSION_PATCH_BITS) & CL_VERSION_MINOR_MASK)

#define CL_VERSION_PATCH(version) ((version) & CL_VERSION_PATCH_MASK)

#define CL_MAKE_VERSION(major, minor, patch) \
    (((major) & CL_VERSION_MAJOR_MASK) << \
     (CL_VERSION_MINOR_BITS + CL_VERSION_PATCH_BITS)) | \
    (((minor) & CL_VERSION_MINOR_MASK) << \
     CL_VERSION_PATCH_BITS) | \
    ((patch) & CL_VERSION_PATCH_MASK))
```

3.4.3.2. Version name pairing

It is sometimes necessary to associate a version to an entity it applies to (e.g. extension or built-in kernel). This is done using a dedicated `cl_name_version` structure, defined as follows:

```
typedef struct cl_name_version {
    cl_version    version;
    char          name[CL_NAME_VERSION_MAX_NAME_SIZE];
} cl_name_version;
```

The `name` field is an array of `CL_NAME_VERSION_MAX_NAME_SIZE` bytes used as storage for a NUL-terminated string whose maximum length is therefore `CL_NAME_VERSION_MAX_NAME_SIZE - 1`.

[1] This value for `memory_scope` can only be used with `atomic_work_item_fence` with flags set to `CLK_IMAGE_MEM_FENCE`.

Chapter 4. The OpenCL Platform Layer

This section describes the OpenCL platform layer which implements platform-specific features that allow applications to query OpenCL devices, device configuration information, and to create OpenCL contexts using one or more devices.

4.1. Querying Platform Info

The list of platforms available can be obtained with the function:

```
cl_int clGetPlatformIDs(  
    cl_uint num_entries,  
    cl_platform_id* platforms,  
    cl_uint* num_platforms);
```

- *num_entries* is the number of `cl_platform_id` entries that can be added to *platforms*. If *platforms* is not `NULL`, the *num_entries* must be greater than zero.
- *platforms* returns a list of OpenCL platforms found. The `cl_platform_id` values returned in *platforms* can be used to identify a specific OpenCL platform. If *platforms* is `NULL`, this argument is ignored. The number of OpenCL platforms returned is the minimum of the value specified by *num_entries* or the number of OpenCL platforms available.
- *num_platforms* returns the number of OpenCL platforms available. If *num_platforms* is `NULL`, this argument is ignored.

`clGetPlatformIDs` returns `CL_SUCCESS` if the function is executed successfully. Otherwise, it returns one of the following errors:

- `CL_INVALID_VALUE` if *num_entries* is equal to zero and *platforms* is not `NULL` or if both *num_platforms* and *platforms* are `NULL`.
- `CL_OUT_OF_HOST_MEMORY` if there is a failure to allocate resources required by the OpenCL implementation on the host.

Specific information about an OpenCL platform can be obtained with the function:

```
cl_int clGetPlatformInfo(  
    cl_platform_id platform,  
    cl_platform_info param_name,  
    size_t param_value_size,  
    void* param_value,  
    size_t* param_value_size_ret);
```

- *platform* refers to the platform ID returned by `clGetPlatformIDs` or can be `NULL`. If *platform* is `NULL`, the behavior is implementation-defined.
- *param_name* is an enumeration constant that identifies the platform information being queried. It can be one of the following values as specified in the [Platform Queries](#) table.

- *param_value* is a pointer to memory location where appropriate values for a given *param_name*, as specified in the [Platform Queries](#) table, will be returned. If *param_value* is **NULL**, it is ignored.
- *param_value_size* specifies the size in bytes of memory pointed to by *param_value*. This size in bytes must be \geq size of return type specified in the [Platform Queries](#) table.
- *param_value_size_ret* returns the actual size in bytes of data being queried by *param_name*. If *param_value_size_ret* is **NULL**, it is ignored.

The information that can be queried using [clGetPlatformInfo](#) is specified in the [Platform Queries](#) table.

Table 3. List of supported *param_names* by [clGetPlatformInfo](#)

Platform Info	Return Type	Description
CL_PLATFORM_PROFILE ^[1]	char[] ^[2]	<p>OpenCL profile string. Returns the profile name supported by the implementation. The profile name returned can be one of the following strings:</p> <p>FULL_PROFILE - if the implementation supports the OpenCL specification (functionality defined as part of the core specification and does not require any extensions to be supported).</p> <p>EMBEDDED_PROFILE - if the implementation supports the OpenCL embedded profile. The embedded profile is defined to be a subset for each version of OpenCL. The embedded profile for OpenCL is described in OpenCL Embedded Profile.</p>
CL_PLATFORM_VERSION	char[]	<p>OpenCL version string. Returns the OpenCL version supported by the implementation. This version string has the following format:</p> <p><i>OpenCL</i><space><major_version.minor_version><space><platform-specific information></p> <p>The <i>major_version.minor_version</i> value returned will be one of 1.0, 1.1, 1.2, 2.0, 2.1, 2.2 or 3.0.</p>
CL_PLATFORM_NUMERIC_VERSION missing before version 3.0.	cl_version	<p>Returns the detailed (major, minor, patch) version supported by the platform. The major and minor version numbers returned must match those returned via CL_PLATFORM_VERSION.</p>
CL_PLATFORM_NAME	char[]	Platform name string.
CL_PLATFORM_VENDOR	char[]	Platform vendor string.

Platform Info	Return Type	Description
<code>CL_PLATFORM_EXTENSIONS</code>	<code>char[]</code>	Returns a space separated list of extension names (the extension names themselves do not contain any spaces) supported by the platform. Each extension that is supported by all devices associated with this platform must be reported here.
<code>CL_PLATFORM_EXTENSIONS_WITH_VERSION</code> missing before version 3.0.	<code>cl_name_version[]</code>	Returns an array of description (name and version) structures that lists all the extensions supported by the platform. The same extension name must not be reported more than once. The list of extensions reported must match the list reported via <code>CL_PLATFORM_EXTENSIONS</code> .
<code>CL_PLATFORM_HOST_TIMER_RESOLUTION</code> missing before version 2.1.	<code>cl_ulong</code>	Returns the resolution of the host timer in nanoseconds as used by <code>clGetDeviceAndHostTimer</code> . Support for device and host timer synchronization is required for platforms supporting OpenCL 2.1 or 2.2. This value must be 0 for devices that do not support device and host timer synchronization.

`clGetPlatformInfo` returns `CL_SUCCESS` if the function is executed successfully. Otherwise, it returns one of the following errors ^[3].

- `CL_INVALID_PLATFORM` if *platform* is not a valid platform.
- `CL_INVALID_VALUE` if *param_name* is not one of the supported values or if size in bytes specified by *param_value_size* is < size of return type as specified in the [OpenCL Platform Queries](#) table, and *param_value* is not a `NULL` value.
- `CL_OUT_OF_HOST_MEMORY` if there is a failure to allocate resources required by the OpenCL implementation on the host.

4.2. Querying Devices

The list of devices available on a platform can be obtained using the function ^[4]:

```
cl_int clGetDeviceIDs(
    cl_platform_id platform,
    cl_device_type device_type,
    cl_uint num_entries,
    cl_device_id* devices,
    cl_uint* num_devices);
```

- *platform* refers to the platform ID returned by `clGetPlatformIDs` or can be `NULL`. If *platform* is

`NULL`, the behavior is implementation-defined.

- `device_type` is a bitfield that identifies the type of OpenCL device. The `device_type` can be used to query specific OpenCL devices or all OpenCL devices available. The valid values for `device_type` are specified in the [Device Types](#) table.
- `num_entries` is the number of `cl_device_id` entries that can be added to `devices`. If `devices` is not `NULL`, the `num_entries` must be greater than zero.
- `devices` returns a list of OpenCL devices found. The `cl_device_id` values returned in `devices` can be used to identify a specific OpenCL device. If `devices` is `NULL`, this argument is ignored. The number of OpenCL devices returned is the minimum of the value specified by `num_entries` or the number of OpenCL devices whose type matches `device_type`.
- `num_devices` returns the number of OpenCL devices available that match `device_type`. If `num_devices` is `NULL`, this argument is ignored.

Table 4. List of supported `device_types` by `clGetDeviceIDs`

Device Type	Description
<code>CL_DEVICE_TYPE_CPU</code>	An OpenCL device similar to a traditional CPU (Central Processing Unit). The host processor that executes OpenCL host code may also be considered a CPU OpenCL device.
<code>CL_DEVICE_TYPE_GPU</code>	An OpenCL device similar to a GPU (Graphics Processing Unit). Many systems include a dedicated processor for graphics or rendering that may be considered a GPU OpenCL device.
<code>CL_DEVICE_TYPE_ACCELERATOR</code>	Dedicated devices that may accelerate OpenCL programs, such as FPGAs (Field Programmable Gate Arrays), DSPs (Digital Signal Processors), or AI (Artificial Intelligence) processors.
<code>CL_DEVICE_TYPE_CUSTOM</code> <code>missing before</code> version 1.2.	Specialized devices that implement some of the OpenCL runtime APIs but do not support all required OpenCL functionality.
<code>CL_DEVICE_TYPE_DEFAULT</code>	The default OpenCL device in the platform. The default OpenCL device must not be a <code>CL_DEVICE_TYPE_CUSTOM</code> device.
<code>CL_DEVICE_TYPE_ALL</code>	All OpenCL devices available in the platform, except for <code>CL_DEVICE_TYPE_CUSTOM</code> devices.

The device type is purely informational and has no semantic meaning.

Some devices may be more than one type. For example, a `CL_DEVICE_TYPE_CPU` device may also be a `CL_DEVICE_TYPE_GPU` device, or a `CL_DEVICE_TYPE_ACCELERATOR` device may also be some other, more descriptive device type. `CL_DEVICE_TYPE_CUSTOM` devices must not be combined with any other device types.

One device in the platform should be a `CL_DEVICE_TYPE_DEFAULT` device. The default device should

also be a more specific device type, such as `CL_DEVICE_TYPE_CPU` or `CL_DEVICE_TYPE_GPU`.

`clGetDeviceIDs` returns `CL_SUCCESS` if the function is executed successfully. Otherwise, it returns one of the following errors:

- `CL_INVALID_PLATFORM` if *platform* is not a valid platform.
- `CL_INVALID_DEVICE_TYPE` if *device_type* is not a valid value.
- `CL_INVALID_VALUE` if *num_entries* is equal to zero and *devices* is not `NULL` or if both *num_devices* and *devices* are `NULL`.
- `CL_DEVICE_NOT_FOUND` if no OpenCL devices that matched *device_type* were found.
- `CL_OUT_OF_RESOURCES` if there is a failure to allocate resources required by the OpenCL implementation on the device.
- `CL_OUT_OF_HOST_MEMORY` if there is a failure to allocate resources required by the OpenCL implementation on the host.

The application can query specific capabilities of the OpenCL device(s) returned by `clGetDeviceIDs`. This can be used by the application to determine which device(s) to use.

To get specific information about an OpenCL device, call the function:

```
cl_int clGetDeviceInfo(  
    cl_device_id device,  
    cl_device_info param_name,  
    size_t param_value_size,  
    void* param_value,  
    size_t* param_value_size_ret);
```

- *device* may be a device returned by `clGetDeviceIDs` or a sub-device created by `clCreateSubDevices`. If *device* is a sub-device, the specific information for the sub-device will be returned. The information that can be queried using `clGetDeviceInfo` is specified in the [Device Queries](#) table.
- *param_name* is an enumeration constant that identifies the device information being queried. It can be one of the following values as specified in the [Device Queries](#) table.
- *param_value* is a pointer to memory location where appropriate values for a given *param_name*, as specified in the [Device Queries](#) table, will be returned. If *param_value* is `NULL`, it is ignored.
- *param_value_size* specifies the size in bytes of memory pointed to by *param_value*. This size in bytes must be \geq size of return type specified in the [Device Queries](#) table.
- *param_value_size_ret* returns the actual size in bytes of data being queried by *param_name*. If *param_value_size_ret* is `NULL`, it is ignored.

The device queries described in the [Device Queries](#) table should return the same information for a root-level device i.e. a device returned by `clGetDeviceIDs` and any sub-devices created from this device except for the following queries:

- `CL_DEVICE_GLOBAL_MEM_CACHE_SIZE`
- `CL_DEVICE_BUILT_IN_KERNELS`
- `CL_DEVICE_PARENT_DEVICE`
- `CL_DEVICE_PARTITION_TYPE`
- `CL_DEVICE_REFERENCE_COUNT`

Table 5. List of supported `param_names` by `clGetDeviceInfo`

Device Info	Return Type	Description
<code>CL_DEVICE_TYPE</code>	<code>cl_device_type</code>	<p>The type or types of the OpenCL device.</p> <p>Please see the Device Types table for supported device types and device type combinations.</p>
<code>CL_DEVICE_VENDOR_ID</code> ^[5]	<code>cl_uint</code>	<p>A unique device vendor identifier.</p> <p>If the vendor has a PCI vendor ID, the low 16 bits must contain that PCI vendor ID, and the remaining bits must be set to zero. Otherwise, the value returned must be a valid Khronos vendor ID represented by type <code>cl_khronos_vendor_id</code>. Khronos vendor IDs are allocated starting at 0x10000, to distinguish them from the PCI vendor ID namespace.</p>
<code>CL_DEVICE_MAX_COMPUTE_UNITS</code>	<code>cl_uint</code>	<p>The number of parallel compute units on the OpenCL device. A work-group executes on a single compute unit. The minimum value is 1.</p>
<code>CL_DEVICE_MAX_WORK_ITEM_DIMENSIONS</code>	<code>cl_uint</code>	<p>Maximum dimensions that specify the global and local work-item IDs used by the data parallel execution model. (Refer to clEnqueueNDRangeKernel). The minimum value is 3 for devices that are not of type <code>CL_DEVICE_TYPE_CUSTOM</code>.</p>
<code>CL_DEVICE_MAX_WORK_ITEM_SIZES</code>	<code>size_t[]</code>	<p>Maximum number of work-items that can be specified in each dimension of the work-group to clEnqueueNDRangeKernel.</p> <p>Returns <i>n</i> <code>size_t</code> entries, where <i>n</i> is the value returned by the query for <code>CL_DEVICE_MAX_WORK_ITEM_DIMENSIONS</code>.</p> <p>The minimum value is (1, 1, 1) for devices that are not of type <code>CL_DEVICE_TYPE_CUSTOM</code>.</p>

Device Info	Return Type	Description
CL_DEVICE_MAX_WORK_GROUP_SIZE	size_t	Maximum number of work-items in a work-group that a device is capable of executing on a single compute unit, for any given kernel-instance running on the device. (Refer also to clEnqueueNDRangeKernel and CL_KERNEL_WORK_GROUP_SIZE). The minimum value is 1. The returned value is an upper limit and will not necessarily maximize performance. This maximum may be larger than supported by a specific kernel (refer to the CL_KERNEL_WORK_GROUP_SIZE query of clGetKernelWorkGroupInfo).
CL_DEVICE_PREFERRED_VECTOR_WIDTH_CHAR CL_DEVICE_PREFERRED_VECTOR_WIDTH_SHORT CL_DEVICE_PREFERRED_VECTOR_WIDTH_INT CL_DEVICE_PREFERRED_VECTOR_WIDTH_LONG CL_DEVICE_PREFERRED_VECTOR_WIDTH_FLOAT CL_DEVICE_PREFERRED_VECTOR_WIDTH_DOUBLE CL_DEVICE_PREFERRED_VECTOR_WIDTH_HALF CL_DEVICE_PREFERRED_VECTOR_WIDTH_HALF is missing before version 1.1.	cl_uint	Preferred native vector width size for built-in scalar types that can be put into vectors. The vector width is defined as the number of scalar elements that can be stored in the vector. If double precision is not supported, CL_DEVICE_PREFERRED_VECTOR_WIDTH_DOUBLE must return 0. If the cl_khr_fp16 extension is not supported, CL_DEVICE_PREFERRED_VECTOR_WIDTH_HALF must return 0.

Device Info	Return Type	Description
CL_DEVICE_NATIVE_VECTOR_WIDTH_CHAR CL_DEVICE_NATIVE_VECTOR_WIDTH_SHORT CL_DEVICE_NATIVE_VECTOR_WIDTH_INT CL_DEVICE_NATIVE_VECTOR_WIDTH_LONG CL_DEVICE_NATIVE_VECTOR_WIDTH_FLOAT CL_DEVICE_NATIVE_VECTOR_WIDTH_DOUBLE CL_DEVICE_NATIVE_VECTOR_WIDTH_HALF missing before version 1.1.	cl_uint	Returns the native ISA vector width. The vector width is defined as the number of scalar elements that can be stored in the vector. If double precision is not supported, CL_DEVICE_NATIVE_VECTOR_WIDTH_DOUBLE must return 0. If the cl_khr_fp16 extension is not supported, CL_DEVICE_NATIVE_VECTOR_WIDTH_HALF must return 0.
CL_DEVICE_MAX_CLOCK_FREQUENCY	cl_uint	Clock frequency of the device in MHz. The meaning of this value is implementation-defined. For devices with multiple clock domains, the clock frequency for any of the clock domains may be returned. For devices that dynamically change frequency for power or thermal reasons, the returned clock frequency may be any valid frequency. Note: This definition is missing before version 2.2. Maximum configured clock frequency of the device in MHz. Note: This definition is deprecated by version 2.2.
CL_DEVICE_ADDRESS_BITS	cl_uint	The default compute device address space size of the global address space specified as an unsigned integer value in bits. Currently supported values are 32 or 64 bits.
CL_DEVICE_MAX_MEM_ALLOC_SIZE	cl_ulong	Max size of memory object allocation in bytes. The minimum value is max(min($1024 \times 1024 \times 1024$, $1/4^{\text{th}}$ of CL_DEVICE_GLOBAL_MEM_SIZE), $32 \times 1024 \times 1024$) for devices that are not of type CL_DEVICE_TYPE_CUSTOM.
CL_DEVICE_IMAGE_SUPPORT	cl_bool	Is CL_TRUE if images are supported by the OpenCL device and CL_FALSE otherwise.
CL_DEVICE_MAX_READ_IMAGE_ARGS ^[6]	cl_uint	Max number of image objects arguments of a kernel declared with the read_only qualifier. The minimum value is 128 if CL_DEVICE_IMAGE_SUPPORT is CL_TRUE, the value is 0 otherwise.

Device Info	Return Type	Description
<code>CL_DEVICE_MAX_WRITE_IMAGE_ARGS</code>	<code>cl_uint</code>	Max number of image objects arguments of a kernel declared with the <code>write_only</code> qualifier. The minimum value is 64 if <code>CL_DEVICE_IMAGE_SUPPORT</code> is <code>CL_TRUE</code> , the value is 0 otherwise.
<code>CL_DEVICE_MAX_READ_WRITE_IMAGE_ARGS</code> <code>missing before</code> version 2.0.	<code>cl_uint</code>	Max number of image objects arguments of a kernel declared with the <code>write_only</code> or <code>read_write</code> qualifier. Support for read-write image arguments is required for an OpenCL 2.0, 2.1, or 2.2 device if <code>CL_DEVICE_IMAGE_SUPPORT</code> is <code>CL_TRUE</code> . The minimum value is 64 if the device supports read-write images arguments, and must be 0 for devices that do not support read-write images.
<code>CL_DEVICE_IL_VERSION</code> <code>missing before</code> version 2.1. Also see extension <code>cl_khr_il_program</code> .	<code>char[]</code>	The intermediate languages that can be supported by <code>clCreateProgramWithIL</code> for this device. Returns a space-separated list of IL version strings of the form <code><IL_Prefix>_<Major_Version>.<Minor_Version></code> . For an OpenCL 2.1 or 2.2 device, SPIR-V is a required IL prefix. If the device does not support intermediate language programs, the value must be "" (an empty string).
<code>CL_DEVICE_ILS_WITH_VERSION</code> <code>missing before</code> version 3.0. Also see extension <code>cl_khr_il_program</code> .	<code>cl_name_version[]</code>	Returns an array of descriptions (name and version) for all supported intermediate languages. Intermediate languages with the same name may be reported more than once but each name and major/minor version combination may only be reported once. The list of intermediate languages reported must match the list reported via <code>CL_DEVICE_IL_VERSION</code> . For an OpenCL 2.1 or 2.2 device, at least one version of SPIR-V must be reported.
<code>CL_DEVICE_IMAGE2D_MAX_WIDTH</code>	<code>size_t</code>	Max width of 2D image or 1D image not created from a buffer object in pixels. The minimum value is 16384 if <code>CL_DEVICE_IMAGE_SUPPORT</code> is <code>CL_TRUE</code> , the value is 0 otherwise.

Device Info	Return Type	Description
CL_DEVICE_IMAGE2D_MAX_HEIGHT	size_t	<p>Max height of 2D image in pixels.</p> <p>The minimum value is 16384 if CL_DEVICE_IMAGE_SUPPORT is CL_TRUE, the value is 0 otherwise.</p>
CL_DEVICE_IMAGE3D_MAX_WIDTH	size_t	<p>Max width of 3D image in pixels.</p> <p>The minimum value is 2048 if CL_DEVICE_IMAGE_SUPPORT is CL_TRUE, the value is 0 otherwise.</p>
CL_DEVICE_IMAGE3D_MAX_HEIGHT	size_t	<p>Max height of 3D image in pixels.</p> <p>The minimum value is 2048 if CL_DEVICE_IMAGE_SUPPORT is CL_TRUE, the value is 0 otherwise.</p>
CL_DEVICE_IMAGE3D_MAX_DEPTH	size_t	<p>Max depth of 3D image in pixels.</p> <p>The minimum value is 2048 if CL_DEVICE_IMAGE_SUPPORT is CL_TRUE, the value is 0 otherwise.</p>
CL_DEVICE_IMAGE_MAX_BUFFER_SIZE missing before version 1.2.	size_t	<p>Max number of pixels for a 1D image created from a buffer object.</p> <p>The minimum value is 65536 if CL_DEVICE_IMAGE_SUPPORT is CL_TRUE, the value is 0 otherwise.</p>
CL_DEVICE_IMAGE_MAX_ARRAY_SIZE missing before version 1.2.	size_t	<p>Max number of images in a 1D or 2D image array.</p> <p>The minimum value is 2048 if CL_DEVICE_IMAGE_SUPPORT is CL_TRUE, the value is 0 otherwise.</p>
CL_DEVICE_MAX_SAMPLERS	cl_uint	<p>Maximum number of samplers that can be used in a kernel.</p> <p>The minimum value is 16 if CL_DEVICE_IMAGE_SUPPORT is CL_TRUE, the value is 0 otherwise.</p>
CL_DEVICE_IMAGE_PITCH_ALIGNMENT missing before version 2.0.	cl_uint	<p>The row pitch alignment size in pixels for 2D images created from a buffer. The value returned must be a power of 2.</p> <p>Support for 2D images created from a buffer is required for an OpenCL 2.0, 2.1, or 2.2 device if CL_DEVICE_IMAGE_SUPPORT is CL_TRUE.</p> <p>This value must be 0 for devices that do not support 2D images created from a buffer.</p>

Device Info	Return Type	Description
CL_DEVICE_IMAGE_BASE_ADDRESS_ALIGNMENT missing before version 2.0.	cl_uint	<p>This query specifies the minimum alignment in pixels of the host_ptr specified to clCreateBuffer or clCreateBufferWithProperties when a 2D image is created from a buffer which was created using CL_MEM_USE_HOST_PTR. The value returned must be a power of 2.</p> <p>Support for 2D images created from a buffer is required for an OpenCL 2.0, 2.1, or 2.2 device if CL_DEVICE_IMAGE_SUPPORT is CL_TRUE.</p> <p>This value must be 0 for devices that do not support 2D images created from a buffer.</p>
CL_DEVICE_MAX_PIPE_ARGS missing before version 2.0.	cl_uint	<p>The maximum number of pipe objects that can be passed as arguments to a kernel. The minimum value is 16 for devices supporting pipes, and must be 0 for devices that do not support pipes.</p>
CL_DEVICE_PIPE_MAX_ACTIVE_RESERVATIONS missing before version 2.0.	cl_uint	<p>The maximum number of reservations that can be active for a pipe per work-item in a kernel. A work-group reservation is counted as one reservation per work-item. The minimum value is 1 for devices supporting pipes, and must be 0 for devices that do not support pipes.</p>
CL_DEVICE_PIPE_MAX_PACKET_SIZE missing before version 2.0.	cl_uint	<p>The maximum size of pipe packet in bytes.</p> <p>Support for pipes is required for an OpenCL 2.0, 2.1, or 2.2 device. The minimum value is 1024 bytes if the device supports pipes, and must be 0 for devices that do not support pipes.</p>
CL_DEVICE_MAX_PARAMETER_SIZE	size_t	<p>Max size in bytes of all arguments that can be passed to a kernel.</p> <p>The minimum value is 1024 for devices that are not of type CL_DEVICE_TYPE_CUSTOM. For this minimum value, only a maximum of 128 arguments can be passed to a kernel. For all other values, a maximum of 255 arguments can be passed to a kernel.</p>

Device Info	Return Type	Description
<code>CL_DEVICE_MEM_BASE_ADDR_ALIGN</code>	<code>cl_uint</code>	Alignment requirement (in bits) for sub-buffer offsets. The minimum value is the size (in bits) of the largest OpenCL built-in data type supported by the device (long16 in FULL profile, long16 or int16 in EMBEDDED profile) for devices that are not of type <code>CL_DEVICE_TYPE_CUSTOM</code> .
<code>CL_DEVICE_MIN_DATA_TYPE_ALIGN_SIZE</code> deprecated by version 1.2.	<code>cl_uint</code>	The minimum value is the size (in bytes) of the largest OpenCL data type supported by the device (long16 in FULL profile, long16 or int16 in EMBEDDED profile).
<code>CL_DEVICE_SINGLE_FP_CONFIG</code> ^[7]	<code>cl_device_fp_config</code>	<p>Describes single precision floating-point capability of the device. This is a bit-field that describes one or more of the following values:</p> <p><code>CL_FP_DENORM</code> - denorms are supported <code>CL_FP_INF_NAN</code> - INF and quiet NaNs are supported <code>CL_FP_ROUND_TO_NEAREST</code> -- round to nearest even rounding mode supported <code>CL_FP_ROUND_TO_ZERO</code> - round to zero rounding mode supported <code>CL_FP_ROUND_TO_INF</code> - round to positive and negative infinity rounding modes supported <code>CL_FP_FMA</code> - IEEE754-2008 fused multiply-add is supported <code>CL_FP_CORRECTLY_ROUNDED_DIVIDE_SQRT</code> - divide and sqrt are correctly rounded as defined by the IEEE754 specification <code>CL_FP_SOFT_FLOAT</code> - Basic floating-point operations (such as addition, subtraction, multiplication) are implemented in software</p> <p>For the full profile, the mandated minimum floating-point capability for devices that are not of type <code>CL_DEVICE_TYPE_CUSTOM</code> is:</p> <p><code>CL_FP_ROUND_TO_NEAREST</code> <code>CL_FP_INF_NAN</code>.</p> <p>For the embedded profile, see the dedicated table.</p>

Device Info	Return Type	Description
CL_DEVICE_DOUBLE_FP_CONFIG ^[7] missing before version 1.2. Also see extension cl_khr_fp64 .	cl_device_fp_config	<p>Describes double precision floating-point capability of the OpenCL device. This is a bit-field that describes one or more of the following values:</p> <p>CL_FP_DENORM - denorms are supported CL_FP_INF_NAN - INF and NaNs are supported CL_FP_ROUND_TO_NEAREST - round to nearest even rounding mode supported CL_FP_ROUND_TO_ZERO - round to zero rounding mode supported CL_FP_ROUND_TO_INF - round to positive and negative infinity rounding modes supported CL_FP_FMA - IEEE754-2008 fused multiply-add is supported CL_FP_SOFT_FLOAT - Basic floating-point operations (such as addition, subtraction, multiplication) are implemented in software</p> <p>Double precision is an optional feature so the mandated minimum double precision floating-point capability is 0.</p> <p>If double precision is supported by the device, then the minimum double precision floating-point capability for OpenCL 2.0 or newer devices is:</p> <p>CL_FP_FMA CL_FP_ROUND_TO_NEAREST CL_FP_INF_NAN CL_FP_DENORM.</p> <p>or for OpenCL 1.0, OpenCL 1.1 or OpenCL 1.2 devices:</p> <p>CL_FP_FMA CL_FP_ROUND_TO_NEAREST CL_FP_ROUND_TO_ZERO CL_FP_ROUND_TO_INF CL_FP_INF_NAN CL_FP_DENORM.</p>
CL_DEVICE_GLOBAL_MEM_CACHE_TYPE	cl_device_mem_cache_type	Type of global memory cache supported. Valid values are: CL_NONE , CL_READ_ONLY_CACHE , and CL_READ_WRITE_CACHE .

Device Info	Return Type	Description
CL_DEVICE_GLOBAL_MEM_CACHELINE_SIZE	cl_uint	Size of global memory cache line in bytes.
CL_DEVICE_GLOBAL_MEM_CACHE_SIZE	cl_ulong	Size of global memory cache in bytes.
CL_DEVICE_GLOBAL_MEM_SIZE	cl_ulong	Size of global device memory in bytes.
CL_DEVICE_MAX_CONSTANT_BUFFER_SIZE	cl_ulong	Max size in bytes of a constant buffer allocation. The minimum value is 64 KB for devices that are not of type CL_DEVICE_TYPE_CUSTOM.
CL_DEVICE_MAX_CONSTANT_ARGS	cl_uint	Max number of arguments declared with the __constant qualifier in a kernel. The minimum value is 8 for devices that are not of type CL_DEVICE_TYPE_CUSTOM.
CL_DEVICE_MAX_GLOBAL_VARIABLE_SIZE missing before version 2.0.	size_t	<p>The maximum number of bytes of storage that may be allocated for any single variable in program scope or inside a function in an OpenCL kernel language declared in the global address space.</p> <p>Support for program scope global variables is required for an OpenCL 2.0, 2.1, or 2.2 device. The minimum value is 64 KB if the device supports program scope global variables, and must be 0 for devices that do not support program scope global variables.</p>
CL_DEVICE_GLOBAL_VARIABLE_PREFERRED_TOTAL_SIZE missing before version 2.0.	size_t	Maximum preferred total size, in bytes, of all program variables in the global address space. This is a performance hint. An implementation may place such variables in storage with optimized device access. This query returns the capacity of such storage. The minimum value is 0.
CL_DEVICE_LOCAL_MEM_TYPE	cl_device_local_mem_type	<p>Type of local memory supported. This can be set to CL_LOCAL implying dedicated local memory storage such as SRAM , or CL_GLOBAL.</p> <p>For custom devices, CL_NONE can also be returned indicating no local memory support.</p>
CL_DEVICE_LOCAL_MEM_SIZE	cl_ulong	Size of local memory region in bytes. The minimum value is 32 KB for devices that are not of type CL_DEVICE_TYPE_CUSTOM.

Device Info	Return Type	Description
CL_DEVICE_ERROR_CORRECTION_SUPPORT	cl_bool	Is CL_TRUE if the device implements error correction for all accesses to compute device memory (global and constant). Is CL_FALSE if the device does not implement such error correction.
CL_DEVICE_HOST_UNIFIED_MEMORY missing before version 1.1 and deprecated by version 2.0.	cl_bool	Is CL_TRUE if the device and the host have a unified memory subsystem and is CL_FALSE otherwise.
CL_DEVICE_PROFILING_TIMER_RESOLUTION	size_t	Describes the resolution of device timer. This is measured in nanoseconds. Refer to Profiling Operations for details.
CL_DEVICE_ENDIAN_LITTLE	cl_bool	Is CL_TRUE if the OpenCL device is a little endian device and CL_FALSE otherwise
CL_DEVICE_AVAILABLE	cl_bool	Is CL_TRUE if the device is available and CL_FALSE otherwise. A device is considered to be available if the device can be expected to successfully execute commands enqueued to the device.
CL_DEVICE_COMPILER_AVAILABLE	cl_bool	Is CL_FALSE if the implementation does not have a compiler available to compile the program source. Is CL_TRUE if the compiler is available. This can be CL_FALSE for the embedded platform profile only.
CL_DEVICE_LINKER_AVAILABLE missing before version 1.2.	cl_bool	Is CL_FALSE if the implementation does not have a linker available. Is CL_TRUE if the linker is available. This can be CL_FALSE for the embedded platform profile only. This must be CL_TRUE if CL_DEVICE_COMPILER_AVAILABLE is CL_TRUE .

Device Info	Return Type	Description
CL_DEVICE_EXECUTION_CAPABILITIES	cl_device_exec_capabilities	<p>Describes the execution capabilities of the device. This is a bit-field that describes one or more of the following values:</p> <p>CL_EXEC_KERNEL - The OpenCL device can execute OpenCL kernels.</p> <p>CL_EXEC_NATIVE_KERNEL - The OpenCL device can execute native kernels.</p> <p>The mandated minimum capability is: CL_EXEC_KERNEL.</p>
CL_DEVICE_QUEUE_PROPERTIES deprecated by version 2.0.	cl_command_queue_properties	See description of CL_DEVICE_QUEUE_ON_HOST_PROPERTIES.
CL_DEVICE_QUEUE_ON_HOST_PROPERTIES missing before version 2.0.	cl_command_queue_properties	<p>Describes the on host command-queue properties supported by the device. This is a bit-field that describes one or more of the following values:</p> <p>CL_QUEUE_OUT_OF_ORDER_EXEC_MODE_ENABLE CL_QUEUE_PROFILING_ENABLE</p> <p>These properties are described in the Queue Properties table.</p> <p>The mandated minimum capability is: CL_QUEUE_PROFILING_ENABLE.</p>

Device Info	Return Type	Description
CL_DEVICE_QUEUE_ON_DEVICE_PROPERTIES missing before version 2.0.	cl_command_queue_properties	<p>Describes the on device command-queue properties supported by the device. This is a bit-field that describes one or more of the following values:</p> <p>CL_QUEUE_OUT_OF_ORDER_EXEC_MODE_ENABLE CL_QUEUE_PROFILING_ENABLE</p> <p>These properties are described in the Queue Properties table.</p> <p>Support for on-device queues is required for an OpenCL 2.0, 2.1, or 2.2 device. When on-device queues are supported, the mandated minimum capability is:</p> <p>CL_QUEUE_OUT_OF_ORDER_EXEC_MODE_ENABLE CL_QUEUE_PROFILING_ENABLE.</p> <p>Must be 0 for devices that do not support on-device queues.</p>
CL_DEVICE_QUEUE_ON_DEVICE_PREFERRED_SIZE missing before version 2.0.	cl_uint	<p>The preferred size of the device queue, in bytes. Applications should use this size for the device queue to ensure good performance.</p> <p>The minimum value is 16 KB for devices supporting on-device queues, and must be 0 for devices that do not support on-device queues.</p>
CL_DEVICE_QUEUE_ON_DEVICE_MAX_SIZE missing before version 2.0.	cl_uint	<p>The maximum size of the device queue in bytes.</p> <p>The minimum value is 256 KB for the full profile and 64 KB for the embedded profile for devices supporting on-device queues, and must be 0 for devices that do not support on-device queues.</p>
CL_DEVICE_MAX_ON_DEVICE_QUEUES missing before version 2.0.	cl_uint	<p>The maximum number of device queues that can be created for this device in a single context.</p> <p>The minimum value is 1 for devices supporting on-device queues, and must be 0 for devices that do not support on-device queues.</p>

Device Info	Return Type	Description
CL_DEVICE_MAX_ON_DEVICE_EVENTS missing before version 2.0.	cl_uint	<p>The maximum number of events in use by a device queue. These refer to events returned by the enqueue_ built-in functions to a device queue or user events returned by the create_user_event built-in function that have not been released.</p> <p>The minimum value is 1024 for devices supporting on-device queues, and must be 0 for devices that do not support on-device queues.</p>
CL_DEVICE_BUILT_IN_KERNELS missing before version 1.2.	char[]	A semi-colon separated list of built-in kernels supported by the device. An empty string is returned if no built-in kernels are supported by the device.
CL_DEVICE_BUILT_IN_KERNELS_WITH_VERSION missing before version 3.0.	cl_name_version[]	Returns an array of descriptions for the built-in kernels supported by the device. Each built-in kernel may only be reported once. The list of reported kernels must match the list returned via CL_DEVICE_BUILT_IN_KERNELS.
CL_DEVICE_PLATFORM	cl_platform_id	The platform associated with this device.
CL_DEVICE_NAME	char[]	Device name string.
CL_DEVICE_VENDOR	char[]	Vendor name string.
CL_DRIVER_VERSION	char[]	OpenCL software driver version string. Follows a vendor-specific format.
CL_DEVICE_PROFILE	char[]	<p>OpenCL profile string. Returns the profile name supported by the device. The profile name returned can be one of the following strings:</p> <p>FULL_PROFILE - if the device supports the OpenCL specification (functionality defined as part of the core specification and does not require any extensions to be supported).</p> <p>EMBEDDED_PROFILE - if the device supports the OpenCL embedded profile.</p>

Device Info	Return Type	Description
CL_DEVICE_VERSION	char[]	<p>OpenCL version string. Returns the OpenCL version supported by the device. This version string has the following format:</p> <p><i>OpenCL<space><major_version.minor_version><space><vendor-specific information></i></p> <p>The major_version.minor_version value returned will be one of 1.0, 1.1, 1.2, 2.0, 2.1, 2.2, or 3.0.</p>
CL_DEVICE_NUMERIC_VERSION missing before version 3.0.	cl_version	<p>Returns the detailed (major, minor, patch) version supported by the device. The major and minor version numbers returned must match those returned via CL_DEVICE_VERSION.</p>

Device Info	Return Type	Description
CL_DEVICE_OPENCL_C_VERSION missing before version 1.1 and deprecated by version 3.0.	char[]	<p>Returns the highest fully backwards compatible OpenCL C version supported by the compiler for the device. For devices supporting compilation from OpenCL C source, this will return a version string with the following format:</p> <p><i>OpenCL<space>C<space><major_version.minor_version><space><vendor-specific information></i></p> <p>For devices that support compilation from OpenCL C source:</p> <p>Because OpenCL 3.0 is backwards compatible with OpenCL C 1.2, an OpenCL 3.0 device must support at least OpenCL C 1.2. An OpenCL 3.0 device may return an OpenCL C version newer than OpenCL C 1.2 if and only if all optional OpenCL C features are supported by the device for the newer version.</p> <p>Support for OpenCL C 2.0 is required for an OpenCL 2.0, OpenCL 2.1, or OpenCL 2.2 device.</p> <p>Support for OpenCL C 1.2 is required for an OpenCL 1.2 device.</p> <p>Support for OpenCL C 1.1 is required for an OpenCL 1.1 device.</p> <p>Support for either OpenCL C 1.0 or OpenCL C 1.1 is required for an OpenCL 1.0 device.</p> <p>For devices that do not support compilation from OpenCL C source, such as when CL_DEVICE_COMPILER_AVAILABLE is CL_FALSE, this query may return an empty string.</p> <p>This query has been superseded by the CL_DEVICE_OPENCL_C_ALL_VERSIONS query, which returns a set of OpenCL C versions supported by a device.</p>

Device Info	Return Type	Description
<p><code>CL_DEVICE_OPENCL_C_ALL_VERSIONS</code></p> <p>missing before version 3.0.</p>	<p><code>cl_name_version[]</code></p>	<p>Returns an array of name, version descriptions listing all the versions of OpenCL C supported by the compiler for the device. In each returned description structure, the name field is required to be "OpenCL C". The list may include both newer non-backwards compatible OpenCL C versions, such as OpenCL C 3.0, and older OpenCL C versions with mandatory backwards compatibility. The version returned by <code>CL_DEVICE_OPENCL_C_VERSION</code> is required to be present in the list.</p> <p>For devices that support compilation from OpenCL C source:</p> <p>Because OpenCL 3.0 is backwards compatible with OpenCL C 1.2, and OpenCL C 1.2 is backwards compatible with OpenCL C 1.1 and OpenCL C 1.0, support for at least OpenCL C 3.0, OpenCL C 1.2, OpenCL C 1.1, and OpenCL C 1.0 is required for an OpenCL 3.0 device.</p> <p>Support for OpenCL C 2.0, OpenCL C 1.2, OpenCL C 1.1, and OpenCL C 1.0 is required for an OpenCL 2.0, OpenCL 2.1, or OpenCL 2.2 device.</p> <p>Support for OpenCL C 1.2, OpenCL C 1.1, and OpenCL C 1.0 is required for an OpenCL 1.2 device.</p> <p>Support for OpenCL C 1.1 and OpenCL C 1.0 is required for an OpenCL 1.1 device.</p> <p>Support for at least OpenCL C 1.0 is required for an OpenCL 1.0 device.</p> <p>For devices that do not support compilation from OpenCL C source, this query may return an empty array.</p>

Device Info	Return Type	Description
CL_DEVICE_OPENCL_C_FEATURES missing before version 3.0.	cl_name_ version[]	Returns an array of optional OpenCL C features supported by the compiler for the device alongside the OpenCL C version that introduced the feature macro. For example, if a compiler supports an OpenCL C 3.0 feature, the returned name will be the full name of the OpenCL C feature macro, and the returned version will be 3.0.0. For devices that do not support compilation from OpenCL C source, this query may return an empty array.

Device Info	Return Type	Description
CL_DEVICE_EXTENSIONS	char[]	<p>Returns a space separated list of extension names (the extension names themselves do not contain any spaces) supported by the device. The list of extension names may include Khronos approved extension names and vendor specified extension names.</p> <p>The following Khronos extension names must be returned by all devices that support OpenCL 1.1:</p> <p>cl_khr_byte_addressable_store cl_khr_global_int32_base_atomics cl_khr_global_int32_extended_atomics cl_khr_local_int32_base_atomics cl_khr_local_int32_extended_atomics</p> <p>Additionally, the following Khronos extension names must be returned by all devices that support OpenCL 1.2 when and only when the optional feature is supported:</p> <p>cl_khr_fp64</p> <p>Additionally, the following Khronos extension names must be returned by all devices that support OpenCL 2.0, OpenCL 2.1, or OpenCL 2.2. For devices that support OpenCL 3.0, these extension names must be returned when and only when the optional feature is supported:</p> <p>cl_khr_3d_image_writes cl_khr_depth_images cl_khr_image2d_from_buffer</p> <p>Please refer to the OpenCL Extension Specification or vendor provided documentation for a detailed description of these extensions.</p>

Device Info	Return Type	Description
CL_DEVICE_EXTENSIONS_WITH_VERSION missing before version 3.0.	cl_name_version[]	Returns an array of description (name and version) structures. The same extension name must not be reported more than once. The list of extensions reported must match the list reported via CL_DEVICE_EXTENSIONS . See CL_DEVICE_EXTENSIONS for a list of extensions that are required to be reported for a given OpenCL version.
CL_DEVICE_PRINTF_BUFFER_SIZE missing before version 1.2.	size_t	Maximum size in bytes of the internal buffer that holds the output of printf calls from a kernel. The minimum value for the FULL profile is 1 MB.
CL_DEVICE_PREFERRED_INTEROP_USER_SYNC missing before version 1.2.	cl_bool	Is CL_TRUE if the devices preference is for the user to be responsible for synchronization, when sharing memory objects between OpenCL and other APIs such as DirectX, CL_FALSE if the device / implementation has a performant path for performing synchronization of memory object shared between OpenCL and other APIs such as DirectX.
CL_DEVICE_PARENT_DEVICE missing before version 1.2.	cl_device_id	Returns the cl_device_id of the parent device to which this sub-device belongs. If <i>device</i> is a root-level device, a NULL value is returned.
CL_DEVICE_PARTITION_MAX_SUB_DEVICES missing before version 1.2.	cl_uint	Returns the maximum number of sub-devices that can be created when a device is partitioned. The value returned cannot exceed CL_DEVICE_MAX_COMPUTE_UNITS .
CL_DEVICE_PARTITION_PROPERTIES missing before version 1.2.	cl_device_partition_property[]	Returns the list of partition types supported by <i>device</i> . This is an array of cl_device_partition_property values drawn from the following list: CL_DEVICE_PARTITION_EQUALLY CL_DEVICE_PARTITION_BY_COUNTS CL_DEVICE_PARTITION_BY_AFFINITY_DOMAIN If the device cannot be partitioned (i.e. there is no partitioning scheme supported by the device that will return at least two sub-devices), a value of 0 will be returned.

Device Info	Return Type	Description
CL_DEVICE_PARTITION_AFFINITY_DOMAIN missing before version 1.2.	cl_device_affinity_domain	Returns the list of supported affinity domains for partitioning the device using CL_DEVICE_PARTITION_BY_AFFINITY_DOMAIN . This is a bit-field that describes one or more of the following values: CL_DEVICE_AFFINITY_DOMAIN_NUMA CL_DEVICE_AFFINITY_DOMAIN_L4_CACHE CL_DEVICE_AFFINITY_DOMAIN_L3_CACHE CL_DEVICE_AFFINITY_DOMAIN_L2_CACHE CL_DEVICE_AFFINITY_DOMAIN_L1_CACHE CL_DEVICE_AFFINITY_DOMAIN_NEXT_PARTITIONABLE If the device does not support any affinity domains, a value of 0 will be returned.
CL_DEVICE_PARTITION_TYPE missing before version 1.2.	cl_device_partition_property[]	Returns the properties argument specified in clCreateSubDevices if device is a sub-device. In the case where the properties argument to clCreateSubDevices is CL_DEVICE_PARTITION_BY_AFFINITY_DOMAIN , CL_DEVICE_AFFINITY_DOMAIN_NEXT_PARTITIONABLE , the affinity domain used to perform the partition will be returned. This can be one of the following values: CL_DEVICE_AFFINITY_DOMAIN_NUMA CL_DEVICE_AFFINITY_DOMAIN_L4_CACHE CL_DEVICE_AFFINITY_DOMAIN_L3_CACHE CL_DEVICE_AFFINITY_DOMAIN_L2_CACHE CL_DEVICE_AFFINITY_DOMAIN_L1_CACHE Otherwise the implementation may either return a <i>param_value_size_ret</i> of 0 i.e. there is no partition type associated with device or can return a property value of 0 (where 0 is used to terminate the partition property list) in the memory that <i>param_value</i> points to.
CL_DEVICE_REFERENCE_COUNT ^[8] missing before version 1.2.	cl_uint	Returns the <i>device</i> reference count. If the device is a root-level device, a reference count of one is returned.

Device Info	Return Type	Description
CL_DEVICE_SVM_CAPABILITIES missing before version 2.0.	cl_device_svm_capabilities	<p>Describes the various shared virtual memory (SVM) memory allocation types the device supports. This is a bit-field that describes a combination of the following values:</p> <p>CL_DEVICE_SVM_COARSE_GRAIN_BUFFER - Support for coarse-grain buffer sharing using clSVMAlloc. Memory consistency is guaranteed at synchronization points and the host must use calls to clEnqueueMapBuffer and clEnqueueUnmapMemObject.</p> <p>CL_DEVICE_SVM_FINE_GRAIN_BUFFER - Support for fine-grain buffer sharing using clSVMAlloc. Memory consistency is guaranteed at synchronization points without need for clEnqueueMapBuffer and clEnqueueUnmapMemObject.</p> <p>CL_DEVICE_SVM_FINE_GRAIN_SYSTEM - Support for sharing the host's entire virtual memory including memory allocated using malloc. Memory consistency is guaranteed at synchronization points.</p> <p>CL_DEVICE_SVM_ATOMICS - Support for the OpenCL 2.0 atomic operations that provide memory consistency across the host and all OpenCL devices supporting fine-grain SVM allocations.</p> <p>The mandated minimum capability for an OpenCL 2.0, 2.1, or 2.2 device is CL_DEVICE_SVM_COARSE_GRAIN_BUFFER.</p> <p>For other device versions there is no mandated minimum capability.</p>
CL_DEVICE_PREFERRED_PLATFORM_ATOMIC_ALIGNMENT missing before version 2.0.	cl_uint	Returns the value representing the preferred alignment in bytes for OpenCL 2.0 fine-grained SVM atomic types. This query can return 0 which indicates that the preferred alignment is aligned to the natural size of the type.
CL_DEVICE_PREFERRED_GLOBAL_ATOMIC_ALIGNMENT missing before version 2.0.	cl_uint	Returns the value representing the preferred alignment in bytes for OpenCL 2.0 atomic types to global memory. This query can return 0 which indicates that the preferred alignment is aligned to the natural size of the type.

Device Info	Return Type	Description
CL_DEVICE_PREFERRED_LOCAL_ATOMIC_ALIGNMENT missing before version 2.0.	cl_uint	Returns the value representing the preferred alignment in bytes for OpenCL 2.0 atomic types to local memory. This query can return 0 which indicates that the preferred alignment is aligned to the natural size of the type.
CL_DEVICE_MAX_NUM_SUB_GROUPS missing before version 2.1.	cl_uint	<p>Maximum number of sub-groups in a work-group that a device is capable of executing on a single compute unit, for any given kernel-instance running on the device.</p> <p>The minimum value is 1 if the device supports sub-groups, and must be 0 for devices that do not support sub-groups. Support for sub-groups is required for an OpenCL 2.1 or 2.2 device.</p> <p>(Refer also to clGetKernelSubGroupInfo.)</p>
CL_DEVICE_SUB_GROUP_INDEPENDENT_FORWARD_PROGRESS missing before version 2.1.	cl_bool	<p>Is CL_TRUE if this device supports independent forward progress of sub-groups, CL_FALSE otherwise.</p> <p>This query must return CL_TRUE for devices that support the cl_khr_subgroups extension, and must return CL_FALSE for devices that do not support sub-groups.</p>

Device Info	Return Type	Description
CL_DEVICE_ATOMIC_MEMORY_CAPABILITIES missing before version 3.0.	cl_device_atomic_capabilities	<p>Describes the various memory orders and scopes that the device supports for atomic memory operations. This is a bit-field that describes a combination of the following values:</p> <p>CL_DEVICE_ATOMIC_ORDER_RELAXED - Support for the relaxed memory order.</p> <p>CL_DEVICE_ATOMIC_ORDER_ACQ_REL - Support for the acquire, release, and acquire-release memory orders.</p> <p>CL_DEVICE_ATOMIC_ORDER_SEQ_CST - Support for the sequentially consistent memory order.</p> <p>Because atomic memory orders are hierarchical, a device that supports a strong memory order must also support all weaker memory orders.</p> <p>CL_DEVICE_ATOMIC_SCOPE_WORK_ITEM^[9] - Support for memory ordering constraints that apply to a single work-item.</p> <p>CL_DEVICE_ATOMIC_SCOPE_WORK_GROUP - Support for memory ordering constraints that apply to all work-items in a work-group.</p> <p>CL_DEVICE_ATOMIC_SCOPE_DEVICE - Support for memory ordering constraints that apply to all work-items executing on the device.</p> <p>CL_DEVICE_ATOMIC_SCOPE_ALL_DEVICES - Support for memory ordering constraints that apply to all work-items executing across all devices that can share SVM memory with each other and the host process.</p> <p>Because atomic scopes are hierarchical, a device that supports a wide scope must also support all narrower scopes, except for the work-item scope, which is a special case.</p> <p>The mandated minimum capability is:</p> <p>CL_DEVICE_ATOMIC_ORDER_RELAXED CL_DEVICE_ATOMIC_SCOPE_WORK_GROUP</p>

Device Info	Return Type	Description
CL_DEVICE_ATOMIC_FENCE_CAPABILITIES missing before version 3.0.	cl_device_atomic_capabilities	Describes the various memory orders and scopes that the device supports for atomic fence operations. This is a bit-field that has the same set of possible values as described for CL_DEVICE_ATOMIC_MEMORY_CAPABILITIES . The mandated minimum capability is: CL_DEVICE_ATOMIC_ORDER_RELAXED CL_DEVICE_ATOMIC_ORDER_ACQ_REL CL_DEVICE_ATOMIC_SCOPE_WORK_GROUP
CL_DEVICE_NON_UNIFORM_WORK_GROUP_SUPPORT missing before version 3.0.	cl_bool	Is CL_TRUE if the device supports non-uniform work-groups, and CL_FALSE otherwise.
CL_DEVICE_WORK_GROUP_COLLECTIVE_FUNCTIONS_SUPPORT missing before version 3.0.	cl_bool	Is CL_TRUE if the device supports work-group collective functions e.g. work_group_broadcast , work_group_reduce , and work_group_scan , and CL_FALSE otherwise.
CL_DEVICE_GENERIC_ADDRESS_SPACE_SUPPORT missing before version 3.0.	cl_bool	Is CL_TRUE if the device supports the generic address space and its associated built-in functions, and CL_FALSE otherwise.
CL_DEVICE_DEVICE_ENQUEUE_CAPABILITIES missing before version 3.0.	cl_device_device_enqueue_capabilities	Describes device-side enqueue capabilities of the device. This is a bit-field that describes one or more of the following values: CL_DEVICE_QUEUE_SUPPORTED - Device supports device-side enqueue and on-device queues. CL_DEVICE_QUEUE_REPLACEABLE_DEFAULT - Device supports a replaceable default on-device queue. If CL_DEVICE_QUEUE_REPLACEABLE_DEFAULT is set, CL_DEVICE_QUEUE_SUPPORTED must also be set. Devices that set CL_DEVICE_QUEUE_SUPPORTED for CL_DEVICE_DEVICE_ENQUEUE_CAPABILITIES must also return CL_TRUE for CL_DEVICE_GENERIC_ADDRESS_SPACE_SUPPORT .

Device Info	Return Type	Description
CL_DEVICE_PIPE_SUPPORT missing before version 3.0.	cl_bool	Is CL_TRUE if the device supports pipes, and CL_FALSE otherwise. Devices that return CL_TRUE for CL_DEVICE_PIPE_SUPPORT must also return CL_TRUE for CL_DEVICE_GENERIC_ADDRESS_SPACE_SUPPORT .
CL_DEVICE_PREFERRED_WORK_GROUP_SIZE_MULTIPLE missing before version 3.0.	size_t	Returns the preferred multiple of work-group size for the given device. This is a performance hint intended as a guide when specifying the local work size argument to clEnqueueNDRangeKernel . (Refer also to clGetKernelWorkGroupInfo where CL_KERNEL_PREFERRED_WORK_GROUP_SIZE_MULTIPLE can return a different value to CL_DEVICE_PREFERRED_WORK_GROUP_SIZE_MULTIPLE which may be more optimal.)
CL_DEVICE_LATEST_CONFORMANCE_VERSION_PASSED missing before version 3.0.	char[]	Returns the latest version of the conformance test suite that this device has fully passed in accordance with the official conformance process.

clGetDeviceInfo returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_DEVICE** if *device* is not a valid device.
- **CL_INVALID_VALUE** if *param_name* is not one of the supported values or if size in bytes specified by *param_value_size* is < size of return type as specified in the [Device Queries](#) table and *param_value* is not a **NULL** value or if *param_name* is a value that is available as an extension and the corresponding extension is not supported by the device.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

To query device and host timestamps, call the function:

```
cl_int clGetDeviceAndHostTimer(
    cl_device_id device,
    cl_ulong* device_timestamp,
    cl_ulong* host_timestamp);
```



clGetDeviceAndHostTimer is missing before version 2.1.

- *device* is a device returned by [clGetDeviceIDs](#).
- *device_timestamp* will be updated with the value of the device timer in nanoseconds. The resolution of the timer is the same as the device profiling timer returned by [clGetDeviceInfo](#) and the `CL_DEVICE_PROFILING_TIMER_RESOLUTION` query.
- *host_timestamp* will be updated with the value of the host timer in nanoseconds at the closest possible point in time to that at which *device_timer* was returned. The resolution of the timer may be queried via [clGetPlatformInfo](#) and the flag `CL_PLATFORM_HOST_TIMER_RESOLUTION`.

[clGetDeviceAndHostTimer](#) returns a reasonably synchronized pair of timestamps from the device timer and the host timer as seen by *device*. Implementations may need to execute this query with a high latency in order to provide reasonable synchronization of the timestamps. The host timestamp and device timestamp returned by this function and [clGetHostTimer](#) each have an implementation-defined timebase. The timestamps will always be in their respective timebases regardless of which query function is used. The timestamp returned from [clGetEventProfilingInfo](#) for an event on a device and a device timestamp queried from the same device will always be in the same timebase.

[clGetDeviceAndHostTimer](#) will return `CL_SUCCESS` with a time value in *host_timestamp* if provided. Otherwise, it returns one of the following errors:

- `CL_INVALID_DEVICE` if *device* is not a valid device.
- `CL_INVALID_OPERATION` if the platform associated with *device* does not support device and host timer synchronization.
- `CL_INVALID_VALUE` if *host_timestamp* or *device_timestamp* is `NULL`.
- `CL_OUT_OF_RESOURCES` if there is a failure to allocate resources required by the OpenCL implementation on the device.
- `CL_OUT_OF_HOST_MEMORY` if there is a failure to allocate resources required by the OpenCL implementation on the host.

To query the host clock, call the function:

```
cl_int clGetHostTimer(
    cl_device_id device,
    cl_ulong* host_timestamp);
```



[clGetHostTimer](#) is missing before version 2.1.

- *device* is a device returned by [clGetDeviceIDs](#).
- *host_timestamp* will be updated with the value of the current timer in nanoseconds. The resolution of the timer may be queried via [clGetPlatformInfo](#) and the flag `CL_PLATFORM_HOST_TIMER_RESOLUTION`.

[clGetHostTimer](#) returns the current value of the host clock as seen by *device*. This value is in the same timebase as the *host_timestamp* returned from [clGetDeviceAndHostTimer](#). The implementation will return with as low a latency as possible to allow a correlation with a

subsequent application sampled time. The host timestamp and device timestamp returned by this function and `clGetDeviceAndHostTimer` each have an implementation-defined timebase. The timestamps will always be in their respective timebases regardless of which query function is used. The timestamp returned from `clGetEventProfilingInfo` for an event on a device and a device timestamp queried from the same device will always be in the same timebase.

`clGetHostTimer` will return `CL_SUCCESS` with a time value in *host_timestamp* if provided. Otherwise, it returns one of the following errors:

- `CL_INVALID_DEVICE` if *device* is not a valid device.
- `CL_INVALID_OPERATION` if the platform associated with *device* does not support device and host timer synchronization.
- `CL_INVALID_VALUE` if *host_timestamp* is `NULL`.
- `CL_OUT_OF_RESOURCES` if there is a failure to allocate resources required by the OpenCL implementation on the device.
- `CL_OUT_OF_HOST_MEMORY` if there is a failure to allocate resources required by the OpenCL implementation on the host.

4.3. Partitioning a Device



Partitioning devices is [missing before](#) version 1.2.

To create sub-devices partitioning an OpenCL device, call the function:

```
cl_int clCreateSubDevices(  
    cl_device_id in_device,  
    const cl_device_partition_property* properties,  
    cl_uint num_devices,  
    cl_device_id* out_devices,  
    cl_uint* num_devices_ret);
```



`clCreateSubDevices` is [missing before](#) version 1.2.

- *in_device* is the device to be partitioned.
- *properties* specifies how *in_device* is to be partitioned, described by a partition name and its corresponding value. Each partition name is immediately followed by the corresponding desired value. The list is terminated with 0. The list of supported partitioning schemes is described in the [Sub-device Partition](#) table. Only one of the listed partitioning schemes can be specified in *properties*.
- *num_devices* is the size of memory pointed to by *out_devices* specified as the number of `cl_device_id` entries.
- *out_devices* is the buffer where the OpenCL sub-devices will be returned. If *out_devices* is `NULL`, this argument is ignored. If *out_devices* is not `NULL`, *num_devices* must be greater than or equal to the number of sub-devices that *device* may be partitioned into according to the partitioning

scheme specified in *properties*.

- *num_devices_ret* returns the number of sub-devices that *device* may be partitioned into according to the partitioning scheme specified in *properties*. If *num_devices_ret* is **NULL**, it is ignored.

clCreateSubDevices creates an array of sub-devices that each reference a non-intersecting set of compute units within *in_device*, according to the partition scheme given by *properties*. The output sub-devices may be used in every way that the root (or parent) device can be used, including creating contexts, building programs, further calls to **clCreateSubDevices** and creating command-queues. When a command-queue is created against a sub-device, the commands enqueued on the queue are executed only on the sub-device.

Table 6. List of supported partition schemes by **clCreateSubDevices**

Partition Property	Partition Value	Description
CL_DEVICE_PARTITION_EQUALLY missing before version 1.2.	cl_uint	Split the aggregate device into as many smaller aggregate devices as can be created, each containing <i>n</i> compute units. The value <i>n</i> is passed as the value accompanying this property. If <i>n</i> does not divide evenly into CL_DEVICE_MAX_COMPUTE_UNITS , then the remaining compute units are not used.
CL_DEVICE_PARTITION_BY_COUNTS missing before version 1.2.	cl_uint	<p>This property is followed by a list of compute unit counts terminated with 0 or CL_DEVICE_PARTITION_BY_COUNTS_LIST_END. For each non-zero count <i>m</i> in the list, a sub-device is created with <i>m</i> compute units in it.</p> <p>The number of non-zero count entries in the list may not exceed CL_DEVICE_PARTITION_MAX_SUB_DEVICES.</p> <p>The total number of compute units specified may not exceed CL_DEVICE_MAX_COMPUTE_UNITS.</p>

Partition Property	Partition Value	Description
CL_DEVICE_PARTITION_BY_AFFINITY_DOMAIN missing before version 1.2.	cl_device_affinity_domain	<p>Split the device into smaller aggregate devices containing one or more compute units that all share part of a cache hierarchy. The value accompanying this property may be drawn from the following list:</p> <p>CL_DEVICE_AFFINITY_DOMAIN_NUMA - Split the device into sub-devices comprised of compute units that share a NUMA node.</p> <p>CL_DEVICE_AFFINITY_DOMAIN_L4_CACHE - Split the device into sub-devices comprised of compute units that share a level 4 data cache.</p> <p>CL_DEVICE_AFFINITY_DOMAIN_L3_CACHE - Split the device into sub-devices comprised of compute units that share a level 3 data cache.</p> <p>CL_DEVICE_AFFINITY_DOMAIN_L2_CACHE - Split the device into sub-devices comprised of compute units that share a level 2 data cache.</p> <p>CL_DEVICE_AFFINITY_DOMAIN_L1_CACHE - Split the device into sub-devices comprised of compute units that share a level 1 data cache.</p> <p>CL_DEVICE_AFFINITY_DOMAIN_NEXT_PARTITIONABLE - Split the device along the next partitionable affinity domain. The implementation shall find the first level along which the device or sub-device may be further subdivided in the order NUMA, L4, L3, L2, L1, and partition the device into sub-devices comprised of compute units that share memory subsystems at this level.</p> <p>The user may determine what happened by calling clGetDeviceInfo(CL_DEVICE_PARTITION_TYPE) on the sub-devices.</p>

clCreateSubDevices returns **CL_SUCCESS** if the partition is created successfully. Otherwise, it returns a **NULL** value with the following error values returned in *errcode_ret*:

- **CL_INVALID_DEVICE** if *in_device* is not a valid device.
- **CL_INVALID_VALUE** if values specified in *properties* are not valid or if values specified in *properties* are valid but not supported by the device.

- `CL_INVALID_VALUE` if *out_devices* is not `NULL` and *num_devices* is less than the number of sub-devices created by the partition scheme.
- `CL_DEVICE_PARTITION_FAILED` if the partition name is supported by the implementation but *in_device* could not be further partitioned.
- `CL_INVALID_DEVICE_PARTITION_COUNT` if the partition name specified in *properties* is `CL_DEVICE_PARTITION_BY_COUNTS` and the number of sub-devices requested exceeds `CL_DEVICE_PARTITION_MAX_SUB_DEVICES` or the total number of compute units requested exceeds `CL_DEVICE_MAX_COMPUTE_UNITS` for *in_device*, or the number of compute units requested for one or more sub-devices is less than zero or the number of sub-devices requested exceeds `CL_DEVICE_MAX_COMPUTE_UNITS` for *in_device*.
- `CL_OUT_OF_RESOURCES` if there is a failure to allocate resources required by the OpenCL implementation on the device.
- `CL_OUT_OF_HOST_MEMORY` if there is a failure to allocate resources required by the OpenCL implementation on the host.

A few examples that describe how to specify partition properties in *properties* argument to `clCreateSubDevices` are given below:

To partition a device containing 16 compute units into two sub-devices, each containing 8 compute units, pass the following in *properties*:

```
{ CL_DEVICE_PARTITION_EQUALLY, 8,
  0 } // 0 terminates the property list
```

To partition a device with four compute units into two sub-devices with one sub-device containing 3 compute units and the other sub-device 1 compute unit, pass the following in *properties* argument:

```
{ CL_DEVICE_PARTITION_BY_COUNTS,
  3, 1, CL_DEVICE_PARTITION_BY_COUNTS_LIST_END,
  0 } // 0 terminates the property list
```

To split a device along the outermost cache line (if any), pass the following in *properties* argument:

```
{ CL_DEVICE_PARTITION_BY_AFFINITY_DOMAIN,
  CL_DEVICE_AFFINITY_DOMAIN_NEXT_PARTITIONABLE,
  0 } // 0 terminates the property list
```

To retain a device, call the function:

```
cl_int clRetainDevice(
    cl_device_id device);
```



clRetainDevice is **missing before** version 1.2.

- *device* is the OpenCL device to retain.

clRetainDevice increments the *device* reference count if *device* is a valid sub-device created by a call to **clCreateSubDevices**. If *device* is a root level device i.e. a **cl_device_id** returned by **clGetDeviceIDs**, the *device* reference count remains unchanged.

clRetainDevice returns **CL_SUCCESS** if the function is executed successfully or the device is a root-level device. Otherwise, it returns one of the following errors:

- **CL_INVALID_DEVICE** if *device* is not a valid device.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

To release a device, call the function:

```
cl_int clReleaseDevice(  
    cl_device_id device);
```



clReleaseDevice is **missing before** version 1.2.

- *device* is the OpenCL device to release.

clReleaseDevice decrements the *device* reference count if *device* is a valid sub-device created by a call to **clCreateSubDevices**. If *device* is a root level device i.e. a **cl_device_id** returned by **clGetDeviceIDs**, the *device* reference count remains unchanged.

clReleaseDevice returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_DEVICE** if *device* is not a valid device.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

After the *device* reference count becomes zero and all the objects attached to *device* (such as command-queues) are released, the *device* object is deleted. Using this function to release a reference that was not obtained by creating the object or by calling **clRetainDevice** causes undefined behavior.

4.4. Contexts

To create an OpenCL context, call the function:

```
cl_context clCreateContext(  
    const cl_context_properties* properties,  
    cl_uint num_devices,  
    const cl_device_id* devices,  
    void (CL_CALLBACK* pfn_notify)(const char* errinfo, const void* private_info,  
size_t cb, void* user_data),  
    void* user_data,  
    cl_int* errcode_ret);
```

- *properties* specifies a list of context property names and their corresponding values. Each property name is immediately followed by the corresponding desired value. The list is terminated with 0. The list of supported properties is described in the [Context Properties](#) table. *properties* can be `NULL` in which case the platform that is selected is implementation-defined.
- *num_devices* is the number of devices specified in the *devices* argument.
- *devices* is a pointer to a list of unique devices returned by [clGetDeviceIDs](#) or sub-devices created by [clCreateSubDevices](#) for a platform. ^[10]
- *pfn_notify* is a callback function that can be registered by the application. This callback function will be used by the OpenCL implementation to report information on errors during context creation as well as errors that occur at runtime in this context. This callback function may be called asynchronously by the OpenCL implementation. It is the application's responsibility to ensure that the callback function is thread-safe. If *pfn_notify* is `NULL`, no callback function is registered.
- *user_data* will be passed as the *user_data* argument when *pfn_notify* is called. *user_data* can be `NULL`.
- *errcode_ret* will return an appropriate error code. If *errcode_ret* is `NULL`, no error code is returned.

The parameters to the callback function *pfn_notify* are:

- *errinfo* is a pointer to an error string.
- *private_info* and *cb* represent a pointer to binary data that is returned by the OpenCL implementation that can be used to log additional information helpful in debugging the error.
- *user_data* is a pointer to user supplied data.

Contexts are used by the OpenCL runtime for managing objects such as command-queues, memory, program and kernel objects and for executing kernels on one or more devices specified in the context.

Table 7. List of supported context creation properties by [clCreateContext](#)

Context Property	Property Value	Description
CL_CONTEXT_PLATFORM	cl_platform_id	Specifies the platform to use.
CL_CONTEXT_INTEROP_USER_SYNC	cl_bool	Specifies whether the user is responsible for synchronization between OpenCL and other APIs. Please refer to the specific sections in the OpenCL Extension Specification that describe sharing with other APIs for restrictions on using this flag. If CL_CONTEXT_INTEROP_USER_SYNC is not specified, a default of CL_FALSE is assumed.



There are a number of cases where error notifications need to be delivered due to an error that occurs outside a context. Such notifications may not be delivered through the *pfn_notify* callback. Where these notifications go is implementation-defined.

clCreateContext returns a valid non-zero context and *errcode_ret* is set to CL_SUCCESS if the context is created successfully. Otherwise, it returns a NULL value with the following error values returned in *errcode_ret*:

- CL_INVALID_PLATFORM if *properties* is NULL and no platform could be selected or if platform value specified in *properties* is not a valid platform.
- CL_INVALID_PROPERTY if context property name in *properties* is not a supported property name, if the value specified for a supported property name is not valid, or if the same property name is specified more than once. This error code is missing before version 1.1.
- CL_INVALID_VALUE if *devices* is NULL.
- CL_INVALID_VALUE if *num_devices* is equal to zero.
- CL_INVALID_VALUE if *pfn_notify* is NULL but *user_data* is not NULL.
- CL_INVALID_DEVICE if any device in *devices* is not a valid device.
- CL_DEVICE_NOT_AVAILABLE if a device in *devices* is currently not available even though the device was returned by **clGetDeviceIDs**.
- CL_OUT_OF_RESOURCES if there is a failure to allocate resources required by the OpenCL implementation on the device.
- CL_OUT_OF_HOST_MEMORY if there is a failure to allocate resources required by the OpenCL implementation on the host.



It is possible that a device(s) becomes unavailable after a context and command-queues that use this device(s) have been created and commands have been queued to command-queues. In this case the behavior of OpenCL API calls that use this context (and command-queues) are considered to be implementation-defined. The user callback function, if specified, when the context is created can be used to record appropriate information in the *errinfo*, *private_info* arguments passed to

the callback function when the device becomes unavailable.

To create an OpenCL context from a specific device type^[11], call the function:

```
cl_context clCreateContextFromType(  
    const cl_context_properties* properties,  
    cl_device_type device_type,  
    void (CL_CALLBACK* pfn_notify)(const char* errinfo, const void* private_info,  
    size_t cb, void* user_data),  
    void* user_data,  
    cl_int* errcode_ret);
```

- *properties* specifies a list of context property names and their corresponding values. Each property name is immediately followed by the corresponding desired value. The list of supported properties is described in the [Context Properties](#) table. *properties* can also be `NULL` in which case the platform that is selected is implementation-defined.
- *device_type* is a bit-field that identifies the type of device and is described in the [Device Types](#) table.
- *pfn_notify* and *user_data* are described in [clCreateContext](#).
- *errcode_ret* will return an appropriate error code. If *errcode_ret* is `NULL`, no error code is returned.

Only devices that are returned by [clGetDeviceIDs](#) for *device_type* are used to create the context. The context does not reference any sub-devices that may have been created from these devices.

[clCreateContextFromType](#) returns a valid non-zero context and *errcode_ret* is set to `CL_SUCCESS` if the context is created successfully. Otherwise, it returns a `NULL` value with the following error values returned in *errcode_ret*:

- `CL_INVALID_PLATFORM` if *properties* is `NULL` and no platform could be selected or if platform value specified in *properties* is not a valid platform.
- `CL_INVALID_PROPERTY` if context property name in *properties* is not a supported property name, if the value specified for a supported property name is not valid, or if the same property name is specified more than once. This error code is [missing before](#) version 1.1.
- `CL_INVALID_VALUE` if *pfn_notify* is `NULL` but *user_data* is not `NULL`.
- `CL_INVALID_DEVICE_TYPE` if *device_type* is not a valid value.
- `CL_DEVICE_NOT_AVAILABLE` if no devices that match *device_type* and property values specified in *properties* are currently available.
- `CL_DEVICE_NOT_FOUND` if no devices that match *device_type* and property values specified in *properties* were found.
- `CL_OUT_OF_RESOURCES` if there is a failure to allocate resources required by the OpenCL implementation on the device.
- `CL_OUT_OF_HOST_MEMORY` if there is a failure to allocate resources required by the OpenCL implementation on the host.

To retain a context, call the function:

```
cl_int clRetainContext(  
    cl_context context);
```

- *context* specifies the OpenCL context to retain.

clRetainContext increments the *context* reference count.

clCreateContext and **clCreateContextFromType** perform an implicit retain. This is very helpful for 3rd party libraries, which typically get a context passed to them by the application. However, it is possible that the application may delete the context without informing the library. Allowing functions to attach to (i.e. retain) and release a context solves the problem of a context being used by a library no longer being valid.

clRetainContext returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_CONTEXT** if *context* is not a valid OpenCL context.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

To release a context, call the function:

```
cl_int clReleaseContext(  
    cl_context context);
```

- *context* specifies the OpenCL context to release.

clReleaseContext decrements the *context* reference count. After the reference count becomes zero and all the objects attached to *context* (such as memory objects, command-queues) are released, the *context* is deleted. Using this function to release a reference that was not obtained by creating the object or by calling **clRetainContext** causes undefined behavior.

clReleaseContext returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_CONTEXT** if *context* is not a valid OpenCL context.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

To query information about a context, call the function:

```

cl_int clGetContextInfo(
    cl_context context,
    cl_context_info param_name,
    size_t param_value_size,
    void* param_value,
    size_t* param_value_size_ret);

```

- *context* specifies the OpenCL context being queried.
- *param_name* is an enumeration constant that specifies the information to query.
- *param_value* is a pointer to memory where the appropriate result being queried is returned. If *param_value* is **NULL**, it is ignored.
- *param_value_size* specifies the size in bytes of memory pointed to by *param_value*. This size must be greater than or equal to the size of return type as described in the [Context Attributes](#) table.
- *param_value_size_ret* returns the actual size in bytes of data being queried by *param_name*. If *param_value_size_ret* is **NULL**, it is ignored.

The list of supported *param_name* values and the information returned in *param_value* by **clGetContextInfo** is described in the [Context Attributes](#) table.

Table 8. List of supported *param_names* by **clGetContextInfo**

Context Info	Return Type	Description
CL_CONTEXT_REFERENCE_COUNT ^[12]	cl_uint	Return the <i>context</i> reference count.
CL_CONTEXT_NUM_DEVICES	cl_uint	Return the number of devices in <i>context</i> .
missing before version 1.1.		
CL_CONTEXT_DEVICES	cl_device_id[]	Return the list of devices and sub-devices in <i>context</i> .

Context Info	Return Type	Description
<code>CL_CONTEXT_PROPERTIES</code>	<code>cl_context_properties[]</code>	<p>Return the properties argument specified in clCreateContext or clCreateContextFromType.</p> <p>If the <i>properties</i> argument specified in clCreateContext or clCreateContextFromType used to create <i>context</i> was not <code>NULL</code>, the implementation must return the values specified in the properties argument in the same order and without including additional properties.</p> <p>If the <i>properties</i> argument specified in clCreateContext or clCreateContextFromType used to create <i>context</i> was <code>NULL</code>, the implementation must return <i>param_value_size_ret</i> equal to 0, indicating that there are no properties to be returned.</p>

[clGetContextInfo](#) returns `CL_SUCCESS` if the function is executed successfully. Otherwise, it returns one of the following errors:

- `CL_INVALID_CONTEXT` if *context* is not a valid context.
- `CL_INVALID_VALUE` if *param_name* is not one of the supported values or if size in bytes specified by *param_value_size* is < size of return type as specified in the [Context Attributes](#) table and *param_value* is not a `NULL` value.
- `CL_OUT_OF_RESOURCES` if there is a failure to allocate resources required by the OpenCL implementation on the device.
- `CL_OUT_OF_HOST_MEMORY` if there is a failure to allocate resources required by the OpenCL implementation on the host.

To register a callback function with a context that is called when the context is destroyed, call the function

```
cl_int clSetContextDestructorCallback(
    cl_context context,
    void (CL_CALLBACK* pfn_notify)(cl_context context, void* user_data),
    void* user_data);
```



[clSetContextDestructorCallback](#) is [missing before](#) version 3.0.

- *context* specifies the OpenCL context to register the callback to.
- *pfn_notify* is the callback function to register. This callback function may be called asynchronously by the OpenCL implementation. It is the application's responsibility to ensure that the callback function is thread-safe. The parameters to this callback function are:

- *context* is the OpenCL context being deleted. When the callback function is called by the implementation, this context is no longer valid. *context* is only provided for reference purposes.
- *user_data* is a pointer to user-supplied data.
- *user_data* will be passed as the *user_data* argument when *pfn_notify* is called. *user_data* can be **NULL**.

Each call to **clSetContextDestructorCallback** registers the specified callback function on a destructor callback stack associated with *context*. The registered callback functions are called in the reverse order in which they were registered. If a context callback function was specified when *context* was created, it will not be called after any context destructor callback is called. Therefore, the context destructor callback provides a mechanism for an application to safely re-use or free any *user_data* specified for the context callback function when *context* was created.

clSetContextDestructorCallback returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_CONTEXT** if *context* is not a valid context.
- **CL_INVALID_VALUE** if *pfn_notify* is **NULL**.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

[1] The platform profile returns the profile that is implemented by the OpenCL framework. If the platform profile returned is **FULL_PROFILE**, the OpenCL framework will support devices that are **FULL_PROFILE** and may also support devices that are **EMBEDDED_PROFILE**. The compiler must be available for all devices i.e. **CL_DEVICE_COMPILER_AVAILABLE** is **CL_TRUE**. If the platform profile returned is **EMBEDDED_PROFILE**, then devices that are only **EMBEDDED_PROFILE** are supported.

[2] A null terminated string is returned by OpenCL query function calls if the return type of the information being queried is a **char[]**.

[3] The OpenCL specification does not describe the order of precedence for error codes returned by API calls.

[4] **clGetDeviceIDs** may return all or a subset of the actual physical devices present in the platform and that match *device_type*.

[5] OpenCL adopters must report a valid vendor ID for their implementation. If there is no valid PCI vendor ID defined for the physical device, implementations must obtain a Khronos vendor ID. This is a unique identifier greater than the largest PCI vendor ID (**0x10000**) and is representable by a **cl_uint**. Khronos vendor IDs are synchronized across APIs by utilizing Vulkan's vk.xml as the central Khronos vendor ID registry. An ID must be reserved here prior to use in OpenCL, regardless of whether a vendor implements Vulkan. Only once the ID has been allotted may it be exposed to OpenCL by proposing a merge request against cl.xml, in the **main** branch of the OpenCL-Docs project. The merge must define a new enumerant by adding an **<enum>** tag to the **cl_khronos_vendor_id <enums>** tag, with the **<value>** attribute set as the acquired Khronos vendor ID. The **<name>** attribute must identify the vendor/adopter, and be of the form **CL_KHRONOS_VENDOR_ID_<vendor>**.

[6] A kernel that uses an image argument with the **write_only** or **read_write** image qualifier may result in additional **read_only** images resources being created internally by an implementation. The internally created **read_only** image resources will count against the max supported read image arguments given by **CL_DEVICE_MAX_READ_IMAGE_ARGS**. Enqueueing a kernel that requires more images than the implementation can support will result in a **CL_OUT_OF_RESOURCES** error being returned.

[7] The optional rounding modes should be included as a device capability only if it is supported natively. All explicit conversion functions with specific rounding modes must still operate correctly.

[8] The reference count returned should be considered immediately stale. It is unsuitable for general use in applications. This feature is provided for identifying memory leaks.

[9] Note that this flag does not provide meaning for atomic memory operations, but only for atomic fence operations in certain circumstances, refer to the Memory Scope section of the OpenCL C specification.

[10] Duplicate devices specified in *devices* are ignored.

[11] `clCreateContextFromType` may may create a context for all or a subset of the actual physical devices present in the platform that match *device_type*.

[12] The reference count returned should be considered immediately stale. It is unsuitable for general use in applications. This feature is provided for identifying memory leaks.

Chapter 5. The OpenCL Runtime

In this section we describe the API calls that manage OpenCL objects such as command-queues, memory objects, program objects, kernel objects for kernel functions in a program and calls that allow you to enqueue commands to a command-queue such as executing a kernel, reading, or writing a memory object.

5.1. Command-Queues

OpenCL objects such as memory, program and kernel objects are created using a context. Operations on these objects are performed using a command-queue. The command-queue can be used to queue a set of operations (referred to as commands) in order. Having multiple command-queues allows applications to queue multiple independent commands without requiring synchronization. Note that this should work as long as these objects are not being shared. Sharing of objects across multiple command-queues will require the application to perform appropriate synchronization. This is described in [Shared OpenCL Objects](#)

To create a host or device command-queue on a specific device, call the function

```
cl_command_queue clCreateCommandQueueWithProperties(  
    cl_context context,  
    cl_device_id device,  
    const cl_queue_properties* properties,  
    cl_int* errcode_ret);
```



clCreateCommandQueueWithProperties is [missing before](#) version 2.0. Also see extension **cl_khr_create_command_queue**.

- *context* must be a valid OpenCL context.
- *device* must be a device or sub-device associated with *context*. It can either be in the list of devices and sub-devices specified when *context* is created using [clCreateContext](#) or be a root device with the same device type as specified when *context* is created using [clCreateContextFromType](#).
- *properties* specifies a list of properties for the command-queue and their corresponding values. Each property name is immediately followed by the corresponding desired value. The list is terminated with 0. The list of supported properties is described in the [table below](#). If a supported property and its value is not specified in *properties*, its default value will be used. *properties* can be **NULL** in which case the default values for supported command-queue properties will be used.
- *errcode_ret* will return an appropriate error code. If *errcode_ret* is **NULL**, no error code is returned.

Table 9. List of supported queue creation properties by [clCreateCommandQueueWithProperties](#)

Queue Property	Property Value	Description
<code>CL_QUEUE_PROPERTIES</code>	<code>cl_command_queue_properties</code>	<p>This is a bitfield and can be set to a combination of the following values:</p> <p><code>CL_QUEUE_OUT_OF_ORDER_EXEC_MODE_ENABLE</code> - Determines whether the commands queued in the command-queue are executed in-order or out-of-order. If set, the commands in the command-queue are executed out-of-order. Otherwise, commands are executed in-order.</p> <p><code>CL_QUEUE_PROFILING_ENABLE</code> - Enable or disable profiling of commands in the command-queue. If set, the profiling of commands is enabled. Otherwise profiling of commands is disabled.</p> <p><code>CL_QUEUE_ON_DEVICE</code> - Indicates that this is a device queue. If <code>CL_QUEUE_ON_DEVICE</code> is set, <code>CL_QUEUE_OUT_OF_ORDER_EXEC_MODE_ENABLE</code> ^[1] must also be set. missing before version 2.0.</p> <p><code>CL_QUEUE_ON_DEVICE_DEFAULT</code> ^[2] - indicates that this is the default device queue. This can only be used with <code>CL_QUEUE_ON_DEVICE</code>. missing before version 2.0.</p> <p>If <code>CL_QUEUE_PROPERTIES</code> is not specified an in-order host command-queue is created for the specified device</p>
<code>CL_QUEUE_SIZE</code> missing before version 2.0.	<code>cl_uint</code>	<p>Specifies the size of the device queue in bytes.</p> <p>This can only be specified if <code>CL_QUEUE_ON_DEVICE</code> is set in <code>CL_QUEUE_PROPERTIES</code>. This must be a value \leq <code>CL_DEVICE_QUEUE_ON_DEVICE_MAX_SIZE</code>.</p> <p>For best performance, this should be \leq <code>CL_DEVICE_QUEUE_ON_DEVICE_PREFERRED_SIZE</code>.</p> <p>If <code>CL_QUEUE_SIZE</code> is not specified, the device queue is created with <code>CL_DEVICE_QUEUE_ON_DEVICE_PREFERRED_SIZE</code> as the size of the queue.</p>

`clCreateCommandQueueWithProperties` returns a valid non-zero command-queue and `errcode_ret` is set to `CL_SUCCESS` if the command-queue is created successfully. Otherwise, it returns a `NULL` value with one of the following error values returned in `errcode_ret`:

- `CL_INVALID_CONTEXT` if `context` is not a valid context.

- **CL_INVALID_DEVICE** if *device* is not a valid device or is not associated with *context*.
- **CL_INVALID_VALUE** if values specified in *properties* are not valid.
- **CL_INVALID_QUEUE_PROPERTIES** if values specified in *properties* are valid but are not supported by the device.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

To create a host command-queue on a specific device, call the function

```
cl_command_queue clCreateCommandQueue(
    cl_context context,
    cl_device_id device,
    cl_command_queue_properties properties,
    cl_int* errcode_ret);
```



clCreateCommandQueue is deprecated by version 2.0.

- *context* must be a valid OpenCL context.
- *device* must be a device or sub-device associated with *context*. It can either be in the list of devices and sub-devices specified when *context* is created using **clCreateContext** or be a root device with the same device type as specified when *context* is created using **clCreateContextFromType**.
- *properties* specifies a list of properties for the command-queue. This is a bit-field and the supported properties are described in the [table](#) below. Only command-queue properties specified in this table can be used, otherwise the value specified in *properties* is considered to be not valid. *properties* can be 0 in which case the default values for supported command-queue properties will be used.

Table 10. List of supported **cl_command_queue_property** values by **clCreateCommandQueue**

Command-Queue Properties	Description
CL_QUEUE_OUT_OF_ORDER_EXEC_MODE_ENABLE	Determines whether the commands queued in the command-queue are executed in-order or out-of-order. If set, the commands in the command-queue are executed out-of-order. Otherwise, commands are executed in-order.
CL_QUEUE_PROFILING_ENABLE	Enable or disable profiling of commands in the command-queue. If set, the profiling of commands is enabled. Otherwise profiling of commands is disabled.

- *errcode_ret* will return an appropriate error code. If *errcode_ret* is **NULL**, no error code is returned.

clCreateCommandQueue returns a valid non-zero command-queue and *errcode_ret* is set to **CL_SUCCESS** if the command-queue is created successfully. Otherwise, it returns a **NULL** value with one of the following error values returned in *errcode_ret*:

- **CL_INVALID_CONTEXT** if *context* is not a valid context.
- **CL_INVALID_DEVICE** if *device* is not a valid device or is not associated with *context*.
- **CL_INVALID_VALUE** if values specified in *properties* are not valid.
- **CL_INVALID_QUEUE_PROPERTIES** if values specified in *properties* are valid but are not supported by the device.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

To replace the default command-queue on a device, call the function

```
cl_int clSetDefaultDeviceCommandQueue(  
    cl_context context,  
    cl_device_id device,  
    cl_command_queue command_queue);
```



clSetDefaultDeviceCommandQueue is missing before version 2.1.

- *context* is the OpenCL context used to create *command_queue*.
- *device* is a valid OpenCL device associated with *context*.
- *command_queue* specifies a command-queue object which replaces the default device command-queue

clSetDefaultDeviceCommandQueue may be used to replace a default device command-queue created with **clCreateCommandQueueWithProperties** and the **CL_QUEUE_ON_DEVICE_DEFAULT** flag.

clSetDefaultDeviceCommandQueue returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_CONTEXT** if *context* is not a valid context.
- **CL_INVALID_DEVICE** if *device* is not a valid device or is not associated with *context*.
- **CL_INVALID_OPERATION** if *device* does not support a replaceable default on-device queue.
- **CL_INVALID_COMMAND_QUEUE** if *command_queue* is not a valid command-queue for *device*.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

To retain a command-queue, call the function

```
cl_int clRetainCommandQueue(  
    cl_command_queue command_queue);
```

- *command_queue* specifies the command-queue to be retained.

The *command_queue* reference count is incremented.

clCreateCommandQueueWithProperties and **clCreateCommandQueue** perform an implicit retain. This is very helpful for 3rd party libraries, which typically get a command-queue passed to them by the application. However, it is possible that the application may delete the command-queue without informing the library. Allowing functions to attach to (i.e. retain) and release a command-queue solves the problem of a command-queue being used by a library no longer being valid.

clRetainCommandQueue returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_COMMAND_QUEUE** if *command_queue* is not a valid command-queue.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

To release a command-queue, call the function

```
cl_int clReleaseCommandQueue(  
    cl_command_queue command_queue);
```

- *command_queue* specifies the command-queue to be released.

The *command_queue* reference count is decremented.

After the *command_queue* reference count becomes zero and all commands queued to *command_queue* have finished (eg. kernel-instances, memory object updates etc.), the command-queue is deleted.

clReleaseCommandQueue performs an implicit flush to issue any previously queued OpenCL commands in *command_queue*. Using this function to release a reference that was not obtained by creating the object or by calling **clRetainCommandQueue** causes undefined behavior.

clReleaseCommandQueue returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_COMMAND_QUEUE** if *command_queue* is not a valid command-queue.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

implementation on the host.

To query information about a command-queue, call the function

```
cl_int clGetCommandQueueInfo(  
    cl_command_queue command_queue,  
    cl_command_queue_info param_name,  
    size_t param_value_size,  
    void* param_value,  
    size_t* param_value_size_ret);
```

- *command_queue* specifies the command-queue being queried.
- *param_name* specifies the information to query.
- *param_value* is a pointer to memory where the appropriate result being queried is returned. If *param_value* is **NULL**, it is ignored.
- *param_value_size* is used to specify the size in bytes of memory pointed to by *param_value*. This size must be \geq size of return type as described in the [Command-Queue Parameter](#) table. If *param_value* is **NULL**, it is ignored.
- *param_value_size_ret* returns the actual size in bytes of data being queried by *param_name*. If *param_value_size_ret* is **NULL**, it is ignored.

The list of supported *param_name* values and the information returned in *param_value* by **clGetCommandQueueInfo** is described in the [Command-Queue Parameter](#) table.

Table 11. List of supported *param_names* by **clGetCommandQueueInfo**

Queue Info	Return Type	Description
CL_QUEUE_CONTEXT	cl_context	Return the context specified when the command-queue is created.
CL_QUEUE_DEVICE	cl_device_id	Return the device specified when the command-queue is created.
CL_QUEUE_REFERENCE_COUNT ^[3]	cl_uint	Return the command-queue reference count.
CL_QUEUE_PROPERTIES	cl_command_queue_properties	Return the currently specified properties for the command-queue. These properties are specified by the value associated with the CL_QUEUE_PROPERTIES passed in <i>properties</i> argument in clCreateCommandQueueWithProperties , or the value of the <i>properties</i> argument in clCreateCommandQueue .

Queue Info	Return Type	Description
CL_QUEUE_PROPERTIES_ARRAY missing before version 3.0.	cl_queue_properties[]	Return the properties argument specified in clCreateCommandQueueWithProperties . If the <i>properties</i> argument specified in clCreateCommandQueueWithProperties used to create <i>command_queue</i> was not NULL , the implementation must return the values specified in the properties argument in the same order and without including additional properties. If <i>command_queue</i> was created using clCreateCommandQueue , or if the <i>properties</i> argument specified in clCreateCommandQueueWithProperties was NULL , the implementation must return <i>param_value_size_ret</i> equal to 0, indicating that there are no properties to be returned.
CL_QUEUE_SIZE missing before version 2.0.	cl_uint	Return the size of the device command-queue. To be considered valid for this query, <i>command_queue</i> must be a device command-queue.
CL_QUEUE_DEVICE_DEFAULT missing before version 2.1.	cl_command_queue	Return the current default command-queue for the underlying device.

clGetCommandQueueInfo returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_COMMAND_QUEUE** if *command_queue* is not a valid command-queue, or if *command_queue* is not a valid command-queue for *param_name*.
- **CL_INVALID_VALUE** if *param_name* is not one of the supported values or if size in bytes specified by *param_value_size* is < size of return type as specified in the [Command-Queue Parameter](#) table, and *param_value* is not a **NULL** value.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

To enable or disable the properties of a command-queue, call the function

```
cl_int clSetCommandQueueProperty(
    cl_command_queue command_queue,
    cl_command_queue_properties properties,
    cl_bool enable,
    cl_command_queue_properties* old_properties);
```



clSetCommandQueueProperty is deprecated by version 1.1.

- *command_queue* specifies the command-queue being modified.
- *properties* specifies the new list of properties for the command-queue. This is a bit-field and the supported properties are described in the [Command-Queue Properties table](#) for **clCreateCommandQueue**. Only command-queue properties specified in this table can be used, otherwise the value specified in *properties* is considered to be not valid.
- *enable* determines whether the values specified by *properties* are enabled (if *enable* is **CL_TRUE**) or disabled (if *enable* is **CL_FALSE**) for the command-queue.
- *old_properties* returns the command-queue properties before they were changed by **clSetCommandQueueProperty**. If *old_properties* is **NULL**, it is ignored.

clSetCommandQueueProperty may unconditionally return an error if no devices in the context associated with *command_queue* support modifying the properties of a command-queue. Support for modifying the properties of a command-queue is required only for OpenCL 1.0 devices.

clSetCommandQueueProperty returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_COMMAND_QUEUE** if *command_queue* is not a valid command-queue.
- **CL_INVALID_OPERATION** if no devices in the context associated with *command_queue* support modifying the properties of a command-queue.
- **CL_INVALID_VALUE** if values specified in *properties* are not valid.
- **CL_INVALID_QUEUE_PROPERTIES** if values specified in *properties* are valid but are not supported by the device.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

5.2. Buffer Objects

A *buffer* object stores a one-dimensional collection of elements. Elements of a *buffer* object can be a scalar data type (such as an int, float), vector data type, or a user-defined structure.

5.2.1. Creating Buffer Objects

A **buffer object** may be created using the function

```
cl_mem clCreateBuffer(
    cl_context context,
    cl_mem_flags flags,
    size_t size,
    void* host_ptr,
    cl_int* errcode_ret);
```

A **buffer object** may also be created with additional properties using the function

```
cl_mem clCreateBufferWithProperties(
    cl_context context,
    const cl_mem_properties* properties,
    cl_mem_flags flags,
    size_t size,
    void* host_ptr,
    cl_int* errcode_ret);
```



clCreateBufferWithProperties is [missing before](#) version 3.0.

- *context* is a valid OpenCL context used to create the buffer object.
- *properties* is an optional list of properties for the buffer object and their corresponding values. The list is terminated with the special property `0`. If no properties are required, *properties* may be `NULL`. OpenCL 3.0 does not define any optional properties for buffers.
- *flags* is a bit-field that is used to specify allocation and usage information about the image memory object being created and is described in the [supported memory flag values](#) table.
- *size* is the size in bytes of the buffer memory object to be allocated.
- *host_ptr* is a pointer to the buffer data that may already be allocated by the application. The size of the buffer that *host_ptr* points to must be greater than or equal to *size* bytes.
- *errcode_ret* may return an appropriate error code. If *errcode_ret* is `NULL`, no error code is returned.

The alignment requirements for data stored in buffer objects are described in [Alignment of Application Data Types](#).

If **clCreateBuffer** or **clCreateBufferWithProperties** is called with `CL_MEM_USE_HOST_PTR` set in its *flags* argument, the contents of the memory pointed to by *host_ptr* at the time of the **clCreateBuffer** call define the initial contents of the buffer object.

If **clCreateBuffer** or **clCreateBufferWithProperties** is called with a pointer returned by **clSVMAAlloc** as its *host_ptr* argument, and `CL_MEM_USE_HOST_PTR` is set in its *flags* argument, **clCreateBuffer** or **clCreateBufferWithProperties** will succeed and return a valid non-zero buffer object as long as the *size* argument is no larger than the *size* argument passed in the original **clSVMAAlloc** call. The new buffer object returned has the shared memory as the underlying storage. Locations in the buffers underlying shared memory can be operated on using atomic operations to the devices level of support as defined in the memory model.

clCreateBuffer and **clCreateBufferWithProperties** returns a valid non-zero buffer object and *errcode_ret* is set to **CL_SUCCESS** if the buffer object is created successfully. Otherwise, they return a **NULL** value with one of the following error values returned in *errcode_ret*:

- **CL_INVALID_CONTEXT** if *context* is not a valid context.
- **CL_INVALID_PROPERTY** if a property name in *properties* is not a supported property name, if the value specified for a supported property name is not valid, or if the same property name is specified more than once.
- **CL_INVALID_VALUE** if values specified in *flags* are not valid as defined in the [Memory Flags](#) table.
- **CL_INVALID_BUFFER_SIZE** if *size* is 0, or if *size* is greater than **CL_DEVICE_MAX_MEM_ALLOC_SIZE** for all devices in *context*, or if **CL_MEM_USE_HOST_PTR** is set in *flags* and *host_ptr* is a pointer returned by **clSVMAlloc** and *size* is greater than the size passed to **clSVMAlloc**.
- **CL_INVALID_HOST_PTR** if *host_ptr* is **NULL** and **CL_MEM_USE_HOST_PTR** or **CL_MEM_COPY_HOST_PTR** are set in *flags* or if *host_ptr* is not **NULL** but **CL_MEM_COPY_HOST_PTR** or **CL_MEM_USE_HOST_PTR** are not set in *flags*.
- **CL_MEM_OBJECT_ALLOCATION_FAILURE** if there is a failure to allocate memory for buffer object.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

Table 12. List of supported memory flag values

Memory Flags	Description
CL_MEM_READ_WRITE	This flag specifies that the memory object will be read and written by a kernel. This is the default.
CL_MEM_WRITE_ONLY	<p>This flag specifies that the memory object will be written but not read by a kernel.</p> <p>Reading from a buffer or image object created with CL_MEM_WRITE_ONLY inside a kernel is undefined.</p> <p>CL_MEM_READ_WRITE and CL_MEM_WRITE_ONLY are mutually exclusive.</p>
CL_MEM_READ_ONLY	<p>This flag specifies that the memory object is a readonly memory object when used inside a kernel.</p> <p>Writing to a buffer or image object created with CL_MEM_READ_ONLY inside a kernel is undefined.</p> <p>CL_MEM_READ_WRITE or CL_MEM_WRITE_ONLY and CL_MEM_READ_ONLY are mutually exclusive.</p>

Memory Flags	Description
CL_MEM_USE_HOST_PTR	<p>This flag is valid only if host_ptr is not NULL. If specified, it indicates that the application wants the OpenCL implementation to use memory referenced by host_ptr as the storage bits for the memory object.</p> <p>The contents of the memory pointed to by host_ptr at the time of the clCreateBuffer, clCreateBufferWithProperties, clCreateImage, clCreateImageWithProperties, clCreateImage2D, or clCreateImage3D call define the initial contents of the memory object.</p> <p>OpenCL implementations are allowed to cache the contents pointed to by host_ptr in device memory. This cached copy can be used when kernels are executed on a device.</p> <p>The result of OpenCL commands that operate on multiple buffer objects created with the same host_ptr or from overlapping host or SVM regions is considered to be undefined.</p>
CL_MEM_ALLOC_HOST_PTR	<p>This flag specifies that the application wants the OpenCL implementation to allocate memory from host accessible memory.</p> <p>CL_MEM_ALLOC_HOST_PTR and CL_MEM_USE_HOST_PTR are mutually exclusive.</p>

Memory Flags	Description
CL_MEM_COPY_HOST_PTR 	<p>This flag is valid only if <code>host_ptr</code> is not NULL. If specified, it indicates that the application wants the OpenCL implementation to allocate memory for the memory object and copy the data from memory referenced by <code>host_ptr</code>. The implementation will copy the memory immediately and <code>host_ptr</code> is available for reuse by the application when the <code>clCreateBuffer</code>, <code>clCreateBufferWithProperties</code>, <code>clCreateImage</code>, <code>clCreateImageWithProperties</code>, <code>clCreateImage2D</code>, or <code>clCreateImage3D</code> operation returns.</p> <p>CL_MEM_COPY_HOST_PTR and CL_MEM_USE_HOST_PTR are mutually exclusive.</p> <p>CL_MEM_COPY_HOST_PTR can be used with CL_MEM_ALLOC_HOST_PTR to initialize the contents of the <code>cl_mem</code> object allocated using host-accessible (e.g. PCIe) memory.</p>
CL_MEM_HOST_WRITE_ONLY missing before version 1.2.	<p>This flag specifies that the host will only write to the memory object (using OpenCL APIs that enqueue a write or a map for write). This can be used to optimize write access from the host (e.g. enable write-combined allocations for memory objects for devices that communicate with the host over a system bus such as PCIe).</p>
CL_MEM_HOST_READ_ONLY missing before version 1.2.	<p>This flag specifies that the host will only read the memory object (using OpenCL APIs that enqueue a read or a map for read).</p> <p>CL_MEM_HOST_WRITE_ONLY and CL_MEM_HOST_READ_ONLY are mutually exclusive.</p>
CL_MEM_HOST_NO_ACCESS missing before version 1.2.	<p>This flag specifies that the host will not read or write the memory object.</p> <p>CL_MEM_HOST_WRITE_ONLY or CL_MEM_HOST_READ_ONLY and CL_MEM_HOST_NO_ACCESS are mutually exclusive.</p>

Memory Flags	Description
<code>CL_MEM_KERNEL_READ_AND_WRITE</code> missing before version 2.0.	This flag is only used by <code>clGetSupportedImageFormats</code> to query image formats that may be both read from and written to by the same kernel instance. To create a memory object that may be read from and written to use <code>CL_MEM_READ_WRITE</code> .

To create a new buffer object (referred to as a sub-buffer object) from an existing buffer object, call the function

```
cl_mem clCreateSubBuffer(
    cl_mem buffer,
    cl_mem_flags flags,
    cl_buffer_create_type buffer_create_type,
    const void* buffer_create_info,
    cl_int* errcode_ret);
```



`clCreateSubBuffer` is missing before version 1.1.

- *buffer* must be a valid buffer object and cannot be a sub-buffer object.
- *flags* is a bit-field that is used to specify allocation and usage information about the sub-buffer memory object being created and is described in the [Memory Flags](#) table. If the `CL_MEM_READ_WRITE`, `CL_MEM_READ_ONLY`, or `CL_MEM_WRITE_ONLY` values are not specified in *flags*, they are inherited from the corresponding memory access qualifiers associated with *buffer*. The `CL_MEM_USE_HOST_PTR`, `CL_MEM_ALLOC_HOST_PTR`, and `CL_MEM_COPY_HOST_PTR` values cannot be specified in *flags* but are inherited from the corresponding memory access qualifiers associated with *buffer*. If `CL_MEM_COPY_HOST_PTR` is specified in the memory access qualifier values associated with *buffer* it does not imply any additional copies when the sub-buffer is created from *buffer*. If the `CL_MEM_HOST_WRITE_ONLY`, `CL_MEM_HOST_READ_ONLY`, or `CL_MEM_HOST_NO_ACCESS` values are not specified in *flags*, they are inherited from the corresponding memory access qualifiers associated with *buffer*.
- *buffer_create_type* and *buffer_create_info* describe the type of buffer object to be created. The list of supported values for *buffer_create_type* and corresponding descriptor that *buffer_create_info* points to is described in the [SubBuffer Attributes](#) table.

Table 13. List of supported buffer creation types by `clCreateSubBuffer`

Buffer Creation Type	Description
CL_BUFFER_CREATE_TYPE_REGION missing before version 1.1.	<p>Create a buffer object that represents a specific region in <i>buffer</i>.</p> <p><i>buffer_create_info</i> is a pointer to a cl_buffer_region structure specifying a region of the buffer.</p> <p>If <i>buffer</i> is created with CL_MEM_USE_HOST_PTR, the <i>host_ptr</i> associated with the buffer object returned is <i>host_ptr</i> + <i>origin</i>.</p> <p>The buffer object returned references the data store allocated for buffer and points to the region specified by <i>buffer_create_info</i> in this data store.</p>

clCreateSubBuffer returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors in *errcode_ret*:

- **CL_INVALID_MEM_OBJECT** if *buffer* is not a valid buffer object or is a sub-buffer object.
- **CL_INVALID_VALUE** if *buffer* was created with **CL_MEM_WRITE_ONLY** and *flags* specifies **CL_MEM_READ_WRITE** or **CL_MEM_READ_ONLY**, or if *buffer* was created with **CL_MEM_READ_ONLY** and *flags* specifies **CL_MEM_READ_WRITE** or **CL_MEM_WRITE_ONLY**, or if *flags* specifies **CL_MEM_USE_HOST_PTR** or **CL_MEM_ALLOC_HOST_PTR** or **CL_MEM_COPY_HOST_PTR**.
- **CL_INVALID_VALUE** if *buffer* was created with **CL_MEM_HOST_WRITE_ONLY** and *flags* specify **CL_MEM_HOST_READ_ONLY**, or if *buffer* was created with **CL_MEM_HOST_READ_ONLY** and *flags* specify **CL_MEM_HOST_WRITE_ONLY**, or if *buffer* was created with **CL_MEM_HOST_NO_ACCESS** and *flags* specify **CL_MEM_HOST_READ_ONLY** or **CL_MEM_HOST_WRITE_ONLY**.
- **CL_INVALID_VALUE** if the value specified in *buffer_create_type* is not valid.
- **CL_INVALID_VALUE** if value(s) specified in *buffer_create_info* (for a given *buffer_create_type*) is not valid or if *buffer_create_info* is **NULL**.
- **CL_MEM_OBJECT_ALLOCATION_FAILURE** if there is a failure to allocate memory for sub-buffer object.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.
- **CL_INVALID_VALUE** if the region specified by the **cl_buffer_region** structure passed in *buffer_create_info* is out of bounds in *buffer*.
- **CL_INVALID_BUFFER_SIZE** if the *size* field of the **cl_buffer_region** structure passed in *buffer_create_info* is 0.
- **CL_MISALIGNED_SUB_BUFFER_OFFSET** if there are no devices in *context* associated with *buffer* for which the *origin* field of the **cl_buffer_region** structure passed in *buffer_create_info* is aligned to

the `CL_DEVICE_MEM_BASE_ADDR_ALIGN` value.



Concurrent reading from, writing to and copying between both a buffer object and its sub-buffer object(s) is undefined. Concurrent reading from, writing to and copying between overlapping sub-buffer objects created with the same buffer object is undefined. Only reading from both a buffer object and its sub-buffer objects or reading from multiple overlapping sub-buffer objects is defined.

The `cl_buffer_region` structure specifies a region of a buffer object:

```
typedef struct cl_buffer_region {
    size_t    origin;
    size_t    size;
} cl_buffer_region;
```

- *origin* is the offset in bytes of the region.
- *size* is the size in bytes of the region.

Constraints on the values of *origin* and *size* are specified for the `clCreateSubBuffer` function to which this structure is passed.

5.2.2. Reading, Writing and Copying Buffer Objects

The following functions enqueue commands to read from a buffer object to host memory or write to a buffer object from host memory.

To read from a buffer object to host memory or to write to a buffer object from host memory call one of the functions

```
cl_int clEnqueueReadBuffer(
    cl_command_queue command_queue,
    cl_mem buffer,
    cl_bool blocking_read,
    size_t offset,
    size_t size,
    void* ptr,
    cl_uint num_events_in_wait_list,
    const cl_event* event_wait_list,
    cl_event* event);
```

```

cl_int clEnqueueWriteBuffer(
    cl_command_queue command_queue,
    cl_mem buffer,
    cl_bool blocking_write,
    size_t offset,
    size_t size,
    const void* ptr,
    cl_uint num_events_in_wait_list,
    const cl_event* event_wait_list,
    cl_event* event);

```

- *command_queue* is a valid host command-queue in which the read / write command will be queued. *command_queue* and *buffer* must be created with the same OpenCL context.
- *buffer* refers to a valid buffer object.
- *blocking_read* and *blocking_write* indicate if the read and write operations are *blocking* or *non-blocking* (see below).
- *offset* is the offset in bytes in the buffer object to read from or write to.
- *size* is the size in bytes of data being read or written.
- *ptr* is the pointer to buffer in host memory where data is to be read into or to be written from.
- *event_wait_list* and *num_events_in_wait_list* specify events that need to complete before this particular command can be executed. If *event_wait_list* is **NULL**, then this particular command does not wait on any event to complete. If *event_wait_list* is **NULL**, *num_events_in_wait_list* must be 0. If *event_wait_list* is not **NULL**, the list of events pointed to by *event_wait_list* must be valid and *num_events_in_wait_list* must be greater than 0. The events specified in *event_wait_list* act as synchronization points. The context associated with events in *event_wait_list* and *command_queue* must be the same. The memory associated with *event_wait_list* can be reused or freed after the function returns.
- *event* returns an event object that identifies this read / write command and can be used to query or queue a wait for this command to complete. If *event* is **NULL** or the enqueue is unsuccessful, no event will be created and therefore it will not be possible to query the status of this command or to wait for this command to complete. If *event_wait_list* and *event* are not **NULL**, *event* must not refer to an element of the *event_wait_list* array.

If *blocking_read* is **CL_TRUE** i.e. the read command is blocking, **clEnqueueReadBuffer** does not return until the buffer data has been read and copied into memory pointed to by *ptr*.

If *blocking_read* is **CL_FALSE** i.e. the read command is non-blocking, **clEnqueueReadBuffer** queues a non-blocking read command and returns. The contents of the buffer that *ptr* points to cannot be used until the read command has completed. The *event* argument returns an event object which can be used to query the execution status of the read command. When the read command has completed, the contents of the buffer that *ptr* points to can be used by the application.

If *blocking_write* is **CL_TRUE**, the write command is blocking and does not return until the command is complete, including transfer of the data. The memory pointed to by *ptr* can be reused by the application after the **clEnqueueWriteBuffer** call returns.

If *blocking_write* is `CL_FALSE`, the OpenCL implementation will use *ptr* to perform a non-blocking write. As the write is non-blocking the implementation can return immediately. The memory pointed to by *ptr* cannot be reused by the application after the call returns. The *event* argument returns an event object which can be used to query the execution status of the write command. When the write command has completed, the memory pointed to by *ptr* can then be reused by the application.

`clEnqueueReadBuffer` and `clEnqueueWriteBuffer` return `CL_SUCCESS` if the function is executed successfully. Otherwise, they return one of the following errors:

- `CL_INVALID_COMMAND_QUEUE` if *command_queue* is not a valid host command-queue.
- `CL_INVALID_CONTEXT` if the context associated with *command_queue* and *buffer* are not the same or if the context associated with *command_queue* and events in *event_wait_list* are not the same.
- `CL_INVALID_MEM_OBJECT` if *buffer* is not a valid buffer object.
- `CL_INVALID_VALUE` if the region being read or written specified by (*offset*, *size*) is out of bounds or if *ptr* is a `NULL` value.
- `CL_INVALID_EVENT_WAIT_LIST` if *event_wait_list* is `NULL` and *num_events_in_wait_list* > 0, or *event_wait_list* is not `NULL` and *num_events_in_wait_list* is 0, or if event objects in *event_wait_list* are not valid events.
- `CL_MISALIGNED_SUB_BUFFER_OFFSET` if *buffer* is a sub-buffer object and *offset* specified when the sub-buffer object is created is not aligned to `CL_DEVICE_MEM_BASE_ADDR_ALIGN` value for device associated with *queue*. This error code is [missing before](#) version 1.1.
- `CL_EXEC_STATUS_ERROR_FOR_EVENTS_IN_WAIT_LIST` if the read and write operations are blocking and the execution status of any of the events in *event_wait_list* is a negative integer value. This error code is [missing before](#) version 1.1.
- `CL_MEM_OBJECT_ALLOCATION_FAILURE` if there is a failure to allocate memory for data store associated with *buffer*.
- `CL_INVALID_OPERATION` if `clEnqueueReadBuffer` is called on *buffer* which has been created with `CL_MEM_HOST_WRITE_ONLY` or `CL_MEM_HOST_NO_ACCESS`.
- `CL_INVALID_OPERATION` if `clEnqueueWriteBuffer` is called on *buffer* which has been created with `CL_MEM_HOST_READ_ONLY` or `CL_MEM_HOST_NO_ACCESS`.
- `CL_OUT_OF_RESOURCES` if there is a failure to allocate resources required by the OpenCL implementation on the device.
- `CL_OUT_OF_HOST_MEMORY` if there is a failure to allocate resources required by the OpenCL implementation on the host.

The following functions enqueue commands to read a 2D or 3D rectangular region from a buffer object to host memory or write a 2D or 3D rectangular region to a buffer object from host memory.

```

cl_int clEnqueueReadBufferRect(
    cl_command_queue command_queue,
    cl_mem buffer,
    cl_bool blocking_read,
    const size_t* buffer_origin,
    const size_t* host_origin,
    const size_t* region,
    size_t buffer_row_pitch,
    size_t buffer_slice_pitch,
    size_t host_row_pitch,
    size_t host_slice_pitch,
    void* ptr,
    cl_uint num_events_in_wait_list,
    const cl_event* event_wait_list,
    cl_event* event);

```



clEnqueueReadBufferRect is missing before version 1.1.

```

cl_int clEnqueueWriteBufferRect(
    cl_command_queue command_queue,
    cl_mem buffer,
    cl_bool blocking_write,
    const size_t* buffer_origin,
    const size_t* host_origin,
    const size_t* region,
    size_t buffer_row_pitch,
    size_t buffer_slice_pitch,
    size_t host_row_pitch,
    size_t host_slice_pitch,
    const void* ptr,
    cl_uint num_events_in_wait_list,
    const cl_event* event_wait_list,
    cl_event* event);

```



clEnqueueWriteBufferRect is missing before version 1.1.

- *command_queue* refers to a valid host command-queue in which the read / write command will be queued. *command_queue* and *buffer* must be created with the same OpenCL context.
- *buffer* refers to a valid buffer object.
- *blocking_read* and *blocking_write* indicate if the read and write operations are *blocking* or *non-blocking* (see below).
- *buffer_origin* defines the (x, y, z) offset in the memory region associated with *buffer*. For a 2D rectangle region, the z value given by *buffer_origin*[2] should be 0. The offset in bytes is computed as *buffer_origin*[2] × *buffer_slice_pitch* + *buffer_origin*[1] × *buffer_row_pitch* + *buffer_origin*[0].

- *host_origin* defines the (x, y, z) offset in the memory region pointed to by *ptr*. For a 2D rectangle region, the z value given by *host_origin*[2] should be 0. The offset in bytes is computed as $host_origin[2] \times host_slice_pitch + host_origin[1] \times host_row_pitch + host_origin[0]$.
- *region* defines the (*width* in bytes, *height* in rows, *depth* in slices) of the 2D or 3D rectangle being read or written. For a 2D rectangle copy, the *depth* value given by *region*[2] should be 1. The values in *region* cannot be 0.
- *buffer_row_pitch* is the length of each row in bytes to be used for the memory region associated with *buffer*. If *buffer_row_pitch* is 0, *buffer_row_pitch* is computed as *region*[0].
- *buffer_slice_pitch* is the length of each 2D slice in bytes to be used for the memory region associated with *buffer*. If *buffer_slice_pitch* is 0, *buffer_slice_pitch* is computed as $region[1] \times buffer_row_pitch$.
- *host_row_pitch* is the length of each row in bytes to be used for the memory region pointed to by *ptr*. If *host_row_pitch* is 0, *host_row_pitch* is computed as *region*[0].
- *host_slice_pitch* is the length of each 2D slice in bytes to be used for the memory region pointed to by *ptr*. If *host_slice_pitch* is 0, *host_slice_pitch* is computed as $region[1] \times host_row_pitch$.
- *ptr* is the pointer to buffer in host memory where data is to be read into or to be written from.
- *event_wait_list* and *num_events_in_wait_list* specify events that need to complete before this particular command can be executed. If *event_wait_list* is **NULL**, then this particular command does not wait on any event to complete. If *event_wait_list* is **NULL**, *num_events_in_wait_list* must be 0. If *event_wait_list* is not **NULL**, the list of events pointed to by *event_wait_list* must be valid and *num_events_in_wait_list* must be greater than 0. The events specified in *event_wait_list* act as synchronization points. The context associated with events in *event_wait_list* and *command_queue* must be the same. The memory associated with *event_wait_list* can be reused or freed after the function returns.
- *event* returns an event object that identifies this read / write command and can be used to query or queue a wait for this command to complete. If *event* is **NULL** or the enqueue is unsuccessful, no event will be created and therefore it will not be possible to query the status of this command or to wait for this command to complete. If *event_wait_list* and *event* are not **NULL**, *event* must not refer to an element of the *event_wait_list* array.

If *blocking_read* is **CL_TRUE** i.e. the read command is blocking, **clEnqueueReadBufferRect** does not return until the buffer data has been read and copied into memory pointed to by *ptr*.

If *blocking_read* is **CL_FALSE** i.e. the read command is non-blocking, **clEnqueueReadBufferRect** queues a non-blocking read command and returns. The contents of the buffer that *ptr* points to cannot be used until the read command has completed. The *event* argument returns an event object which can be used to query the execution status of the read command. When the read command has completed, the contents of the buffer that *ptr* points to can be used by the application.

If *blocking_write* is **CL_TRUE**, the write command is blocking and does not return until the command is complete, including transfer of the data. The memory pointed to by *ptr* can be reused by the application after the **clEnqueueWriteBufferRect** call returns.

If *blocking_write* is **CL_FALSE**, the OpenCL implementation will use *ptr* to perform a non-blocking write. As the write is non-blocking the implementation can return immediately. The memory

pointed to by *ptr* cannot be reused by the application after the call returns. The *event* argument returns an event object which can be used to query the execution status of the write command. When the write command has completed, the memory pointed to by *ptr* can then be reused by the application.

clEnqueueReadBufferRect and **clEnqueueWriteBufferRect** return **CL_SUCCESS** if the function is executed successfully. Otherwise, they return one of the following errors:

- **CL_INVALID_COMMAND_QUEUE** if *command_queue* is not a valid host command-queue.
- **CL_INVALID_CONTEXT** if the context associated with *command_queue* and *buffer* are not the same or if the context associated with *command_queue* and events in *event_wait_list* are not the same.
- **CL_INVALID_MEM_OBJECT** if *buffer* is not a valid buffer object.
- **CL_INVALID_VALUE** if *buffer_origin*, *host_origin*, or *region* is **NULL**.
- **CL_INVALID_VALUE** if the region being read or written specified by (*buffer_origin*, *region*, *buffer_row_pitch*, *buffer_slice_pitch*) is out of bounds.
- **CL_INVALID_VALUE** if any *region* array element is 0.
- **CL_INVALID_VALUE** if *buffer_row_pitch* is not 0 and is less than *region*[0].
- **CL_INVALID_VALUE** if *host_row_pitch* is not 0 and is less than *region*[0].
- **CL_INVALID_VALUE** if *buffer_slice_pitch* is not 0 and is less than *region*[1] × *buffer_row_pitch* and not a multiple of *buffer_row_pitch*.
- **CL_INVALID_VALUE** if *host_slice_pitch* is not 0 and is less than *region*[1] × *host_row_pitch* and not a multiple of *host_row_pitch*.
- **CL_INVALID_VALUE** if *ptr* is **NULL**.
- **CL_INVALID_EVENT_WAIT_LIST** if *event_wait_list* is **NULL** and *num_events_in_wait_list* > 0, or *event_wait_list* is not **NULL** and *num_events_in_wait_list* is 0, or if event objects in *event_wait_list* are not valid events.
- **CL_MISALIGNED_SUB_BUFFER_OFFSET** if *buffer* is a sub-buffer object and *offset* specified when the sub-buffer object is created is not aligned to **CL_DEVICE_MEM_BASE_ADDR_ALIGN** value for device associated with *queue*. This error code is **missing before** version 1.1.
- **CL_EXEC_STATUS_ERROR_FOR_EVENTS_IN_WAIT_LIST** if the read and write operations are blocking and the execution status of any of the events in *event_wait_list* is a negative integer value. This error code is **missing before** version 1.1.
- **CL_MEM_OBJECT_ALLOCATION_FAILURE** if there is a failure to allocate memory for data store associated with *buffer*.
- **CL_INVALID_OPERATION** if **clEnqueueReadBufferRect** is called on *buffer* which has been created with **CL_MEM_HOST_WRITE_ONLY** or **CL_MEM_HOST_NO_ACCESS**.
- **CL_INVALID_OPERATION** if **clEnqueueWriteBufferRect** is called on *buffer* which has been created with **CL_MEM_HOST_READ_ONLY** or **CL_MEM_HOST_NO_ACCESS**.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL

implementation on the host.

Calling **clEnqueueReadBuffer** to read a region of the buffer object with the *ptr* argument value set to *host_ptr + offset*, where *host_ptr* is a pointer to the memory region specified when the buffer object being read is created with **CL_MEM_USE_HOST_PTR**, must meet the following requirements in order to avoid undefined behavior:

- All commands that use this buffer object or a memory object (buffer or image) created from this buffer object have finished execution before the read command begins execution.
- The buffer object or memory objects created from this buffer object are not mapped.
- The buffer object or memory objects created from this buffer object are not used by any command-queue until the read command has finished execution.

Calling **clEnqueueReadBufferRect** to read a region of the buffer object with the *ptr* argument value set to *host_ptr* and *host_origin*, *buffer_origin* values are the same, where *host_ptr* is a pointer to the memory region specified when the buffer object being read is created with **CL_MEM_USE_HOST_PTR**, must meet the same requirements given above for **clEnqueueReadBuffer**.



Calling **clEnqueueWriteBuffer** to update the latest bits in a region of the buffer object with the *ptr* argument value set to *host_ptr + offset*, where *host_ptr* is a pointer to the memory region specified when the buffer object being written is created with **CL_MEM_USE_HOST_PTR**, must meet the following requirements in order to avoid undefined behavior:

- The host memory region given by (*host_ptr + offset*, *cb*) contains the latest bits when the enqueued write command begins execution.
- The buffer object or memory objects created from this buffer object are not mapped.
- The buffer object or memory objects created from this buffer object are not used by any command-queue until the write command has finished execution.

Calling **clEnqueueWriteBufferRect** to update the latest bits in a region of the buffer object with the *ptr* argument value set to *host_ptr* and *host_origin*, *buffer_origin* values are the same, where *host_ptr* is a pointer to the memory region specified when the buffer object being written is created with **CL_MEM_USE_HOST_PTR**, must meet the following requirements in order to avoid undefined behavior:

- The host memory region given by (*buffer_origin region*) contains the latest bits when the enqueued write command begins execution.
- The buffer object or memory objects created from this buffer object are not mapped.
- The buffer object or memory objects created from this buffer object are not

used by any command-queue until the write command has finished execution.

To enqueue a command to copy a buffer object identified by *src_buffer* to another buffer object identified by *dst_buffer*, call the function

```
cl_int clEnqueueCopyBuffer(  
    cl_command_queue command_queue,  
    cl_mem src_buffer,  
    cl_mem dst_buffer,  
    size_t src_offset,  
    size_t dst_offset,  
    size_t size,  
    cl_uint num_events_in_wait_list,  
    const cl_event* event_wait_list,  
    cl_event* event);
```

- *command_queue* refers to a host command-queue in which the copy command will be queued. The OpenCL context associated with *command_queue*, *src_buffer* and *dst_buffer* must be the same.
- *src_offset* refers to the offset where to begin copying data from *src_buffer*.
- *dst_offset* refers to the offset where to begin copying data into *dst_buffer*.
- *size* refers to the size in bytes to copy.
- *event_wait_list* and *num_events_in_wait_list* specify events that need to complete before this particular command can be executed. If *event_wait_list* is **NULL**, then this particular command does not wait on any event to complete. If *event_wait_list* is **NULL**, *num_events_in_wait_list* must be 0. If *event_wait_list* is not **NULL**, the list of events pointed to by *event_wait_list* must be valid and *num_events_in_wait_list* must be greater than 0. The events specified in *event_wait_list* act as synchronization points. The context associated with events in *event_wait_list* and *command_queue* must be the same. The memory associated with *event_wait_list* can be reused or freed after the function returns.
- *event* returns an event object that identifies this copy command and can be used to query or queue a wait for this command to complete. If *event* is **NULL** or the enqueue is unsuccessful, no event will be created and therefore it will not be possible to query the status of this command or to wait for this command to complete. If *event_wait_list* and *event* are not **NULL**, *event* must not refer to an element of the *event_wait_list* array.

clEnqueueCopyBuffer returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_COMMAND_QUEUE** if *command_queue* is not a valid host command-queue.
- **CL_INVALID_CONTEXT** if the context associated with *command_queue*, *src_buffer* and *dst_buffer* are not the same or if the context associated with *command_queue* and events in *event_wait_list* are not the same.
- **CL_INVALID_MEM_OBJECT** if *src_buffer* and *dst_buffer* are not valid buffer objects.
- **CL_INVALID_VALUE** if *src_offset*, *dst_offset*, *size*, *src_offset* + *size* or *dst_offset* + *size* require

accessing elements outside the *src_buffer* and *dst_buffer* buffer objects respectively.

- **CL_INVALID_EVENT_WAIT_LIST** if *event_wait_list* is **NULL** and *num_events_in_wait_list* > 0, or *event_wait_list* is not **NULL** and *num_events_in_wait_list* is 0, or if event objects in *event_wait_list* are not valid events.
- **CL_MISALIGNED_SUB_BUFFER_OFFSET** if *src_buffer* is a sub-buffer object and *offset* specified when the sub-buffer object is created is not aligned to **CL_DEVICE_MEM_BASE_ADDR_ALIGN** value for device associated with *queue*. This error code is **missing before** version 1.1.
- **CL_MISALIGNED_SUB_BUFFER_OFFSET** if *dst_buffer* is a sub-buffer object and *offset* specified when the sub-buffer object is created is not aligned to **CL_DEVICE_MEM_BASE_ADDR_ALIGN** value for device associated with *queue*. This error code is **missing before** version 1.1.
- **CL_MEM_COPY_OVERLAP** if *src_buffer* and *dst_buffer* are the same buffer or sub-buffer object and the source and destination regions overlap or if *src_buffer* and *dst_buffer* are different sub-buffers of the same associated buffer object and they overlap. The regions overlap if $src_offset \leq dst_offset \leq src_offset + size - 1$ or if $dst_offset \leq src_offset \leq dst_offset + size - 1$.
- **CL_MEM_OBJECT_ALLOCATION_FAILURE** if there is a failure to allocate memory for data store associated with *src_buffer* or *dst_buffer*.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

To enqueue a command to copy a 2D or 3D rectangular region from the buffer object identified by *src_buffer* to a 2D or 3D region in the buffer object identified by *dst_buffer*, call the function

```
cl_int clEnqueueCopyBufferRect(  
    cl_command_queue command_queue,  
    cl_mem src_buffer,  
    cl_mem dst_buffer,  
    const size_t* src_origin,  
    const size_t* dst_origin,  
    const size_t* region,  
    size_t src_row_pitch,  
    size_t src_slice_pitch,  
    size_t dst_row_pitch,  
    size_t dst_slice_pitch,  
    cl_uint num_events_in_wait_list,  
    const cl_event* event_wait_list,  
    cl_event* event);
```



clEnqueueCopyBufferRect is **missing before** version 1.1.

- *command_queue* refers to the host command-queue in which the copy command will be queued. The OpenCL context associated with *command_queue*, *src_buffer* and *dst_buffer* must be the same.

- *src_origin* defines the (x, y, z) offset in the memory region associated with *src_buffer*. For a 2D rectangle region, the z value given by *src_origin*[2] should be 0. The offset in bytes is computed as *src_origin*[2] × *src_slice_pitch* + *src_origin*[1] × *src_row_pitch* + *src_origin*[0].
- *dst_origin* defines the (x, y, z) offset in the memory region associated with *dst_buffer*. For a 2D rectangle region, the z value given by *dst_origin*[2] should be 0. The offset in bytes is computed as *dst_origin*[2] × *dst_slice_pitch* + *dst_origin*[1] × *dst_row_pitch* + *dst_origin*[0].
- *region* defines the (width in bytes, height in rows, depth in slices) of the 2D or 3D rectangle being copied. For a 2D rectangle, the *depth* value given by *region*[2] should be 1. The values in *region* cannot be 0.
- *src_row_pitch* is the length of each row in bytes to be used for the memory region associated with *src_buffer*. If *src_row_pitch* is 0, *src_row_pitch* is computed as *region*[0].
- *src_slice_pitch* is the length of each 2D slice in bytes to be used for the memory region associated with *src_buffer*. If *src_slice_pitch* is 0, *src_slice_pitch* is computed as *region*[1] × *src_row_pitch*.
- *dst_row_pitch* is the length of each row in bytes to be used for the memory region associated with *dst_buffer*. If *dst_row_pitch* is 0, *dst_row_pitch* is computed as *region*[0].
- *dst_slice_pitch* is the length of each 2D slice in bytes to be used for the memory region associated with *dst_buffer*. If *dst_slice_pitch* is 0, *dst_slice_pitch* is computed as *region*[1] × *dst_row_pitch*.
- *event_wait_list* and *num_events_in_wait_list* specify events that need to complete before this particular command can be executed. If *event_wait_list* is **NULL**, then this particular command does not wait on any event to complete. If *event_wait_list* is **NULL**, *num_events_in_wait_list* must be 0. If *event_wait_list* is not **NULL**, the list of events pointed to by *event_wait_list* must be valid and *num_events_in_wait_list* must be greater than 0. The events specified in *event_wait_list* act as synchronization points. The context associated with events in *event_wait_list* and *command_queue* must be the same. The memory associated with *event_wait_list* can be reused or freed after the function returns.
- *event* returns an event object that identifies this copy command and can be used to query or queue a wait for this command to complete. If *event* is **NULL** or the enqueue is unsuccessful, no event will be created and therefore it will not be possible to query the status of this command or to wait for this command to complete. If *event_wait_list* and *event* are not **NULL**, *event* must not refer to an element of the *event_wait_list* array.

Copying begins at the source offset and destination offset which are computed as described below in the description for *src_origin* and *dst_origin*. Each byte of the region's width is copied from the source offset to the destination offset. After copying each width, the source and destination offsets are incremented by their respective source and destination row pitches. After copying each 2D rectangle, the source and destination offsets are incremented by their respective source and destination slice pitches.



If *src_buffer* and *dst_buffer* are the same buffer object, *src_row_pitch* must equal *dst_row_pitch* and *src_slice_pitch* must equal *dst_slice_pitch*.

clEnqueueCopyBufferRect returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_COMMAND_QUEUE** if *command_queue* is not a valid host command-queue.

- **CL_INVALID_CONTEXT** if the context associated with *command_queue*, *src_buffer* and *dst_buffer* are not the same or if the context associated with *command_queue* and events in *event_wait_list* are not the same.
- **CL_INVALID_MEM_OBJECT** if *src_buffer* and *dst_buffer* are not valid buffer objects.
- **CL_INVALID_VALUE** if *src_origin*, *dst_origin*, or *region* is **NULL**.
- **CL_INVALID_VALUE** if (*src_origin*, *region*, *src_row_pitch*, *src_slice_pitch*) or (*dst_origin*, *region*, *dst_row_pitch*, *dst_slice_pitch*) require accessing elements outside the *src_buffer* and *dst_buffer* buffer objects respectively.
- **CL_INVALID_VALUE** if any *region* array element is 0.
- **CL_INVALID_VALUE** if *src_row_pitch* is not 0 and is less than *region*[0].
- **CL_INVALID_VALUE** if *dst_row_pitch* is not 0 and is less than *region*[0].
- **CL_INVALID_VALUE** if *src_slice_pitch* is not 0 and is less than $region[1] \times src_row_pitch$ or if *src_slice_pitch* is not 0 and is not a multiple of *src_row_pitch*.
- **CL_INVALID_VALUE** if *dst_slice_pitch* is not 0 and is less than $region[1] \times dst_row_pitch$ or if *dst_slice_pitch* is not 0 and is not a multiple of *dst_row_pitch*.
- **CL_INVALID_VALUE** if *src_buffer* and *dst_buffer* are the same buffer object and *src_slice_pitch* is not equal to *dst_slice_pitch* and *src_row_pitch* is not equal to *dst_row_pitch*.
- **CL_INVALID_EVENT_WAIT_LIST** if *event_wait_list* is **NULL** and *num_events_in_wait_list* > 0, or *event_wait_list* is not **NULL** and *num_events_in_wait_list* is 0, or if event objects in *event_wait_list* are not valid events.
- **CL_MEM_COPY_OVERLAP** if *src_buffer* and *dst_buffer* are the same buffer or sub-buffer object and the source and destination regions overlap or if *src_buffer* and *dst_buffer* are different sub-buffers of the same associated buffer object and they overlap. Refer to [Checking for Memory Copy Overlap](#) for details on how to determine if source and destination regions overlap.
- **CL_MISALIGNED_SUB_BUFFER_OFFSET** if *src_buffer* is a sub-buffer object and *offset* specified when the sub-buffer object is created is not aligned to **CL_DEVICE_MEM_BASE_ADDR_ALIGN** value for device associated with *queue*. This error code is [missing before](#) version 1.1.
- **CL_MISALIGNED_SUB_BUFFER_OFFSET** if *dst_buffer* is a sub-buffer object and *offset* specified when the sub-buffer object is created is not aligned to **CL_DEVICE_MEM_BASE_ADDR_ALIGN** value for device associated with *queue*. This error code is [missing before](#) version 1.1.
- **CL_MEM_OBJECT_ALLOCATION_FAILURE** if there is a failure to allocate memory for data store associated with *src_buffer* or *dst_buffer*.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

5.2.3. Filling Buffer Objects



Filling buffer objects is [missing before](#) version 1.2.

To enqueue a command to fill a buffer object with a pattern of a given pattern size, call the function

```
cl_int clEnqueueFillBuffer(  
    cl_command_queue command_queue,  
    cl_mem buffer,  
    const void* pattern,  
    size_t pattern_size,  
    size_t offset,  
    size_t size,  
    cl_uint num_events_in_wait_list,  
    const cl_event* event_wait_list,  
    cl_event* event);
```



clEnqueueFillBuffer is missing before version 1.2.

- *command_queue* refers to the host command-queue in which the fill command will be queued. The OpenCL context associated with *command_queue* and *buffer* must be the same.
- *buffer* is a valid buffer object.
- *pattern* is a pointer to the data pattern of size *pattern_size* in bytes. *pattern* will be used to fill a region in *buffer* starting at *offset* and is *size* bytes in size. The data pattern must be a scalar or vector integer or floating-point data type supported by OpenCL as described in [Shared Application Scalar Data Types](#) and [Supported Application Vector Data Types](#). For example, if *buffer* is to be filled with a pattern of `float4` values, then *pattern* will be a pointer to a `cl_float4` value and *pattern_size* will be `sizeof(cl_float4)`. The maximum value of *pattern_size* is the size of the largest integer or floating-point vector data type supported by the OpenCL device. The memory associated with *pattern* can be reused or freed after the function returns.
- *offset* is the location in bytes of the region being filled in *buffer* and must be a multiple of *pattern_size*.
- *size* is the size in bytes of region being filled in *buffer* and must be a multiple of *pattern_size*.
- *event_wait_list* and *num_events_in_wait_list* specify events that need to complete before this particular command can be executed. If *event_wait_list* is `NULL`, then this particular command does not wait on any event to complete. If *event_wait_list* is `NULL`, *num_events_in_wait_list* must be 0. If *event_wait_list* is not `NULL`, the list of events pointed to by *event_wait_list* must be valid and *num_events_in_wait_list* must be greater than 0. The events specified in *event_wait_list* act as synchronization points. The context associated with events in *event_wait_list* and *command_queue* must be the same. The memory associated with *event_wait_list* can be reused or freed after the function returns.
- *event* returns an event object that identifies this command and can be used to query or queue a wait for this command to complete. If *event* is `NULL` or the enqueue is unsuccessful, no event will be created and therefore it will not be possible to query the status of this command or to wait for this command to complete. If *event_wait_list* and *event* are not `NULL`, *event* must not refer to an element of the *event_wait_list* array.

The usage information which indicates whether the memory object can be read or written by a kernel and/or the host and is given by the `cl_mem_flags` argument value specified when *buffer* is

created is ignored by `clEnqueueFillBuffer`.

`clEnqueueFillBuffer` returns `CL_SUCCESS` if the function is executed successfully. Otherwise, it returns one of the following errors:

- `CL_INVALID_COMMAND_QUEUE` if *command_queue* is not a valid host command-queue.
- `CL_INVALID_CONTEXT` if the context associated with *command_queue* and *buffer* are not the same or if the context associated with *command_queue* and events in *event_wait_list* are not the same.
- `CL_INVALID_MEM_OBJECT` if *buffer* is not a valid buffer object.
- `CL_INVALID_VALUE` if *offset* or *offset + size* require accessing elements outside the *buffer* buffer object respectively.
- `CL_INVALID_VALUE` if *pattern* is `NULL` or if *pattern_size* is 0 or if *pattern_size* is not one of { 1, 2, 4, 8, 16, 32, 64, 128 }.
- `CL_INVALID_VALUE` if *offset* and *size* are not a multiple of *pattern_size*.
- `CL_INVALID_EVENT_WAIT_LIST` if *event_wait_list* is `NULL` and *num_events_in_wait_list* > 0, or *event_wait_list* is not `NULL` and *num_events_in_wait_list* is 0, or if event objects in *event_wait_list* are not valid events.
- `CL_MISALIGNED_SUB_BUFFER_OFFSET` if *buffer* is a sub-buffer object and offset specified when the sub-buffer object is created is not aligned to `CL_DEVICE_MEM_BASE_ADDR_ALIGN` value for device associated with *queue*. This error code is [missing before](#) version 1.1.
- `CL_MEM_OBJECT_ALLOCATION_FAILURE` if there is a failure to allocate memory for data store associated with *buffer*.
- `CL_OUT_OF_RESOURCES` if there is a failure to allocate resources required by the OpenCL implementation on the device.
- `CL_OUT_OF_HOST_MEMORY` if there is a failure to allocate resources required by the OpenCL implementation on the host.

5.2.4. Mapping Buffer Objects

To enqueue a command to map a region of the buffer object given by *buffer* into the host address space and returns a pointer to this mapped region, call the function

```
void* clEnqueueMapBuffer(  
    cl_command_queue command_queue,  
    cl_mem buffer,  
    cl_bool blocking_map,  
    cl_map_flags map_flags,  
    size_t offset,  
    size_t size,  
    cl_uint num_events_in_wait_list,  
    const cl_event* event_wait_list,  
    cl_event* event,  
    cl_int* errcode_ret);
```

- *command_queue* must be a valid host command-queue.
- *blocking_map* indicates if the map operation is *blocking* or *non-blocking*.

If *blocking_map* is **CL_TRUE**, **clEnqueueMapBuffer** does not return until the specified region in *buffer* is mapped into the host address space and the application can access the contents of the mapped region using the pointer returned by **clEnqueueMapBuffer**.

If *blocking_map* is **CL_FALSE** i.e. map operation is non-blocking, the pointer to the mapped region returned by **clEnqueueMapBuffer** cannot be used until the map command has completed. The *event* argument returns an event object which can be used to query the execution status of the map command. When the map command is completed, the application can access the contents of the mapped region using the pointer returned by **clEnqueueMapBuffer**.

- *map_flags* is a bit-field and is described in the [Memory Map Flags](#) table.
- *buffer* is a valid buffer object. The OpenCL context associated with *command_queue* and *buffer* must be the same.
- *offset* and *size* are the offset in bytes and the size of the region in the buffer object that is being mapped.
- *event_wait_list* and *num_events_in_wait_list* specify events that need to complete before this particular command can be executed. If *event_wait_list* is **NULL**, then this particular command does not wait on any event to complete. If *event_wait_list* is **NULL**, *num_events_in_wait_list* must be 0. If *event_wait_list* is not **NULL**, the list of events pointed to by *event_wait_list* must be valid and *num_events_in_wait_list* must be greater than 0. The events specified in *event_wait_list* act as synchronization points. The context associated with events in *event_wait_list* and *command_queue* must be the same. The memory associated with *event_wait_list* can be reused or freed after the function returns.
- *event* returns an event object that identifies this command and can be used to query or queue a wait for this command to complete. If *event* is **NULL** or the enqueue is unsuccessful, no event will be created and therefore it will not be possible to query the status of this command or to wait for this command to complete. If *event_wait_list* and *event* are not **NULL**, *event* must not refer to an element of the *event_wait_list* array.
- *errcode_ret* will return an appropriate error code. If *errcode_ret* is **NULL**, no error code is returned.

clEnqueueMapBuffer will return a pointer to the mapped region. The *errcode_ret* is set to **CL_SUCCESS**.

A **NULL** pointer is returned otherwise with one of the following error values returned in *errcode_ret*:

- **CL_INVALID_COMMAND_QUEUE** if *command_queue* is not a valid host command-queue.
- **CL_INVALID_CONTEXT** if context associated with *command_queue* and *buffer* are not the same or if the context associated with *command_queue* and events in *event_wait_list* are not the same.
- **CL_INVALID_MEM_OBJECT** if *buffer* is not a valid buffer object.
- **CL_INVALID_VALUE** if region being mapped given by (*offset*, *size*) is out of bounds or if *size* is 0 or if values specified in *map_flags* are not valid.

- **CL_INVALID_EVENT_WAIT_LIST** if *event_wait_list* is **NULL** and *num_events_in_wait_list* > 0, or *event_wait_list* is not **NULL** and *num_events_in_wait_list* is 0, or if event objects in *event_wait_list* are not valid events.
- **CL_MISALIGNED_SUB_BUFFER_OFFSET** if *buffer* is a sub-buffer object and *offset* specified when the sub-buffer object is created is not aligned to **CL_DEVICE_MEM_BASE_ADDR_ALIGN** value for the device associated with *queue*. This error code is **missing before** version 1.1.
- **CL_MAP_FAILURE** if there is a failure to map the requested region into the host address space. This error cannot occur for buffer objects created with **CL_MEM_USE_HOST_PTR** or **CL_MEM_ALLOC_HOST_PTR**.
- **CL_EXEC_STATUS_ERROR_FOR_EVENTS_IN_WAIT_LIST** if the map operation is blocking and the execution status of any of the events in *event_wait_list* is a negative integer value. This error code is **missing before** version 1.1.
- **CL_MEM_OBJECT_ALLOCATION_FAILURE** if there is a failure to allocate memory for data store associated with *buffer*.
- **CL_INVALID_OPERATION** if *buffer* has been created with **CL_MEM_HOST_WRITE_ONLY** or **CL_MEM_HOST_NO_ACCESS** and **CL_MAP_READ** is set in *map_flags* or if *buffer* has been created with **CL_MEM_HOST_READ_ONLY** or **CL_MEM_HOST_NO_ACCESS** and **CL_MAP_WRITE** or **CL_MAP_WRITE_INVALIDATE_REGION** is set in *map_flags*.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.
- **CL_INVALID_OPERATION** if mapping would lead to overlapping regions being mapped for writing.

The pointer returned maps a region starting at *offset* and is at least *size* bytes in size. The result of a memory access outside this region is undefined.

If the buffer object is created with **CL_MEM_USE_HOST_PTR** set in *mem_flags*, the following will be true:

- The *host_ptr* specified in **clCreateBuffer** or **clCreateBufferWithProperties** will contain the latest bits in the region being mapped when the **clEnqueueMapBuffer** command has completed.
- The pointer value returned by **clEnqueueMapBuffer** will be derived from the *host_ptr* specified when the buffer object is created.

Mapped buffer objects are unmapped using **clEnqueueUnmapMemObject**. This is described in **Unmapping Mapped Memory Objects**.

Table 14. List of supported map flag values

Map Flags	Description
CL_MAP_READ	<p>This flag specifies that the region being mapped in the memory object is being mapped for reading.</p> <p>The pointer returned by clEnqueueMapBuffer (clEnqueueMapImage) is guaranteed to contain the latest bits in the region being mapped when the clEnqueueMapBuffer (clEnqueueMapImage) command has completed.</p>
CL_MAP_WRITE	<p>This flag specifies that the region being mapped in the memory object is being mapped for writing.</p> <p>The pointer returned by clEnqueueMapBuffer (clEnqueueMapImage) is guaranteed to contain the latest bits in the region being mapped when the clEnqueueMapBuffer (clEnqueueMapImage) command has completed.</p>
CL_MAP_WRITE_INVALIDATE_REGION missing before version 1.2.	<p>This flag specifies that the region being mapped in the memory object is being mapped for writing.</p> <p>The contents of the region being mapped are to be discarded. This is typically the case when the region being mapped is overwritten by the host. This flag allows the implementation to no longer guarantee that the pointer returned by clEnqueueMapBuffer (clEnqueueMapImage) contains the latest bits in the region being mapped which can be a significant performance enhancement.</p> <p>CL_MAP_READ or CL_MAP_WRITE and CL_MAP_WRITE_INVALIDATE_REGION are mutually exclusive.</p>

5.3. Image Objects

An *image* object is used to store a one-, two- or three-dimensional texture, frame-buffer or image. The elements of an image object are selected from a list of predefined image formats. The minimum number of elements in a memory object is one.

5.3.1. Creating Image Objects

An **image object** may be created using the function

```
cl_mem clCreateImage(  
    cl_context context,  
    cl_mem_flags flags,  
    const cl_image_format* image_format,  
    const cl_image_desc* image_desc,  
    void* host_ptr,  
    cl_int* errcode_ret);
```



clCreateImage is [missing before](#) version 1.2.

An **image object** may also be created with additional properties using the function

```
cl_mem clCreateImageWithProperties(  
    cl_context context,  
    const cl_mem_properties* properties,  
    cl_mem_flags flags,  
    const cl_image_format* image_format,  
    const cl_image_desc* image_desc,  
    void* host_ptr,  
    cl_int* errcode_ret);
```



clCreateImageWithProperties is [missing before](#) version 3.0.

- *context* is a valid OpenCL context used to create the image object.
- *properties* is an optional list of properties for the image object and their corresponding values. The list is terminated with the special property **0**. If no properties are required, *properties* may be **NULL**. OpenCL 3.0 does not define any optional properties for images.
- *flags* is a bit-field that is used to specify allocation and usage information about the image memory object being created and is described in the [supported memory flag values](#) table.
- *image_format* is a pointer to a structure that describes format properties of the image to be allocated. A 1D image buffer or 2D image can be created from a buffer by specifying a buffer object in the *image_desc*→*mem_object*. A 2D image can be created from another 2D image object by specifying an image object in the *image_desc*→*mem_object*. Refer to the [Image Format Descriptor](#) section for a detailed description of the image format descriptor.
- *image_desc* is a pointer to a structure that describes type and dimensions of the image to be allocated. Refer to the [Image Descriptor](#) section for a detailed description of the image descriptor.
- *host_ptr* is a pointer to the image data that may already be allocated by the application. Refer to the [table below](#) for a description of how large the buffer that *host_ptr* points to must be.
- *errcode_ret* will return an appropriate error code. If *errcode_ret* is **NULL**, no error code is

returned.

The alignment requirements for data stored in image objects are described in [Alignment of Application Data Types](#).

For all image types except `CL_MEM_OBJECT_IMAGE1D_BUFFER`, if the value specified for *flags* is 0, the default is used which is `CL_MEM_READ_WRITE`.

For `CL_MEM_OBJECT_IMAGE1D_BUFFER` image type, or an image created from another memory object (image or buffer), if the `CL_MEM_READ_WRITE`, `CL_MEM_READ_ONLY` or `CL_MEM_WRITE_ONLY` values are not specified in *flags*, they are inherited from the corresponding memory access qualifiers associated with *mem_object*. The `CL_MEM_USE_HOST_PTR`, `CL_MEM_ALLOC_HOST_PTR` and `CL_MEM_COPY_HOST_PTR` values cannot be specified in *flags* but are inherited from the corresponding memory access qualifiers associated with *mem_object*. If `CL_MEM_COPY_HOST_PTR` is specified in the memory access qualifier values associated with *mem_object* it does not imply any additional copies when the image is created from *mem_object*. If the `CL_MEM_HOST_WRITE_ONLY`, `CL_MEM_HOST_READ_ONLY` or `CL_MEM_HOST_NO_ACCESS` values are not specified in *flags*, they are inherited from the corresponding memory access qualifiers associated with *mem_object*.

For a 3D image or 2D image array, the image data specified by *host_ptr* is stored as a linear sequence of adjacent 2D image slices or 2D images respectively. Each 2D image is a linear sequence of adjacent scanlines. Each scanline is a linear sequence of image elements.

For a 2D image, the image data specified by *host_ptr* is stored as a linear sequence of adjacent scanlines. Each scanline is a linear sequence of image elements.

For a 1D image array, the image data specified by *host_ptr* is stored as a linear sequence of adjacent 1D images. Each 1D image is stored as a single scanline which is a linear sequence of adjacent elements.

For 1D image or 1D image buffer, the image data specified by *host_ptr* is stored as a single scanline which is a linear sequence of adjacent elements.

Image elements are stored according to their image format as described in the [Image Format Descriptor](#) section.

`clCreateImage` and `clCreateImageWithProperties` returns a valid non-zero image object and *errcode_ret* is set to `CL_SUCCESS` if the image object is created successfully. Otherwise, they return a `NULL` value with one of the following error values returned in *errcode_ret*:

- `CL_INVALID_CONTEXT` if *context* is not a valid context.
- `CL_INVALID_PROPERTY` if a property name in *properties* is not a supported property name, if the value specified for a supported property name is not valid, or if the same property name is specified more than once.
- `CL_INVALID_VALUE` if values specified in *flags* are not valid.
- `CL_INVALID_IMAGE_FORMAT_DESCRIPTOR` if values specified in *image_format* are not valid or if *image_format* is `NULL`.
- `CL_INVALID_IMAGE_FORMAT_DESCRIPTOR` if a 2D image is created from a buffer and the row pitch and

base address alignment does not follow the rules described for creating a 2D image from a buffer.

- **CL_INVALID_IMAGE_FORMAT_DESCRIPTOR** if a 2D image is created from a 2D image object and the rules described above are not followed.
- **CL_INVALID_IMAGE_DESCRIPTOR** if values specified in *image_desc* are not valid or if *image_desc* is **NULL**.
- **CL_INVALID_IMAGE_SIZE** if image dimensions specified in *image_desc* exceed the maximum image dimensions described in the [Device Queries](#) table for all devices in *context*.
- **CL_INVALID_HOST_PTR** if *host_ptr* is **NULL** and **CL_MEM_USE_HOST_PTR** or **CL_MEM_COPY_HOST_PTR** are set in *flags* or if *host_ptr* is not **NULL** but **CL_MEM_COPY_HOST_PTR** or **CL_MEM_USE_HOST_PTR** are not set in *flags*.
- **CL_INVALID_VALUE** if an image is being created from another memory object (buffer or image) under one of the following circumstances: 1) *mem_object* was created with **CL_MEM_WRITE_ONLY** and *flags* specifies **CL_MEM_READ_WRITE** or **CL_MEM_READ_ONLY**, 2) *mem_object* was created with **CL_MEM_READ_ONLY** and *flags* specifies **CL_MEM_READ_WRITE** or **CL_MEM_WRITE_ONLY**, 3) *flags* specifies **CL_MEM_USE_HOST_PTR** or **CL_MEM_ALLOC_HOST_PTR** or **CL_MEM_COPY_HOST_PTR**.
- **CL_INVALID_VALUE** if an image is being created from another memory object (buffer or image) and *mem_object* was created with **CL_MEM_HOST_WRITE_ONLY** and *flags* specifies **CL_MEM_HOST_READ_ONLY**, or if *mem_object* was created with **CL_MEM_HOST_READ_ONLY** and *flags* specifies **CL_MEM_HOST_WRITE_ONLY**, or if *mem_object* was created with **CL_MEM_HOST_NO_ACCESS** and *flags* specifies **CL_MEM_HOST_READ_ONLY** or **CL_MEM_HOST_WRITE_ONLY**.
- **CL_IMAGE_FORMAT_NOT_SUPPORTED** if there are no devices in *context* that support *image_format*.
- **CL_MEM_OBJECT_ALLOCATION_FAILURE** if there is a failure to allocate memory for image object.
- **CL_INVALID_OPERATION** if there are no devices in *context* that support images (i.e. **CL_DEVICE_IMAGE_SUPPORT** specified in the [Device Queries](#) table is **CL_FALSE**).
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

Table 15. Required *host_ptr* buffer sizes for images

Image Type	Size of buffer that <i>host_ptr</i> points to
CL_MEM_OBJECT_IMAGE1D missing before version 1.2.	$\geq \text{image_row_pitch}$
CL_MEM_OBJECT_IMAGE1D_BUFFER missing before version 1.2.	$\geq \text{image_row_pitch}$
CL_MEM_OBJECT_IMAGE2D	$\geq \text{image_row_pitch} \times \text{image_height}$
CL_MEM_OBJECT_IMAGE3D	$\geq \text{image_slice_pitch} \times \text{image_depth}$

Image Type	Size of buffer that <i>host_ptr</i> points to
CL_MEM_OBJECT_IMAGE1D_ARRAY missing before version 1.2.	$\geq \text{image_slice_pitch} \times \text{image_array_size}$
CL_MEM_OBJECT_IMAGE2D_ARRAY missing before version 1.2.	$\geq \text{image_slice_pitch} \times \text{image_array_size}$

A 2D image object can be created using the following function

```
cl_mem clCreateImage2D(
    cl_context context,
    cl_mem_flags flags,
    const cl_image_format* image_format,
    size_t image_width,
    size_t image_height,
    size_t image_row_pitch,
    void* host_ptr,
    cl_int* errcode_ret);
```



clCreateImage2D is deprecated by version 1.2.

- *context* is a valid OpenCL context on which the image object is to be created.
- *flags* is a bit-field that is used to specify allocation and usage information about the image memory object being created and is described in the [supported memory flag values](#) table. If the value specified for *flags* is 0, the default is used which is CL_MEM_READ_WRITE.
- *image_format* is a pointer to a structure that describes format properties of the image to be allocated. Refer to the [Image Format Descriptor](#) section for a detailed description of the image format descriptor.
- *image_width* and *image_height* are the width and height of the image in pixels. These must be values greater than or equal to 1.
- *image_row_pitch* is the scan-line pitch in bytes. This must be 0 if *host_ptr* is NULL and can be either 0 or $\geq \text{image_width} \times \text{size of element in bytes}$ if *host_ptr* is not NULL. If *host_ptr* is not NULL and *image_row_pitch* is 0, *image_row_pitch* is calculated as $\text{image_width} \times \text{size of element in bytes}$. If *image_row_pitch* is not 0, it must be a multiple of the image element size in bytes.
- *host_ptr* is a pointer to the image data that may already be allocated by the application. Refer to the CL_MEM_OBJECT_IMAGE2D entry in the [required host_ptr buffer size table](#) for a description of how large the buffer that *host_ptr* points to must be. The image data specified by *host_ptr* is stored as a linear sequence of adjacent scanlines. Each scanline is a linear sequence of image elements. Image elements are stored according to their image format as described in the [Image Format Descriptor](#) section.
- *errcode_ret* will return an appropriate error code. If *errcode_ret* is NULL, no error code is returned.

clCreateImage2D returns a valid non-zero image object created and the *errcode_ret* is set to **CL_SUCCESS** if the image object is created successfully. Otherwise, it returns a **NULL** value with one of the following error values returned in *errcode_ret*:

- **CL_INVALID_CONTEXT** if *context* is not a valid context.
- **CL_INVALID_VALUE** if values specified in *flags* are not valid.
- **CL_INVALID_IMAGE_FORMAT_DESCRIPTOR** if values specified in *image_format* are not valid or if *image_format* is **NULL**.
- **CL_INVALID_IMAGE_SIZE** if *image_width* or *image_height* are 0 or if they exceed the maximum values specified in **CL_DEVICE_IMAGE2D_MAX_WIDTH** or **CL_DEVICE_IMAGE2D_MAX_HEIGHT** respectively for all devices in *context* or if values specified by *image_row_pitch* do not follow rules described in the argument description above.
- **CL_INVALID_HOST_PTR** if *host_ptr* is **NULL** and **CL_MEM_USE_HOST_PTR** or **CL_MEM_COPY_HOST_PTR** are set in *flags* or if *host_ptr* is not **NULL** but **CL_MEM_COPY_HOST_PTR** or **CL_MEM_USE_HOST_PTR** are not set in *flags*.
- **CL_IMAGE_FORMAT_NOT_SUPPORTED** if there are no devices in *context* that support *image_format*.
- **CL_MEM_OBJECT_ALLOCATION_FAILURE** if there is a failure to allocate memory for image object.
- **CL_INVALID_OPERATION** if there are no devices in *context* that support images (i.e. **CL_DEVICE_IMAGE_SUPPORT** specified in the [Device Queries](#) table is **CL_FALSE**).
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

A **3D image** object can be created using the following function

```
cl_mem clCreateImage3D(
    cl_context context,
    cl_mem_flags flags,
    const cl_image_format* image_format,
    size_t image_width,
    size_t image_height,
    size_t image_depth,
    size_t image_row_pitch,
    size_t image_slice_pitch,
    void* host_ptr,
    cl_int* errcode_ret);
```



clCreateImage3D is deprecated by version 1.2.

- *context* is a valid OpenCL context on which the image object is to be created.
- *flags* is a bit-field that is used to specify allocation and usage information about the image memory object being created and is described in the [supported memory flag values](#) table. If the value specified for *flags* is 0, the default is used which is **CL_MEM_READ_WRITE**.

- *image_format* is a pointer to a structure that describes format properties of the image to be allocated. Refer to the [Image Format Descriptor](#) section for a detailed description of the image format descriptor.
- *image_width* and *image_height* are the width and height of the image in pixels. These must be values greater than or equal to 1.
- *image_depth* is the depth of the image in pixels. For [clCreateImage3D](#), this must be a value > 1 .
- *image_row_pitch* is the scan-line pitch in bytes. This must be 0 if *host_ptr* is `NULL` and can be either 0 or $\geq \text{image_width} \times \text{size of element in bytes}$ if *host_ptr* is not `NULL`. If *host_ptr* is not `NULL` and *image_row_pitch* is 0, *image_row_pitch* is calculated as $\text{image_width} \times \text{size of element in bytes}$. If *image_row_pitch* is not 0, it must be a multiple of the image element size in bytes.
- *image_slice_pitch* is the size in bytes of each 2D slice in the 3D image. This must be 0 if *host_ptr* is `NULL` and can be 0 or $\geq \text{image_row_pitch} \times \text{image_height}$ if *host_ptr* is not `NULL`. If *host_ptr* is not `NULL` and *image_slice_pitch* is 0, *image_slice_pitch* is calculated as $\text{image_row_pitch} \times \text{image_height}$. If *image_slice_pitch* is not 0, it must be a multiple of the *image_row_pitch*.
- *host_ptr* is a pointer to the image data that may already be allocated by the application. Refer to the `CL_MEM_OBJECT_IMAGE3D` entry in the [required *host_ptr* buffer size table](#) for a description of how large the buffer that *host_ptr* points to must be. The image data specified by *host_ptr* is stored as a linear sequence of adjacent 2D slices. Each scanline is a linear sequence of image elements. Image elements are stored according to their image format as described in the [Image Format Descriptor](#) section.
- *errcode_ret* will return an appropriate error code. If *errcode_ret* is `NULL`, no error code is returned.

[clCreateImage3D](#) returns a valid non-zero image object created and the *errcode_ret* is set to `CL_SUCCESS` if the image object is created successfully. Otherwise, it returns a `NULL` value with one of the following error values returned in *errcode_ret*:

- `CL_INVALID_CONTEXT` if *context* is not a valid context.
- `CL_INVALID_VALUE` if values specified in *flags* are not valid.
- `CL_INVALID_IMAGE_FORMAT_DESCRIPTOR` if values specified in *image_format* are not valid or if *image_format* is `NULL`.
- `CL_INVALID_IMAGE_SIZE` if *image_width* or *image_height* are 0 or if $\text{image_depth} \leq 1$, or if they exceed the maximum values specified in `CL_DEVICE_IMAGE3D_MAX_WIDTH`, `CL_DEVICE_IMAGE3D_MAX_HEIGHT` or `CL_DEVICE_IMAGE3D_MAX_DEPTH` respectively for all devices in *context*, or if values specified by *image_row_pitch* and *image_slice_pitch* do not follow rules described in the argument description above.
- `CL_INVALID_HOST_PTR` if *host_ptr* is `NULL` and `CL_MEM_USE_HOST_PTR` or `CL_MEM_COPY_HOST_PTR` are set in *flags* or if *host_ptr* is not `NULL` but `CL_MEM_COPY_HOST_PTR` or `CL_MEM_USE_HOST_PTR` are not set in *flags*.
- `CL_IMAGE_FORMAT_NOT_SUPPORTED` if there are no devices in *context* that support *image_format*.
- `CL_MEM_OBJECT_ALLOCATION_FAILURE` if there is a failure to allocate memory for image object.
- `CL_INVALID_OPERATION` if there are no devices in *context* that support images (i.e. `CL_DEVICE_IMAGE_SUPPORT` specified in the [Device Queries](#) table is `CL_FALSE`).

- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

5.3.1.1. Image Format Descriptor

The **cl_image_format** image format descriptor structure describes an image format, and is defined as:

```
typedef struct cl_image_format {
    cl_channel_order    image_channel_order;
    cl_channel_type     image_channel_data_type;
} cl_image_format;
```

- **image_channel_order** specifies the number of channels and the channel layout i.e. the memory layout in which channels are stored in the image. Valid values are described in the [Image Channel Order](#) table.
- **image_channel_data_type** describes the size of the channel data type. The list of supported values is described in the [Image Channel Data Types](#) table. The number of bits per element determined by the **image_channel_data_type** and **image_channel_order** must be a power of two.

Table 16. List of supported Image Channel Order Values

Image Channel Order	Description
CL_R, CL_A,	Single channel image formats where the single channel represents a RED or ALPHA component.
CL_DEPTH missing before version 2.0.	A single channel image format where the single channel represents a DEPTH component.
CL_LUMINANCE	A single channel image format where the single channel represents a LUMINANCE value. The LUMINANCE value is replicated into the RED , GREEN , and BLUE components.
CL_INTENSITY,	A single channel image format where the single channel represents an INTENSITY value. The INTENSITY value is replicated into the RED , GREEN , BLUE , and ALPHA components.
CL_RG, CL_RA	Two channel image formats. The first channel always represents a RED component. The second channel represents a GREEN component or an ALPHA component.
CL_Rx missing before version 1.1.	A two channel image format, where the first channel represents a RED component and the second channel is ignored.

Image Channel Order	Description
CL_RGB	A three channel image format, where the three channels represent RED, GREEN, and BLUE components.
CL_RGx missing before version 1.1.	A three channel image format, where the first two channels represent RED and GREEN components and the third channel is ignored.
CL_RGBA, CL_ARGB, CL_BGRA, CL_ABGR CL_ABGR is missing before version 2.0.	Four channel image formats, where the four channels represent RED, GREEN, BLUE, and ALPHA components.
CL_RGBx missing before version 1.1.	A four channel image format, where the first three channels represent RED, GREEN, and BLUE components and the fourth channel is ignored.
CL_sRGB missing before version 2.0.	A three channel image format, where the three channels represent RED, GREEN, and BLUE components in the sRGB color space.
CL_sRGBA, CL_sBGRA missing before version 2.0.	Four channel image formats, where the first three channels represent RED, GREEN, and BLUE components in the sRGB color space. The fourth channel represents an ALPHA component.
CL_sRGBx missing before version 2.0.	A four channel image format, where the three channels represent RED, GREEN, and BLUE components in the sRGB color space. The fourth channel is ignored.

Table 17. List of supported Image Channel Data Types

Image Channel Data Type	Description
CL_SNORM_INT8	Each channel component is a normalized signed 8-bit integer value
CL_SNORM_INT16	Each channel component is a normalized signed 16-bit integer value
CL_UNORM_INT8	Each channel component is a normalized unsigned 8-bit integer value
CL_UNORM_INT16	Each channel component is a normalized unsigned 16-bit integer value
CL_UNORM_SHORT_565	Represents a normalized 5-6-5 3-channel RGB image. The channel order must be CL_RGB or CL_RGBx.
CL_UNORM_SHORT_555	Represents a normalized x-5-5-5 4-channel xRGB image. The channel order must be CL_RGB or CL_RGBx.

Image Channel Data Type	Description
CL_UNORM_INT_101010	Represents a normalized x-10-10-10 4-channel xRGB image. The channel order must be CL_RGB or CL_RGBx.
CL_UNORM_INT_101010_2	Represents a normalized 10-10-10-2 four-channel RGBA image. The channel order must be CL_RGBA.
CL_SIGNED_INT8	Each channel component is an unnormalized signed 8-bit integer value
CL_SIGNED_INT16	Each channel component is an unnormalized signed 16-bit integer value
CL_SIGNED_INT32	Each channel component is an unnormalized signed 32-bit integer value
CL_UNSIGNED_INT8	Each channel component is an unnormalized unsigned 8-bit integer value
CL_UNSIGNED_INT16	Each channel component is an unnormalized unsigned 16-bit integer value
CL_UNSIGNED_INT32	Each channel component is an unnormalized unsigned 32-bit integer value
CL_HALF_FLOAT	Each channel component is a 16-bit half-float value
CL_FLOAT	Each channel component is a single precision floating-point value

For example, to specify a normalized unsigned 8-bit / channel RGBA image, `image_channel_order = CL_RGBA`, and `image_channel_data_type = CL_UNORM_INT8`. The memory layout of this image format is described below:

R	G	B	A	...
---	---	---	---	-----

with the corresponding byte offsets

0	1	2	3	...
---	---	---	---	-----

Similar, if `image_channel_order = CL_RGBA` and `image_channel_data_type = CL_SIGNED_INT16`, the memory layout of this image format is described below:

R	G	B	A	...
---	---	---	---	-----

with the corresponding byte offsets

0	2	4	6	...
---	---	---	---	-----

`image_channel_data_type` values of `CL_UNORM_SHORT_565`, `CL_UNORM_SHORT_555`, `CL_UNORM_INT_101010`, and

`CL_UNORM_INT_101010_2` are special cases of packed image formats where the channels of each element are packed into a single unsigned short or unsigned int. For these special packed image formats, the channels are normally packed with the first channel in the most significant bits of the bitfield, and successive channels occupying progressively less significant locations. For `CL_UNORM_SHORT_565`, R is in bits 15:11, G is in bits 10:5 and B is in bits 4:0. For `CL_UNORM_SHORT_555`, bit 15 is undefined, R is in bits 14:10, G in bits 9:5 and B in bits 4:0. For `CL_UNORM_INT_101010`, bits 31:30 are undefined, R is in bits 29:20, G in bits 19:10 and B in bits 9:0. For `CL_UNORM_INT_101010_2`, R is in bits 31:22, G in bits 21:12, B in bits 11:2 and A in bits 1:0.

OpenCL implementations must maintain the minimum precision specified by the number of bits in `image_channel_data_type`. If the image format specified by `image_channel_order`, and `image_channel_data_type` cannot be supported by the OpenCL implementation, then the call to `clCreateImage`, `clCreateImageWithProperties`, `clCreateImage2D`, or `clCreateImage3D` will return a `NULL` memory object.

5.3.1.2. Image Descriptor

The `cl_image_desc` image descriptor structure describes the image type and dimensions of an image or image array when creating an image using `clCreateImage` or `clCreateImageWithProperties`, and is defined as:

```
typedef struct cl_image_desc {
    cl_mem_object_type    image_type;
    size_t                image_width;
    size_t                image_height;
    size_t                image_depth;
    size_t                image_array_size;
    size_t                image_row_pitch;
    size_t                image_slice_pitch;
    cl_uint               num_mip_levels;
    cl_uint               num_samples;
    union {
        cl_mem buffer;
        cl_mem mem_object;
    };
} cl_image_desc;
```

- `image_type` describes the image type and must be either `CL_MEM_OBJECT_IMAGE1D`, `CL_MEM_OBJECT_IMAGE1D_BUFFER`, `CL_MEM_OBJECT_IMAGE1D_ARRAY`, `CL_MEM_OBJECT_IMAGE2D`, `CL_MEM_OBJECT_IMAGE2D_ARRAY`, or `CL_MEM_OBJECT_IMAGE3D`.
- `image_width` is the width of the image in pixels. For a 2D image and image array, the image width must be a value ≥ 1 and $\leq \text{CL_DEVICE_IMAGE2D_MAX_WIDTH}$. For a 3D image, the image width must be a value ≥ 1 and $\leq \text{CL_DEVICE_IMAGE3D_MAX_WIDTH}$. For a 1D image buffer, the image width must be a value ≥ 1 and $\leq \text{CL_DEVICE_IMAGE_MAX_BUFFER_SIZE}$. For a 1D image and 1D image array, the image width must be a value ≥ 1 and $\leq \text{CL_DEVICE_IMAGE2D_MAX_WIDTH}$.
- `image_height` is the height of the image in pixels. This is only used if the image is a 2D or 3D image, or a 2D image array. For a 2D image or image array, the image height must be a value ≥ 1

and \leq `CL_DEVICE_IMAGE2D_MAX_HEIGHT`. For a 3D image, the image height must be a value ≥ 1 and \leq `CL_DEVICE_IMAGE3D_MAX_HEIGHT`.

- `image_depth` is the depth of the image in pixels. This is only used if the image is a 3D image and must be a value ≥ 1 and \leq `CL_DEVICE_IMAGE3D_MAX_DEPTH`.
- `image_array_size` ^[4] is the number of images in the image array. This is only used if the image is a 1D or 2D image array. The values for `image_array_size`, if specified, must be a value ≥ 1 and \leq `CL_DEVICE_IMAGE_MAX_ARRAY_SIZE`.
- `image_row_pitch` is the scan-line pitch in bytes. This must be 0 if `host_ptr` is `NULL` and can be either 0 or \geq `image_width` \times size of element in bytes if `host_ptr` is not `NULL`. If `host_ptr` is not `NULL` and `image_row_pitch` = 0, `image_row_pitch` is calculated as `image_width` \times size of element in bytes. If `image_row_pitch` is not 0, it must be a multiple of the image element size in bytes. For a 2D image created from a buffer, the pitch specified (or computed if pitch specified is 0) must be a multiple of the maximum of the `CL_DEVICE_IMAGE_PITCH_ALIGNMENT` value for all devices in the context associated with the buffer specified by `mem_object` that support images.
- `image_slice_pitch` is the size in bytes of each 2D slice in the 3D image or the size in bytes of each image in a 1D or 2D image array. This must be 0 if `host_ptr` is `NULL`. If `host_ptr` is not `NULL`, `image_slice_pitch` can be either 0 or \geq `image_row_pitch` \times `image_height` for a 2D image array or 3D image and can be either 0 or \geq `image_row_pitch` for a 1D image array. If `host_ptr` is not `NULL` and `image_slice_pitch` = 0, `image_slice_pitch` is calculated as `image_row_pitch` \times `image_height` for a 2D image array or 3D image and `image_row_pitch` for a 1D image array. If `image_slice_pitch` is not 0, it must be a multiple of the `image_row_pitch`.
- `num_mip_levels` and `num_samples` must be 0.
- `mem_object` may refer to a valid buffer or image memory object. `mem_object` can be a buffer memory object if `image_type` is `CL_MEM_OBJECT_IMAGE1D_BUFFER` or `CL_MEM_OBJECT_IMAGE2D` ^[5]. `mem_object` can be an image object if `image_type` is `CL_MEM_OBJECT_IMAGE2D` ^[6]. Otherwise it must be `NULL`. The image pixels are taken from the memory objects data store. When the contents of the specified memory objects data store are modified, those changes are reflected in the contents of the image object and vice-versa at corresponding synchronization points.

For a 1D image buffer created from a buffer object, the `image_width` \times size of element in bytes must be \leq size of the buffer object. The image data in the buffer object is stored as a single scanline which is a linear sequence of adjacent elements.

For a 2D image created from a buffer object, the `image_row_pitch` \times `image_height` must be \leq size of the buffer object specified by `mem_object`. The image data in the buffer object is stored as a linear sequence of adjacent scanlines. Each scanline is a linear sequence of image elements padded to `image_row_pitch` bytes.

For an image object created from another image object, the values specified in the image descriptor except for `mem_object` must match the image descriptor information associated with `mem_object`.

Image elements are stored according to their image format as described in [Image Format Descriptor](#).

If the buffer object specified by `mem_object` was created with `CL_MEM_USE_HOST_PTR`, the `host_ptr` specified to `clCreateBuffer` or `clCreateBufferWithProperties` must be aligned to the maximum of

the `CL_DEVICE_IMAGE_BASE_ADDRESS_ALIGNMENT` value for all devices in the context associated with the buffer specified by `mem_object` that support images.

Creating a 2D image object from another 2D image object creates a new 2D image object that shares the image data store with `mem_object` but views the pixels in the image with a different image channel order. Restrictions are:

- All of the values specified in `image_desc` must match the image descriptor information associated with `mem_object`, except for `mem_object`.
- The image channel data type specified in `image_format` must match the image channel data type associated with `mem_object`.
- The image channel order specified in `image_format` must be compatible with the image channel order associated with `mem_object`. Compatible image channel orders ^[7] are:

Image Channel Order in <code>image_format</code> :	Image Channel Order associated with <code>mem_object</code> :
<code>CL_sBGRA</code>	<code>CL_BGRA</code>
<code>CL_BGRA</code>	<code>CL_sBGRA</code>
<code>CL_sRGBA</code>	<code>CL_RGBA</code>
<code>CL_RGBA</code>	<code>CL_sRGBA</code>
<code>CL_sRGB</code>	<code>CL_RGB</code>
<code>CL_RGB</code>	<code>CL_sRGB</code>
<code>CL_sRGBx</code>	<code>CL_RGBx</code>
<code>CL_RGBx</code>	<code>CL_sRGBx</code>
<code>CL_DEPTH</code>	<code>CL_R</code>



Concurrent reading from, writing to and copying between both a buffer object and 1D image buffer or 2D image object associated with the buffer object is undefined. Only reading from both a buffer object and 1D image buffer or 2D image object associated with the buffer object is defined.

Writing to an image created from a buffer and then reading from this buffer in a kernel even if appropriate synchronization operations (such as a barrier) are performed between the writes and reads is undefined. Similarly, writing to the buffer and reading from the image created from this buffer with appropriate synchronization between the writes and reads is undefined.

5.3.2. Querying List of Supported Image Formats

To get the list of image formats supported by an OpenCL implementation for a specified context, image type, and allocation information, call the function

```

cl_int clGetSupportedImageFormats(
    cl_context context,
    cl_mem_flags flags,
    cl_mem_object_type image_type,
    cl_uint num_entries,
    cl_image_format* image_formats,
    cl_uint* num_image_formats);

```

- *context* is a valid OpenCL context on which the image object(s) will be created.
- *flags* is a bit-field that is used to specify usage information about the image formats being queried and is described in the [Memory Flags](#) table. *flags* may be `CL_MEM_READ_WRITE` to query image formats that may be read from and written to by different kernel instances when correctly ordered by event dependencies, or `CL_MEM_READ_ONLY` to query image formats that may be read from by a kernel, or `CL_MEM_WRITE_ONLY` to query image formats that may be written to by a kernel, or `CL_MEM_KERNEL_READ_AND_WRITE` to query image formats that may be both read from and written to by the same kernel instance. Please see [Image Format Mapping](#) for clarification.
- *image_type* describes the image type and must be either `CL_MEM_OBJECT_IMAGE1D`, `CL_MEM_OBJECT_IMAGE1D_BUFFER`, `CL_MEM_OBJECT_IMAGE2D`, `CL_MEM_OBJECT_IMAGE3D`, `CL_MEM_OBJECT_IMAGE1D_ARRAY`, or `CL_MEM_OBJECT_IMAGE2D_ARRAY`.
- *num_entries* specifies the number of entries that can be returned in the memory location given by *image_formats*.
- *image_formats* is a pointer to a memory location where the list of supported image formats are returned. Each entry describes a `cl_image_format` structure supported by the OpenCL implementation. If *image_formats* is `NULL`, it is ignored.
- *num_image_formats* is the actual number of supported image formats for a specific *context* and values specified by *flags*. If *num_image_formats* is `NULL`, it is ignored.

clGetSupportedImageFormats returns a union of image formats supported by all devices in the context.

clGetSupportedImageFormats returns `CL_SUCCESS` if the function is executed successfully. Otherwise, it returns one of the following errors:

- `CL_INVALID_CONTEXT` if *context* is not a valid context.
- `CL_INVALID_VALUE` if *flags* or *image_type* are not valid, or if *num_entries* is 0 and *image_formats* is not `NULL`.
- `CL_OUT_OF_RESOURCES` if there is a failure to allocate resources required by the OpenCL implementation on the device.
- `CL_OUT_OF_HOST_MEMORY` if there is a failure to allocate resources required by the OpenCL implementation on the host.

If `CL_DEVICE_IMAGE_SUPPORT` specified in the [Device Queries](#) table is `CL_TRUE`, the values assigned to `CL_DEVICE_MAX_READ_IMAGE_ARGS`, `CL_DEVICE_MAX_WRITE_IMAGE_ARGS`, `CL_DEVICE_IMAGE2D_MAX_WIDTH`, `CL_DEVICE_IMAGE2D_MAX_HEIGHT`, `CL_DEVICE_IMAGE3D_MAX_WIDTH`, `CL_DEVICE_IMAGE3D_MAX_HEIGHT`, `CL_DEVICE_IMAGE3D_MAX_DEPTH`, and `CL_DEVICE_MAX_SAMPLERS` by the implementation must be greater

than or equal to the minimum values specified in the [Device Queries](#) table.

5.3.2.1. Minimum List of Supported Image Formats

The tables below describe the required minimum lists of supported image formats. To query all image formats supported by an implementation, call the function [clGetSupportedImageFormats](#).

For full profile devices supporting OpenCL 2.0, 2.1, or 2.2, the minimum list of supported image formats for either reading or writing in a kernel is:

Table 18. Minimum list of supported image formats for reading or writing (OpenCL 2.0, 2.1, or 2.2)

num_channels	channel_order	channel_data_type
1	CL_R	CL_UNORM_INT8 CL_UNORM_INT16 CL_SNORM_INT8 CL_SNORM_INT16 CL_SIGNED_INT8 CL_SIGNED_INT16 CL_SIGNED_INT32 CL_UNSIGNED_INT8 CL_UNSIGNED_INT16 CL_UNSIGNED_INT32 CL_HALF_FLOAT CL_FLOAT
1	CL_DEPTH ^[8]	CL_UNORM_INT16 CL_FLOAT
2	CL_RG	CL_UNORM_INT8 CL_UNORM_INT16 CL_SNORM_INT8 CL_SNORM_INT16 CL_SIGNED_INT8 CL_SIGNED_INT16 CL_SIGNED_INT32 CL_UNSIGNED_INT8 CL_UNSIGNED_INT16 CL_UNSIGNED_INT32 CL_HALF_FLOAT CL_FLOAT

num_channels	channel_order	channel_data_type
4	CL_RGBA	CL_UNORM_INT8 CL_UNORM_INT16 CL_SNORM_INT8 CL_SNORM_INT16 CL_SIGNED_INT8 CL_SIGNED_INT16 CL_SIGNED_INT32 CL_UNSIGNED_INT8 CL_UNSIGNED_INT16 CL_UNSIGNED_INT32 CL_HALF_FLOAT CL_FLOAT
4	CL_BGRA	CL_UNORM_INT8
4	CL_sRGBA ^[9]	CL_UNORM_INT8

For full profile devices supporting other OpenCL versions, such as OpenCL 1.2 or OpenCL 3.0, the minimum list of supported image formats for either reading or writing in a kernel is:

Table 19. Minimum list of required image formats for reading or writing

num_channels	channel_order	channel_data_type
4	CL_RGBA	CL_UNORM_INT8 CL_UNORM_INT16 CL_SIGNED_INT8 CL_SIGNED_INT16 CL_SIGNED_INT32 CL_UNSIGNED_INT8 CL_UNSIGNED_INT16 CL_UNSIGNED_INT32 CL_HALF_FLOAT CL_FLOAT
4	CL_BGRA	CL_UNORM_INT8

For full profile devices that support reading from and writing to the same image object from the same kernel instance (see `CL_DEVICE_MAX_READ_WRITE_IMAGE_ARGS`), the minimum list of supported image formats for reading and writing in the same kernel instance is:

Table 20. Minimum list of required image formats for reading and writing

num_channels	channel_order	channel_data_type
1	CL_R	CL_UNORM_INT8 CL_SIGNED_INT8 CL_SIGNED_INT16 CL_SIGNED_INT32 CL_UNSIGNED_INT8 CL_UNSIGNED_INT16 CL_UNSIGNED_INT32 CL_HALF_FLOAT CL_FLOAT
4	CL_RGBA	CL_UNORM_INT8 CL_SIGNED_INT8 CL_SIGNED_INT16 CL_SIGNED_INT32 CL_UNSIGNED_INT8 CL_UNSIGNED_INT16 CL_UNSIGNED_INT32 CL_HALF_FLOAT CL_FLOAT

5.3.2.2. Image format mapping to OpenCL kernel language image access qualifiers

Image arguments to kernels may have the `read_only`, `write_only` or `read_write` qualifier. Not all image formats supported by the device and platform are valid to be passed to all of these access qualifiers. For each access qualifier, only images whose format is in the list of formats returned by `clGetSupportedImageFormats` with the given flag arguments in the [Image Format Mapping](#) table are permitted. It is not valid to pass an image supporting writing as both a `read_only` image and a `write_only` image parameter, or to a `read_write` image parameter and any other image parameter.

Table 21. Mapping from format flags passed to `clGetSupportedImageFormats` to OpenCL kernel language image access qualifiers

Access Qualifier	Memory Flags
<code>read_only</code>	CL_MEM_READ_ONLY, CL_MEM_READ_WRITE, CL_MEM_KERNEL_READ_AND_WRITE
<code>write_only</code>	CL_MEM_WRITE_ONLY, CL_MEM_READ_WRITE, CL_MEM_KERNEL_READ_AND_WRITE
<code>read_write</code>	CL_MEM_KERNEL_READ_AND_WRITE

5.3.3. Reading, Writing and Copying Image Objects

The following functions enqueue commands to read from an image or image array object to host memory or write to an image or image array object from host memory.


```

cl_int clEnqueueReadImage(
    cl_command_queue command_queue,
    cl_mem image,
    cl_bool blocking_read,
    const size_t* origin,
    const size_t* region,
    size_t row_pitch,
    size_t slice_pitch,
    void* ptr,
    cl_uint num_events_in_wait_list,
    const cl_event* event_wait_list,
    cl_event* event);

```

```

cl_int clEnqueueWriteImage(
    cl_command_queue command_queue,
    cl_mem image,
    cl_bool blocking_write,
    const size_t* origin,
    const size_t* region,
    size_t input_row_pitch,
    size_t input_slice_pitch,
    const void* ptr,
    cl_uint num_events_in_wait_list,
    const cl_event* event_wait_list,
    cl_event* event);

```

- *command_queue* refers to the host command-queue in which the read / write command will be queued. *command_queue* and *image* must be created with the same OpenCL context.
- *image* refers to a valid image or image array object.
- *blocking_read* and *blocking_write* indicate if the read and write operations are *blocking* or *non-blocking*.
- *origin* defines the (x, y, z) offset in pixels in the 1D, 2D or 3D image, the (x, y) offset and the image index in the 2D image array or the (x) offset and the image index in the 1D image array. If *image* is a 2D image object, *origin*[2] must be 0. If *image* is a 1D image or 1D image buffer object, *origin*[1] and *origin*[2] must be 0. If *image* is a 1D image array object, *origin*[2] must be 0. If *image* is a 1D image array object, *origin*[1] describes the image index in the 1D image array. If *image* is a 2D image array object, *origin*[2] describes the image index in the 2D image array.
- *region* defines the (*width*, *height*, *depth*) in pixels of the 1D, 2D or 3D rectangle, the (*width*, *height*) in pixels of the 2D rectangle and the number of images of a 2D image array or the (*width*) in pixels of the 1D rectangle and the number of images of a 1D image array. If *image* is a 2D image object, *region*[2] must be 1. If *image* is a 1D image or 1D image buffer object, *region*[1] and *region*[2] must be 1. If *image* is a 1D image array object, *region*[2] must be 1. The values in *region* cannot be 0.
- *row_pitch* in **clEnqueueReadImage** and *input_row_pitch* in **clEnqueueWriteImage** is the length of each row in bytes. This value must be greater than or equal to the element size in

bytes \times width. If *row_pitch* (or *input_row_pitch*) is set to 0, the appropriate row pitch is calculated based on the size of each element in bytes multiplied by *width*.

- *slice_pitch* in **clEnqueueReadImage** and *input_slice_pitch* in **clEnqueueWriteImage** is the size in bytes of the 2D slice of the 3D region of a 3D image or each image of a 1D or 2D image array being read or written respectively. This must be 0 if *image* is a 1D or 2D image. Otherwise this value must be greater than or equal to *row_pitch* \times *height*. If *slice_pitch* (or *input_slice_pitch*) is set to 0, the appropriate slice pitch is calculated based on the *row_pitch* \times *height*.
- *ptr* is the pointer to a buffer in host memory where image data is to be read from or to be written to. The alignment requirements for *ptr* are specified in [Alignment of Application Data Types](#).
- *event_wait_list* and *num_events_in_wait_list* specify events that need to complete before this particular command can be executed. If *event_wait_list* is **NULL**, then this particular command does not wait on any event to complete. If *event_wait_list* is **NULL**, *num_events_in_wait_list* must be 0. If *event_wait_list* is not **NULL**, the list of events pointed to by *event_wait_list* must be valid and *num_events_in_wait_list* must be greater than 0. The events specified in *event_wait_list* act as synchronization points. The context associated with events in *event_wait_list* and *command_queue* must be the same. The memory associated with *event_wait_list* can be reused or freed after the function returns.
- *event* returns an event object that identifies this read / write command and can be used to query or queue a wait for this command to complete. If *event* is **NULL** or the enqueue is unsuccessful, no event will be created and therefore it will not be possible to query the status of this command or to wait for this command to complete. If *event_wait_list* and *event* are not **NULL**, *event* must not refer to an element of the *event_wait_list* array.

If *blocking_read* is **CL_TRUE** i.e. the read command is blocking, **clEnqueueReadImage** does not return until the buffer data has been read and copied into memory pointed to by *ptr*.

If *blocking_read* is **CL_FALSE** i.e. the read command is non-blocking, **clEnqueueReadImage** queues a non-blocking read command and returns. The contents of the buffer that *ptr* points to cannot be used until the read command has completed. The *event* argument returns an event object which can be used to query the execution status of the read command. When the read command has completed, the contents of the buffer that *ptr* points to can be used by the application.

If *blocking_write* is **CL_TRUE**, the write command is blocking and does not return until the command is complete, including transfer of the data. The memory pointed to by *ptr* can be reused by the application after the **clEnqueueWriteImage** call returns.

If *blocking_write* is **CL_FALSE**, the OpenCL implementation will use *ptr* to perform a non-blocking write. As the write is non-blocking the implementation can return immediately. The memory pointed to by *ptr* cannot be reused by the application after the call returns. The *event* argument returns an event object which can be used to query the execution status of the write command. When the write command has completed, the memory pointed to by *ptr* can then be reused by the application.

clEnqueueReadImage and **clEnqueueWriteImage** return **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_COMMAND_QUEUE** if *command_queue* is not a valid host command-queue.
- **CL_INVALID_CONTEXT** if the context associated with *command_queue* and *image* are not the same or if the context associated with *command_queue* and events in *event_wait_list* are not the same.
- **CL_INVALID_MEM_OBJECT** if *image* is not a valid image object.
- **CL_INVALID_VALUE** if *origin* or *region* is **NULL**.
- **CL_INVALID_VALUE** if the region being read or written specified by *origin* and *region* is out of bounds.
- **CL_INVALID_VALUE** if values in *origin* and *region* do not follow rules described in the argument description for *origin* and *region*.
- **CL_INVALID_VALUE** if *image* is a 1D or 2D image and *slice_pitch* or *input_slice_pitch* is not 0.
- **CL_INVALID_VALUE** if *ptr* is **NULL**.
- **CL_INVALID_EVENT_WAIT_LIST** if *event_wait_list* is **NULL** and *num_events_in_wait_list* > 0, or *event_wait_list* is not **NULL** and *num_events_in_wait_list* is 0, or if event objects in *event_wait_list* are not valid events.
- **CL_INVALID_IMAGE_SIZE** if image dimensions (image width, height, specified or compute row and/or slice pitch) for *image* are not supported by device associated with *queue*.
- **CL_IMAGE_FORMAT_NOT_SUPPORTED** if image format (image channel order and data type) for *image* are not supported by device associated with *queue*.
- **CL_MEM_OBJECT_ALLOCATION_FAILURE** if there is a failure to allocate memory for data store associated with *image*.
- **CL_INVALID_OPERATION** if the device associated with *command_queue* does not support images (i.e. **CL_DEVICE_IMAGE_SUPPORT** specified in the [Device Queries](#) table is **CL_FALSE**).
- **CL_INVALID_OPERATION** if **clEnqueueReadImage** is called on *image* which has been created with **CL_MEM_HOST_WRITE_ONLY** or **CL_MEM_HOST_NO_ACCESS**.
- **CL_INVALID_OPERATION** if **clEnqueueWriteImage** is called on *image* which has been created with **CL_MEM_HOST_READ_ONLY** or **CL_MEM_HOST_NO_ACCESS**.
- **CL_EXEC_STATUS_ERROR_FOR_EVENTS_IN_WAIT_LIST** if the read and write operations are blocking and the execution status of any of the events in *event_wait_list* is a negative integer value. This error code is [missing before](#) version 1.1.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.



Calling **clEnqueueReadImage** to read a region of the *image* with the *ptr* argument value set to $host_ptr + (origin[2] \times image\ slice\ pitch + origin[1] \times image\ row\ pitch + origin[0] \times bytes\ per\ pixel)$, where *host_ptr* is a pointer to the memory region specified when the *image* being read is created with **CL_MEM_USE_HOST_PTR**, must meet the following requirements in order to avoid undefined behavior:

- All commands that use this image object have finished execution before the

read command begins execution.

- The *row_pitch* and *slice_pitch* argument values in **clEnqueueReadImage** must be set to the image row pitch and slice pitch.
- The image object is not mapped.
- The image object is not used by any command-queue until the read command has finished execution.

Calling **clEnqueueWriteImage** to update the latest bits in a region of the *image* with the *ptr* argument value set to $host_ptr + (origin[2] \times image\ slice\ pitch + origin[1] \times image\ row\ pitch + origin[0] \times bytes\ per\ pixel)$, where *host_ptr* is a pointer to the memory region specified when the *image* being written is created with **CL_MEM_USE_HOST_PTR**, must meet the following requirements in order to avoid undefined behavior:

- The host memory region being written contains the latest bits when the enqueued write command begins execution.
- The *input_row_pitch* and *input_slice_pitch* argument values in **clEnqueueWriteImage** must be set to the image row pitch and slice pitch.
- The image object is not mapped.
- The image object is not used by any command-queue until the write command has finished execution.

To enqueue a command to copy image objects, call the function

```
cl_int clEnqueueCopyImage(  
    cl_command_queue command_queue,  
    cl_mem src_image,  
    cl_mem dst_image,  
    const size_t* src_origin,  
    const size_t* dst_origin,  
    const size_t* region,  
    cl_uint num_events_in_wait_list,  
    const cl_event* event_wait_list,  
    cl_event* event);
```

- *src_image* and *dst_image* can be 1D, 2D, 3D image or a 1D, 2D image array objects. It is possible to copy subregions between any combinations of source and destination types, provided that the dimensions of the subregions are the same e.g., one can copy a rectangular region from a 2D image to a slice of a 3D image.
- *command_queue* refers to the host command-queue in which the copy command will be queued. The OpenCL context associated with *command_queue*, *src_image* and *dst_image* must be the same.
- *src_origin* defines the (x, y, z) offset in pixels in the 1D, 2D or 3D image, the (x, y) offset and the image index in the 2D image array or the (x) offset and the image index in the 1D image array. If *image* is a 2D image object, *src_origin*[2] must be 0. If *src_image* is a 1D image object,

src_origin[1] and *src_origin[2]* must be 0. If *src_image* is a 1D image array object, *src_origin[2]* must be 0. If *src_image* is a 1D image array object, *src_origin[1]* describes the image index in the 1D image array. If *src_image* is a 2D image array object, *src_origin[2]* describes the image index in the 2D image array.

- *dst_origin* defines the (x, y, z) offset in pixels in the 1D, 2D or 3D image, the (x, y) offset and the image index in the 2D image array or the (x) offset and the image index in the 1D image array. If *dst_image* is a 2D image object, *dst_origin[2]* must be 0. If *dst_image* is a 1D image or 1D image buffer object, *dst_origin[1]* and *dst_origin[2]* must be 0. If *dst_image* is a 1D image array object, *dst_origin[2]* must be 0. If *dst_image* is a 1D image array object, *dst_origin[1]* describes the image index in the 1D image array. If *dst_image* is a 2D image array object, *dst_origin[2]* describes the image index in the 2D image array.
- *region* defines the (width, height, depth) in pixels of the 1D, 2D or 3D rectangle, the (width, height) in pixels of the 2D rectangle and the number of images of a 2D image array or the (width) in pixels of the 1D rectangle and the number of images of a 1D image array. If *src_image* or *dst_image* is a 2D image object, *region[2]* must be 1. If *src_image* or *dst_image* is a 1D image or 1D image buffer object, *region[1]* and *region[2]* must be 1. If *src_image* or *dst_image* is a 1D image array object, *region[2]* must be 1. The values in *region* cannot be 0.
- *event_wait_list* and *num_events_in_wait_list* specify events that need to complete before this particular command can be executed. If *event_wait_list* is **NULL**, then this particular command does not wait on any event to complete. If *event_wait_list* is **NULL**, *num_events_in_wait_list* must be 0. If *event_wait_list* is not **NULL**, the list of events pointed to by *event_wait_list* must be valid and *num_events_in_wait_list* must be greater than 0. The events specified in *event_wait_list* act as synchronization points. The context associated with events in *event_wait_list* and *command_queue* must be the same. The memory associated with *event_wait_list* can be reused or freed after the function returns.
- *event* returns an event object that identifies this copy command and can be used to query or queue a wait for this command to complete. If *event* is **NULL** or the enqueue is unsuccessful, no event will be created and therefore it will not be possible to query the status of this command or to wait for this command to complete. If *event_wait_list* and *event* are not **NULL**, *event* must not refer to an element of the *event_wait_list* array.

It is currently a requirement that the *src_image* and *dst_image* image memory objects for **clEnqueueCopyImage** must have the exact same image format (i.e. the **cl_image_format** descriptor specified when *src_image* and *dst_image* are created must match).

clEnqueueCopyImage returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_COMMAND_QUEUE** if *command_queue* is not a valid host command-queue.
- **CL_INVALID_CONTEXT** if the context associated with *command_queue*, *src_image* and *dst_image* are not the same or if the context associated with *command_queue* and events in *event_wait_list* are not the same.
- **CL_INVALID_MEM_OBJECT** if *src_image* and *dst_image* are not valid image objects.
- **CL_IMAGE_FORMAT_MISMATCH** if *src_image* and *dst_image* do not use the same image format.
- **CL_INVALID_VALUE** if *src_origin*, *dst_origin*, or *region* is **NULL**.

- **CL_INVALID_VALUE** if the 2D or 3D rectangular region specified by *src_origin* and *src_origin + region* refers to a region outside *src_image*, or if the 2D or 3D rectangular region specified by *dst_origin* and *dst_origin + region* refers to a region outside *dst_image*.
- **CL_INVALID_VALUE** if values in *src_origin*, *dst_origin* and *region* do not follow rules described in the argument description for *src_origin*, *dst_origin* and *region*.
- **CL_INVALID_EVENT_WAIT_LIST** if *event_wait_list* is **NULL** and *num_events_in_wait_list* > 0, or *event_wait_list* is not **NULL** and *num_events_in_wait_list* is 0, or if event objects in *event_wait_list* are not valid events.
- **CL_INVALID_IMAGE_SIZE** if image dimensions (image width, height, specified or compute row and/or slice pitch) for *src_image* or *dst_image* are not supported by device associated with *queue*.
- **CL_IMAGE_FORMAT_NOT_SUPPORTED** if image format (image channel order and data type) for *src_image* or *dst_image* are not supported by device associated with *queue*.
- **CL_MEM_OBJECT_ALLOCATION_FAILURE** if there is a failure to allocate memory for data store associated with *src_image* or *dst_image*.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.
- **CL_INVALID_OPERATION** if the device associated with *command_queue* does not support images (i.e. **CL_DEVICE_IMAGE_SUPPORT** specified in the [Device Queries](#) table is **CL_FALSE**).
- **CL_MEM_COPY_OVERLAP** if *src_image* and *dst_image* are the same image object and the source and destination regions overlap.

5.3.4. Filling Image Objects



Filling image objects is [missing before](#) version 1.2.

To enqueue a command to fill an image object with a specified color, call the function

```
cl_int clEnqueueFillImage(
    cl_command_queue command_queue,
    cl_mem image,
    const void* fill_color,
    const size_t* origin,
    const size_t* region,
    cl_uint num_events_in_wait_list,
    const cl_event* event_wait_list,
    cl_event* event);
```



clEnqueueFillImage is [missing before](#) version 1.2.

- *command_queue* refers to the host command-queue in which the fill command will be queued.

The OpenCL context associated with *command_queue* and *image* must be the same.

- *image* is a valid image object.
- *fill_color* is the color used to fill the image. The fill color is a single floating-point value if the channel order is **CL_DEPTH**. Otherwise, the fill color is a four component RGBA floating-point color value if the *image* channel data type is not an unnormalized signed or unsigned integer type, is a four component signed integer value if the *image* channel data type is an unnormalized signed integer type and is a four component unsigned integer value if the *image* channel data type is an unnormalized unsigned integer type. The fill color will be converted to the appropriate image channel format and order associated with *image*.
- *origin* defines the (x, y, z) offset in pixels in the 1D, 2D or 3D image, the (x, y) offset and the image index in the 2D image array or the (x) offset and the image index in the 1D image array. If *image* is a 2D image object, *origin*[2] must be 0. If *image* is a 1D image or 1D image buffer object, *origin*[1] and *origin*[2] must be 0. If *image* is a 1D image array object, *origin*[2] must be 0. If *image* is a 1D image array object, *origin*[1] describes the image index in the 1D image array. If *image* is a 2D image array object, *origin*[2] describes the image index in the 2D image array.
- *region* defines the (*width*, *height*, *depth*) in pixels of the 1D, 2D or 3D rectangle, the (*width*, *height*) in pixels of the 2D rectangle and the number of images of a 2D image array or the (*width*) in pixels of the 1D rectangle and the number of images of a 1D image array. If *image* is a 2D image object, *region*[2] must be 1. If *image* is a 1D image or 1D image buffer object, *region*[1] and *region*[2] must be 1. If *image* is a 1D image array object, *region*[2] must be 1. The values in *region* cannot be 0.
- *event_wait_list* and *num_events_in_wait_list* specify events that need to complete before this particular command can be executed. If *event_wait_list* is **NULL**, then this particular command does not wait on any event to complete. If *event_wait_list* is **NULL**, *num_events_in_wait_list* must be 0. If *event_wait_list* is not **NULL**, the list of events pointed to by *event_wait_list* must be valid and *num_events_in_wait_list* must be greater than 0. The events specified in *event_wait_list* act as synchronization points. The context associated with events in *event_wait_list* and *command_queue* must be the same. The memory associated with *event_wait_list* can be reused or freed after the function returns.
- *event* returns an event object that identifies this command and can be used to query or queue a wait for this command to complete. If *event* is **NULL** or the enqueue is unsuccessful, no event will be created and therefore it will not be possible to query the status of this command or to wait for this command to complete. If *event_wait_list* and *event* are not **NULL**, *event* must not refer to an element of the *event_wait_list* array.

The usage information which indicates whether the memory object can be read or written by a kernel and/or the host and is given by the **cl_mem_flags** argument value specified when *image* is created is ignored by **clEnqueueFillImage**.

clEnqueueFillImage returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_COMMAND_QUEUE** if *command_queue* is not a valid host command-queue.
- **CL_INVALID_CONTEXT** if the context associated with *command_queue* and *image* are not the same or if the context associated with *command_queue* and events in *event_wait_list* are not the same.

- **CL_INVALID_MEM_OBJECT** if *image* is not a valid image object.
- **CL_INVALID_VALUE** if *fill_color* is **NULL**.
- **CL_INVALID_VALUE** if *origin* or *region* is **NULL**.
- **CL_INVALID_VALUE** if the region being filled as specified by *origin* and *region* is out of bounds.
- **CL_INVALID_VALUE** if values in *origin* and *region* do not follow rules described in the argument description for *origin* and *region*.
- **CL_INVALID_EVENT_WAIT_LIST** if *event_wait_list* is **NULL** and *num_events_in_wait_list* > 0, or *event_wait_list* is not **NULL** and *num_events_in_wait_list* is 0, or if event objects in *event_wait_list* are not valid events.
- **CL_INVALID_IMAGE_SIZE** if image dimensions (image width, height, specified or compute row and/or slice pitch) for *image* are not supported by device associated with *queue*.
- **CL_IMAGE_FORMAT_NOT_SUPPORTED** if image format (image channel order and data type) for *image* are not supported by device associated with *queue*.
- **CL_MEM_OBJECT_ALLOCATION_FAILURE** if there is a failure to allocate memory for data store associated with *image*.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

5.3.5. Copying between Image and Buffer Objects

To enqueue a command to copy an image object to a buffer object, call the function

```
cl_int clEnqueueCopyImageToBuffer(
    cl_command_queue command_queue,
    cl_mem src_image,
    cl_mem dst_buffer,
    const size_t* src_origin,
    const size_t* region,
    size_t dst_offset,
    cl_uint num_events_in_wait_list,
    const cl_event* event_wait_list,
    cl_event* event);
```

- *command_queue* must be a valid host command-queue. The OpenCL context associated with *command_queue*, *src_image* and *dst_buffer* must be the same.
- *src_image* is a valid image object.
- *dst_buffer* is a valid buffer object.
- *src_origin* defines the (x, y, z) offset in pixels in the 1D, 2D or 3D image, the (x, y) offset and the image index in the 2D image array or the (x) offset and the image index in the 1D image array. If *src_image* is a 2D image object, *src_origin*[2] must be 0. If *src_image* is a 1D image or 1D image

buffer object, *src_origin*[1] and *src_origin*[2] must be 0. If *src_image* is a 1D image array object, *src_origin*[2] must be 0. If *src_image* is a 1D image array object, *src_origin*[1] describes the image index in the 1D image array. If *src_image* is a 2D image array object, *src_origin*[2] describes the image index in the 2D image array.

- *region* defines the (*width*, *height*, *depth*) in pixels of the 1D, 2D or 3D rectangle, the (*width*, *height*) in pixels of the 2D rectangle and the number of images of a 2D image array or the (*width*) in pixels of the 1D rectangle and the number of images of a 1D image array. If *src_image* is a 2D image object, *region*[2] must be 1. If *src_image* is a 1D image or 1D image buffer object, *region*[1] and *region*[2] must be 1. If *src_image* is a 1D image array object, *region*[2] must be 1. The values in *region* cannot be 0.
- *dst_offset* refers to the offset where to begin copying data into *dst_buffer*. The size in bytes of the region to be copied referred to as *dst_cb* is computed as $width \times height \times depth \times bytes/image\ element$ if *src_image* is a 3D image object, is computed as $width \times height \times bytes/image\ element$ if *src_image* is a 2D image, is computed as $width \times height \times arraysize \times bytes/image\ element$ if *src_image* is a 2D image array object, is computed as $width \times bytes/image\ element$ if *src_image* is a 1D image or 1D image buffer object and is computed as $width \times arraysize \times bytes/image\ element$ if *src_image* is a 1D image array object.
- *event_wait_list* and *num_events_in_wait_list* specify events that need to complete before this particular command can be executed. If *event_wait_list* is **NULL**, then this particular command does not wait on any event to complete. If *event_wait_list* is **NULL**, *num_events_in_wait_list* must be 0. If *event_wait_list* is not **NULL**, the list of events pointed to by *event_wait_list* must be valid and *num_events_in_wait_list* must be greater than 0. The events specified in *event_wait_list* act as synchronization points. The context associated with events in *event_wait_list* and *command_queue* must be the same. The memory associated with *event_wait_list* can be reused or freed after the function returns.
- *event* returns an event object that identifies this copy command and can be used to query or queue a wait for this command to complete. If *event* is **NULL** or the enqueue is unsuccessful, no event will be created and therefore it will not be possible to query the status of this command or to wait for this command to complete. If *event_wait_list* and *event* are not **NULL**, *event* must not refer to an element of the *event_wait_list* array.

clEnqueueCopyImageToBuffer returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_COMMAND_QUEUE** if *command_queue* is not a valid host command-queue.
- **CL_INVALID_CONTEXT** if the context associated with *command_queue*, *src_image* and *dst_buffer* are not the same or if the context associated with *command_queue* and events in *event_wait_list* are not the same.
- **CL_INVALID_MEM_OBJECT** if *src_image* is not a valid image object or *dst_buffer* is not a valid buffer object or if *src_image* is a 1D image buffer object created from *dst_buffer*.
- **CL_INVALID_VALUE** if *src_origin* or *region* is **NULL**.
- **CL_INVALID_VALUE** if the 1D, 2D or 3D rectangular region specified by *src_origin* and *src_origin* + *region* refers to a region outside *src_image*, or if the region specified by *dst_offset* and *dst_offset* + *dst_cb* to a region outside *dst_buffer*.
- **CL_INVALID_VALUE** if values in *src_origin* and *region* do not follow rules described in the

argument description for *src_origin* and *region*.

- **CL_INVALID_EVENT_WAIT_LIST** if *event_wait_list* is **NULL** and *num_events_in_wait_list* > 0, or *event_wait_list* is not **NULL** and *num_events_in_wait_list* is 0, or if event objects in *event_wait_list* are not valid events.
- **CL_MISALIGNED_SUB_BUFFER_OFFSET** if *dst_buffer* is a sub-buffer object and *offset* specified when the sub-buffer object is created is not aligned to **CL_DEVICE_MEM_BASE_ADDR_ALIGN** value for device associated with *queue*. This error code is **missing before** version 1.1.
- **CL_INVALID_IMAGE_SIZE** if image dimensions (image width, height, specified or compute row and/or slice pitch) for *src_image* are not supported by device associated with *queue*.
- **CL_IMAGE_FORMAT_NOT_SUPPORTED** if image format (image channel order and data type) for *src_image* are not supported by device associated with *queue*.
- **CL_MEM_OBJECT_ALLOCATION_FAILURE** if there is a failure to allocate memory for data store associated with *src_image* or *dst_buffer*.
- **CL_INVALID_OPERATION** if the device associated with *command_queue* does not support images (i.e. **CL_DEVICE_IMAGE_SUPPORT** specified in the **Device Queries** table is **CL_FALSE**).
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

To enqueue a command to copy a buffer object to an image object, call the function

```
cl_int clEnqueueCopyBufferToImage(  
    cl_command_queue command_queue,  
    cl_mem src_buffer,  
    cl_mem dst_image,  
    size_t src_offset,  
    const size_t* dst_origin,  
    const size_t* region,  
    cl_uint num_events_in_wait_list,  
    const cl_event* event_wait_list,  
    cl_event* event);
```

- *command_queue* must be a valid host command-queue. The OpenCL context associated with *command_queue*, *src_buffer* and *dst_image* must be the same.
- *src_buffer* is a valid buffer object.
- *dst_image* is a valid image object.
- *src_offset* refers to the offset where to begin copying data from *src_buffer*.
- *dst_origin* defines the (x, y, z) offset in pixels in the 1D, 2D or 3D image, the (x, y) offset and the image index in the 2D image array or the (x) offset and the image index in the 1D image array. If *dst_image* is a 2D image object, *dst_origin*[2] must be 0. If *dst_image* is a 1D image or 1D image buffer object, *dst_origin*[1] and *dst_origin*[2] must be 0. If *dst_image* is a 1D image array object, *dst_origin*[2] must be 0. If *dst_image* is a 1D image array object, *dst_origin*[1] describes the image

index in the 1D image array. If *dst_image* is a 2D image array object, *dst_origin*[2] describes the image index in the 2D image array.

- *region* defines the (*width*, *height*, *depth*) in pixels of the 1D, 2D or 3D rectangle, the (*width*, *height*) in pixels of the 2D rectangle and the number of images of a 2D image array or the (*width*) in pixels of the 1D rectangle and the number of images of a 1D image array. If *dst_image* is a 2D image object, *region*[2] must be 1. If *dst_image* is a 1D image or 1D image buffer object, *region*[1] and *region*[2] must be 1. If *dst_image* is a 1D image array object, *region*[2] must be 1. The values in *region* cannot be 0.
- *event_wait_list* and *num_events_in_wait_list* specify events that need to complete before this particular command can be executed. If *event_wait_list* is **NULL**, then this particular command does not wait on any event to complete. If *event_wait_list* is **NULL**, *num_events_in_wait_list* must be 0. If *event_wait_list* is not **NULL**, the list of events pointed to by *event_wait_list* must be valid and *num_events_in_wait_list* must be greater than 0. The events specified in *event_wait_list* act as synchronization points. The context associated with events in *event_wait_list* and *command_queue* must be the same. The memory associated with *event_wait_list* can be reused or freed after the function returns.
- *event* returns an event object that identifies this copy command and can be used to query or queue a wait for this command to complete. If *event* is **NULL** or the enqueue is unsuccessful, no event will be created and therefore it will not be possible to query the status of this command or to wait for this command to complete. If *event_wait_list* and *event* are not **NULL**, *event* must not refer to an element of the *event_wait_list* array.

The size in bytes of the region to be copied from *src_buffer* referred to as *src_cb* is computed as $width \times height \times depth \times bytes/image\ element$ if *dst_image* is a 3D image object, is computed as $width \times height \times bytes/image\ element$ if *dst_image* is a 2D image, is computed as $width \times height \times arraysize \times bytes/image\ element$ if *dst_image* is a 2D image array object, is computed as $width \times bytes/image\ element$ if *dst_image* is a 1D image or 1D image buffer object and is computed as $width \times arraysize \times bytes/image\ element$ if *dst_image* is a 1D image array object.

clEnqueueCopyBufferToImage returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_COMMAND_QUEUE** if *command_queue* is not a valid host command-queue.
- **CL_INVALID_CONTEXT** if the context associated with *command_queue*, *src_buffer* and *dst_image* are not the same or if the context associated with *command_queue* and events in *event_wait_list* are not the same.
- **CL_INVALID_MEM_OBJECT** if *src_buffer* is not a valid buffer object or *dst_image* is not a valid image object or if *dst_image* is a 1D image buffer object created from *src_buffer*.
- **CL_INVALID_VALUE** if *dst_origin* or *region* is **NULL**.
- **CL_INVALID_VALUE** if the 1D, 2D or 3D rectangular region specified by *dst_origin* and *dst_origin* + *region* refer to a region outside *dst_image*, or if the region specified by *src_offset* and *src_offset* + *src_cb* refer to a region outside *src_buffer*.
- **CL_INVALID_VALUE** if values in *dst_origin* and *region* do not follow rules described in the argument description for *dst_origin* and *region*.
- **CL_INVALID_EVENT_WAIT_LIST** if *event_wait_list* is **NULL** and *num_events_in_wait_list* > 0, or

event_wait_list is not **NULL** and *num_events_in_wait_list* is 0, or if event objects in *event_wait_list* are not valid events.

- **CL_MISALIGNED_SUB_BUFFER_OFFSET** if *src_buffer* is a sub-buffer object and *offset* specified when the sub-buffer object is created is not aligned to **CL_DEVICE_MEM_BASE_ADDR_ALIGN** value for device associated with *queue*. This error code is **missing before** version 1.1.
- **CL_INVALID_IMAGE_SIZE** if image dimensions (image width, height, specified or compute row and/or slice pitch) for *dst_image* are not supported by device associated with *queue*.
- **CL_IMAGE_FORMAT_NOT_SUPPORTED** if image format (image channel order and data type) for *dst_image* are not supported by device associated with *queue*.
- **CL_MEM_OBJECT_ALLOCATION_FAILURE** if there is a failure to allocate memory for data store associated with *src_buffer* or *dst_image*.
- **CL_INVALID_OPERATION** if the device associated with *command_queue* does not support images (i.e. **CL_DEVICE_IMAGE_SUPPORT** specified in the **Device Queries** table is **CL_FALSE**).
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

5.3.6. Mapping Image Objects

To enqueue a command to map a region in the image object given by *image* into the host address space and returns a pointer to this mapped region, call the function

```
void* clEnqueueMapImage(  
    cl_command_queue command_queue,  
    cl_mem image,  
    cl_bool blocking_map,  
    cl_map_flags map_flags,  
    const size_t* origin,  
    const size_t* region,  
    size_t* image_row_pitch,  
    size_t* image_slice_pitch,  
    cl_uint num_events_in_wait_list,  
    const cl_event* event_wait_list,  
    cl_event* event,  
    cl_int* errcode_ret);
```

- *command_queue* must be a valid host command-queue.
- *image* is a valid image object. The OpenCL context associated with *command_queue* and *image* must be the same.
- *blocking_map* indicates if the map operation is *blocking* or *non-blocking*.
- *map_flags* is a bit-field and is described in the **Memory Map Flags** table.
- *origin* defines the (x, y, z) offset in pixels in the 1D, 2D or 3D image, the (x, y) offset and the

image index in the 2D image array or the (x) offset and the image index in the 1D image array. If *image* is a 2D image object, *origin*[2] must be 0. If *image* is a 1D image or 1D image buffer object, *origin*[1] and *origin*[2] must be 0. If *image* is a 1D image array object, *origin*[2] must be 0. If *image* is a 1D image array object, *origin*[1] describes the image index in the 1D image array. If *image* is a 2D image array object, *origin*[2] describes the image index in the 2D image array.

- *region* defines the (*width*, *height*, *depth*) in pixels of the 1D, 2D or 3D rectangle, the (*width*, *height*) in pixels of the 2D rectangle and the number of images of a 2D image array or the (*width*) in pixels of the 1D rectangle and the number of images of a 1D image array. If *image* is a 2D image object, *region*[2] must be 1. If *image* is a 1D image or 1D image buffer object, *region*[1] and *region*[2] must be 1. If *image* is a 1D image array object, *region*[2] must be 1. The values in *region* cannot be 0.
- *image_row_pitch* returns the scan-line pitch in bytes for the mapped region. This must be a non-NULL value.
- *image_slice_pitch* returns the size in bytes of each 2D slice of a 3D image or the size of each 1D or 2D image in a 1D or 2D image array for the mapped region. For a 1D and 2D image, zero is returned if this argument is not NULL. For a 3D image, 1D and 2D image array, *image_slice_pitch* must be a non-NULL value.
- *event_wait_list* and *num_events_in_wait_list* specify events that need to complete before **clEnqueueMapImage** can be executed. If *event_wait_list* is NULL, then **clEnqueueMapImage** does not wait on any event to complete. If *event_wait_list* is NULL, *num_events_in_wait_list* must be 0. If *event_wait_list* is not NULL, the list of events pointed to by *event_wait_list* must be valid and *num_events_in_wait_list* must be greater than 0. The events specified in *event_wait_list* act as synchronization points. The context associated with events in *event_wait_list* and *command_queue* must be the same. The memory associated with *event_wait_list* can be reused or freed after the function returns.
- *event* returns an event object that identifies this command and can be used to query or queue a wait for this command to complete. If *event* is NULL or the enqueue is unsuccessful, no event will be created and therefore it will not be possible to query the status of this command or to wait for this command to complete. If *event_wait_list* and *event* are not NULL, *event* must not refer to an element of the *event_wait_list* array.
- *errcode_ret* will return an appropriate error code. If *errcode_ret* is NULL, no error code is returned.

If *blocking_map* is CL_TRUE, **clEnqueueMapImage** does not return until the specified region in *image* is mapped into the host address space and the application can access the contents of the mapped region using the pointer returned by **clEnqueueMapImage**.

If *blocking_map* is CL_FALSE i.e. map operation is non-blocking, the pointer to the mapped region returned by **clEnqueueMapImage** cannot be used until the map command has completed. The *event* argument returns an event object which can be used to query the execution status of the map command. When the map command is completed, the application can access the contents of the mapped region using the pointer returned by **clEnqueueMapImage**.

clEnqueueMapImage will return a pointer to the mapped region. The *errcode_ret* is set to CL_SUCCESS.

A `NULL` pointer is returned otherwise with one of the following error values returned in `errcode_ret`:

- `CL_INVALID_COMMAND_QUEUE` if `command_queue` is not a valid host command-queue.
- `CL_INVALID_CONTEXT` if context associated with `command_queue` and `image` are not the same or if context associated with `command_queue` and events in `event_wait_list` are not the same.
- `CL_INVALID_MEM_OBJECT` if `image` is not a valid image object.
- `CL_INVALID_VALUE` if `origin` or `region` is `NULL`.
- `CL_INVALID_VALUE` if region being mapped given by (`origin`, `origin` + `region`) is out of bounds or if values specified in `map_flags` are not valid.
- `CL_INVALID_VALUE` if values in `origin` and `region` do not follow rules described in the argument description for `origin` and `region`.
- `CL_INVALID_VALUE` if `image_row_pitch` is `NULL`.
- `CL_INVALID_VALUE` if `image` is a 3D image, 1D or 2D image array object and `image_slice_pitch` is `NULL`.
- `CL_INVALID_EVENT_WAIT_LIST` if `event_wait_list` is `NULL` and `num_events_in_wait_list` > 0, or `event_wait_list` is not `NULL` and `num_events_in_wait_list` is 0, or if event objects in `event_wait_list` are not valid events.
- `CL_INVALID_IMAGE_SIZE` if image dimensions (image width, height, specified or compute row and/or slice pitch) for `image` are not supported by device associated with `queue`.
- `CL_IMAGE_FORMAT_NOT_SUPPORTED` if image format (image channel order and data type) for `image` are not supported by device associated with `queue`.
- `CL_MAP_FAILURE` if there is a failure to map the requested region into the host address space. This error cannot occur for image objects created with `CL_MEM_USE_HOST_PTR` or `CL_MEM_ALLOC_HOST_PTR`.
- `CL_EXEC_STATUS_ERROR_FOR_EVENTS_IN_WAIT_LIST` if the map operation is blocking and the execution status of any of the events in `event_wait_list` is a negative integer value. This error code is [missing before](#) version 1.1.
- `CL_MEM_OBJECT_ALLOCATION_FAILURE` if there is a failure to allocate memory for data store associated with `image`.
- `CL_INVALID_OPERATION` if the device associated with `command_queue` does not support images (i.e. `CL_DEVICE_IMAGE_SUPPORT` specified in the [Device Queries](#) table is `CL_FALSE`).
- `CL_INVALID_OPERATION` if `image` has been created with `CL_MEM_HOST_WRITE_ONLY` or `CL_MEM_HOST_NO_ACCESS` and `CL_MAP_READ` is set in `map_flags` or if `image` has been created with `CL_MEM_HOST_READ_ONLY` or `CL_MEM_HOST_NO_ACCESS` and `CL_MAP_WRITE` or `CL_MAP_WRITE_INVALIDATE_REGION` is set in `map_flags`.
- `CL_OUT_OF_RESOURCES` if there is a failure to allocate resources required by the OpenCL implementation on the device.
- `CL_OUT_OF_HOST_MEMORY` if there is a failure to allocate resources required by the OpenCL implementation on the host.
- `CL_INVALID_OPERATION` if mapping would lead to overlapping regions being mapped for writing.

The pointer returned maps a 1D, 2D or 3D region starting at `origin` and is at least `region[0]` pixels in

size for a 1D image, 1D image buffer or 1D image array, $(image_row_pitch \times region[1])$ pixels in size for a 2D image or 2D image array, and $(image_slice_pitch \times region[2])$ pixels in size for a 3D image. The result of a memory access outside this region is undefined.

If the image object is created with `CL_MEM_USE_HOST_PTR` set in *mem_flags*, the following will be true:

- The *host_ptr* specified in `clCreateImage`, `clCreateImageWithProperties`, `clCreateImage2D`, or `clCreateImage3D` is guaranteed to contain the latest bits in the region being mapped when the `clEnqueueMapImage` command has completed.
- The pointer value returned by `clEnqueueMapImage` will be derived from the *host_ptr* specified when the image object is created.

Mapped image objects are unmapped using `clEnqueueUnmapMemObject`. This is described in [Unmapping Mapped Memory Objects](#).

5.3.7. Image Object Queries

To get information that is common to all memory objects, use the `clGetMemObjectInfo` function described in [Memory Object Queries](#).

To get information specific to an image object created with `clCreateImage`, `clCreateImageWithProperties`, `clCreateImage2D`, or `clCreateImage3D` call the function

```
cl_int clGetImageInfo(
    cl_mem image,
    cl_image_info param_name,
    size_t param_value_size,
    void* param_value,
    size_t* param_value_size_ret);
```

- *image* specifies the image object being queried.
- *param_name* specifies the information to query. The list of supported *param_name* types and the information returned in *param_value* by `clGetImageInfo` is described in the [Image Object Queries](#) table.
- *param_value* is a pointer to memory where the appropriate result being queried is returned. If *param_value* is `NULL`, it is ignored.
- *param_value_size* is used to specify the size in bytes of memory pointed to by *param_value*. This size must be \geq size of return type as described in the [Image Object Queries](#) table.
- *param_value_size_ret* returns the actual size in bytes of data being queried by *param_name*. If *param_value_size_ret* is `NULL`, it is ignored.

Table 22. List of supported *param_names* by `clGetImageInfo`

Image Info	Return type	Description
CL_IMAGE_FORMAT	cl_image_format	Return the image format descriptor specified when <i>image</i> is created with clCreateImage , clCreateImageWithProperties , clCreateImage2D or clCreateImage3D .
CL_IMAGE_ELEMENT_SIZE	size_t	Return size of each element of the image memory object given by <i>image</i> in bytes.
CL_IMAGE_ROW_PITCH	size_t	Returns the row pitch in bytes of a row of elements of the image object given by <i>image</i> . If <i>image</i> was created with a non-zero value for <i>image_row_pitch</i> , then the value provided for <i>image_row_pitch</i> by the application is returned, otherwise the returned value is calculated as $CL_IMAGE_WIDTH \times CL_IMAGE_ELEMENT_SIZE$.
CL_IMAGE_SLICE_PITCH	size_t	Returns the slice pitch in bytes of a 2D slice for the 3D image object or size of each image in a 1D or 2D image array given by <i>image</i> . If <i>image</i> was created with a non-zero value for <i>image_slice_pitch</i> then the value provided for <i>image_slice_pitch</i> by the application is returned, otherwise the returned value is calculated as: - $CL_IMAGE_ROW_PITCH$ for 1D image arrays. - $CL_IMAGE_HEIGHT \times CL_IMAGE_ROW_PITCH$ for 3D images and 2D image arrays. For a 1D image, 1D image buffer and 2D image object return 0.
CL_IMAGE_WIDTH	size_t	Return width of the image in pixels.
CL_IMAGE_HEIGHT	size_t	Return height of the image in pixels. For a 1D image, 1D image buffer and 1D image array object, height = 0.
CL_IMAGE_DEPTH	size_t	Return depth of the image in pixels. For a 1D image, 1D image buffer, 2D image or 1D and 2D image array object, depth = 0.
CL_IMAGE_ARRAY_SIZE missing before version 1.2.	size_t	Return number of images in the image array. If <i>image</i> is not an image array, 0 is returned.
CL_IMAGE_BUFFER missing before version 1.2 and deprecated by version 2.0.	cl_mem	Return buffer object associated with <i>image</i> .
CL_IMAGE_NUM_MIP_LEVELS missing before version 1.2.	cl_uint	Return <i>num_mip_levels</i> associated with <i>image</i> .

Image Info	Return type	Description
CL_IMAGE_NUM_SAMPLES	cl_uint	Return <code>num_samples</code> associated with <i>image</i> .
missing before version 1.2.		

clGetImageInfo returns `CL_SUCCESS` if the function is executed successfully. Otherwise, it returns one of the following errors:

- `CL_INVALID_VALUE` if *param_name* is not valid, or if size in bytes specified by *param_value_size* is < size of return type as described in the [Image Object Queries](#) table and *param_value* is not `NULL`.
- `CL_INVALID_MEM_OBJECT` if *image* is a not a valid image object.
- `CL_OUT_OF_RESOURCES` if there is a failure to allocate resources required by the OpenCL implementation on the device.
- `CL_OUT_OF_HOST_MEMORY` if there is a failure to allocate resources required by the OpenCL implementation on the host.

5.4. Pipes



Pipes are missing before version 2.0.

A *pipe* is a memory object that stores data organized as a FIFO. Pipe objects can only be accessed using built-in functions that read from and write to a pipe. Pipe objects are not accessible from the host. A pipe object encapsulates the following information:

- Packet size in bytes
- Maximum capacity in packets
- Information about the number of packets currently in the pipe
- Data packets

5.4.1. Creating Pipe Objects

To create a **pipe object**, call the function

```
cl_mem clCreatePipe(
    cl_context context,
    cl_mem_flags flags,
    cl_uint pipe_packet_size,
    cl_uint pipe_max_packets,
    const cl_pipe_properties* properties,
    cl_int* errcode_ret);
```



clCreatePipe is missing before version 2.0.

- *context* is a valid OpenCL context used to create the pipe object.

- *flags* is a bit-field that is used to specify allocation and usage information such as the memory arena that should be used to allocate the pipe object and how it will be used. The [Memory Flags](#) table describes the possible values for *flags*. Only `CL_MEM_READ_WRITE` and `CL_MEM_HOST_NO_ACCESS` can be specified when creating a pipe object. If the value specified for *flags* is 0, the default is used which is `CL_MEM_READ_WRITE | CL_MEM_HOST_NO_ACCESS`.
- *pipe_packet_size* is the size in bytes of a pipe packet.
- *pipe_max_packets* specifies the pipe capacity by specifying the maximum number of packets the pipe can hold.
- *properties* specifies a list of properties for the pipe and their corresponding values. Each property name is immediately followed by the corresponding desired value. The list is terminated with 0. Currently, in all OpenCL versions, *properties* must be `NULL`.
- *errcode_ret* will return an appropriate error code. If *errcode_ret* is `NULL`, no error code is returned.

clCreatePipe returns a valid non-zero pipe object and *errcode_ret* is set to `CL_SUCCESS` if the pipe object is created successfully. Otherwise, it returns a `NULL` value with one of the following error values returned in *errcode_ret*:

- `CL_INVALID_CONTEXT` if *context* is not a valid context.
- `CL_INVALID_OPERATION` if no devices in *context* support pipes.
- `CL_INVALID_VALUE` if values specified in *flags* are not as defined above.
- `CL_INVALID_VALUE` if *properties* is not `NULL`.
- `CL_INVALID_PIPE_SIZE` if *pipe_packet_size* is 0 or the *pipe_packet_size* exceeds `CL_DEVICE_PIPE_MAX_PACKET_SIZE` value specified in the [Device Queries](#) table for all devices in *context* or if *pipe_max_packets* is 0.
- `CL_MEM_OBJECT_ALLOCATION_FAILURE` if there is a failure to allocate memory for the pipe object.
- `CL_OUT_OF_RESOURCES` if there is a failure to allocate resources required by the OpenCL implementation on the device.
- `CL_OUT_OF_HOST_MEMORY` if there is a failure to allocate resources required by the OpenCL implementation on the host.

Pipes follow the same memory consistency model as defined for buffer and image objects. The pipe state i.e. contents of the pipe across kernel-instances (on the same or different devices) is enforced at a synchronization point.

5.4.2. Pipe Object Queries

To get information that is common to all memory objects, use the **clGetMemObjectInfo** function described in [Memory Object Queries](#).

To get information specific to a pipe object created with **clCreatePipe**, call the function

```
cl_int clGetPipeInfo(
    cl_mem pipe,
    cl_pipe_info param_name,
    size_t param_value_size,
    void* param_value,
    size_t* param_value_size_ret);
```



clGetPipeInfo is **missing before** version 2.0.

- *pipe* specifies the pipe object being queried.
- *param_name* specifies the information to query. The list of supported *param_name* types and the information returned in *param_value* by **clGetPipeInfo** is described in the [Pipe Object Queries](#) table.
- *param_value* is a pointer to memory where the appropriate result being queried is returned. If *param_value* is **NULL**, it is ignored.
- *param_value_size* is used to specify the size in bytes of memory pointed to by *param_value*. This size must be \geq size of return type as described in the [Pipe Object Queries](#) table.
- *param_value_size_ret* returns the actual size in bytes of data being queried by *param_name*. If *param_value_size_ret* is **NULL**, it is ignored.

clGetPipeInfo returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_MEM_OBJECT** if *pipe* is a not a valid pipe object.
- **CL_INVALID_VALUE** if *param_name* is not valid, or if size in bytes specified by *param_value_size* is $<$ size of return type as described in the [Pipe Object Queries](#) table and *param_value* is not **NULL**.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

Table 23. List of supported *param_names* by **clGetPipeInfo**

Pipe Info	Return type	Description
CL_PIPE_PACKET_SIZE missing before version 2.0.	cl_uint	Return pipe packet size specified when <i>pipe</i> is created with clCreatePipe .
CL_PIPE_MAX_PACKETS missing before version 2.0.	cl_uint	Return max. number of packets specified when <i>pipe</i> is created with clCreatePipe .

Pipe Info	Return type	Description
CL_PIPE_PROPERTIES missing before version 3.0.	cl_pipe_properties[]	Return the properties argument specified in clCreatePipe . If the <i>properties</i> argument specified in clCreatePipe used to create <i>pipe</i> was not NULL , the implementation must return the values specified in the properties argument in the same order and without including additional properties. If the <i>properties</i> argument specified in clCreatePipe used to create <i>pipe</i> was NULL , the implementation must return <i>param_value_size_ret</i> equal to 0, indicating that there are no properties to be returned.

5.5. Querying, Unmapping, Migrating, Retaining and Releasing Memory Objects

5.5.1. Retaining and Releasing Memory Objects

To retain a memory object, call the function

```
cl_int clRetainMemObject(
    cl_mem memobj);
```

- *memobj* specifies the memory object to be retained.

The *memobj* reference count is incremented.

clRetainMemObject returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_MEM_OBJECT** if *memobj* is not a valid memory object (buffer or image object).
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

clCreateBuffer, **clCreateBufferWithProperties**, **clCreateSubBuffer**, **clCreateImage**, **clCreateImageWithProperties**, **clCreateImage2D**, **clCreateImage3D** and **clCreatePipe** perform an implicit retain.

To release a memory object, call the function

```
cl_int clReleaseMemObject(
    cl_mem memobj);
```

- *memobj* specifies the memory object to be released.

The *memobj* reference count is decremented.

clReleaseMemObject returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_MEM_OBJECT** if *memobj* is not a valid memory object.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

After the *memobj* reference count becomes zero and commands queued for execution on a command-queue(s) that use *memobj* have finished, the memory object is deleted. If *memobj* is a buffer object, *memobj* cannot be deleted until all sub-buffer objects associated with *memobj* are deleted. Using this function to release a reference that was not obtained by creating the object or by calling **clRetainMemObject** causes undefined behavior.

To register a callback function with a memory object that is called when the memory object is destroyed, call the function

```
cl_int clSetMemObjectDestructorCallback(
    cl_mem memobj,
    void (CL_CALLBACK* pfn_notify)(cl_mem memobj, void* user_data),
    void* user_data);
```



clSetMemObjectDestructorCallback is missing before version 1.1.

- *memobj* specifies the memory object to register the callback to.
- *pfn_notify* is the callback function to register. This callback function may be called asynchronously by the OpenCL implementation. It is the application's responsibility to ensure that the callback function is thread-safe. The parameters to this callback function are:
 - *memobj* is the memory object being deleted. When the callback function is called by the implementation, this memory object is no longer valid. *memobj* is only provided for reference purposes.
 - *user_data* is a pointer to user-supplied data.
- *user_data* will be passed as the *user_data* argument when *pfn_notify* is called. *user_data* can be **NULL**.

Each call to **clSetMemObjectDestructorCallback** registers the specified callback function on a destructor callback stack associated with *memobj*. The registered callback functions are called in

the reverse order in which they were registered. The registered callback functions are called and then the memory object's resources are freed and the memory object is deleted. Therefore, the memory object destructor callback provides a mechanism for an application to safely re-use or free a *host_ptr* that was specified when *memobj* was created and used as the storage bits for the memory object.

clSetMemObjectDestructorCallback returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_MEM_OBJECT** if *memobj* is not a valid memory object.
- **CL_INVALID_VALUE** if *pfn_notify* is **NULL**.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

When the user callback function is called by the implementation, the contents of the memory region pointed to by *host_ptr* (if the memory object is created with **CL_MEM_USE_HOST_PTR**) are undefined. The callback function is typically used by the application to either free or reuse the memory region pointed to by *host_ptr*.

The behavior of calling expensive system routines, OpenCL API calls to create contexts or command-queues, or blocking OpenCL operations from the following list below, in a callback is undefined.

- **clFinish**,
- **clWaitForEvents**,
- blocking calls to **clEnqueueReadBuffer**, **clEnqueueReadBufferRect**, **clEnqueueWriteBuffer**, **clEnqueueWriteBufferRect**,
- blocking calls to **clEnqueueReadImage** and **clEnqueueWriteImage**,
- blocking calls to **clEnqueueMapBuffer**, **clEnqueueMapImage**,
- blocking calls to **clBuildProgram**, **clCompileProgram** or **clLinkProgram**

If an application needs to wait for completion of a routine from the above list in a callback, please use the non-blocking form of the function, and assign a completion callback to it to do the remainder of your work. Note that when a callback (or other code) enqueues commands to a command-queue, the commands are not required to begin execution until the queue is flushed. In standard usage, blocking enqueue calls serve this role by implicitly flushing the queue. Since blocking calls are not permitted in callbacks, those callbacks that enqueue commands on a command-queue should either call **clFlush** on the queue before returning or arrange for **clFlush** to be called later on another thread.

The user callback function may not call OpenCL APIs with the memory object for which the callback function is invoked and for such cases the behavior of OpenCL APIs is considered to be undefined.



5.5.2. Unmapping Mapped Memory Objects

To enqueue a command to unmap a previously mapped region of a memory object, call the function

```
cl_int clEnqueueUnmapMemObject(  
    cl_command_queue command_queue,  
    cl_mem memobj,  
    void* mapped_ptr,  
    cl_uint num_events_in_wait_list,  
    const cl_event* event_wait_list,  
    cl_event* event);
```

- *command_queue* must be a valid host command-queue.
- *memobj* is a valid memory (buffer or image) object. The OpenCL context associated with *command_queue* and *memobj* must be the same.
- *mapped_ptr* is the host address returned by a previous call to [clEnqueueMapBuffer](#), or [clEnqueueMapImage](#) for *memobj*.
- *event_wait_list* and *num_events_in_wait_list* specify events that need to complete before [clEnqueueUnmapMemObject](#) can be executed. If *event_wait_list* is **NULL**, then [clEnqueueUnmapMemObject](#) does not wait on any event to complete. If *event_wait_list* is **NULL**, *num_events_in_wait_list* must be 0. If *event_wait_list* is not **NULL**, the list of events pointed to by *event_wait_list* must be valid and *num_events_in_wait_list* must be greater than 0. The events specified in *event_wait_list* act as synchronization points. The context associated with events in *event_wait_list* and *command_queue* must be the same. The memory associated with *event_wait_list* can be reused or freed after the function returns.
- *event* returns an event object that identifies this command and can be used to query or queue a wait for this command to complete. If *event* is **NULL** or the enqueue is unsuccessful, no event will be created and therefore it will not be possible to query the status of this command or to wait for this command to complete. If *event_wait_list* and *event* are not **NULL**, *event* must not refer to an element of the *event_wait_list* array.

Reads or writes from the host using the pointer returned by [clEnqueueMapBuffer](#) or [clEnqueueMapImage](#) are considered to be complete.

[clEnqueueMapBuffer](#) and [clEnqueueMapImage](#) increment the mapped count of the memory object. The initial mapped count value of the memory object is zero. Multiple calls to [clEnqueueMapBuffer](#), or [clEnqueueMapImage](#) on the same memory object will increment this mapped count by appropriate number of calls. [clEnqueueUnmapMemObject](#) decrements the mapped count of the memory object.

[clEnqueueMapBuffer](#), and [clEnqueueMapImage](#) act as synchronization points for a region of the buffer object being mapped.

[clEnqueueUnmapMemObject](#) returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_COMMAND_QUEUE** if *command_queue* is not a valid host command-queue.
- **CL_INVALID_MEM_OBJECT** if *memobj* is not a valid memory object or is a pipe object.
- **CL_INVALID_VALUE** if *mapped_ptr* is not a valid pointer returned by **clEnqueueMapBuffer** or **clEnqueueMapImage** for *memobj*.
- **CL_INVALID_EVENT_WAIT_LIST** if *event_wait_list* is **NULL** and *num_events_in_wait_list* > 0, or if *event_wait_list* is not **NULL** and *num_events_in_wait_list* is 0, or if event objects in *event_wait_list* are not valid events.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.
- **CL_INVALID_CONTEXT** if context associated with *command_queue* and *memobj* are not the same or if the context associated with *command_queue* and events in *event_wait_list* are not the same.

5.5.3. Accessing mapped regions of a memory object

This section describes the behavior of OpenCL commands that access mapped regions of a memory object.

The contents of the region of a memory object and associated memory objects (sub-buffer objects or 1D image buffer objects that overlap this region) mapped for writing (i.e. **CL_MAP_WRITE** or **CL_MAP_WRITE_INVALIDATE_REGION** is set in *map_flags* argument to **clEnqueueMapBuffer**, or **clEnqueueMapImage**) are considered to be undefined until this region is unmapped.

Multiple commands in command-queues can map a region or overlapping regions of a memory object and associated memory objects (sub-buffer objects or 1D image buffer objects that overlap this region) for reading (i.e. *map_flags* = **CL_MAP_READ**). The contents of the regions of a memory object mapped for reading can also be read by kernels and other OpenCL commands (such as **clEnqueueCopyBuffer**) executing on a device(s).

Mapping (and unmapping) overlapped regions in a memory object and/or associated memory objects (sub-buffer objects or 1D image buffer objects that overlap this region) for writing is an error and will result in **CL_INVALID_OPERATION** error returned by **clEnqueueMapBuffer**, or **clEnqueueMapImage**.

If a memory object is currently mapped for writing, the application must ensure that the memory object is unmapped before any enqueued kernels or commands that read from or write to this memory object or any of its associated memory objects (sub-buffer or 1D image buffer objects) or its parent object (if the memory object is a sub-buffer or 1D image buffer object) begin execution; otherwise the behavior is undefined.

If a memory object is currently mapped for reading, the application must ensure that the memory object is unmapped before any enqueued kernels or commands that write to this memory object or any of its associated memory objects (sub-buffer or 1D image buffer objects) or its parent object (if the memory object is a sub-buffer or 1D image buffer object) begin execution; otherwise the behavior is undefined.

A memory object is considered as mapped if there are one or more active mappings for the memory object irrespective of whether the mapped regions span the entire memory object.

Accessing the contents of the memory region referred to by the mapped pointer that has been unmapped is undefined.

The mapped pointer returned by `clEnqueueMapBuffer` or `clEnqueueMapImage` can be used as the `ptr` argument value to `clEnqueueReadBuffer`, `clEnqueueWriteBuffer`, `clEnqueueReadBufferRect`, `clEnqueueWriteBufferRect`, `clEnqueueReadImage`, or `clEnqueueWriteImage` provided the rules described above are adhered to.

5.5.4. Migrating Memory Objects



Migrating memory objects is [missing before](#) version 1.2.

This section describes a mechanism for assigning which device an OpenCL memory object resides. A user may wish to have more explicit control over the location of their memory objects on creation. This could be used to:

- Ensure that an object is allocated on a specific device prior to usage.
- Preemptively migrate an object from one device to another.

To enqueue a command to indicate which device a set of memory objects should be associated with, call the function

```
cl_int clEnqueueMigrateMemObjects(  
    cl_command_queue command_queue,  
    cl_uint num_mem_objects,  
    const cl_mem* mem_objects,  
    cl_mem_migration_flags flags,  
    cl_uint num_events_in_wait_list,  
    const cl_event* event_wait_list,  
    cl_event* event);
```



`clEnqueueMigrateMemObjects` is [missing before](#) version 1.2.

- `command_queue` is a valid host command-queue. The specified set of memory objects in `mem_objects` will be migrated to the OpenCL device associated with `command_queue` or to the host if the `CL_MIGRATE_MEM_OBJECT_HOST` has been specified.
- `num_mem_objects` is the number of memory objects specified in `mem_objects`.
- `mem_objects` is a pointer to a list of memory objects.
- `flags` is a bit-field that is used to specify migration options. The [Memory Migration Flags](#) describes the possible values for flags.
- `event_wait_list` and `num_events_in_wait_list` specify events that need to complete before this particular command can be executed. If `event_wait_list` is `NULL`, then this particular command does not wait on any event to complete. If `event_wait_list` is `NULL`, `num_events_in_wait_list` must

be 0. If *event_wait_list* is not **NULL**, the list of events pointed to by *event_wait_list* must be valid and *num_events_in_wait_list* must be greater than 0. The events specified in *event_wait_list* act as synchronization points. The context associated with events in *event_wait_list* and *command_queue* must be the same. The memory associated with *event_wait_list* can be reused or freed after the function returns.

- *event* returns an event object that identifies this command and can be used to query or queue a wait for this command to complete. If *event* is **NULL** or the enqueue is unsuccessful, no event will be created and therefore it will not be possible to query the status of this command or to wait for this command to complete. If *event_wait_list* and *event* are not **NULL**, *event* must not refer to an element of the *event_wait_list* array.

Table 24. List of supported migration flags by **clEnqueueMigrateMemObjects**

Memory Migration Flags	Description
CL_MIGRATE_MEM_OBJECT_HOST missing before version 1.2.	This flag indicates that the specified set of memory objects are to be migrated to the host, regardless of the target command-queue.
CL_MIGRATE_MEM_OBJECT_CONTENT_UNDEFINED missing before version 1.2.	This flag indicates that the contents of the set of memory objects are undefined after migration. The specified set of memory objects are migrated to the device associated with <i>command_queue</i> without incurring the overhead of migrating their contents.

Typically, memory objects are implicitly migrated to a device for which enqueued commands, using the memory object, are targeted. **clEnqueueMigrateMemObjects** allows this migration to be explicitly performed ahead of the dependent commands. This allows a user to preemptively change the association of a memory object, through regular command-queue scheduling, in order to prepare for another upcoming command. This also permits an application to overlap the placement of memory objects with other unrelated operations before these memory objects are needed potentially hiding transfer latencies. Once the event, returned from **clEnqueueMigrateMemObjects**, has been marked **CL_COMPLETE** the memory objects specified in *mem_objects* have been successfully migrated to the device associated with *command_queue*. The migrated memory object shall remain resident on the device until another command is enqueued that either implicitly or explicitly migrates it away.

clEnqueueMigrateMemObjects can also be used to direct the initial placement of a memory object, after creation, possibly avoiding the initial overhead of instantiating the object on the first enqueued command to use it.

The user is responsible for managing the event dependencies, associated with this command, in order to avoid overlapping access to memory objects. Improperly specified event dependencies passed to **clEnqueueMigrateMemObjects** could result in undefined results.

clEnqueueMigrateMemObjects return **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_COMMAND_QUEUE** if *command_queue* is not a valid host command-queue.

- **CL_INVALID_CONTEXT** if the context associated with *command_queue* and memory objects in *mem_objects* are not the same or if the context associated with *command_queue* and events in *event_wait_list* are not the same.
- **CL_INVALID_MEM_OBJECT** if any of the memory objects in *mem_objects* is not a valid memory object.
- **CL_INVALID_VALUE** if *num_mem_objects* is zero or if *mem_objects* is **NULL**.
- **CL_INVALID_VALUE** if *flags* is not 0 or is not any of the values described in the table above.
- **CL_INVALID_EVENT_WAIT_LIST** if *event_wait_list* is **NULL** and *num_events_in_wait_list* > 0, or *event_wait_list* is not **NULL** and *num_events_in_wait_list* is 0, or if event objects in *event_wait_list* are not valid events.
- **CL_MEM_OBJECT_ALLOCATION_FAILURE** if there is a failure to allocate memory for the specified set of memory objects in *mem_objects*.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

5.5.5. Memory Object Queries

To get information that is common to all memory objects (buffer and image objects), call the function

```
cl_int clGetMemObjectInfo(
    cl_mem memobj,
    cl_mem_info param_name,
    size_t param_value_size,
    void* param_value,
    size_t* param_value_size_ret);
```

- *memobj* specifies the memory object being queried.
- *param_name* specifies the information to query. The list of supported *param_name* types and the information returned in *param_value* by **clGetMemObjectInfo** is described in the [Memory Object Info](#) table.
- *param_value* is a pointer to memory where the appropriate result being queried is returned. If *param_value* is **NULL**, it is ignored.
- *param_value_size* is used to specify the size in bytes of memory pointed to by *param_value*. This size must be ≥ size of return type as described in the [Memory Object Info](#) table.
- *param_value_size_ret* returns the actual size in bytes of data being queried by *param_name*. If *param_value_size_ret* is **NULL**, it is ignored.

Table 25. List of supported *param_names* by **clGetMemObjectInfo**

Memory Object Info	Return type	Description
CL_MEM_TYPE	cl_mem_object_type	<p>Returns one of the following values:</p> <p>CL_MEM_OBJECT_BUFFER if <i>memobj</i> is created with clCreateBuffer, clCreateBufferWithProperties, or clCreateSubBuffer.</p> <p>CL_MEM_OBJECT_IMAGE2D if <i>memobj</i> is created with clCreateImage2D.</p> <p>CL_MEM_OBJECT_IMAGE3D if <i>memobj</i> is created with clCreateImage3D.</p> <p>The value of <i>image_desc</i> → <i>image_type</i> if <i>memobj</i> is created with clCreateImage or clCreateImageWithProperties.</p> <p>CL_MEM_OBJECT_PIPE if <i>memobj</i> is created with clCreatePipe.</p>
CL_MEM_FLAGS	cl_mem_flags	<p>Return the flags argument value specified when <i>memobj</i> is created with clCreateBuffer, clCreateBufferWithProperties, clCreateSubBuffer, clCreateImage, clCreateImageWithProperties, clCreateImage2D, clCreateImage3D, or clCreatePipe.</p> <p>If <i>memobj</i> is a sub-buffer the memory access qualifiers inherited from parent buffer is also returned.</p>
CL_MEM_SIZE	size_t	Return actual size of the data store associated with <i>memobj</i> in bytes.

Memory Object Info	Return type	Description
CL_MEM_HOST_PTR	void*	<p>If <i>memobj</i> is created with clCreateBuffer, clCreateBufferWithProperties, clCreateImage, clCreateImageWithProperties, clCreateImage2D, or clCreateImage3D, and CL_MEM_USE_HOST_PTR is specified in <i>mem_flags</i>, return the <i>host_ptr</i> argument value specified when <i>memobj</i> is created.</p> <p>Otherwise, if <i>memobj</i> is created with clCreateSubBuffer, and <i>memobj</i> is created from a buffer that was created with CL_MEM_USE_HOST_PTR specified in <i>mem_flags</i>, return the <i>host_ptr</i> passed to clCreateBuffer or clCreateBufferWithProperties, plus the origin value specified in <i>buffer_create_info</i> when <i>memobj</i> is created.</p> <p>Otherwise, returns NULL.</p>
CL_MEM_MAP_COUNT ^[10]	cl_uint	Map count.
CL_MEM_REFERENCE_COUNT ^[11]	cl_uint	Return <i>memobj</i> reference count.
CL_MEM_CONTEXT	cl_context	Return context specified when memory object is created. If <i>memobj</i> is created using clCreateSubBuffer , the context associated with the memory object specified as the <i>buffer</i> argument to clCreateSubBuffer is returned.
CL_MEM_ASSOCIATED_MEMOBJECT missing before version 1.1.	cl_mem	<p>Return memory object from which <i>memobj</i> is created.</p> <p>This returns the memory object specified as <i>buffer</i> argument to clCreateSubBuffer if <i>memobj</i> is a subbuffer object created using clCreateSubBuffer.</p> <p>This returns <i>image_desc</i> → <i>mem_object</i> if <i>memobj</i> is an image object created using clCreateImage or clCreateImageWithProperties.</p> <p>Otherwise, returns NULL.</p>
CL_MEM_OFFSET missing before version 1.1.	size_t	<p>Return offset if <i>memobj</i> is a sub-buffer object created using clCreateSubBuffer.</p> <p>This return 0 if <i>memobj</i> is not a subbuffer object.</p>

Memory Object Info	Return type	Description
CL_MEM_USES_SVM_POINTER missing before version 2.0.	cl_bool	Return CL_TRUE if <i>memobj</i> is a buffer object that was created with CL_MEM_USE_HOST_PTR or is a sub-buffer object of a buffer object that was created with CL_MEM_USE_HOST_PTR and the <i>host_ptr</i> specified when the buffer object was created is a SVM pointer; otherwise returns CL_FALSE.
CL_MEM_PROPERTIES missing before version 3.0.	cl_mem_properties[]	<p>Return the properties argument specified in clCreateBufferWithProperties or clCreateImageWithProperties.</p> <p>If the <i>properties</i> argument specified in clCreateBufferWithProperties or clCreateImageWithProperties used to create <i>memobj</i> was not NULL, the implementation must return the values specified in the properties argument in the same order and without including additional properties.</p> <p>If <i>memobj</i> was created using clCreateBuffer, clCreateSubBuffer, clCreateImage, clCreateImage2D, or clCreateImage3D, or if the <i>properties</i> argument specified in clCreateBufferWithProperties or clCreateImageWithProperties was NULL, the implementation must return <i>param_value_size_ret</i> equal to 0, indicating that there are no properties to be returned.</p>

[clGetMemObjectInfo](#) returns CL_SUCCESS if the function is executed successfully. Otherwise, it returns one of the following errors:

- CL_INVALID_MEM_OBJECT if *memobj* is a not a valid memory object.
- CL_INVALID_VALUE if *param_name* is not valid, or if size in bytes specified by *param_value_size* is < size of return type as described in the [Memory Object Info](#) table and *param_value* is not NULL.
- CL_OUT_OF_RESOURCES if there is a failure to allocate resources required by the OpenCL implementation on the device.
- CL_OUT_OF_HOST_MEMORY if there is a failure to allocate resources required by the OpenCL implementation on the host.

5.6. Shared Virtual Memory



Shared virtual memory is [missing before](#) version 2.0.

Shared virtual memory (a.k.a. SVM) allows the host and kernels executing on devices to directly share complex, pointer-containing data structures such as trees and linked lists. It also eliminates the need to marshal data between the host and devices. As a result, SVM substantially simplifies OpenCL programming and may improve performance.

5.6.1. SVM sharing granularity: coarse- and fine- grained sharing

OpenCL maintains memory consistency in a coarse-grained fashion in regions of buffers. We call this coarse-grained sharing. Many platforms such as those with integrated CPU-GPU processors and ones using the SVM-related PCI-SIG IOMMU services can do better, and can support sharing at a granularity smaller than a buffer. We call this fine-grained sharing.

- Coarse-grained sharing: Coarse-grain sharing may be used for memory and virtual pointer sharing between multiple devices as well as between the host and one or more devices. The shared memory region is a memory buffer allocated using `clSVMAlloc`. Memory consistency is guaranteed at synchronization points and the host can use calls to `clEnqueueSVMMap` and `clEnqueueSVMUnmap` or create a `cl_mem` buffer object using the SVM pointer and use OpenCL's existing host API functions `clEnqueueMapBuffer` and `clEnqueueUnmapMemObject` to update regions of the buffer. What coarse-grain buffer SVM adds to OpenCL's earlier buffer support are the ability to share virtual memory pointers and a guarantee that concurrent access to the same memory allocation from multiple kernels on a single device is valid. The coarse-grain buffer SVM provides a memory consistency model similar to the global memory consistency model described in *sections 3.3.1 and 3.4.3* of the OpenCL 1.2 specification. This memory consistency applies to the regions of buffers being shared in a coarse-grained fashion. It is enforced at the synchronization points between commands enqueued to command-queues in a single context with the additional consideration that multiple kernels concurrently running on the same device may safely share the data.
- Fine-grained sharing: Shared virtual memory where memory consistency is maintained at a granularity smaller than a buffer. How fine-grained SVM is used depends on whether the device supports SVM atomic operations.
 - If SVM atomic operations are supported, they provide memory consistency for loads and stores by the host and kernels executing on devices supporting SVM. This means that the host and devices can concurrently read and update the same memory. The consistency provided by SVM atomics is in addition to the consistency provided at synchronization points. There is no need for explicit calls to `clEnqueueSVMMap` and `clEnqueueSVMUnmap` or `clEnqueueMapBuffer` and `clEnqueueUnmapMemObject` on a `cl_mem` buffer object created using the SVM pointer.
 - If SVM atomic operations are not supported, the host and devices can concurrently read the same memory locations and can concurrently update non-overlapping memory regions, but attempts to update the same memory locations are undefined. Memory consistency is guaranteed at synchronization points without the need for explicit calls to `clEnqueueSVMMap` and `clEnqueueSVMUnmap` or `clEnqueueMapBuffer` and `clEnqueueUnmapMemObject` on a `cl_mem` buffer object created using the SVM pointer.
- There are two kinds of fine-grain sharing support. Devices may support either fine-grain buffer sharing or fine-grain system sharing.
 - Fine-grain buffer sharing provides fine-grain SVM only within buffers and is an extension of

coarse-grain sharing. To support fine-grain buffer sharing in an OpenCL context, all devices in the context must support `CL_DEVICE_SVM_FINE_GRAIN_BUFFER`.

- Fine-grain system sharing enables fine-grain sharing of the host's entire virtual memory, including memory regions allocated by the system **malloc** API. OpenCL buffer objects are unnecessary and programmers can pass pointers allocated using **malloc** to OpenCL kernels.

As an illustration of fine-grain SVM using SVM atomic operations to maintain memory consistency, consider the following example. The host and a set of devices can simultaneously access and update a shared work-queue data structure holding work-items to be done. The host can use atomic operations to insert new work-items into the queue at the same time as the devices using similar atomic operations to remove work-items for processing.

It is the programmer's responsibility to ensure that no host code or executing kernels attempt to access a shared memory region after that memory is freed. We require the SVM implementation to work with either 32- or 64- bit host applications subject to the following requirement: the address space size must be the same for the host and all OpenCL devices in the context.

To allocate a shared virtual memory buffer (referred to as a SVM buffer) that can be shared by the host and all devices in an OpenCL context that support shared virtual memory, call the function

```
void* clSVMAlloc(  
    cl_context context,  
    cl_svm_mem_flags flags,  
    size_t size,  
    cl_uint alignment);
```



`clSVMAlloc` is [missing before](#) version 2.0.

- *context* is a valid OpenCL context used to create the SVM buffer.
- *flags* is a bit-field that is used to specify allocation and usage information. The [SVM Memory Flags](#) table describes the possible values for *flags*.
- *size* is the size in bytes of the SVM buffer to be allocated.
- *alignment* is the minimum alignment in bytes that is required for the newly created buffers memory region. It must be a power of two up to the largest data type supported by the OpenCL device. For the full profile, the largest data type is long16. For the embedded profile, it is long16 if the device supports 64-bit integers; otherwise it is int16. If alignment is 0, a default alignment will be used that is equal to the size of largest data type supported by the OpenCL implementation.

Table 26. List of supported SVM memory flag values

SVM Memory Flags	Description
<code>CL_MEM_READ_WRITE</code>	This flag specifies that the SVM buffer will be read and written by a kernel. This is the default.

SVM Memory Flags	Description
<code>CL_MEM_WRITE_ONLY</code>	<p>This flag specifies that the SVM buffer will be written but not read by a kernel.</p> <p>Reading from a SVM buffer created with <code>CL_MEM_WRITE_ONLY</code> inside a kernel is undefined.</p> <p><code>CL_MEM_READ_WRITE</code> and <code>CL_MEM_WRITE_ONLY</code> are mutually exclusive.</p>
<code>CL_MEM_READ_ONLY</code>	<p>This flag specifies that the SVM buffer object is a read-only memory object when used inside a kernel.</p> <p>Writing to a SVM buffer created with <code>CL_MEM_READ_ONLY</code> inside a kernel is undefined.</p> <p><code>CL_MEM_READ_WRITE</code> or <code>CL_MEM_WRITE_ONLY</code> and <code>CL_MEM_READ_ONLY</code> are mutually exclusive.</p>
<code>CL_MEM_SVM_FINE_GRAIN_BUFFER</code> <code>missing before</code> version 2.0.	This specifies that the application wants the OpenCL implementation to do a fine-grained allocation.
<code>CL_MEM_SVM_ATOMICS</code> <code>missing before</code> version 2.0.	This flag is valid only if <code>CL_MEM_SVM_FINE_GRAIN_BUFFER</code> is specified in flags. It is used to indicate that SVM atomic operations can control visibility of memory accesses in this SVM buffer.

If `CL_MEM_SVM_FINE_GRAIN_BUFFER` is not specified, the buffer can be created as a coarse grained SVM allocation. Similarly, if `CL_MEM_SVM_ATOMICS` is not specified, the buffer can be created without support for SVM atomic operations (refer to an OpenCL kernel language specifications).

Calling `clSVMAlloc` does not itself provide consistency for the shared memory region. When the host cannot use the SVM atomic operations, it must rely on OpenCL's guaranteed memory consistency at synchronization points.

For SVM to be used efficiently, the host and any devices sharing a buffer containing virtual memory pointers should have the same endianness. If the context passed to `clSVMAlloc` has devices with mixed endianness and the OpenCL implementation is unable to implement SVM because of that mixed endianness, `clSVMAlloc` will fail and return `NULL`.

Although SVM is generally not supported for image objects, `clCreateImage` and `clCreateImageWithProperties` may create an image from a buffer (a 1D image from a buffer or a 2D image from buffer) if the buffer specified in its image description parameter is a SVM buffer. Such images have a linear memory representation so their memory can be shared using SVM. However, fine grained sharing and atomics are not supported for image reads and writes in a kernel.

`clSVMAlloc` returns a valid non-`NULL` shared virtual memory address if the SVM buffer is

successfully allocated. Otherwise, like **malloc**, it returns a **NULL** pointer value. **clSVMAlloc** will fail if

- *context* is not a valid context, or no devices in *context* support SVM.
- *flags* does not contain **CL_MEM_SVM_FINE_GRAIN_BUFFER** but does contain **CL_MEM_SVM_ATOMICS**.
- Values specified in *flags* do not follow rules described for supported values in the [SVM Memory Flags](#) table.
- **CL_MEM_SVM_FINE_GRAIN_BUFFER** or **CL_MEM_SVM_ATOMICS** is specified in *flags* and these are not supported by at least one device in *context*.
- The values specified in *flags* are not valid, i.e. don't match those defined in the [SVM Memory Flags](#) table.
- *size* is 0 or > **CL_DEVICE_MAX_MEM_ALLOC_SIZE** value for any device in *context*.
- *alignment* is not a power of two or the OpenCL implementation cannot support the specified alignment for at least one device in *context*.
- There was a failure to allocate resources.

To free a shared virtual memory buffer allocated using **clSVMAlloc**, call the function

```
void clSVMFree(  
    cl_context context,  
    void* svm_pointer);
```



clSVMFree is [missing before](#) version 2.0.

- *context* is a valid OpenCL context used to create the SVM buffer. If no devices in *context* support SVM, no action occurs.
- *svm_pointer* must be the value returned by a call to **clSVMAlloc**. If a **NULL** pointer is passed in *svm_pointer*, no action occurs.

Note that **clSVMFree** does not wait for previously enqueued commands that may be using *svm_pointer* to finish before freeing *svm_pointer*. It is the responsibility of the application to make sure that enqueued commands that use *svm_pointer* have finished before freeing *svm_pointer*. This can be done by enqueueing a blocking operation such as **clFinish**, **clWaitForEvents**, **clEnqueueReadBuffer** or by registering a callback with the events associated with enqueued commands and when the last enqueued command has finished freeing *svm_pointer*.

The behavior of using *svm_pointer* after it has been freed is undefined. In addition, if a buffer object is created using **clCreateBuffer** or **clCreateBufferWithProperties** with *svm_pointer*, the buffer object must first be released before the *svm_pointer* is freed.

The **clEnqueueSVMFree** API can also be used to enqueue a callback to free the shared virtual memory buffer allocated using **clSVMAlloc** or a shared system memory pointer.

To enqueue a command to free the shared virtual memory allocated using **clSVMAlloc** or a shared system memory pointer, call the function

```

cl_int clEnqueueSVMFree(
    cl_command_queue command_queue,
    cl_uint num_svm_pointers,
    void* svm_pointers[],
    void (CL_CALLBACK* pfn_free_func)(cl_command_queue queue, cl_uint
num_svm_pointers, void* svm_pointers[], void* user_data),
    void* user_data,
    cl_uint num_events_in_wait_list,
    const cl_event* event_wait_list,
    cl_event* event);

```



clEnqueueSVMFree is missing before version 2.0.

- *command_queue* is a valid host command-queue.
- *svm_pointers* and *num_svm_pointers* specify shared virtual memory pointers to be freed. Each pointer in *svm_pointers* that was allocated using **clSVMAlloc** must have been allocated from the same context from which *command_queue* was created. The memory associated with *svm_pointers* can be reused or freed after the function returns.
- *pfn_free_func* specifies the callback function to be called to free the SVM pointers. This callback function may be called asynchronously by the OpenCL implementation. It is the application's responsibility to ensure that the callback function is thread-safe. *pfn_free_func* takes four arguments: *queue* which is the command-queue in which **clEnqueueSVMFree** was enqueued, the count and list of SVM pointers to free and *user_data* which is a pointer to user specified data. If *pfn_free_func* is **NULL**, all pointers specified in *svm_pointers* must be allocated using **clSVMAlloc** and the OpenCL implementation will free these SVM pointers. *pfn_free_func* must be a valid callback function if any SVM pointer to be freed is a shared system memory pointer i.e. not allocated using **clSVMAlloc**. If *pfn_free_func* is a valid callback function, the OpenCL implementation will call *pfn_free_func* to free all the SVM pointers specified in *svm_pointers*.
- *user_data* will be passed as the *user_data* argument when *pfn_free_func* is called. *user_data* can be **NULL**.
- *event_wait_list* and *num_events_in_wait_list* specify events that need to complete before **clEnqueueSVMFree** can be executed. If *event_wait_list* is **NULL**, then **clEnqueueSVMFree** does not wait on any event to complete. If *event_wait_list* is **NULL**, *num_events_in_wait_list* must be 0. If *event_wait_list* is not **NULL**, the list of events pointed to by *event_wait_list* must be valid and *num_events_in_wait_list* must be greater than 0. The events specified in *event_wait_list* act as synchronization points. The context associated with events in *event_wait_list* and *command_queue* must be the same. The memory associated with *event_wait_list* can be reused or freed after the function returns.
- *event* returns an event object that identifies this command and can be used to query or queue a wait for this command to complete. If *event* is **NULL** or the enqueue is unsuccessful, no event will be created and therefore it will not be possible to query the status of this command or to wait for this command to complete. If *event_wait_list* and *event* are not **NULL**, *event* must not refer to an element of the *event_wait_list* array.

clEnqueueSVMFree returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it

returns one of the following errors:

- **CL_INVALID_COMMAND_QUEUE** if *command_queue* is not a valid host command-queue.
- **CL_INVALID_OPERATION** if the device associated with *command_queue* does not support SVM.
- **CL_INVALID_VALUE** if *num_svm_pointers* is 0 and *svm_pointers* is non-**NULL**, or if *svm_pointers* is **NULL** and *num_svm_pointers* is not 0.
- **CL_INVALID_EVENT_WAIT_LIST** if *event_wait_list* is **NULL** and *num_events_in_wait_list* > 0, or *event_wait_list* is not **NULL** and *num_events_in_wait_list* is 0, or if event objects in *event_wait_list* are not valid events.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

To enqueue a command to do a memcpy operation, call the function

```
cl_int clEnqueueSVMMemcpy(  
    cl_command_queue command_queue,  
    cl_bool blocking_copy,  
    void* dst_ptr,  
    const void* src_ptr,  
    size_t size,  
    cl_uint num_events_in_wait_list,  
    const cl_event* event_wait_list,  
    cl_event* event);
```



clEnqueueSVMMemcpy is missing before version 2.0.

- *command_queue* refers to the host command-queue in which the read / write command will be queued. If either *dst_ptr* or *src_ptr* is allocated using **clSVMAlloc** then the OpenCL context allocated against must match that of *command_queue*.
- *blocking_copy* indicates if the copy operation is *blocking* or *non-blocking*.
- If *blocking_copy* is **CL_TRUE** i.e. the copy command is blocking, **clEnqueueSVMMemcpy** does not return until the buffer data has been copied into memory pointed to by *dst_ptr*.
- *size* is the size in bytes of data being copied.
- *dst_ptr* is the pointer to a host or SVM memory allocation where data is copied to.
- *src_ptr* is the pointer to a host or SVM memory allocation where data is copied from.
- *event_wait_list* and *num_events_in_wait_list* specify events that need to complete before this particular command can be executed. If *event_wait_list* is **NULL**, then this particular command does not wait on any event to complete. If *event_wait_list* is **NULL**, *num_events_in_wait_list* must be 0. If *event_wait_list* is not **NULL**, the list of events pointed to by *event_wait_list* must be valid and *num_events_in_wait_list* must be greater than 0. The events specified in *event_wait_list* act as synchronization points. The context associated with events in *event_wait_list* and

command_queue must be the same. The memory associated with *event_wait_list* can be reused or freed after the function returns.

- *event* returns an event object that identifies this read / write command and can be used to query or queue a wait for this command to complete. If *event* is **NULL** or the enqueue is unsuccessful, no event will be created and therefore it will not be possible to query the status of this command or to wait for this command to complete. If *event_wait_list* and *event* are not **NULL**, *event* must not refer to an element of the *event_wait_list* array.

If *blocking_copy* is **CL_FALSE** i.e. the copy command is non-blocking, **clEnqueueSVMMemcpy** queues a non-blocking copy command and returns. The contents of the buffer that *dst_ptr* points to cannot be used until the copy command has completed. The *event* argument returns an event object which can be used to query the execution status of the read command. When the copy command has completed, the contents of the buffer that *dst_ptr* points to can be used by the application.

If the memory allocation(s) containing *dst_ptr* and/or *src_ptr* are allocated using **clSVMAlloc** and either is not allocated from the same context from which *command_queue* was created the behavior is undefined.

clEnqueueSVMMemcpy returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_COMMAND_QUEUE** if *command_queue* is not a valid host command-queue.
- **CL_INVALID_OPERATION** if the device associated with *command_queue* does not support SVM.
- **CL_INVALID_CONTEXT** if the context associated with *command_queue* and events in *event_wait_list* are not the same.
- **CL_INVALID_EVENT_WAIT_LIST** if *event_wait_list* is **NULL** and *num_events_in_wait_list* > 0, or *event_wait_list* is not **NULL** and *num_events_in_wait_list* is 0, or if event objects in *event_wait_list* are not valid events.
- **CL_EXEC_STATUS_ERROR_FOR_EVENTS_IN_WAIT_LIST** if the copy operation is blocking and the execution status of any of the events in *event_wait_list* is a negative integer value.
- **CL_INVALID_VALUE** if *dst_ptr* or *src_ptr* is **NULL**.
- **CL_MEM_COPY_OVERLAP** if the values specified for *dst_ptr*, *src_ptr* and *size* result in an overlapping copy.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

To enqueue a command to fill a region in memory with a pattern of a given pattern size, call the function

```

cl_int clEnqueueSVMMemFill(
    cl_command_queue command_queue,
    void* svm_ptr,
    const void* pattern,
    size_t pattern_size,
    size_t size,
    cl_uint num_events_in_wait_list,
    const cl_event* event_wait_list,
    cl_event* event);

```



clEnqueueSVMMemFill is missing before version 2.0.

- *command_queue* refers to the host command-queue in which the fill command will be queued. The OpenCL context associated with *command_queue* and SVM pointer referred to by *svm_ptr* must be the same.
- *svm_ptr* is a pointer to a memory region that will be filled with *pattern*. It must be aligned to *pattern_size* bytes. If *svm_ptr* is allocated using **clSVMAlloc** then it must be allocated from the same context from which *command_queue* was created. Otherwise the behavior is undefined.
- *pattern* is a pointer to the data pattern of size *pattern_size* in bytes. *pattern* will be used to fill a region in *buffer* starting at *svm_ptr* and is *size* bytes in size. The data pattern must be a scalar or vector integer or floating-point data type supported by OpenCL as described in [Shared Application Scalar Data Types](#) and [Supported Application Vector Data Types](#). For example, if region pointed to by *svm_ptr* is to be filled with a pattern of float4 values, then *pattern* will be a pointer to a `cl_float4` value and *pattern_size* will be `sizeof(cl_float4)`. The maximum value of *pattern_size* is the size of the largest integer or floating-point vector data type supported by the OpenCL device. The memory associated with *pattern* can be reused or freed after the function returns.
- *size* is the size in bytes of region being filled starting with *svm_ptr* and must be a multiple of *pattern_size*.
- *event_wait_list* and *num_events_in_wait_list* specify events that need to complete before this particular command can be executed. If *event_wait_list* is `NULL`, then this particular command does not wait on any event to complete. If *event_wait_list* is `NULL`, *num_events_in_wait_list* must be 0. If *event_wait_list* is not `NULL`, the list of events pointed to by *event_wait_list* must be valid and *num_events_in_wait_list* must be greater than 0. The events specified in *event_wait_list* act as synchronization points. The context associated with events in *event_wait_list* and *command_queue* must be the same. The memory associated with *event_wait_list* can be reused or freed after the function returns.
- *event* returns an event object that identifies this command and can be used to query or queue a wait for this command to complete. If *event* is `NULL` or the enqueue is unsuccessful, no event will be created and therefore it will not be possible to query the status of this command or to wait for this command to complete. If *event_wait_list* and *event* are not `NULL`, *event* must not refer to an element of the *event_wait_list* array.

clEnqueueSVMMemFill returns `CL_SUCCESS` if the function is executed successfully. Otherwise, it returns one of the following errors:

- `CL_INVALID_COMMAND_QUEUE` if *command_queue* is not a valid host command-queue.
- `CL_INVALID_OPERATION` if the device associated with *command_queue* does not support SVM.
- `CL_INVALID_CONTEXT` if the context associated with *command_queue* and events in *event_wait_list* are not the same.
- `CL_INVALID_VALUE` if *svm_ptr* is `NULL`.
- `CL_INVALID_VALUE` if *svm_ptr* is not aligned to *pattern_size* bytes.
- `CL_INVALID_VALUE` if *pattern* is `NULL` or if *pattern_size* is 0 or if *pattern_size* is not one of {1, 2, 4, 8, 16, 32, 64, 128}.
- `CL_INVALID_VALUE` if *size* is not a multiple of *pattern_size*.
- `CL_INVALID_EVENT_WAIT_LIST` if *event_wait_list* is `NULL` and *num_events_in_wait_list* > 0, or *event_wait_list* is not `NULL` and *num_events_in_wait_list* is 0, or if event objects in *event_wait_list* are not valid events.
- `CL_OUT_OF_RESOURCES` if there is a failure to allocate resources required by the OpenCL implementation on the device.
- `CL_OUT_OF_HOST_MEMORY` if there is a failure to allocate resources required by the OpenCL implementation on the host.

To enqueue a command that will allow the host to update a region of a SVM buffer, call the function

```
cl_int clEnqueueSVMMap(
    cl_command_queue command_queue,
    cl_bool blocking_map,
    cl_map_flags flags,
    void* svm_ptr,
    size_t size,
    cl_uint num_events_in_wait_list,
    const cl_event* event_wait_list,
    cl_event* event);
```



`clEnqueueSVMMap` is missing before version 2.0.

- *command_queue* must be a valid host command-queue.
- *blocking_map* indicates if the map operation is *blocking* or *non-blocking*.
- *map_flags* is a bit-field and is described in the [Memory Map Flags](#) table.
- *svm_ptr* and *size* are a pointer to a memory region and size in bytes that will be updated by the host. If *svm_ptr* is allocated using `clSVMAlloc` then it must be allocated from the same context from which *command_queue* was created. Otherwise the behavior is undefined.
- *event_wait_list* and *num_events_in_wait_list* specify events that need to complete before this particular command can be executed. If *event_wait_list* is `NULL`, then this particular command does not wait on any event to complete. If *event_wait_list* is `NULL`, *num_events_in_wait_list* must be 0. If *event_wait_list* is not `NULL`, the list of events pointed to by *event_wait_list* must be valid and *num_events_in_wait_list* must be greater than 0. The events specified in *event_wait_list* act

as synchronization points. The context associated with events in *event_wait_list* and *command_queue* must be the same. The memory associated with *event_wait_list* can be reused or freed after the function returns.

- *event* returns an event object that identifies this command and can be used to query or queue a wait for this command to complete. If *event* is **NULL** or the enqueue is unsuccessful, no event will be created and therefore it will not be possible to query the status of this command or to wait for this command to complete. If *event_wait_list* and *event* are not **NULL**, *event* must not refer to an element of the *event_wait_list* array.

If *blocking_map* is **CL_TRUE**, **clEnqueueSVMMap** does not return until the application can access the contents of the SVM region specified by *svm_ptr* and *size* on the host.

If *blocking_map* is **CL_FALSE** i.e. map operation is non-blocking, the region specified by *svm_ptr* and *size* cannot be used until the map command has completed. The *event* argument returns an event object which can be used to query the execution status of the map command. When the map command is completed, the application can access the contents of the region specified by *svm_ptr* and *size*.

Note that since we are enqueueing a command with a SVM buffer, the region is already mapped in the host address space.

clEnqueueSVMMap returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_COMMAND_QUEUE** if *command_queue* is not a valid host command-queue.
- **CL_INVALID_OPERATION** if the device associated with *command_queue* does not support SVM.
- **CL_INVALID_CONTEXT** if context associated with *command_queue* and events in *event_wait_list* are not the same.
- **CL_INVALID_VALUE** if *svm_ptr* is **NULL**.
- **CL_INVALID_VALUE** if *size* is 0 or if values specified in *map_flags* are not valid.
- **CL_INVALID_EVENT_WAIT_LIST** if *event_wait_list* is **NULL** and *num_events_in_wait_list* > 0, or *event_wait_list* is not **NULL** and *num_events_in_wait_list* is 0, or if event objects in *event_wait_list* are not valid events.
- **CL_EXEC_STATUS_ERROR_FOR_EVENTS_IN_WAIT_LIST** if the map operation is blocking and the execution status of any of the events in *event_wait_list* is a negative integer value.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

To enqueue a command to indicate that the host has completed updating the region given by *svm_ptr* and which was specified in a previous call to **clEnqueueSVMMap**, call the function


```
cl_int clEnqueueSVMUnmap(
    cl_command_queue command_queue,
    void* svm_ptr,
    cl_uint num_events_in_wait_list,
    const cl_event* event_wait_list,
    cl_event* event);
```



clEnqueueSVMUnmap is missing before version 2.0.

- *command_queue* must be a valid host command-queue.
- *svm_ptr* is a pointer that was specified in a previous call to **clEnqueueSVMMap**. If *svm_ptr* is allocated using **clSVMAlloc** then it must be allocated from the same context from which *command_queue* was created. Otherwise the behavior is undefined.
- *event_wait_list* and *num_events_in_wait_list* specify events that need to complete before **clEnqueueSVMUnmap** can be executed. If *event_wait_list* is **NULL**, then **clEnqueueSVMUnmap** does not wait on any event to complete. If *event_wait_list* is **NULL**, *num_events_in_wait_list* must be 0. If *event_wait_list* is not **NULL**, the list of events pointed to by *event_wait_list* must be valid and *num_events_in_wait_list* must be greater than 0. The events specified in *event_wait_list* act as synchronization points. The context associated with events in *event_wait_list* and *command_queue* must be the same. The memory associated with *event_wait_list* can be reused or freed after the function returns.
- *event* returns an event object that identifies this command and can be used to query or queue a wait for this command to complete. If *event* is **NULL** or the enqueue is unsuccessful, no event will be created and therefore it will not be possible to query the status of this command or to wait for this command to complete. If *event_wait_list* and *event* are not **NULL**, *event* must not refer to an element of the *event_wait_list* array.

clEnqueueSVMMap and **clEnqueueSVMUnmap** act as synchronization points for the region of the SVM buffer specified in these calls.

clEnqueueSVMUnmap returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_COMMAND_QUEUE** if *command_queue* is not a valid host command-queue.
- **CL_INVALID_OPERATION** if the device associated with *command_queue* does not support SVM.
- **CL_INVALID_CONTEXT** if context associated with *command_queue* and events in *event_wait_list* are not the same.
- **CL_INVALID_VALUE** if *svm_ptr* is **NULL**.
- **CL_INVALID_EVENT_WAIT_LIST** if *event_wait_list* is **NULL** and *num_events_in_wait_list* > 0, or if *event_wait_list* is not **NULL** and *num_events_in_wait_list* is 0, or if event objects in *event_wait_list* are not valid events.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL

implementation on the host.



If a coarse-grained SVM buffer is currently mapped for writing, the application must ensure that the SVM buffer is unmapped before any enqueued kernels or commands that read from or write to this SVM buffer or any of its associated `cl_mem` buffer objects begin execution; otherwise the behavior is undefined.

If a coarse-grained SVM buffer is currently mapped for reading, the application must ensure that the SVM buffer is unmapped before any enqueued kernels or commands that write to this memory object or any of its associated `cl_mem` buffer objects begin execution; otherwise the behavior is undefined.

A SVM buffer is considered as mapped if there are one or more active mappings for the SVM buffer irrespective of whether the mapped regions span the entire SVM buffer.

The above note does not apply to fine-grained SVM buffers (fine-grained buffers allocated using `clSVMAlloc` or fine-grained system allocations).

To enqueue a command to indicate which device a set of ranges of SVM allocations should be associated with, call the function

```
cl_int clEnqueueSVMigrateMem(  
    cl_command_queue command_queue,  
    cl_uint num_svm_pointers,  
    const void** svm_pointers,  
    const size_t* sizes,  
    cl_mem_migration_flags flags,  
    cl_uint num_events_in_wait_list,  
    const cl_event* event_wait_list,  
    cl_event* event);
```



`clEnqueueSVMigrateMem` is missing before version 2.1.

- `command_queue` is a valid host command-queue. The specified set of allocation ranges will be migrated to the OpenCL device associated with `command_queue`.
- `num_svm_pointers` is the number of pointers in the specified `svm_pointers` array, and the number of sizes in the `sizes` array, if `sizes` is not `NULL`.
- `svm_pointers` is a pointer to an array of pointers. Each pointer in this array must be within an allocation produced by a call to `clSVMAlloc`.
- `sizes` is an array of sizes. The pair `svm_pointers[i]` and `sizes[i]` together define the starting address and number of bytes in a range to be migrated. `sizes` may be `NULL` indicating that every allocation containing any `svm_pointer[i]` is to be migrated. Also, if `sizes[i]` is zero, then the entire allocation containing `svm_pointer[i]` is migrated.
- `flags` is a bit-field that is used to specify migration options. The [Memory Migration Flags](#) describes the possible values for `flags`.

- *event_wait_list* and *num_events_in_wait_list* specify events that need to complete before this particular command can be executed. If *event_wait_list* is **NULL**, then this particular command does not wait on any event to complete. If *event_wait_list* is **NULL**, *num_events_in_wait_list* must be 0. If *event_wait_list* is not **NULL**, the list of events pointed to by *event_wait_list* must be valid and *num_events_in_wait_list* must be greater than 0. The events specified in *event_wait_list* act as synchronization points. The context associated with events in *event_wait_list* and *command_queue* must be the same. The memory associated with *event_wait_list* can be reused or freed after the function returns.
- *event* returns an event object that identifies this command and can be used to query or queue a wait for this command to complete. If *event* is **NULL** or the enqueue is unsuccessful, no event will be created and therefore it will not be possible to query the status of this command or to wait for this command to complete. If *event_wait_list* and *event* are not **NULL**, *event* must not refer to an element of the *event_wait_list* array.

Once the event returned by **clEnqueueSVMigrateMem** has become **CL_COMPLETE**, the ranges specified by svm pointers and sizes have been successfully migrated to the device associated with command-queue.

The user is responsible for managing the event dependencies associated with this command in order to avoid overlapping access to SVM allocations. Improperly specified event dependencies passed to **clEnqueueSVMigrateMem** could result in undefined results.

clEnqueueSVMigrateMem returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_COMMAND_QUEUE** if *command_queue* is not a valid host command-queue.
- **CL_INVALID_OPERATION** if the device associated with *command_queue* does not support SVM.
- **CL_INVALID_CONTEXT** if context associated with *command_queue* and events in *event_wait_list* are not the same.
- **CL_INVALID_VALUE** if *num_svm_pointers* is zero or *svm_pointers* is **NULL**.
- **CL_INVALID_VALUE** if *sizes[i]* is non-zero range [*svm_pointers[i]*, *svm_pointers[i]*+*sizes[i]*) is not contained within an existing **clSVMAlloc** allocation.
- **CL_INVALID_EVENT_WAIT_LIST** if *event_wait_list* is **NULL** and *num_events_in_wait_list* > 0, or if *event_wait_list* is not **NULL** and *num_events_in_wait_list* is 0, or if event objects in *event_wait_list* are not valid events.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

5.6.2. Memory consistency for SVM allocations

To ensure memory consistency in SVM allocations, the program can rely on the guaranteed memory consistency at synchronization points. This consistency support already exists in OpenCL 1.x and can be used for coarse-grained SVM allocations or for fine-grained buffer SVM allocations; what SVM adds is the ability to share pointers between the host and all SVM devices.

In addition, sub-buffers can also be used to ensure that each device gets a consistent view of a SVM buffers memory when it is shared by multiple devices. For example, assume that two devices share a SVM pointer. The host can create a `cl_mem` buffer object using `clCreateBuffer` or `clCreateBufferWithProperties` with `CL_MEM_USE_HOST_PTR` and `host_ptr` set to the SVM pointer and then create two disjoint sub-buffers with starting virtual addresses `sb1_ptr` and `sb2_ptr`. These pointers (`sb1_ptr` and `sb2_ptr`) can be passed to kernels executing on the two devices. `clEnqueueMapBuffer` and `clEnqueueUnmapMemObject` and the existing [access rules for memory objects](#) ensure consistency for buffer regions (`sb1_ptr` and `sb2_ptr`) read and written by these kernels.

When the host and devices are able to use SVM atomic operations (i.e. `CL_DEVICE_SVM_ATOMICS` is set in `CL_DEVICE_SVM_CAPABILITIES`), these atomic operations can be used to provide memory consistency at a fine grain in a shared memory region. The effect of these operations is visible to the host and all devices with which that memory is shared.

5.7. Sampler Objects

A sampler object describes how to sample an image when the image is read in the kernel. The built-in functions to read from an image in a kernel take a sampler as an argument. The sampler arguments to the image read function can be sampler objects created using OpenCL functions and passed as argument values to the kernel or can be samplers declared inside a kernel. In this section we discuss how sampler objects are created using OpenCL functions.

5.7.1. Creating Sampler Objects

To create a sampler object, call the function

```
cl_sampler clCreateSamplerWithProperties(
    cl_context context,
    const cl_sampler_properties* sampler_properties,
    cl_int* errcode_ret);
```



`clCreateSamplerWithProperties` is [missing before](#) version 2.0.

- `context` must be a valid OpenCL context.
- `sampler_properties` specifies a list of sampler property names and their corresponding values. Each sampler property name is immediately followed by the corresponding desired value. The list is terminated with 0. The list of supported properties is described in the [Sampler Properties](#) table. If a supported property and its value is not specified in `sampler_properties`, its default value will be used. `sampler_properties` can be `NULL` in which case the default values for supported sampler properties will be used.

Table 27. List of supported sampler creation properties by `clCreateSamplerWithProperties`

Sampler Property	Property Value	Description
<code>CL_SAMPLER_NORMALIZED_COORDS</code>	<code>cl_bool</code>	<p>A boolean value that specifies whether the image coordinates specified are normalized or not.</p> <p>The default value (i.e. the value used if this property is not specified in <code>sampler_properties</code>) is <code>CL_TRUE</code>.</p>
<code>CL_SAMPLER_ADDRESSING_MODE</code>	<code>cl_addressing_mode</code>	<p>Specifies how out-of-range image coordinates are handled when reading from an image. Valid values are:</p> <p><code>CL_ADDRESS_NONE</code> - Behavior is undefined for out-of-range image coordinates.</p> <p><code>CL_ADDRESS_CLAMP_TO_EDGE</code> - Out-of-range image coordinates are clamped to the edge of the image.</p> <p><code>CL_ADDRESS_CLAMP</code> - Out-of-range image coordinates are assigned a border color value.</p> <p><code>CL_ADDRESS_REPEAT</code> - Out-of-range image coordinates read from the image as if the image data were replicated in all dimensions.</p> <p><code>CL_ADDRESS_MIRRORED_REPEAT</code> - Out-of-range image coordinates read from the image as if the image data were replicated in all dimensions, mirroring the image contents at the edge of each replication.</p> <p>The default is <code>CL_ADDRESS_CLAMP</code>.</p>
<code>CL_SAMPLER_FILTER_MODE</code>	<code>cl_filter_mode</code>	<p>Specifies the type of filter that is applied when reading an image. Valid values are:</p> <p><code>CL_FILTER_NEAREST</code> - Returns the image element nearest to the image coordinate.</p> <p><code>CL_FILTER_LINEAR</code> - Returns a weighted average of the four image elements nearest to the image coordinate.</p> <p>The default value is <code>CL_FILTER_NEAREST</code>.</p>

- `errcode_ret` will return an appropriate error code. If `errcode_ret` is `NULL`, no error code is

returned.

clCreateSamplerWithProperties returns a valid non-zero sampler object and *errcode_ret* is set to **CL_SUCCESS** if the sampler object is created successfully. Otherwise, it returns a **NULL** value with one of the following error values returned in *errcode_ret*:

- **CL_INVALID_CONTEXT** if *context* is not a valid context.
- **CL_INVALID_VALUE** if the property name in *sampler_properties* is not a supported property name, if the value specified for a supported property name is not valid, or if the same property name is specified more than once.
- **CL_INVALID_OPERATION** if images are not supported by any device associated with *context* (i.e. **CL_DEVICE_IMAGE_SUPPORT** specified in the [Device Queries](#) table is **CL_FALSE**).
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

To create a sampler object, call the function

```
cl_sampler clCreateSampler(  
    cl_context context,  
    cl_bool normalized_coords,  
    cl_addressing_mode addressing_mode,  
    cl_filter_mode filter_mode,  
    cl_int* errcode_ret);
```



clCreateSampler is deprecated by version 2.0.

- *context* must be a valid OpenCL context.
- *normalized_coords* has the same interpretation as **CL_SAMPLER_NORMALIZED_COORDS** in the [sampler creation properties table](#).
- *addressing_mode* has the same interpretation as **CL_SAMPLER_ADDRESSING_MODE** in the [sampler creation properties table](#).
- *filter_mode* has the same interpretation as **CL_SAMPLER_FILTER_MODE** in the [sampler creation properties table](#).
- *errcode_ret* will return an appropriate error code. If *errcode_ret* is **NULL**, no error code is returned.

clCreateSampler returns a valid non-zero sampler object and *errcode_ret* is set to **CL_SUCCESS** if the sampler object is created successfully. Otherwise, it returns a **NULL** value with one of the following error values returned in *errcode_ret*:

- **CL_INVALID_CONTEXT** if *context* is not a valid context.
- **CL_INVALID_VALUE** if *addressing_mode*, *filter_mode*, *normalized_coords* or a combination of these arguments are not valid.

- **CL_INVALID_OPERATION** if images are not supported by any device associated with *context* (i.e. **CL_DEVICE_IMAGE_SUPPORT** specified in the [Device Queries](#) table is **CL_FALSE**).
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

To retain a sampler object, call the function

```
cl_int clRetainSampler(
    cl_sampler sampler);
```

- *sampler* specifies the sampler to be released.

The *sampler* reference count is incremented. [clCreateSamplerWithProperties](#) and [clCreateSampler](#) perform an implicit retain.

[clRetainSampler](#) returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_SAMPLER** if *sampler* is not a valid sampler object.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

To release a sampler object, call the function

```
cl_int clReleaseSampler(
    cl_sampler sampler);
```

- *sampler* specifies the sampler to be released.

The *sampler* reference count is decremented. The sampler object is deleted after the reference count becomes zero and commands queued for execution on a command-queue(s) that use *sampler* have finished.

[clReleaseSampler](#) returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_SAMPLER** if *sampler* is not a valid sampler object.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

Using this function to release a reference that was not obtained by creating the object or by calling `clRetainSampler` causes undefined behavior.

5.7.2. Sampler Object Queries

To return information about a sampler object, call the function

```
cl_int clGetSamplerInfo(  
    cl_sampler sampler,  
    cl_sampler_info param_name,  
    size_t param_value_size,  
    void* param_value,  
    size_t* param_value_size_ret);
```

- *sampler* specifies the sampler being queried.
- *param_name* specifies the information to query. The list of supported *param_name* types and the information returned in *param_value* by `clGetSamplerInfo` is described in the [Sampler Object Queries](#) table.
- *param_value* is a pointer to memory where the appropriate result being queried is returned. If *param_value* is `NULL`, it is ignored.
- *param_value_size* is used to specify the size in bytes of memory pointed to by *param_value*. This size must be \geq size of return type as described in the [Sampler Object Queries](#) table.
- *param_value_size_ret* returns the actual size in bytes of data being queried by *param_name*. If *param_value_size_ret* is `NULL`, it is ignored.

Table 28. List of supported *param_names* by `clGetSamplerInfo`

Sampler Info	Return Type	Description
<code>CL_SAMPLER_REFERENCE_COUNT</code> ^[12]	<code>cl_uint</code>	Return the <i>sampler</i> reference count.
<code>CL_SAMPLER_CONTEXT</code>	<code>cl_context</code>	Return the context specified when the sampler is created.
<code>CL_SAMPLER_NORMALIZED_COORDS</code>	<code>cl_bool</code>	Return the normalized coords value associated with <i>sampler</i> .
<code>CL_SAMPLER_ADDRESSING_MODE</code>	<code>cl_addressing_mode</code>	Return the addressing mode value associated with <i>sampler</i> .
<code>CL_SAMPLER_FILTER_MODE</code>	<code>cl_filter_mode</code>	Return the filter mode value associated with <i>sampler</i> .

Sampler Info	Return Type	Description
CL_SAMPLER_PROPERTIES missing before version 3.0.	cl_sampler_properties[]	Return the properties argument specified in clCreateSamplerWithProperties . If the <i>properties</i> argument specified in clCreateSamplerWithProperties used to create <i>sampler</i> was not NULL , the implementation must return the values specified in the properties argument in the same order and without including additional properties. If <i>sampler</i> was created using clCreateSampler , or if the <i>properties</i> argument specified in clCreateSamplerWithProperties was NULL , the implementation must return <i>param_value_size_ret</i> equal to 0, indicating that there are no properties to be returned.

clGetSamplerInfo returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_VALUE** if *param_name* is not valid, or if size in bytes specified by *param_value_size* is < size of return type as described in the [Sampler Object Queries](#) table and *param_value* is not **NULL**.
- **CL_INVALID_SAMPLER** if *sampler* is a not a valid sampler object.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

5.8. Program Objects

An OpenCL program consists of a set of kernels that are identified as functions declared with the **__kernel** qualifier in the program source. OpenCL programs may also contain auxiliary functions and constant data that can be used by kernel functions. The program executable can be generated *online* or *offline* by the OpenCL compiler for the appropriate target device(s).

A program object encapsulates the following information:

- An associated context.
- A program source or binary.
- The latest successfully built program executable, library or compiled binary, the list of devices for which the program executable, library or compiled binary is built, the build options used and a build log.
- The number of kernel objects currently attached.

5.8.1. Creating Program Objects

To create a program object for a context and load source code into that object, call the function

```
cl_program clCreateProgramWithSource(  
    cl_context context,  
    cl_uint count,  
    const char** strings,  
    const size_t* lengths,  
    cl_int* errcode_ret);
```

- *context* must be a valid OpenCL context.
- *strings* is an array of *count* pointers to optionally null-terminated character strings that make up the source code.
- *lengths* argument is an array with the number of chars in each string (the string length). If an element in *lengths* is zero, its accompanying string is null-terminated. If *lengths* is `NULL`, all strings in the *strings* argument are considered null-terminated. Any length value passed in that is greater than zero excludes the null terminator in its count.
- *errcode_ret* will return an appropriate error code. If *errcode_ret* is `NULL`, no error code is returned.

The source code specified by *strings* will be loaded into the program object.

The devices associated with the program object are the devices associated with *context*. The source code specified by *strings* is either an OpenCL C program source, header or implementation-defined source for custom devices that support an online compiler. OpenCL C++ is not supported as an online-compiled kernel language through this interface.

`clCreateProgramWithSource` returns a valid non-zero program object and *errcode_ret* is set to `CL_SUCCESS` if the program object is created successfully. Otherwise, it returns a `NULL` value with one of the following error values returned in *errcode_ret*:

- `CL_INVALID_CONTEXT` if *context* is not a valid context.
- `CL_INVALID_VALUE` if *count* is zero or if *strings* or any entry in *strings* is `NULL`.
- `CL_OUT_OF_RESOURCES` if there is a failure to allocate resources required by the OpenCL implementation on the device.
- `CL_OUT_OF_HOST_MEMORY` if there is a failure to allocate resources required by the OpenCL implementation on the host.

To create a program object for a context and load code in an intermediate language into that object, call the function

```
cl_program clCreateProgramWithIL(
    cl_context context,
    const void* il,
    size_t length,
    cl_int* errcode_ret);
```



clCreateProgramWithIL is missing before version 2.1. Also see extension **cl_khr_il_program**.

- *context* must be a valid OpenCL context.
- *il* is a pointer to a *length*-byte block of memory containing SPIR-V or an implementation-defined intermediate language.
- *errcode_ret* will return an appropriate error code. If *errcode_ret* is **NULL**, no error code is returned.

The intermediate language pointed to by *il* and with length in bytes *length* will be loaded into the program object. The devices associated with the program object are the devices associated with *context*.

clCreateProgramWithIL returns a valid non-zero program object and *errcode_ret* is set to **CL_SUCCESS** if the program object is created successfully. Otherwise, it returns a **NULL** value with one of the following error values returned in *errcode_ret*:

- **CL_INVALID_CONTEXT** if *context* is not a valid context.
- **CL_INVALID_OPERATION** if no devices in *context* support intermediate language programs.
- **CL_INVALID_VALUE** if *il* is **NULL** or if *length* is zero.
- **CL_INVALID_VALUE** if the *length*-byte memory pointed to by *il* does not contain well-formed intermediate language input that can be consumed by the OpenCL runtime.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

To create a program object for a context and load binary bits into that object, call the function

```
cl_program clCreateProgramWithBinary(
    cl_context context,
    cl_uint num_devices,
    const cl_device_id* device_list,
    const size_t* lengths,
    const unsigned char** binaries,
    cl_int* binary_status,
    cl_int* errcode_ret);
```

- *context* must be a valid OpenCL context.
- *device_list* is a pointer to a list of devices that are in *context*. *device_list* must be a non-NULL value. The binaries are loaded for devices specified in this list.
- *num_devices* is the number of devices listed in *device_list*.
- *lengths* is an array of the size in bytes of the program binaries to be loaded for devices specified by *device_list*.
- *binaries* is an array of pointers to program binaries to be loaded for devices specified by *device_list*. For each device given by *device_list*[i], the pointer to the program binary for that device is given by *binaries*[i] and the length of this corresponding binary is given by *lengths*[i]. *lengths*[i] cannot be zero and *binaries*[i] cannot be a NULL pointer.

The devices associated with the program object will be the list of devices specified by *device_list*. The list of devices specified by *device_list* must be devices associated with *context*.

The program binaries specified by *binaries* will be loaded into the program object. They contain bits that describe one of the following:

- a program executable to be run on the device(s) associated with *context*,
- a compiled program for device(s) associated with *context*, or
- a library of compiled programs for device(s) associated with *context*.

The program binary can consist of either or both:

- Device-specific code and/or,
- Implementation-specific intermediate representation (IR) which will be converted to the device-specific code.
- *binary_status* returns whether the program binary for each device specified in *device_list* was loaded successfully or not. It is an array of *num_devices* entries and returns **CL_SUCCESS** in *binary_status*[i] if binary was successfully loaded for device specified by *device_list*[i]; otherwise returns **CL_INVALID_VALUE** if *lengths*[i] is zero or if *binaries*[i] is a NULL value or **CL_INVALID_BINARY** in *binary_status*[i] if program binary is not a valid binary for the specified device. If *binary_status* is NULL, it is ignored.
- *errcode_ret* will return an appropriate error code. If *errcode_ret* is NULL, no error code is returned.

OpenCL allows applications to create a program object using the program source or binary and build appropriate program executables. This can be very useful as it allows applications to load program source and then compile and link to generate a program executable online on its first instance for appropriate OpenCL devices in the system. These executables can now be queried and cached by the application. The cached executables can be read and loaded by the application, which can help significantly reduce the application initialization time.

clCreateProgramWithBinary returns a valid non-zero program object and *errcode_ret* is set to **CL_SUCCESS** if the program object is created successfully. Otherwise, it returns a NULL value with one of the following error values returned in *errcode_ret*:

- `CL_INVALID_CONTEXT` if *context* is not a valid context.
- `CL_INVALID_VALUE` if *device_list* is `NULL` or *num_devices* is zero.
- `CL_INVALID_DEVICE` if any device in *device_list* is not in the list of devices associated with *context*.
- `CL_INVALID_VALUE` if *lengths* or *binaries* is `NULL` or if any entry in *lengths*[i] is zero or *binaries*[i] is `NULL`.
- `CL_INVALID_BINARY` if an invalid program binary was encountered for any device. *binary_status* will return specific status for each device.
- `CL_OUT_OF_RESOURCES` if there is a failure to allocate resources required by the OpenCL implementation on the device.
- `CL_OUT_OF_HOST_MEMORY` if there is a failure to allocate resources required by the OpenCL implementation on the host.

To create a program object for a context and loads the information related to the built-in kernels into that object, call the function

```
cl_program clCreateProgramWithBuiltInKernels(
    cl_context context,
    cl_uint num_devices,
    const cl_device_id* device_list,
    const char* kernel_names,
    cl_int* errcode_ret);
```



`clCreateProgramWithBuiltInKernels` is missing before version 1.2.

- *context* must be a valid OpenCL context.
- *num_devices* is the number of devices listed in *device_list*.
- *device_list* is a pointer to a list of devices that are in *context*. *device_list* must be a non-`NULL` value. The built-in kernels are loaded for devices specified in this list.
- *kernel_names* is a semi-colon separated list of built-in kernel names.

The devices associated with the program object will be the list of devices specified by *device_list*. The list of devices specified by *device_list* must be devices associated with *context*.

`clCreateProgramWithBuiltInKernels` returns a valid non-zero program object and *errcode_ret* is set to `CL_SUCCESS` if the program object is created successfully. Otherwise, it returns a `NULL` value with one of the following error values returned in *errcode_ret*:

- `CL_INVALID_CONTEXT` if *context* is not a valid context.
- `CL_INVALID_VALUE` if *device_list* is `NULL` or *num_devices* is zero.
- `CL_INVALID_VALUE` if *kernel_names* is `NULL` or *kernel_names* contains a kernel name that is not supported by any of the devices in *device_list*.
- `CL_INVALID_DEVICE` if any device in *device_list* is not in the list of devices associated with *context*.
- `CL_OUT_OF_RESOURCES` if there is a failure to allocate resources required by the OpenCL

implementation on the device.

- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

5.8.2. Retaining and Releasing Program Objects

To retain a program object, call the function

```
cl_int clRetainProgram(  
    cl_program program);
```

- *program* is the program object to be retained.

The *program* reference count is incremented. All APIs that create a program do an implicit retain.

clRetainProgram returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_PROGRAM** if *program* is not a valid program object.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

To release a program object, call the function

```
cl_int clReleaseProgram(  
    cl_program program);
```

- *program* is the program object to be released.

The *program* reference count is decremented. The program object is deleted after all kernel objects associated with *program* have been deleted and the *program* reference count becomes zero.

clReleaseProgram returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_PROGRAM** if *program* is not a valid program object.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

Using this function to release a reference that was not obtained by creating the object or by calling **clRetainProgram** causes undefined behavior.

To register a callback function with a program object that is called when the program object is destroyed, call the function

```
cl_int clSetProgramReleaseCallback(  
    cl_program program,  
    void (CL_CALLBACK* pfn_notify)(cl_program program, void* user_data),  
    void* user_data);
```



clSetProgramReleaseCallback is missing before version 2.2 and deprecated by version 3.0.

- *program* specifies the memory object to register the callback to.
- *pfn_notify* is the callback function to register. This callback function may be called asynchronously by the OpenCL implementation. It is the application's responsibility to ensure that the callback function is thread-safe. The parameters to this callback function are:
 - *program* is the program being deleted. When the callback function is called by the implementation, this program object is not longer valid. *program* is only provided for reference purposes.
 - *user_data* is a pointer to user supplied data.
- *user_data* will be passed as the *user_data* argument when *pfn_notify* is called. *user_data* can be **NULL**.

Each call to **clSetProgramReleaseCallback** registers the specified callback function on a callback stack associated with *program*. The registered callback functions are called in the reverse order in which they were registered. The registered callback functions are called after destructors (if any) for program scope global variables (if any) are called and before the program object is deleted. This provides a mechanism for an application to be notified when destructors for program scope global variables are complete.

clSetProgramReleaseCallback may unconditionally return an error if no devices in the context associated with *program* support destructors for program scope global variables. Support for constructors and destructors for program scope global variables is required only for OpenCL 2.2 devices.

clSetProgramReleaseCallback returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_PROGRAM** if *program* is not a valid program object.
- **CL_INVALID_OPERATION** if no devices in the context associated with *program* support destructors for program scope global variables.
- **CL_INVALID_VALUE** if *pfn_notify* is **NULL**.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

5.8.3. Setting SPIR-V specialization constants



Specialization constants are [missing before](#) version 2.2.

To set the value of a specialization constant, call the function

```
cl_int clSetProgramSpecializationConstant(  
    cl_program program,  
    cl_uint spec_id,  
    size_t spec_size,  
    const void* spec_value);
```



clSetProgramSpecializationConstant is [missing before](#) version 2.2.

- *program* must be a valid OpenCL program created from an intermediate language (e.g. SPIR-V).
- *spec_id* identifies the specialization constant whose value will be set.
- *spec_size* specifies the size in bytes of the data pointed to by *spec_value*. This should be 1 for boolean constants. For all other constant types this should match the size of the specialization constant in the module.
- *spec_value* is a pointer to the memory location that contains the value of the specialization constant. The data pointed to by *spec_value* are copied and can be safely reused by the application after **clSetProgramSpecializationConstant** returns. This specialization value will be used by subsequent calls to **clBuildProgram** until another call to **clSetProgramSpecializationConstant** changes it. If a specialization constant is a boolean constant, *spec_value* should be a pointer to a **cl_uchar** value. A value of zero will set the specialization constant to false; any other value will set it to true.

Calling this function multiple times for the same specialization constant shall cause the last provided value to override any previously specified value. The values are used by a subsequent **clBuildProgram** call for the *program*.

Application is not required to provide values for every specialization constant contained in the module. If the value is not set by this API call, default values will be used during the build.

clSetProgramSpecializationConstant returns **CL_SUCCESS** if the function is executed successfully.

Otherwise, it returns one of the following errors:

- **CL_INVALID_PROGRAM** if *program* is not a valid program object created from an intermediate language (e.g. SPIR-V), or if the intermediate language does not support specialization constants.
- **CL_INVALID_OPERATION** if no devices associated with *program* support intermediate language programs.
- **CL_COMPILER_NOT_AVAILABLE** if *program* is created with **clCreateProgramWithIL** and a compiler is not available, i.e. **CL_DEVICE_COMPILER_AVAILABLE** specified in the [Device Queries](#) table is set to **CL_FALSE**.
- **CL_INVALID_SPEC_ID** if *spec_id* is not a valid specialization constant identifier.

- `CL_INVALID_VALUE` if *spec_size* does not match the size of the specialization constant in the module, or if *spec_value* is `NULL`.
- `CL_OUT_OF_RESOURCES` if there is a failure to allocate resources required by the OpenCL implementation on the device.
- `CL_OUT_OF_HOST_MEMORY` if there is a failure to allocate resources required by the OpenCL implementation on the host.

5.8.4. Building Program Executables

To build (compile & link) a program executable, call the function

```
cl_int clBuildProgram(
    cl_program program,
    cl_uint num_devices,
    const cl_device_id* device_list,
    const char* options,
    void (CL_CALLBACK* pfn_notify)(cl_program program, void* user_data),
    void* user_data);
```

- *program* is the program object.
- *device_list* is a pointer to a list of devices associated with *program*. If *device_list* is a `NULL` value, the program executable is built for all devices associated with *program* for which a source or binary has been loaded. If *device_list* is a non-`NULL` value, the program executable is built for devices specified in this list for which a source or binary has been loaded.
- *num_devices* is the number of devices listed in *device_list*.
- *options* is a pointer to a null-terminated string of characters that describes the build options to be used for building the program executable. The list of supported options is described in [Compiler Options](#). If the program was created using `clCreateProgramWithBinary` and *options* is a `NULL` pointer, the program will be built as if *options* were the same as when the program binary was originally built. If the program was created using `clCreateProgramWithBinary` and *options* string contains anything other than the same options in the same order (whitespace ignored) as when the program binary was originally built, then the behavior is implementation-defined. Otherwise, if *options* is a `NULL` pointer then it will have the same result as the empty string.
- *pfn_notify* is a function pointer to a notification routine. The notification routine is a callback function that an application can register and which will be called when the program executable has been built (successfully or unsuccessfully). If *pfn_notify* is not `NULL`, `clBuildProgram` does not need to wait for the build to complete and can return immediately once the build operation can begin. Any state changes of the program object that result from calling `clBuildProgram` (e.g. build status or log) will be observable from this callback function. The build operation can begin if the context, program whose sources are being compiled and linked, list of devices and build options specified are all valid and appropriate host and device resources needed to perform the build are available. If *pfn_notify* is `NULL`, `clBuildProgram` does not return until the build has completed. This callback function may be called asynchronously by the OpenCL implementation. It is the application's responsibility to ensure that the callback function is

thread-safe.

- *user_data* will be passed as an argument when *pfn_notify* is called. *user_data* can be **NULL**.

The program executable is built from the program source or binary for all the devices, or a specific device(s) in the OpenCL context associated with *program*. OpenCL allows program executables to be built using the source or the binary. **clBuildProgram** must be called for *program* created using **clCreateProgramWithSource**, **clCreateProgramWithIL** or **clCreateProgramWithBinary** to build the program executable for one or more devices associated with *program*. If *program* is created with **clCreateProgramWithBinary**, then the program binary must be an executable binary (not a compiled binary or library).

The executable binary can be queried using **clGetProgramInfo**(*program*, **CL_PROGRAM_BINARIES**, ...) and can be specified to **clCreateProgramWithBinary** to create a new program object.

clBuildProgram returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_PROGRAM** if *program* is not a valid program object.
- **CL_INVALID_VALUE** if *device_list* is **NULL** and *num_devices* is greater than zero, or if *device_list* is not **NULL** and *num_devices* is zero.
- **CL_INVALID_VALUE** if *pfn_notify* is **NULL** but *user_data* is not **NULL**.
- **CL_INVALID_DEVICE** if any device in *device_list* is not in the list of devices associated with *program*.
- **CL_INVALID_BINARY** if *program* is created with **clCreateProgramWithBinary** and devices listed in *device_list* do not have a valid program binary loaded.
- **CL_INVALID_BUILD_OPTIONS** if the build options specified by *options* are invalid.
- **CL_COMPILER_NOT_AVAILABLE** if *program* is created with **clCreateProgramWithSource** or **clCreateProgramWithIL** and a compiler is not available, i.e. **CL_DEVICE_COMPILER_AVAILABLE** specified in the [Device Queries](#) table is set to **CL_FALSE**.
- **CL_BUILD_PROGRAM_FAILURE** if there is a failure to build the program executable. This error will be returned if **clBuildProgram** does not return until the build has completed.
- **CL_INVALID_OPERATION** if the build of a program executable for any of the devices listed in *device_list* by a previous call to **clBuildProgram** for *program* has not completed.
- **CL_INVALID_OPERATION** if there are kernel objects attached to *program*.
- **CL_INVALID_OPERATION** if *program* was not created with **clCreateProgramWithSource**, **clCreateProgramWithIL** or **clCreateProgramWithBinary**.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

5.8.5. Separate Compilation and Linking of Programs



Separate compilation and linking are [missing before](#) version 1.2.

OpenCL programs are compiled and linked to support the following:

- Separate compilation and link stages. Program sources can be compiled to generate a compiled binary object and linked in a separate stage with other compiled program objects to the program executable.
- Embedded headers. In OpenCL 1.0 and 1.1, the `-I` build option could be used to specify the list of directories to be searched for headers files that are included by a program source(s). OpenCL 1.2 extends this by allowing the header sources to come from program objects instead of just header files.
- Libraries. The linker can be used to link compiled objects and libraries into a program executable or to create a library of compiled binaries.

To compile a program's source for all the devices or a specific device(s) in the OpenCL context associated with the program, call the function

```
cl_int clCompileProgram(  
    cl_program program,  
    cl_uint num_devices,  
    const cl_device_id* device_list,  
    const char* options,  
    cl_uint num_input_headers,  
    const cl_program* input_headers,  
    const char** header_include_names,  
    void (CL_CALLBACK* pfn_notify)(cl_program program, void* user_data),  
    void* user_data);
```



clCompileProgram is [missing before](#) version 1.2.

- *program* is the program object that is the compilation target.
- *device_list* is a pointer to a list of devices associated with *program*. If *device_list* is a **NULL** value, the compile is performed for all devices associated with *program*. If *device_list* is a non-**NULL** value, the compile is performed for devices specified in this list.
- *num_devices* is the number of devices listed in *device_list*.
- *options* is a pointer to a null-terminated string of characters that describes the compilation options to be used for building the program executable. If *options* is a **NULL** pointer then it will have the same result as the empty string. Certain options are ignored when program is created with IL. The list of supported options is as described in [Compiler Options](#).
- *num_input_headers* specifies the number of programs that describe headers in the array referenced by *input_headers*.
- *input_headers* is an array of program embedded headers created with [clCreateProgramWithSource](#).
- *header_include_names* is an array that has a one to one correspondence with *input_headers*.

Each entry in *header_include_names* specifies the include name used by source in *program* that comes from an embedded header. The corresponding entry in *input_headers* identifies the program object which contains the header source to be used. The embedded headers are first searched before the headers in the list of directories specified by the **-I** compile option (as described in [Preprocessor options](#)). If multiple entries in *header_include_names* refer to the same header name, the first one encountered will be used.

- *pfn_notify* is a function pointer to a notification routine. The notification routine is a callback function that an application can register and which will be called when the program executable has been built (successfully or unsuccessfully). If *pfn_notify* is not **NULL**, **clCompileProgram** does not need to wait for the compiler to complete and can return immediately once the compilation can begin. Any state changes of the program object that result from calling **clCompileProgram** (e.g. compile status or log) will be observable from this callback function. The compilation can begin if the context, program whose sources are being compiled, list of devices, input headers, programs that describe input headers and compiler options specified are all valid and appropriate host and device resources needed to perform the compile are available. If *pfn_notify* is **NULL**, **clCompileProgram** does not return until the compiler has completed. This callback function may be called asynchronously by the OpenCL implementation. It is the application's responsibility to ensure that the callback function is thread-safe.
- *user_data* will be passed as an argument when *pfn_notify* is called. *user_data* can be **NULL**.

The pre-processor runs before the program sources are compiled. The compiled binary is built for all devices associated with *program* or the list of devices specified. The compiled binary can be queried using **clGetProgramInfo(program, CL_PROGRAM_BINARIES, ...)** and can be passed to **clCreateProgramWithBinary** to create a new program object.

If *program* was created using **clCreateProgramWithIL**, then *num_input_headers*, *input_headers*, and *header_include_names* are ignored.

For example, consider the following program source:

```
#include <foo.h>
#include <mydir/myinc.h>
__kernel void
image_filter (int n, int m,
              __constant float *filter_weights,
              __read_only image2d_t src_image,
              __write_only image2d_t dst_image)
{
    ...
}
```

This kernel includes two headers *foo.h* and *mydir/myinc.h*. The following describes how these headers can be passed as embedded headers in program objects:

```
cl_program foo_pg = clCreateProgramWithSource(context,
        1, &foo_header_src, NULL, &err);
cl_program myinc_pg = clCreateProgramWithSource(context,
```



```

1, &myinc_header_src, NULL, &err);

// lets assume the program source described above is given
// by program_A and is loaded via clCreateProgramWithSource
cl_program input_headers[2] = { foo_pg, myinc_pg };
char * input_header_names[2] = { foo.h, mydir/myinc.h };
clCompileProgram(program_A,
                 0, NULL, // num_devices & device_list
                 NULL,   // compile_options
                 2,      // num_input_headers
                 input_headers,
                 input_header_names,
                 NULL, NULL); // pfn_notify & user_data

```

clCompileProgram returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_PROGRAM** if *program* is not a valid program object.
- **CL_INVALID_VALUE** if *device_list* is **NULL** and *num_devices* is greater than zero, or if *device_list* is not **NULL** and *num_devices* is zero.
- **CL_INVALID_VALUE** if *num_input_headers* is zero and *header_include_names* or *input_headers* are not **NULL** or if *num_input_headers* is not zero and *header_include_names* or *input_headers* are **NULL**.
- **CL_INVALID_VALUE** if *pfn_notify* is **NULL** but *user_data* is not **NULL**.
- **CL_INVALID_DEVICE** if device in *device_list* is not in the list of devices associated with *program*.
- **CL_INVALID_COMPILER_OPTIONS** if the compiler options specified by *options* are invalid.
- **CL_INVALID_OPERATION** if the compilation or build of a program executable for any of the devices listed in *device_list* by a previous call to **clCompileProgram** or **clBuildProgram** for *program* has not completed.
- **CL_COMPILER_NOT_AVAILABLE** if a compiler is not available, i.e. **CL_DEVICE_COMPILER_AVAILABLE** specified in the [Device Queries](#) table is set to **CL_FALSE**.
- **CL_COMPILE_PROGRAM_FAILURE** if there is a failure to compile the program source. This error will be returned if **clCompileProgram** does not return until the compile has completed.
- **CL_INVALID_OPERATION** if there are kernel objects attached to *program*.
- **CL_INVALID_OPERATION** if *program* has no source or IL available, i.e. it has not been created with **clCreateProgramWithSource** or **clCreateProgramWithIL**.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

To link a set of compiled program objects and libraries for all the devices or a specific device(s) in the OpenCL context and create a library or executable, call the function


```

cl_program clLinkProgram(
    cl_context context,
    cl_uint num_devices,
    const cl_device_id* device_list,
    const char* options,
    cl_uint num_input_programs,
    const cl_program* input_programs,
    void (CL_CALLBACK* pfn_notify)(cl_program program, void* user_data),
    void* user_data,
    cl_int* errcode_ret);

```



clLinkProgram is missing before version 1.2.

- *context* must be a valid OpenCL context.
- *device_list* is a pointer to a list of devices that are in *context*. If *device_list* is a **NULL** value, the link is performed for all devices associated with *context* for which a compiled object is available. If *device_list* is a non-**NULL** value, the link is performed for devices specified in this list for which a compiled object is available.
- *num_devices* is the number of devices listed in *device_list*.
- *options* is a pointer to a null-terminated string of characters that describes the link options to be used for building the program executable. The list of supported options is as described in [Linker Options](#). If the program was created using **clCreateProgramWithBinary** and *options* is a **NULL** pointer, the program will be linked as if *options* were the same as when the program binary was originally built. If the program was created using **clCreateProgramWithBinary** and *options* string contains anything other than the same options in the same order (whitespace ignored) as when the program binary was originally built, then the behavior is implementation-defined. Otherwise, if *options* is a **NULL** pointer then it will have the same result as the empty string.
- *num_input_programs* specifies the number of programs in array referenced by *input_programs*.
- *input_programs* is an array of program objects that are compiled binaries or libraries that are to be linked to create the program executable. For each device in *device_list* or if *device_list* is **NULL** the list of devices associated with context, the following cases occur:
 - All programs specified by *input_programs* contain a compiled binary or library for the device. In this case, a link is performed to generate a program executable for this device.
 - None of the programs contain a compiled binary or library for that device. In this case, no link is performed and there will be no program executable generated for this device.
 - All other cases will return a **CL_INVALID_OPERATION** error.
- *pfn_notify* is a function pointer to a notification routine. The notification routine is a callback function that an application can register and which will be called when the program executable has been built (successfully or unsuccessfully).
- *user_data* will be passed as an argument when *pfn_notify* is called. *user_data* can be **NULL**.

If *pfn_notify* is not **NULL**, **clLinkProgram** does not need to wait for the linker to complete, and can return immediately once the linking operation can begin. Once the linker has completed, the

pfn_notify callback function is called which returns the program object returned by **clLinkProgram**. Any state changes of the program object that result from calling **clLinkProgram** (e.g. link status or log) will be observable from this callback function. This callback function may be called asynchronously by the OpenCL implementation. It is the application's responsibility to ensure that the callback function is thread-safe.

If *pfn_notify* is **NULL**, **clLinkProgram** does not return until the linker has completed.

clLinkProgram creates a new program object which contains the library or executable. The library or executable binary can be queried using **clGetProgramInfo**(*program*, **CL_PROGRAM_BINARIES**, ...) and can be specified to **clCreateProgramWithBinary** to create a new program object.

The devices associated with the returned program object will be the list of devices specified by *device_list* or if *device_list* is **NULL** it will be the list of devices associated with *context*.

The linking operation can begin if the context, list of devices, input programs and linker options specified are all valid and appropriate host and device resources needed to perform the link are available. If the linking operation can begin, **clLinkProgram** returns a valid non-zero program object.

If *pfn_notify* is **NULL**, the *errcode_ret* will be set to **CL_SUCCESS** if the link operation was successful and **CL_LINK_PROGRAM_FAILURE** if there is a failure to link the compiled binaries and/or libraries.

If *pfn_notify* is not **NULL**, **clLinkProgram** does not have to wait until the linker to complete and can return **CL_SUCCESS** in *errcode_ret* if the linking operation can begin. The *pfn_notify* callback function will return a **CL_SUCCESS** or **CL_LINK_PROGRAM_FAILURE** if the linking operation was successful or not.

Otherwise **clLinkProgram** returns a **NULL** program object with an appropriate error in *errcode_ret*. The application should query the linker status of this program object to check if the link was successful or not. The list of errors that can be returned are:

- **CL_INVALID_CONTEXT** if *context* is not a valid context.
- **CL_INVALID_VALUE** if *device_list* is **NULL** and *num_devices* is greater than zero, or if *device_list* is not **NULL** and *num_devices* is zero.
- **CL_INVALID_VALUE** if *num_input_programs* is zero and *input_programs* is **NULL** or if *num_input_programs* is zero and *input_programs* is not **NULL** or if *num_input_programs* is not zero and *input_programs* is **NULL**.
- **CL_INVALID_PROGRAM** if programs specified in *input_programs* are not valid program objects.
- **CL_INVALID_VALUE** if *pfn_notify* is **NULL** but *user_data* is not **NULL**.
- **CL_INVALID_DEVICE** if any device in *device_list* is not in the list of devices associated with *context*.
- **CL_INVALID_LINKER_OPTIONS** if the linker options specified by *options* are invalid.
- **CL_INVALID_OPERATION** if the compilation or build of a program executable for any of the devices listed in *device_list* by a previous call to **clCompileProgram** or **clBuildProgram** for *program* has not completed.
- **CL_INVALID_OPERATION** if the rules for devices containing compiled binaries or libraries as described in *input_programs* argument above are not followed.

- **CL_LINKER_NOT_AVAILABLE** if a linker is not available, i.e. **CL_DEVICE_LINKER_AVAILABLE** specified in the [Device Queries](#) table is set to **CL_FALSE**.
- **CL_LINK_PROGRAM_FAILURE** if there is a failure to link the compiled binaries and/or libraries.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

5.8.6. Compiler Options

The compiler options are categorized as pre-processor options, options for math intrinsics, options that control optimization and miscellaneous options. This specification defines a standard set of options that must be supported by the compiler when building program executables online or offline from OpenCL C/C++ or, where relevant, from an IL. These may be extended by a set of vendor- or platform-specific options.

5.8.6.1. Preprocessor options

These options control the OpenCL C/C++ preprocessor which is run on each program source before actual compilation. These options are ignored for programs created with IL.

-D name

Predefine *name* as a macro, with definition 1.

-D name=definition

The contents of *definition* are tokenized and processed as if they appeared during translation phase three in a **#define** directive. In particular, the definition will be truncated by embedded newline characters.

-D options are processed in the order they are given in the *options* argument to [clBuildProgram](#) or [clCompileProgram](#). Note that a space is required between the **-D** option and the symbol it defines, otherwise behavior is implementation-defined.

-I dir

Add the directory *dir* to the list of directories to be searched for header files. *dir* can optionally be enclosed in double quotes.

This option is not portable due to its dependency on host file system and host operating system. It is supported for backwards compatibility with previous OpenCL versions. Developers are encouraged to create and use explicit header objects by means of [clCompileProgram](#) followed by [clLinkProgram](#).

5.8.6.2. Math Intrinsics Options

These options control compiler behavior regarding floating-point arithmetic. These options trade off between speed and correctness.

-cl-single-precision-constant

This option forces implicit conversions of double-precision floating-point literals to single precision. This option is ignored for programs created with IL.

-cl-denorms-are-zero

This option controls how single precision and double precision denormalized numbers are handled. If specified as a build option, the single precision denormalized numbers may be flushed to zero; double precision denormalized numbers may also be flushed to zero if the optional extension for double precision is supported. This is intended to be a performance hint and the OpenCL compiler can choose not to flush denorms to zero if the device supports single precision (or double precision) denormalized numbers.

This option is ignored for single precision numbers if the device does not support single precision denormalized numbers i.e. `CL_FP_DENORM` bit is not set in `CL_DEVICE_SINGLE_FP_CONFIG`.

This option is ignored for double precision numbers if the device does not support double precision or if it does support double precision but not double precision denormalized numbers i.e. `CL_FP_DENORM` bit is not set in `CL_DEVICE_DOUBLE_FP_CONFIG`.

This flag only applies for scalar and vector single precision floating-point variables and computations on these floating-point variables inside a program. It does not apply to reading from or writing to image objects.

-cl-fp32-correctly-rounded-divide-sqrt

The `-cl-fp32-correctly-rounded-divide-sqrt` build option to `clBuildProgram` or `clCompileProgram` allows an application to specify that single precision floating-point divide (x/y and 1/x) and sqrt used in the program source are correctly rounded. If this build option is not specified, the minimum numerical accuracy of single precision floating-point divide and sqrt are as defined in the OpenCL C or OpenCL SPIR-V Environment specifications.

This build option can only be specified if the `CL_FP_CORRECTLY_ROUNDED_DIVIDE_SQRT` is set in `CL_DEVICE_SINGLE_FP_CONFIG` (as defined in the [Device Queries](#) table) for devices that the program is being build. `clBuildProgram` or `clCompileProgram` will fail to compile the program for a device if the `-cl-fp32-correctly-rounded-divide-sqrt` option is specified and `CL_FP_CORRECTLY_ROUNDED_DIVIDE_SQRT` is not set for the device.

Note: This option is [missing before](#) version 1.2.

5.8.6.3. Optimization Options

These options control various sorts of optimizations. Turning on optimization flags makes the compiler attempt to improve the performance and/or code size at the expense of compilation time and possibly the ability to debug the program.

-cl-opt-disable

This option disables all optimizations. The default is optimizations are enabled.

-cl-strict-aliasing

This option allows the compiler to assume the strictest aliasing rules.

Note: This option is [deprecated by](#) version 1.1.

-cl-uniform-work-group-size

This requires that the global work-size be a multiple of the work-group size specified to [clEnqueueNDRangeKernel](#). Allow optimizations that are made possible by this restriction.

Note: This option is [missing before](#) version 2.0.

-cl-no-subgroup-ifp

This indicates that kernels in this program do not require sub-groups to make independent forward progress. Allows optimizations that are made possible by this restriction. This option has no effect for devices that do not support independent forward progress for sub-groups.

Note: This option is [missing before](#) version 2.1.

The following options control compiler behavior regarding floating-point arithmetic. These options trade off between performance and correctness and must be specifically enabled. These options are not turned on by default since it can result in incorrect output for programs which depend on an exact implementation of IEEE 754 rules/specifications for math functions.

-cl-mad-enable

Allow $a * b + c$ to be replaced by a **mad** instruction. The **mad** instruction may compute $a * b + c$ with reduced accuracy in the embedded profile. See the OpenCL C or OpenCL SPIR-V Environment specification for accuracy details. On some hardware the **mad** instruction may provide better performance than the expanded computation.

-cl-no-signed-zeros

Allow optimizations for floating-point arithmetic that ignore the signedness of zero. IEEE 754 arithmetic specifies the distinct behavior of $+0.0$ and -0.0 values, which then prohibits simplification of expressions such as $x + 0.0$ or $0.0 * x$ (even with [-cl-finite-math-only](#)). This option implies that the sign of a zero result isn't significant.

-cl-unsafe-math-optimizations

Allow optimizations for floating-point arithmetic that (a) assume that arguments and results are valid, (b) may violate the IEEE 754 standard, (c) assume relaxed OpenCL numerical compliance requirements as defined in the unsafe math optimization section of the OpenCL C or OpenCL SPIR-V Environment specifications, and (d) may violate edge case behavior in the OpenCL C or OpenCL SPIR-V Environment specifications. This option includes the [-cl-no-signed-zeros](#), [-cl-mad-enable](#), and [-cl-denorms-are-zero](#)^[13] options.

-cl-finite-math-only

Allow optimizations for floating-point arithmetic that assume that arguments and results are not NaNs, $+\text{Inf}$, $-\text{Inf}$. This option may violate the OpenCL numerical compliance requirements for single precision and double precision floating-point, as well as edge case behavior.

-cl-fast-relaxed-math

Sets the optimization options [-cl-finite-math-only](#) and [-cl-unsafe-math-optimizations](#). This option causes the preprocessor macro `__FAST_RELAXED_MATH__` to be defined in the OpenCL program.

5.8.6.4. Options to Request or Suppress Warnings

Warnings are diagnostic messages that report constructions which are not inherently erroneous but which are risky or suggest there may have been an error. The following language-independent options do not enable specific warnings but control the kinds of diagnostics produced by the OpenCL compiler. These options are ignored for programs created with IL.

-w

Inhibit all warning messages.

-Werror

Make all warnings into errors.

5.8.6.5. Options Controlling the OpenCL C version

The following option controls the version of OpenCL C that the compiler accepts. These options are ignored for programs created with IL.

-cl-std=

Determine the OpenCL C language version to use. A value for this option must be provided. Valid values are:

- **CL1.1**: Support OpenCL C 1.1 language features defined in *section 6* of the OpenCL 1.1 specification or in the unified OpenCL C specification.
- **CL1.2**: Support OpenCL C 1.2 language features defined in *section 6* of the OpenCL 1.2 specification or in the unified OpenCL C specification.
- **CL2.0**: Support OpenCL C 2.0 language features defined in the OpenCL C 2.0 specification or in the unified OpenCL C specification.
- **CL3.0**: Support OpenCL C 3.0 language features defined in the unified OpenCL C specification.

Calls to **clBuildProgram** or **clCompileProgram** with the **-cl-std=CL1.1** option **will fail** to compile the program for any devices with **CL_DEVICE_OPENCL_C_VERSION** equal to OpenCL C 1.0 and when **CL_DEVICE_OPENCL_C_ALL_VERSIONS** does not include OpenCL C 1.1.

Calls to **clBuildProgram** or **clCompileProgram** with the **-cl-std=CL1.2** option **will fail** to compile the program for any devices with **CL_DEVICE_OPENCL_C_VERSION** equal to OpenCL C 1.1 or earlier and when **CL_DEVICE_OPENCL_C_ALL_VERSIONS** does not include OpenCL C 1.2.

Calls to **clBuildProgram** or **clCompileProgram** with the **-cl-std=CL2.0** option **will fail** to compile the program for any devices with **CL_DEVICE_OPENCL_C_VERSION** equal to OpenCL C 1.2 or earlier and when **CL_DEVICE_OPENCL_C_ALL_VERSIONS** does not include OpenCL C 2.0.

Calls to **clBuildProgram** or **clCompileProgram** with the **-cl-std=CL3.0** option **will fail** to compile the program for any devices with **CL_DEVICE_OPENCL_C_VERSION** equal to OpenCL C 2.0 or earlier and when **CL_DEVICE_OPENCL_C_ALL_VERSIONS** does not include OpenCL C 3.0.

If the **-cl-std** build option is not specified, the highest OpenCL C 1.x language version supported by each device is used when compiling the program for each device. Applications are required to specify the **-cl-std=CL2.0** build option to compile or build programs with OpenCL C 2.0 and the **-cl**

-std=CL3.0 build option to compile or build programs with OpenCL C 3.0.

5.8.6.6. Options for Querying Kernel Argument Information



Querying for kernel argument information is [missing before](#) version 1.2.

-cl-kernel-arg-info

This option allows the compiler to store information about the arguments of a kernel(s) in the program executable. The argument information stored includes the argument name, its type, the address space and access qualifiers used. Refer to description of [clGetKernelArgInfo](#) on how to query this information.

5.8.6.7. Options for debugging your program



Debugging options are [missing before](#) version 2.0.

-g

This option can currently be used to generate additional errors for the built-in functions that allow you to enqueue commands on a device (refer to OpenCL kernel languages specifications).

5.8.7. Linker Options



Linker options are [missing before](#) version 1.2.

This specification defines a standard set of linker options that must be supported by the OpenCL C compiler when linking compiled programs online or offline. These linker options are categorized as library linking options and program linking options. These may be extended by a set of vendor- or platform-specific options.

5.8.7.1. Library Linking Options



Library linking options are [missing before](#) version 1.2.

The following options can be specified when creating a library of compiled binaries.

-create-library

Create a library of compiled binaries specified in *input_programs* argument to [clLinkProgram](#).

-enable-link-options

Allows the linker to modify the library behavior based on one or more link options (described in [Program Linking Options](#)) when this library is linked with a program executable. This option must be specified with the create-library option.

5.8.7.2. Program Linking Options

The following options can be specified when linking a program executable.

-cl-denorms-are-zero

`-cl-no-signed-zeros`
`-cl-unsafe-math-optimizations`
`-cl-finite-math-only`
`-cl-fast-relaxed-math`
`-cl-no-subgroup-ifp` (missing before version 2.1)

The options are described in [Math Intrinsic Options](#) and [Optimization Options](#). The linker may apply these options to all compiled program objects specified to `clLinkProgram`. The linker may apply these options only to libraries which were created with the option `-enable-link-options`.

5.8.8. Unloading the OpenCL Compiler

To unload an OpenCL compiler for a platform, call the function

```
cl_int clUnloadPlatformCompiler(  
    cl_platform_id platform);
```



`clUnloadPlatformCompiler` is missing before version 1.2.

- *platform* is the platform to unload.

This function allows the implementation to release the resources allocated by the OpenCL compiler for *platform*. This is a hint from the application and does not guarantee that the compiler will not be used in the future or that the compiler will actually be unloaded by the implementation. Calls to `clBuildProgram`, `clCompileProgram` or `clLinkProgram` after `clUnloadPlatformCompiler` will reload the compiler, if necessary, to build the appropriate program executable.

`clUnloadPlatformCompiler` returns `CL_SUCCESS` if the function is executed successfully. Otherwise, it returns one of the following errors:

- `CL_INVALID_PLATFORM` if *platform* is not a valid platform.

Alternatively, if you are not using OpenCL via the ICD loader, you may unload the OpenCL compiler with the function

```
cl_int clUnloadCompiler(void);
```



`clUnloadCompiler` is deprecated by version 1.2.

This function allows the implementation to release the resources allocated by the OpenCL compiler. This is a hint from the application and does not guarantee that the compiler will not be used in the future or that the compiler will actually be unloaded by the implementation. Calls to `clBuildProgram`, `clCompileProgram` or `clLinkProgram` after `clUnloadCompiler` will reload the compiler, if necessary, to build the appropriate program executable.

`clUnloadCompiler` will always return `CL_SUCCESS`.

5.8.9. Program Object Queries

To return information about a program object, call the function

```
cl_int clGetProgramInfo(  
    cl_program program,  
    cl_program_info param_name,  
    size_t param_value_size,  
    void* param_value,  
    size_t* param_value_size_ret);
```

- *program* specifies the program object being queried.
- *param_name* specifies the information to query. The list of supported *param_name* types and the information returned in *param_value* by **clGetProgramInfo** is described in the [Program Object Queries](#) table.
- *param_value* is a pointer to memory where the appropriate result being queried is returned. If *param_value* is **NULL**, it is ignored.
- *param_value_size* is used to specify the size in bytes of memory pointed to by *param_value*. This size must be \geq size of return type as described in the [Program Object Queries](#) table.
- *param_value_size_ret* returns the actual size in bytes of data being queried by *param_name*. If *param_value_size_ret* is **NULL**, it is ignored.

Table 29. List of supported *param_names* by **clGetProgramInfo**

Program Info	Return Type	Description
CL_PROGRAM_REFERENCE_COUNT ^[14]	cl_uint	Return the <i>program</i> reference count.
CL_PROGRAM_CONTEXT	cl_context	Return the context specified when the program object is created
CL_PROGRAM_NUM_DEVICES	cl_uint	Return the number of devices associated with <i>program</i> .
CL_PROGRAM_DEVICES	cl_device_id[]	Return the list of devices associated with the program object. This can be the devices associated with context on which the program object has been created or can be a subset of devices that are specified when a program object is created using clCreateProgramWithBinary .

Program Info	Return Type	Description
CL_PROGRAM_SOURCE	char[]	<p>Return the program source code specified by clCreateProgramWithSource. The source string returned is a concatenation of all source strings specified to clCreateProgramWithSource with a null terminator. The concatenation strips any nulls in the original source strings.</p> <p>If <i>program</i> is created using clCreateProgramWithBinary, clCreateProgramWithIL or clCreateProgramWithBuiltInKernels, a null string or the appropriate program source code is returned depending on whether or not the program source code is stored in the binary.</p> <p>The actual number of characters that represents the program source code including the null terminator is returned in <i>param_value_size_ret</i>.</p>
CL_PROGRAM_IL missing before version 2.1. Also see extension cl_khr_il_program .	char[]	<p>Returns the program IL for programs created with clCreateProgramWithIL.</p> <p>If <i>program</i> is created with clCreateProgramWithSource, clCreateProgramWithBinary or clCreateProgramWithBuiltInKernels the memory pointed to by <i>param_value</i> will be unchanged and <i>param_value_size_ret</i> will be set to 0.</p>
CL_PROGRAM_BINARY_SIZES	size_t[]	<p>Returns an array that contains the size in bytes of the program binary (could be an executable binary, compiled binary or library binary) for each device associated with program. The size of the array is the number of devices associated with program. If a binary is not available for a device(s), a size of zero is returned.</p> <p>If <i>program</i> is created using clCreateProgramWithBuiltInKernels, the implementation may return zero in any entries of the returned array.</p>

Program Info	Return Type	Description
CL_PROGRAM_BINARIES	unsigned char*[]	<p>Return the program binaries (could be an executable binary, compiled binary or library binary) for all devices associated with program. For each device in program, the binary returned can be the binary specified for the device when program is created with clCreateProgramWithBinary or it can be the executable binary generated by clBuildProgram or clLinkProgram. If <i>program</i> is created with clCreateProgramWithSource or clCreateProgramWithIL, the binary returned is the binary generated by clBuildProgram, clCompileProgram or clLinkProgram. The bits returned can be an implementation-specific intermediate representation (a.k.a. IR) or device specific executable bits or both. The decision on which information is returned in the binary is up to the OpenCL implementation.</p> <p>param_value points to an array of <i>n</i> pointers allocated by the caller, where <i>n</i> is the number of devices associated with program. The buffer sizes needed to allocate the memory that these <i>n</i> pointers refer to can be queried using the CL_PROGRAM_BINARY_SIZES query as described in this table.</p> <p>Each entry in this array is used by the implementation as the location in memory where to copy the program binary for a specific device, if there is a binary available. To find out which device the program binary in the array refers to, use the CL_PROGRAM_DEVICES query to get the list of devices. There is a one-to-one correspondence between the array of <i>n</i> pointers returned by CL_PROGRAM_BINARIES and array of devices returned by CL_PROGRAM_DEVICES.</p>
CL_PROGRAM_NUM_KERNELS missing before version 1.2.	size_t	<p>Returns the number of kernels declared in <i>program</i> that can be created with clCreateKernel. This information is only available after a successful program executable has been built for at least one device in the list of devices associated with <i>program</i>.</p>

Program Info	Return Type	Description
CL_PROGRAM_KERNEL_NAMES missing before version 1.2.	char[]	Returns a semi-colon separated list of kernel names in <i>program</i> that can be created with clCreateKernel . This information is only available after a successful program executable has been built for at least one device in the list of devices associated with <i>program</i> .
CL_PROGRAM_SCOPE_GLOBAL_CTORS_PRESENT missing before version 2.2 and deprecated by version 3.0.	cl_bool	<p>This indicates that the <i>program</i> object contains non-trivial constructor(s) that will be executed by runtime before any kernel from the program is executed. This information is only available after a successful program executable has been built for at least one device in the list of devices associated with <i>program</i>.</p> <p>Querying CL_PROGRAM_SCOPE_GLOBAL_CTORS_PRESENT may unconditionally return CL_FALSE if no devices associated with <i>program</i> support constructors for program scope global variables. Support for constructors and destructors for program scope global variables is required only for OpenCL 2.2 devices.</p>
CL_PROGRAM_SCOPE_GLOBAL_DTORS_PRESENT missing before version 2.2 and deprecated by version 3.0.	cl_bool	<p>This indicates that the program object contains non-trivial destructor(s) that will be executed by runtime when <i>program</i> is destroyed. This information is only available after a successful program executable has been built for at least one device in the list of devices associated with <i>program</i>.</p> <p>Querying CL_PROGRAM_SCOPE_GLOBAL_CTORS_PRESENT may unconditionally return CL_FALSE if no devices associated with <i>program</i> support destructors for program scope global variables. Support for constructors and destructors for program scope global variables is required only for OpenCL 2.2 devices.</p>

clGetProgramInfo returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_VALUE** if *param_name* is not valid, or if size in bytes specified by *param_value_size* is < size of return type as described in the [Program Object Queries](#) table and *param_value* is not **NULL**.
- **CL_INVALID_PROGRAM** if *program* is a not a valid program object.
- **CL_INVALID_PROGRAM_EXECUTABLE** if *param_name* is **CL_PROGRAM_NUM_KERNELS**, **CL_PROGRAM_KERNEL_**

NAMES, `CL_PROGRAM_SCOPE_GLOBAL_CTORS_PRESENT`, or `CL_PROGRAM_SCOPE_GLOBAL_DTORS_PRESENT` and a successful program executable has not been built for at least one device in the list of devices associated with *program*.

- `CL_OUT_OF_RESOURCES` if there is a failure to allocate resources required by the OpenCL implementation on the device.
- `CL_OUT_OF_HOST_MEMORY` if there is a failure to allocate resources required by the OpenCL implementation on the host.

To return build information for each device in the program object, call the function

```
cl_int clGetProgramBuildInfo(  
    cl_program program,  
    cl_device_id device,  
    cl_program_build_info param_name,  
    size_t param_value_size,  
    void* param_value,  
    size_t* param_value_size_ret);
```

- *program* specifies the program object being queried.
- *device* specifies the device for which build information is being queried. *device* must be a valid device associated with *program*.
- *param_name* specifies the information to query. The list of supported *param_name* types and the information returned in *param_value* by `clGetProgramBuildInfo` is described in the [Program Build Queries](#) table.
- *param_value* is a pointer to memory where the appropriate result being queried is returned. If *param_value* is `NULL`, it is ignored.
- *param_value_size* is used to specify the size in bytes of memory pointed to by *param_value*. This size must be \geq size of return type as described in the [Program Build Queries](#) table.
- *param_value_size_ret* returns the actual size in bytes of data being queried by *param_name*. If *param_value_size_ret* is `NULL`, it is ignored.

Table 30. List of supported *param_names* by `clGetProgramBuildInfo`

Program Build Info	Return Type	Description
CL_PROGRAM_BUILD_STATUS	cl_build_status	<p>Returns the build, compile or link status, whichever was performed last on the specified <i>program</i> object for <i>device</i>.</p> <p>This can be one of the following:</p> <p>CL_BUILD_NONE - The build status returned if no clBuildProgram, clCompileProgram or clLinkProgram has been performed on the specified <i>program</i> object for <i>device</i>).</p> <p>CL_BUILD_ERROR - The build status returned if clBuildProgram, clCompileProgram or clLinkProgram - whichever was performed last on the specified <i>program</i> object for <i>device</i> - generated an error.</p> <p>CL_BUILD_SUCCESS - The build status returned if clBuildProgram, clCompileProgram or clLinkProgram - whichever was performed last on the specified <i>program</i> object for <i>device</i> - was successful.</p> <p>CL_BUILD_IN_PROGRESS - The build status returned if clBuildProgram, clCompileProgram or clLinkProgram - whichever was performed last on the specified <i>program</i> object for <i>device</i> - has not finished.</p>
CL_PROGRAM_BUILD_OPTIONS	char[]	<p>Return the build, compile or link options specified by the options argument in clBuildProgram, clCompileProgram or clLinkProgram, whichever was performed last on the specified <i>program</i> object for <i>device</i>.</p> <p>If build status of the specified <i>program</i> for <i>device</i> is CL_BUILD_NONE, an empty string is returned.</p>
CL_PROGRAM_BUILD_LOG	char[]	<p>Return the build, compile or link log for clBuildProgram, clCompileProgram or clLinkProgram, whichever was performed last on program for device.</p> <p>If build status of the specified <i>program</i> for <i>device</i> is CL_BUILD_NONE, an empty string is returned.</p>

Program Build Info	Return Type	Description
CL_PROGRAM_BINARY_TYPE missing before version 1.2.	cl_program_binary_type	Return the program binary type for device. This can be one of the following values: CL_PROGRAM_BINARY_TYPE_NONE - There is no binary associated with the specified <i>program</i> object for <i>device</i> . CL_PROGRAM_BINARY_TYPE_COMPILED_OBJECT - A compiled binary is associated with <i>device</i> . This is the case when the specified <i>program</i> object was created using clCreateProgramWithSource and compiled using clCompileProgram , or when a compiled binary was loaded using clCreateProgramWithBinary . CL_PROGRAM_BINARY_TYPE_LIBRARY - A library binary is associated with <i>device</i> . This is the case when the specified <i>program</i> object was linked by clLinkProgram using the -create-library link option, or when a compiled library binary was loaded using clCreateProgramWithBinary . CL_PROGRAM_BINARY_TYPE_EXECUTABLE - An executable binary is associated with <i>device</i> . This is the case when the specified <i>program</i> object was linked by clLinkProgram without the -create-library link option, or when an executable binary was built using clBuildProgram .
CL_PROGRAM_BUILD_GLOBAL_VARIABLE_TOTAL_SIZE missing before version 2.0.	size_t	The total amount of storage, in bytes, used by program variables in the global address space.

clGetProgramBuildInfo returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_DEVICE** if *device* is not in the list of devices associated with *program*.
- **CL_INVALID_VALUE** if *param_name* is not valid, or if size in bytes specified by *param_value_size* is < size of return type as described in the **Program Build Queries** table and *param_value* is not **NULL**.
- **CL_INVALID_PROGRAM** if *program* is a not a valid program object.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL

implementation on the host.



A program binary (compiled binary, library binary or executable binary) built for a parent device can be used by all its sub-devices. If a program binary has not been built for a sub-device, the program binary associated with the parent device will be used.

A program binary for a device specified with `clCreateProgramWithBinary` or queried using `clGetProgramInfo` can be used as the binary for the associated root device, and all sub-devices created from the root-level device or sub-devices thereof.

5.9. Kernel Objects

A kernel is a function declared in a program. A kernel is identified by the `__kernel` qualifier applied to any function in a program. A kernel object encapsulates the specific `__kernel` function declared in a program and the argument values to be used when executing this `__kernel` function.

5.9.1. Creating Kernel Objects

To create a kernel object, use the function

```
cl_kernel clCreateKernel(  
    cl_program program,  
    const char* kernel_name,  
    cl_int* errcode_ret);
```

- *program* is a program object with a successfully built executable.
- *kernel_name* is a function name in the program declared with the `__kernel` qualifier.
- *errcode_ret* will return an appropriate error code. If *errcode_ret* is `NULL`, no error code is returned.

`clCreateKernel` returns a valid non-zero kernel object and *errcode_ret* is set to `CL_SUCCESS` if the kernel object is created successfully. Otherwise, it returns a `NULL` value with one of the following error values returned in *errcode_ret*:

- `CL_INVALID_PROGRAM` if *program* is not a valid program object.
- `CL_INVALID_PROGRAM_EXECUTABLE` if there is no successfully built executable for *program*.
- `CL_INVALID_KERNEL_NAME` if *kernel_name* is not found in *program*.
- `CL_INVALID_KERNEL_DEFINITION` if the function definition for `__kernel` function given by *kernel_name* such as the number of arguments, the argument types are not the same for all devices for which the *program* executable has been built.
- `CL_INVALID_VALUE` if *kernel_name* is `NULL`.
- `CL_OUT_OF_RESOURCES` if there is a failure to allocate resources required by the OpenCL implementation on the device.

- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

To create kernel objects for all kernel functions in a program, call the function

```
cl_int clCreateKernelsInProgram(
    cl_program program,
    cl_uint num_kernels,
    cl_kernel* kernels,
    cl_uint* num_kernels_ret);
```

- *program* is a program object with a successfully built executable.
- *num_kernels* is the size of memory pointed to by *kernels* specified as the number of **cl_kernel** entries.
- *kernels* is the buffer where the kernel objects for kernels in *program* will be returned. If *kernels* is **NULL**, it is ignored. If *kernels* is not **NULL**, *num_kernels* must be greater than or equal to the number of kernels in *program*.
- *num_kernels_ret* is the number of kernels in *program*. If *num_kernels_ret* is **NULL**, it is ignored.

Kernel objects are not created for any **__kernel** functions in *program* that do not have the same function definition across all devices for which a program executable has been successfully built.

Kernel objects can only be created once you have a program object with a valid program source or binary loaded into the program object and the program executable has been successfully built for one or more devices associated with program. No changes to the program executable are allowed while there are kernel objects associated with a program object. This means that calls to **clBuildProgram** and **clCompileProgram** return **CL_INVALID_OPERATION** if there are kernel objects attached to a program object. The OpenCL context associated with *program* will be the context associated with *kernel*. The list of devices associated with *program* are the devices associated with *kernel*. Devices associated with a program object for which a valid program executable has been built can be used to execute kernels declared in the program object.

clCreateKernelsInProgram will return **CL_SUCCESS** if the kernel objects were successfully allocated. Otherwise, it returns one of the following errors:

- **CL_INVALID_PROGRAM** if *program* is not a valid program object.
- **CL_INVALID_PROGRAM_EXECUTABLE** if there is no successfully built executable for any device in *program*.
- **CL_INVALID_VALUE** if *kernels* is not **NULL** and *num_kernels* is less than the number of kernels in *program*.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

To retain a kernel object, call the function

```
cl_int clRetainKernel(  
    cl_kernel kernel);
```

- *kernel* is the kernel object to be retained.

The *kernel* reference count is incremented.

clRetainKernel returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_KERNEL** if *kernel* is not a valid kernel object.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

clCreateKernel or **clCreateKernelsInProgram** do an implicit retain.

To release a kernel object, call the function

```
cl_int clReleaseKernel(  
    cl_kernel kernel);
```

- *kernel* is the kernel object to be released.

The *kernel* reference count is decremented.

The kernel object is deleted once the number of instances that are retained to *kernel* become zero and the kernel object is no longer needed by any enqueued commands that use *kernel*. Using this function to release a reference that was not obtained by creating the object or by calling **clRetainKernel** causes undefined behavior.

clReleaseKernel returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_KERNEL** if *kernel* is not a valid kernel object.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

5.9.2. Setting Kernel Arguments

To execute a kernel, the kernel arguments must be set.

To set the argument value for a specific argument of a kernel, call the function

```
cl_int clSetKernelArg(
    cl_kernel kernel,
    cl_uint arg_index,
    size_t arg_size,
    const void* arg_value);
```

- *kernel* is a valid kernel object.
- *arg_index* is the argument index. Arguments to the kernel are referred by indices that go from 0 for the leftmost argument to $n - 1$, where n is the total number of arguments declared by a kernel (see below).
- *arg_size* specifies the size of the argument value. If the argument is a memory object, the *arg_size* value must be equal to `sizeof(cl_mem)`. For arguments declared with the `local` qualifier, the size specified will be the size in bytes of the buffer that must be allocated for the `local` argument. If the argument is of type `sampler_t`, the *arg_size* value must be equal to `sizeof(cl_sampler)`. If the argument is of type `queue_t`, the *arg_size* value must be equal to `sizeof(cl_command_queue)`. For all other arguments, the size will be the size of argument type.
- *arg_value* is a pointer to data that should be used as the argument value for argument specified by *arg_index*. The argument data pointed to by *arg_value* is copied and the *arg_value* pointer can therefore be reused by the application after `clSetKernelArg` returns. The argument value specified is the value used by all API calls that enqueue *kernel* (`clEnqueueNDRangeKernel` and `clEnqueueTask`) until the argument value is changed by a call to `clSetKernelArg` for *kernel*.

For example, consider the following kernel:

```
kernel void image_filter (int n,
                          int m,
                          constant float *filter_weights,
                          read_only image2d_t src_image,
                          write_only image2d_t dst_image)
{
    ...
}
```

Argument index values for `image_filter` will be 0 for `n`, 1 for `m`, 2 for `filter_weights`, 3 for `src_image` and 4 for `dst_image`.

If the argument is a memory object (buffer, pipe, image or image array), the *arg_value* entry will be a pointer to the appropriate buffer, pipe, image or image array object. The memory object must be created with the context associated with the kernel object. If the argument is a buffer object, the *arg_value* pointer can be `NULL` or point to a `NULL` value in which case a `NULL` value will be used as the value for the argument declared as a pointer to `global` or `constant` memory in the kernel. If the argument is declared with the `local` qualifier, the *arg_value* entry must be `NULL`. If the argument is of type `sampler_t`, the *arg_value* entry must be a pointer to the sampler object. If the argument is of type `queue_t`, the *arg_value* entry must be a pointer to the device queue object.

If the argument is declared to be a pointer of a built-in scalar or vector type, or a user defined

structure type in the global or constant address space, the memory object specified as argument value must be a buffer object (or `NULL`). If the argument is declared with the `constant` qualifier, the size in bytes of the memory object cannot exceed `CL_DEVICE_MAX_CONSTANT_BUFFER_SIZE` and the number of arguments declared as pointers to `constant` memory cannot exceed `CL_DEVICE_MAX_CONSTANT_ARGS`.

The memory object specified as argument value must be a pipe object if the argument is declared with the `pipe` qualifier.

The memory object specified as argument value must be a 2D image object if the argument is declared to be of type `image2d_t`. The memory object specified as argument value must be a 2D image object with image channel order = `CL_DEPTH` if the argument is declared to be of type `image2d_depth_t`. The memory object specified as argument value must be a 3D image object if argument is declared to be of type `image3d_t`. The memory object specified as argument value must be a 1D image object if the argument is declared to be of type `image1d_t`. The memory object specified as argument value must be a 1D image buffer object if the argument is declared to be of type `image1d_buffer_t`. The memory object specified as argument value must be a 1D image array object if argument is declared to be of type `image1d_array_t`. The memory object specified as argument value must be a 2D image array object if argument is declared to be of type `image2d_array_t`. The memory object specified as argument value must be a 2D image array object with image channel order = `CL_DEPTH` if argument is declared to be of type `image2d_array_depth_t`.

For all other kernel arguments, the `arg_value` entry must be a pointer to the actual data to be used as argument value.

A kernel object does not update the reference count for objects such as memory or sampler objects specified as argument values by `clSetKernelArg`. Users may not rely on a kernel object to retain objects specified as argument values to the kernel.



Implementations shall not allow `cl_kernel` objects to hold reference counts to `cl_kernel` arguments, because no mechanism is provided for the user to tell the kernel to release that ownership right. If the kernel holds ownership rights on kernel args, that would make it impossible for users to tell with certainty when they may safely release user allocated resources associated with OpenCL objects such as the `cl_mem` backing store used with `CL_MEM_USE_HOST_PTR`.

`clSetKernelArg` returns `CL_SUCCESS` if the function was executed successfully. Otherwise, it returns one of the following errors:

- `CL_INVALID_KERNEL` if `kernel` is not a valid kernel object.
- `CL_INVALID_ARG_INDEX` if `arg_index` is not a valid argument index.
- `CL_INVALID_ARG_VALUE` if `arg_value` specified is not a valid value.
- `CL_INVALID_MEM_OBJECT` for an argument declared to be a memory object when the specified `arg_value` is not a valid memory object.
- `CL_INVALID_SAMPLER` for an argument declared to be of type `sampler_t` when the specified `arg_value` is not a valid sampler object.
- `CL_INVALID_DEVICE_QUEUE` for an argument declared to be of type `queue_t` when the specified

arg_value is not a valid device queue object. This error code is [missing before](#) version 2.0.

- **CL_INVALID_ARG_SIZE** if *arg_size* does not match the size of the data type for an argument that is not a memory object or if the argument is a memory object and *arg_size* != `sizeof(cl_mem)` or if *arg_size* is zero and the argument is declared with the local qualifier or if the argument is a sampler and *arg_size* != `sizeof(cl_sampler)`.
- **CL_MAX_SIZE_RESTRICTION_EXCEEDED** if the size in bytes of the memory object (if the argument is a memory object) or *arg_size* (if the argument is declared with `local` qualifier) exceeds a language- specified maximum size restriction for this argument, such as the **MaxByteOffset** SPIR-V decoration. This error code is [missing before](#) version 2.2.
- **CL_INVALID_ARG_VALUE** if the argument is an image declared with the `read_only` qualifier and *arg_value* refers to an image object created with *cl_mem_flags* of **CL_MEM_WRITE_ONLY** or if the image argument is declared with the `write_only` qualifier and *arg_value* refers to an image object created with *cl_mem_flags* of **CL_MEM_READ_ONLY**.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

When **clSetKernelArg** returns an error code different from **CL_SUCCESS**, the internal state of *kernel* may only be modified when that error code is **CL_OUT_OF_RESOURCES** or **CL_OUT_OF_HOST_MEMORY**. When the internal state of *kernel* is modified, it is implementation-defined whether:

- The argument value that was previously set is kept so that it can be used in further kernel enqueues.
- The argument value is unset such that a subsequent kernel enqueue fails with **CL_INVALID_KERNEL_ARGS**.^[15]

To set a SVM pointer as the argument value for a specific argument of a kernel, call the function

```
cl_int clSetKernelArgSVMPointer(  
    cl_kernel kernel,  
    cl_uint arg_index,  
    const void* arg_value);
```



clSetKernelArgSVMPointer is [missing before](#) version 2.0.

- *kernel* is a valid kernel object.
- *arg_index* is the argument index. Arguments to the kernel are referred by indices that go from 0 for the leftmost argument to *n* - 1, where *n* is the total number of arguments declared by a kernel.
- *arg_value* is the SVM pointer that should be used as the argument value for argument specified by *arg_index*. The SVM pointer specified is the value used by all API calls that enqueue *kernel* (**clEnqueueNDRangeKernel** and **clEnqueueTask**) until the argument value is changed by a call to **clSetKernelArgSVMPointer** for *kernel*. The SVM pointer can only be used for arguments that

are declared to be a pointer to `global` or `constant` memory. The SVM pointer value must be aligned according to the arguments type. For example, if the argument is declared to be `global float4 *p`, the SVM pointer value passed for `p` must be at a minimum aligned to a `float4`. The SVM pointer value specified as the argument value can be the pointer returned by `clSVMAlloc` or can be a pointer offset into the SVM region.

`clSetKernelArgSVMPointer` returns `CL_SUCCESS` if the function was executed successfully. Otherwise, it returns one of the following errors:

- `CL_INVALID_KERNEL` if *kernel* is not a valid kernel object.
- `CL_INVALID_OPERATION` if no devices in the context associated with *kernel* support SVM.
- `CL_INVALID_ARG_INDEX` if *arg_index* is not a valid argument index.
- `CL_INVALID_ARG_VALUE` if *arg_value* specified is not a valid value.
- `CL_OUT_OF_RESOURCES` if there is a failure to allocate resources required by the OpenCL implementation on the device.
- `CL_OUT_OF_HOST_MEMORY` if there is a failure to allocate resources required by the OpenCL implementation on the host.

To pass additional information other than argument values to a kernel, call the function

```
cl_int clSetKernelExecInfo(
    cl_kernel kernel,
    cl_kernel_exec_info param_name,
    size_t param_value_size,
    const void* param_value);
```



`clSetKernelExecInfo` is `missing before` version 2.0.

- *kernel* specifies the kernel object being queried.
- *param_name* specifies the information to be passed to kernel. The list of supported *param_name* types and the corresponding values passed in *param_value* is described in the [Kernel Execution Properties](#) table.
- *param_value_size* specifies the size in bytes of the memory pointed to by *param_value*.
- *param_value* is a pointer to memory where the appropriate values determined by *param_name* are specified.

Table 31. List of supported *param_names* by `clSetKernelExecInfo`

Kernel Exec Info	Type	Description
CL_KERNEL_EXEC_INFO_SVM_PTRS missing before version 2.0.	void*[]	SVM pointers must reference locations contained entirely within buffers that are passed to kernel as arguments, or that are passed through the execution information. Non-argument SVM buffers must be specified by passing pointers to those buffers via clSetKernelExecInfo for coarse-grain and fine-grain buffer SVM allocations but not for finegrain system SVM allocations.
CL_KERNEL_EXEC_INFO_SVM_FINE_GRAIN_SYSTEM missing before version 2.0.	cl_bool	This flag indicates whether the kernel uses pointers that are fine grain system SVM allocations. These fine grain system SVM pointers may be passed as arguments or defined in SVM buffers that are passed as arguments to <i>kernel</i> .

clSetKernelExecInfo returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_KERNEL** if *kernel* is a not a valid kernel object.
- **CL_INVALID_OPERATION** if no devices in the context associated with *kernel* support SVM.
- **CL_INVALID_VALUE** if *param_name* is not valid, if *param_value* is **NULL** or if the size specified by *param_value_size* is not valid.
- **CL_INVALID_OPERATION** if *param_name* is **CL_KERNEL_EXEC_INFO_SVM_FINE_GRAIN_SYSTEM** and *param_value* is **CL_TRUE** but no devices in context associated with *kernel* support fine-grain system SVM allocations.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.



Coarse-grain or fine-grain buffer SVM pointers used by a kernel which are not passed as a kernel arguments must be specified using **clSetKernelExecInfo** with **CL_KERNEL_EXEC_INFO_SVM_PTRS**. For example, if SVM buffer A contains a pointer to another SVM buffer B, and the kernel dereferences that pointer, then a pointer to B must either be passed as an argument in the call to that kernel or it must be made available to the kernel using **clSetKernelExecInfo**. For example, we might pass extra SVM pointers as follows:

```
clSetKernelExecInfo(kernel,
                    CL_KERNEL_EXEC_INFO_SVM_PTRS,
                    num_ptrs * sizeof(void *),
```

```
extra_svm_ptr_list);
```

Here `num_ptrs` specifies the number of additional SVM pointers while `extra_svm_ptr_list` specifies a pointer to memory containing those SVM pointers.

When calling `clSetKernelExecInfo` with `CL_KERNEL_EXEC_INFO_SVM_PTRS` to specify pointers to non-argument SVM buffers as extra arguments to a kernel, each of these pointers can be the SVM pointer returned by `clSVMAlloc` or can be a pointer + offset into the SVM region. It is sufficient to provide one pointer for each SVM buffer used.

`CL_KERNEL_EXEC_INFO_SVM_FINE_GRAIN_SYSTEM` is used to indicate whether SVM pointers used by a kernel will refer to system allocations or not.

`CL_KERNEL_EXEC_INFO_SVM_FINE_GRAIN_SYSTEM = CL_FALSE` indicates that the OpenCL implementation may assume that system pointers are not passed as kernel arguments and are not stored inside SVM allocations passed as kernel arguments.

`CL_KERNEL_EXEC_INFO_SVM_FINE_GRAIN_SYSTEM = CL_TRUE` indicates that the OpenCL implementation must assume that system pointers might be passed as kernel arguments and/or stored inside SVM allocations passed as kernel arguments. In this case, if the device to which the kernel is enqueued does not support system SVM pointers, `clEnqueueNDRangeKernel` and `clEnqueueTask` will return a `CL_INVALID_OPERATION` error. If none of the devices in the context associated with kernel support fine-grain system SVM allocations, `clSetKernelExecInfo` will return a `CL_INVALID_OPERATION` error.

If `clSetKernelExecInfo` has not been called with a value for `CL_KERNEL_EXEC_INFO_SVM_FINE_GRAIN_SYSTEM`, the default value is used for this kernel attribute. The default value depends on whether the device on which the kernel is enqueued supports fine-grain system SVM allocations. If so, the default value used is `CL_TRUE` (system pointers might be passed); otherwise, the default is `CL_FALSE`.

A call to `clSetKernelExecInfo` for a given value of *param_name* replaces any prior value passed for that value of *param_name*. Only one *param_value* will be stored for each value of *param_name*.

5.9.3. Copying Kernel Objects



Copying kernel objects is [missing before](#) version 2.1.

To clone a kernel object, call the function

```
cl_kernel clCloneKernel(  
    cl_kernel source_kernel,  
    cl_int* errcode_ret);
```



clCloneKernel is missing before version 2.1.

- *source_kernel* is a valid **cl_kernel** object that will be copied. *source_kernel* will not be modified in any way by this function.
- *errcode_ret* will be assigned an appropriate error code. If *errcode_ret* is **NULL**, no error code is returned.

Cloning is used to make a shallow copy of the kernel object, its arguments and any information passed to the kernel object using **clSetKernelExecInfo**. If the kernel object was ready to be enqueued before copying it, the clone of the kernel object is ready to enqueue.

The returned kernel object is an exact copy of *source_kernel*, with one caveat: the reference count on the returned kernel object is set as if it had been returned by **clCreateKernel**. The reference count of *source_kernel* will not be changed.

The resulting kernel will be in the same state as if **clCreateKernel** is called to create the resultant kernel with the same arguments as those used to create *source_kernel*, the latest call to **clSetKernelArg** or **clSetKernelArgSVMPointer** for each argument index applied to kernel and the last call to **clSetKernelExecInfo** for each value of the param name parameter are applied to the new kernel object.

All arguments of the new kernel object must be intact and it may be correctly used in the same situations as kernel except those that assume a pre-existing reference count. Setting arguments on the new kernel object will not affect *source_kernel* except insofar as the argument points to a shared underlying entity and in that situation behavior is as if two kernel objects had been created and the same argument applied to each. Only the data stored in the kernel object is copied; data referenced by the kernels arguments are not copied. For example, if a buffer or pointer argument is set on a kernel object, the pointer is copied but the underlying memory allocation is not.

clCloneKernel returns a valid non-zero kernel object and *errcode_ret* is set to **CL_SUCCESS** if the kernel is successfully copied. Otherwise it returns a **NULL** value with one of the following error values returned in *errcode_ret*:

- **CL_INVALID_KERNEL** if *kernel* is not a valid kernel object.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

5.9.4. Kernel Object Queries

To return information about a kernel object, call the function

```

cl_int clGetKernelInfo(
    cl_kernel kernel,
    cl_kernel_info param_name,
    size_t param_value_size,
    void* param_value,
    size_t* param_value_size_ret);

```

- *kernel* specifies the kernel object being queried.
- *param_name* specifies the information to query. The list of supported *param_name* types and the information returned in *param_value* by **clGetKernelInfo** is described in the [Kernel Object Queries](#) table.
- *param_value* is a pointer to memory where the appropriate result being queried is returned. If *param_value* is **NULL**, it is ignored.
- *param_value_size* is used to specify the size in bytes of memory pointed to by *param_value*. This size must be \geq size of return type as described in the [Kernel Object Queries](#) table.
- *param_value_size_ret* returns the actual size in bytes of data being queried by *param_name*. If *param_value_size_ret* is **NULL**, it is ignored.

Table 32. List of supported *param_names* by **clGetKernelInfo**

Kernel Info	Return Type	Description
CL_KERNEL_FUNCTION_NAME	char[]	Return the kernel function name.
CL_KERNEL_NUM_ARGS	cl_uint	Return the number of arguments to kernel.
CL_KERNEL_REFERENCE_COUNT ^[16]	cl_uint	Return the <i>kernel</i> reference count.
CL_KERNEL_CONTEXT	cl_context	Return the context associated with <i>kernel</i> .
CL_KERNEL_PROGRAM	cl_program	Return the program object associated with kernel.

Kernel Info	Return Type	Description
CL_KERNEL_ATTRIBUTES missing before version 1.2.	char[]	Returns any attributes specified using the __attribute__ OpenCL C qualifier (or using an OpenCL C++ qualifier syntax [[]]) with the kernel function declaration in the program source. These attributes include attributes described in the earlier OpenCL C kernel language specifications and other attributes supported by an implementation. Attributes are returned as they were declared inside __attribute__((...)) , with any surrounding whitespace and embedded newlines removed. When multiple attributes are present, they are returned as a single, space delimited string. For kernels not created from OpenCL C source and the clCreateProgramWithSource API call the string returned from this query will be empty.

clGetKernelInfo returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_VALUE** if *param_name* is not valid, or if size in bytes specified by *param_value_size* is < size of return type as described in the [Kernel Object Queries](#) table and *param_value* is not **NULL**.
- **CL_INVALID_KERNEL** if *kernel* is a not a valid kernel object.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

To return information about the kernel object that may be specific to a device, call the function

```
cl_int clGetKernelWorkGroupInfo(
    cl_kernel kernel,
    cl_device_id device,
    cl_kernel_work_group_info param_name,
    size_t param_value_size,
    void* param_value,
    size_t* param_value_size_ret);
```

- *kernel* specifies the kernel object being queried.
- *device* identifies a specific device in the list of devices associated with *kernel*. The list of devices is the list of devices in the OpenCL context that is associated with *kernel*. If the list of devices

associated with *kernel* is a single device, *device* can be a **NULL** value.

- *param_name* specifies the information to query. The list of supported *param_name* types and the information returned in *param_value* by **clGetKernelWorkGroupInfo** is described in the [Kernel Object Device Queries](#) table.
- *param_value* is a pointer to memory where the appropriate result being queried is returned. If *param_value* is **NULL**, it is ignored.
- *param_value_size* is used to specify the size in bytes of memory pointed to by *param_value*. This size must be \geq size of return type as described in the [Kernel Object Device Queries](#) table.
- *param_value_size_ret* returns the actual size in bytes of data being queried by *param_name*. If *param_value_size_ret* is **NULL**, it is ignored.

Table 33. List of supported *param_names* by **clGetKernelWorkGroupInfo**

Kernel Work-group Info	Return Type	Description
CL_KERNEL_GLOBAL_WORK_SIZE missing before version 1.2.	size_t[3]	<p>This provides a mechanism for the application to query the maximum global size that can be used to execute a kernel (i.e. <i>global_work_size</i> argument to clEnqueueNDRangeKernel) on a custom device given by device or a built-in kernel on an OpenCL device given by device.</p> <p>If device is not a custom device and kernel is not a built-in kernel, clGetKernelWorkGroupInfo returns the error CL_INVALID_VALUE.</p>
CL_KERNEL_WORK_GROUP_SIZE	size_t	<p>This provides a mechanism for the application to query the maximum work-group size that can be used to execute the kernel on a specific device given by device. The OpenCL implementation uses the resource requirements of the kernel (register usage etc.) to determine what this work-group size should be.</p> <p>As a result and unlike CL_DEVICE_MAX_WORK_GROUP_SIZE this value may vary from one kernel to another as well as one device to another.</p> <p>CL_KERNEL_WORK_GROUP_SIZE will be less than or equal to CL_DEVICE_MAX_WORK_GROUP_SIZE for a given kernel object.</p>
CL_KERNEL_COMPILE_WORK_GROUP_SIZE	size_t[3]	<p>Returns the work-group size specified in the kernel source or IL.</p> <p>If the work-group size is not specified in the kernel source or IL, (0, 0, 0) is returned.</p>

Kernel Work-group Info	Return Type	Description
<code>CL_KERNEL_LOCAL_MEM_SIZE</code>	<code>cl_ulong</code>	<p>Returns the amount of local memory in bytes being used by a kernel. This includes local memory that may be needed by an implementation to execute the kernel, variables declared inside the kernel with the <code>__local</code> address qualifier and local memory to be allocated for arguments to the kernel declared as pointers with the <code>__local</code> address qualifier and whose size is specified with <code>clSetKernelArg</code>.</p> <p>If the local memory size, for any pointer argument to the kernel declared with the <code>__local</code> address qualifier, is not specified, its size is assumed to be 0.</p>
<code>CL_KERNEL_PREFERRED_WORK_GROUP_SIZE_MULTIPLE</code>	<code>size_t</code>	<p>Returns the preferred multiple of work-group size for launch. This is a performance hint. Specifying a work-group size that is not a multiple of the value returned by this query as the value of the local work size argument to <code>clEnqueueNDRangeKernel</code> will not fail to enqueue the kernel for execution unless the work-group size specified is larger than the device maximum.</p>
<code>CL_KERNEL_PRIVATE_MEM_SIZE</code>	<code>cl_ulong</code>	<p>Returns the minimum amount of private memory, in bytes, used by each work-item in the kernel. This value may include any private memory needed by an implementation to execute the kernel, including that used by the language built-ins and variable declared inside the kernel with the <code>__private</code> qualifier.</p>

`clGetKernelWorkGroupInfo` returns `CL_SUCCESS` if the function is executed successfully. Otherwise, it returns one of the following errors:

- `CL_INVALID_DEVICE` if *device* is not in the list of devices associated with *kernel* or if *device* is `NULL` but there is more than one device associated with *kernel*.
- `CL_INVALID_VALUE` if *param_name* is not valid, or if size in bytes specified by *param_value_size* is < size of return type as described in the [Kernel Object Device Queries](#) table and *param_value* is not `NULL`.
- `CL_INVALID_VALUE` if *param_name* is `CL_KERNEL_GLOBAL_WORK_SIZE` and *device* is not a custom device and *kernel* is not a built-in kernel.
- `CL_INVALID_KERNEL` if *kernel* is a not a valid kernel object.
- `CL_OUT_OF_RESOURCES` if there is a failure to allocate resources required by the OpenCL

implementation on the device.

- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

To return information about a kernel object, call the function

```
cl_int clGetKernelSubGroupInfo(  
    cl_kernel kernel,  
    cl_device_id device,  
    cl_kernel_sub_group_info param_name,  
    size_t input_value_size,  
    const void* input_value,  
    size_t param_value_size,  
    void* param_value,  
    size_t* param_value_size_ret);
```



clGetKernelSubGroupInfo is **missing before** version 2.1. Also see extension **cl_khr_subgroups**.

- *kernel* specifies the kernel object being queried.
- *device* identifies a specific device in the list of devices associated with *kernel*. The list of devices is the list of devices in the OpenCL context that is associated with *kernel*. If the list of devices associated with *kernel* is a single device, *device* can be a **NULL** value.
- *param_name* specifies the information to query. The list of supported *param_name* types and the information returned in *param_value* by **clGetKernelSubGroupInfo** is described in the [Kernel Object Sub-group Queries](#) table.
- *input_value_size* is used to specify the size in bytes of memory pointed to by *input_value*. This size must be == size of input type as described in the table below.
- *input_value* is a pointer to memory where the appropriate parameterization of the query is passed from. If *input_value* is **NULL**, it is ignored.
- *param_value* is a pointer to memory where the appropriate result being queried is returned. If *param_value* is **NULL**, it is ignored.
- *param_value_size* is used to specify the size in bytes of memory pointed to by *param_value*. This size must be ≥ size of return type as described in the [Kernel Object Sub-group Queries](#) table.
- *param_value_size_ret* returns the actual size in bytes of data being queried by *param_name*. If *param_value_size_ret* is **NULL**, it is ignored.

Table 34. List of supported *param_names* by **clGetKernelSubGroupInfo**

Kernel Sub-group Info	Input Type	Return Type	Description
CL_KERNEL_MAX_SUB_GROUP_SIZE_FOR_NDRANGE missing before version 2.1. Also see extension cl_khr_subgroups .	size_t*	size_t	Returns the maximum sub-group size for this kernel. All sub-groups must be the same size, while the last sub-group in any work-group (i.e. the sub-group with the maximum index) could be the same or smaller size. The <i>input_value</i> must be an array of size_t values corresponding to the local work size parameter of the intended dispatch. The number of dimensions in the ND-range will be inferred from the value specified for <i>input_value_size</i> .

Kernel Sub-group Info	Input Type	Return Type	Description
<p><code>CL_KERNEL_SUB_GROUP_COUNT_FOR_NDRANGE</code></p> <p>missing before version 2.1. Also see extension <code>cl_khr_subgroups</code>.</p>	<code>size_t*</code>	<code>size_t</code>	<p>Returns the number of sub-groups that will be present in each work-group for a given local work size. All workgroups, apart from the last work-group in each dimension in the presence of non-uniform work-group sizes, will have the same number of sub-groups.</p> <p>The <i>input_value</i> must be an array of <code>size_t</code> values corresponding to the local work size parameter of the intended dispatch. The number of dimensions in the ND-range will be inferred from the value specified for <i>input_value_size</i>.</p>

Kernel Sub-group Info	Input Type	Return Type	Description
CL_KERNEL_LOCAL_SIZE_FOR_SUB_GROUP_COUNT missing before version 2.1. Also see extension cl_khr_subgroups .	size_t	size_t[]	Returns the local size that will generate the requested number of sub-groups for the kernel. The output array must be an array of size_t values corresponding to the local size parameter. Any returned work-group will have one dimension. Other dimensions inferred from the value specified for param_value_size will be filled with the value 1. The returned value will produce an exact number of sub-groups and result in no partial groups for an executing kernel except in the case where the last work-group in a dimension has a size different from that of the other groups. If no work-group size can accommodate the requested number of sub-groups, 0 will be returned in each element of the return array.

Kernel Sub-group Info	Input Type	Return Type	Description
CL_KERNEL_MAX_NUM_SUB_GROUPS missing before version 2.1. Also see extension cl_khr_subgroups .	ignored	size_t	This provides a mechanism for the application to query the maximum number of sub-groups that may make up each work-group to execute a kernel on a specific device given by device. The OpenCL implementation uses the resource requirements of the kernel (register usage etc.) to determine what this work-group size should be. The returned value may be used to compute a work-group size to enqueue the kernel with to give a round number of sub-groups for an enqueue.
CL_KERNEL_COMPILE_NUM_SUB_GROUPS missing before version 2.1. Also see extension cl_khr_subgroups .	ignored	size_t	Returns the number of sub-groups per work-group specified in the kernel source or IL. If the sub-group count is not specified then 0 is returned.

clGetKernelSubGroupInfo returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_DEVICE** if *device* is not in the list of devices associated with *kernel* or if *device* is **NULL** but there is more than one device associated with *kernel*.
- **CL_INVALID_OPERATION** if *device* does not support sub-groups.
- **CL_INVALID_VALUE** if *param_name* is not valid, or if size in bytes specified by *param_value_size* is < size of return type as described in the [Kernel Object Sub-group Queries](#) table and *param_value* is not **NULL**.
- **CL_INVALID_VALUE** if *param_name* is **CL_KERNEL_MAX_SUB_GROUP_SIZE_FOR_NDRANGE**, **CL_KERNEL_SUB_GROUP_COUNT_FOR_NDRANGE** or **CL_KERNEL_LOCAL_SIZE_FOR_SUB_GROUP_COUNT** and the size in bytes specified by *input_value_size* is not valid or if *input_value* is **NULL**.

- **CL_INVALID_KERNEL** if *kernel* is a not a valid kernel object.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

To return information about the arguments of a kernel, call the function

```
cl_int clGetKernelArgInfo(
    cl_kernel kernel,
    cl_uint arg_index,
    cl_kernel_arg_info param_name,
    size_t param_value_size,
    void* param_value,
    size_t* param_value_size_ret);
```



clGetKernelArgInfo is missing before version 1.2.

- *kernel* specifies the kernel object being queried.
- *arg_index* is the argument index. Arguments to the kernel are referred by indices that go from 0 for the leftmost argument to $n - 1$, where n is the total number of arguments declared by a kernel.
- *param_name* specifies the argument information to query. The list of supported *param_name* types and the information returned in *param_value* by **clGetKernelArgInfo** is described in the [Kernel Argument Queries](#) table.
- *param_value* is a pointer to memory where the appropriate result being queried is returned. If *param_value* is **NULL**, it is ignored.
- *param_value_size* is used to specify the size in bytes of memory pointed to by *param_value*. This size must be > size of return type as described in the [Kernel Argument Queries](#) table.
- *param_value_size ret* returns the actual size in bytes of data being queried by *param_name*. If *param_value_size_ret* is **NULL**, it is ignored.

Kernel argument information is only available if the program object associated with *kernel* is created with **clCreateProgramWithSource** and the program executable was built with the **-cl-kernel-arg-info** option specified in options argument to **clBuildProgram** or **clCompileProgram**.

Table 35. List of supported *param_names* by **clGetKernelArgInfo**

Kernel Arg Info	Return Type	Description
CL_KERNEL_ARG_ADDRESS_QUALIFIER missing before version 1.2.	cl_kernel_arg_address_qualifier	Returns the address qualifier specified for the argument given by <i>arg_index</i> . This can be one of the following values: CL_KERNEL_ARG_ADDRESS_GLOBAL CL_KERNEL_ARG_ADDRESS_LOCAL CL_KERNEL_ARG_ADDRESS_CONSTANT CL_KERNEL_ARG_ADDRESS_PRIVATE If no address qualifier is specified, the default address qualifier which is CL_KERNEL_ARG_ADDRESS_PRIVATE is returned.
CL_KERNEL_ARG_ACCESS_QUALIFIER missing before version 1.2.	cl_kernel_arg_access_qualifier	Returns the access qualifier specified for the argument given by <i>arg_index</i> . This can be one of the following values: CL_KERNEL_ARG_ACCESS_READ_ONLY CL_KERNEL_ARG_ACCESS_WRITE_ONLY CL_KERNEL_ARG_ACCESS_READ_WRITE CL_KERNEL_ARG_ACCESS_NONE If argument is not an image type and is not declared with the pipe qualifier, CL_KERNEL_ARG_ACCESS_NONE is returned. If argument is an image type, the access qualifier specified or the default access qualifier is returned.
CL_KERNEL_ARG_TYPE_NAME missing before version 1.2.	char[]	Returns the type name specified for the argument given by <i>arg_index</i> . The type name returned will be the argument type name as it was declared with any whitespace removed. If argument type name is an unsigned scalar type (i.e. unsigned char, unsigned short, unsigned int, unsigned long), uchar, ushort, uint and ulong will be returned. The argument type name returned does not include any type qualifiers.

Kernel Arg Info	Return Type	Description
CL_KERNEL_ARG_TYPE_QUALIFIER missing before version 1.2.	cl_kernel_arg_type_qualifier	Returns a bitfield describing one or more type qualifiers specified for the argument given by <i>arg_index</i> . The returned values can be: CL_KERNEL_ARG_TYPE_CONST ^[17] ^[18] CL_KERNEL_ARG_TYPE_RESTRICT CL_KERNEL_ARG_TYPE_VOLATILE CL_KERNEL_ARG_TYPE_PIPE , or CL_KERNEL_ARG_TYPE_NONE CL_KERNEL_ARG_TYPE_NONE is returned for all parameters passed by value.
CL_KERNEL_ARG_NAME missing before version 1.2.	char[]	Returns the name specified for the argument given by <i>arg_index</i> .

clGetKernelArgInfo returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_ARG_INDEX** if *arg_index* is not a valid argument index.
- **CL_INVALID_VALUE** if *param_name* is not valid, or if size in bytes specified by *param_value* size is < size of return type as described in the [Kernel Argument Queries](#) table and *param_value* is not **NULL**.
- **CL_KERNEL_ARG_INFO_NOT_AVAILABLE** if the argument information is not available for kernel.
- **CL_INVALID_KERNEL** if *kernel* is a not a valid kernel object.

5.10. Executing Kernels

To enqueue a command to execute a kernel on a device, call the function

```
cl_int clEnqueueNDRangeKernel(
    cl_command_queue command_queue,
    cl_kernel kernel,
    cl_uint work_dim,
    const size_t* global_work_offset,
    const size_t* global_work_size,
    const size_t* local_work_size,
    cl_uint num_events_in_wait_list,
    const cl_event* event_wait_list,
    cl_event* event);
```

- *command_queue* is a valid host command-queue. The kernel will be queued for execution on the device associated with *command_queue*.
- *kernel* is a valid kernel object. The OpenCL context associated with *kernel* and *command_queue*

must be the same.

- *work_dim* is the number of dimensions used to specify the global work-items and work-items in the work-group. *work_dim* must be greater than zero and less than or equal to `CL_DEVICE_MAX_WORK_ITEM_DIMENSIONS`. If *global_work_size* is `NULL`, or the value in any passed dimension is 0 then the kernel command will trivially succeed after its event dependencies are satisfied and subsequently update its completion event. The behavior in this situation is similar to that of an enqueued marker, except that unlike a marker, an enqueued kernel with no events passed to *event_wait_list* may run at any time.
- *global_work_offset* can be used to specify an array of *work_dim* unsigned values that describe the offset used to calculate the global ID of a work-item. If *global_work_offset* is `NULL`, the global IDs start at offset (0, 0, 0). *global_work_offset* must be `NULL` before version 1.1.
- *global_work_size* points to an array of *work_dim* unsigned values that describe the number of global work-items in *work_dim* dimensions that will execute the kernel function. The total number of global work-items is computed as $global_work_size[0] \times \dots \times global_work_size[work_dim - 1]$.
- *local_work_size* points to an array of *work_dim* unsigned values that describe the number of work-items that make up a work-group (also referred to as the size of the work-group) that will execute the kernel specified by *kernel*. The total number of work-items in a work-group is computed as $local_work_size[0] \times \dots \times local_work_size[work_dim - 1]$. The total number of work-items in the work-group must be less than or equal to the `CL_KERNEL_WORK_GROUP_SIZE` value specified in the [Kernel Object Device Queries](#) table, and the number of work-items specified in *local_work_size*[0], ..., *local_work_size*[*work_dim* - 1] must be less than or equal to the corresponding values specified by `CL_DEVICE_MAX_WORK_ITEM_SIZES`[0], ..., `CL_DEVICE_MAX_WORK_ITEM_SIZES`[*work_dim* - 1]. The explicitly specified *local_work_size* will be used to determine how to break the global work-items specified by *global_work_size* into appropriate work-group instances.
- *event_wait_list* and *num_events_in_wait_list* specify events that need to complete before this particular command can be executed. If *event_wait_list* is `NULL`, then this particular command does not wait on any event to complete. If *event_wait_list* is `NULL`, *num_events_in_wait_list* must be 0. If *event_wait_list* is not `NULL`, the list of events pointed to by *event_wait_list* must be valid and *num_events_in_wait_list* must be greater than 0. The events specified in *event_wait_list* act as synchronization points. The context associated with events in *event_wait_list* and *command_queue* must be the same. The memory associated with *event_wait_list* can be reused or freed after the function returns.
- *event* returns an event object that identifies this command and can be used to query or wait for this command to complete. If *event* is `NULL` or the enqueue is unsuccessful, no event will be created and therefore it will not be possible to query the status of this command or to wait for this command to complete. If *event_wait_list* and *event* are not `NULL`, *event* must not refer to an element of the *event_wait_list* array.

An ND-range kernel command may require uniform work-groups or may support non-uniform work-groups. To support non-uniform work-groups:

1. The device associated with *command_queue* must support non-uniform work-groups.
2. The program object associated with *kernel* must support non-uniform work-groups. Specifically,

this means:

- a. If the program was created with `clCreateProgramWithSource`, the program must be compiled or built using the `-cl-std=CL2.0` or `-cl-std=CL3.0` build option and without the `-cl-uniform-work-group-size` build option.
- b. If the program was created with `clCreateProgramWithIL` or `clCreateProgramWithBinary`, the program must be compiled or built without the `-cl-uniform-work-group-size` build options.
- c. If the program was created using `clLinkProgram`, all input programs must support non-uniform work-groups.

If non-uniform work-groups are supported, any single dimension for which the global size is not divisible by the local size will be partitioned into two regions. One region will have work-groups that have the same number of work-items as was specified by the local size parameter in that dimension. The other region will have work-groups with less than the number of work items specified by the local size parameter in that dimension. The global IDs and group IDs of the work-items in the first region will be numerically lower than those in the second, and the second region will be at most one work-group wide in that dimension. Work-group sizes could be non-uniform in multiple dimensions, potentially producing work-groups of up to 4 different sizes in a 2D range and 8 different sizes in a 3D range.

If non-uniform work-groups are supported and `local_work_size` is `NULL`, the OpenCL runtime may choose a uniform or non-uniform work-group size.

Otherwise, when non-uniform work-groups are not supported, the size of each work-group must be uniform. If `local_work_size` is specified, the values specified in `global_work_size[0]`, ..., `global_work_size[work_dim - 1]` must be evenly divisible by the corresponding values specified in `local_work_size[0]`, ..., `local_work_size[work_dim - 1]`. If `local_work_size` is `NULL`, the OpenCL runtime must choose a uniform work-group size.

The work-group size to be used for *kernel* can also be specified in the program source or intermediate language. In this case the size of work-group specified by `local_work_size` must match the value specified in the program source.

These work-group instances are executed in parallel across multiple compute units or concurrently on the same compute unit.

Each work-item is uniquely identified by a global identifier. The global ID, which can be read inside the kernel, is computed using the value given by `global_work_size` and `global_work_offset`. In addition, a work-item is also identified within a work-group by a unique local ID. The local ID, which can also be read by the kernel, is computed using the value given by `local_work_size`. The starting local ID is always (0, 0, ..., 0).

`clEnqueueNDRangeKernel` returns `CL_SUCCESS` if the kernel-instance was successfully queued. Otherwise, it returns one of the following errors:

- `CL_INVALID_PROGRAM_EXECUTABLE` if there is no successfully built program executable available for device associated with `command_queue`.
- `CL_INVALID_COMMAND_QUEUE` if `command_queue` is not a valid host command-queue.

- **CL_INVALID_KERNEL** if *kernel* is not a valid kernel object.
- **CL_INVALID_CONTEXT** if context associated with *command_queue* and *kernel* are not the same or if the context associated with *command_queue* and events in *event_wait_list* are not the same.
- **CL_INVALID_KERNEL_ARGS** if the kernel argument values have not been specified.
- **CL_INVALID_WORK_DIMENSION** if *work_dim* is not a valid value (i.e. a value between 1 and **CL_DEVICE_MAX_WORK_ITEM_DIMENSIONS**).
- **CL_INVALID_GLOBAL_WORK_SIZE** if *global_work_size* is NULL or if any of the values specified in *global_work_size*[0], ... *global_work_size*[*work_dim* - 1] are 0. Returning this error code under these circumstances is **deprecated by** version 2.1.
- **CL_INVALID_GLOBAL_WORK_SIZE** if any of the values specified in *global_work_size*[0], ... *global_work_size*[*work_dim* - 1] exceed the maximum value representable by **size_t** on the device on which the kernel-instance will be enqueued.
- **CL_INVALID_GLOBAL_OFFSET** if the value specified in *global_work_size* + the corresponding values in *global_work_offset* for any dimensions is greater than the maximum value representable by **size_t** on the device on which the kernel-instance will be enqueued, or if *global_work_offset* is non-NULL **before** version 1.1.
- **CL_INVALID_WORK_GROUP_SIZE** if *local_work_size* is specified and does not match the required work-group size for *kernel* in the program source.
- **CL_INVALID_WORK_GROUP_SIZE** if *local_work_size* is specified and is not consistent with the required number of sub-groups for *kernel* in the program source.
- **CL_INVALID_WORK_GROUP_SIZE** if *local_work_size* is specified and the total number of work-items in the work-group computed as *local_work_size*[0] × ... *local_work_size*[*work_dim* - 1] is greater than the value specified by **CL_KERNEL_WORK_GROUP_SIZE** in the **Kernel Object Device Queries** table.
- **CL_INVALID_WORK_GROUP_SIZE** if the work-group size must be uniform and the *local_work_size* is not NULL, is not equal to the required work-group size specified in the kernel source, or the *global_work_size* is not evenly divisible by the *local_work_size*.
- **CL_INVALID_WORK_ITEM_SIZE** if the number of work-items specified in any of *local_work_size*[0], ... *local_work_size*[*work_dim* - 1] is greater than the corresponding values specified by **CL_DEVICE_MAX_WORK_ITEM_SIZES**[0], ..., **CL_DEVICE_MAX_WORK_ITEM_SIZES**[*work_dim* - 1].
- **CL_MISALIGNED_SUB_BUFFER_OFFSET** if a sub-buffer object is specified as the value for an argument that is a buffer object and the *offset* specified when the sub-buffer object is created is not aligned to **CL_DEVICE_MEM_BASE_ADDR_ALIGN** value for device associated with *queue*. This error code is **missing before** version 1.1.
- **CL_INVALID_IMAGE_SIZE** if an image object is specified as an argument value and the image dimensions (image width, height, specified or compute row and/or slice pitch) are not supported by device associated with *queue*.
- **CL_IMAGE_FORMAT_NOT_SUPPORTED** if an image object is specified as an argument value and the image format (image channel order and data type) is not supported by device associated with *queue*.
- **CL_OUT_OF_RESOURCES** if there is a failure to queue the execution instance of *kernel* on the command-queue because of insufficient resources needed to execute the kernel. For example, the explicitly specified *local_work_size* causes a failure to execute the kernel because of

insufficient resources such as registers or local memory. Another example would be the number of read-only image args used in *kernel* exceed the `CL_DEVICE_MAX_READ_IMAGE_ARGS` value for device or the number of write-only and read-write image args used in *kernel* exceed the `CL_DEVICE_MAX_READ_WRITE_IMAGE_ARGS` value for device or the number of samplers used in *kernel* exceed `CL_DEVICE_MAX_SAMPLERS` for device.

- `CL_MEM_OBJECT_ALLOCATION_FAILURE` if there is a failure to allocate memory for data store associated with image or buffer objects specified as arguments to *kernel*.
- `CL_INVALID_EVENT_WAIT_LIST` if *event_wait_list* is `NULL` and *num_events_in_wait_list* > 0, or *event_wait_list* is not `NULL` and *num_events_in_wait_list* is 0, or if event objects in *event_wait_list* are not valid events.
- `CL_INVALID_OPERATION` if SVM pointers are passed as arguments to a kernel and the device does not support SVM or if system pointers are passed as arguments to a kernel and/or stored inside SVM allocations passed as kernel arguments and the device does not support fine grain system SVM allocations.
- `CL_OUT_OF_RESOURCES` if there is a failure to allocate resources required by the OpenCL implementation on the device.
- `CL_OUT_OF_HOST_MEMORY` if there is a failure to allocate resources required by the OpenCL implementation on the host.

To enqueue a command to execute a kernel on a device, using a single work-item, call the function

```
cl_int clEnqueueTask(  
    cl_command_queue command_queue,  
    cl_kernel kernel,  
    cl_uint num_events_in_wait_list,  
    const cl_event* event_wait_list,  
    cl_event* event);
```



`clEnqueueTask` is deprecated by version 2.0.

- *command_queue* is a valid host command-queue. The kernel will be queued for execution on the device associated with *command_queue*.
- *kernel* is a valid kernel object. The OpenCL context associated with *kernel* and *command_queue* must be the same.
- *event_wait_list* and *num_events_in_wait_list* specify events that need to complete before this particular command can be executed. If *event_wait_list* is `NULL`, then this particular command does not wait on any event to complete. If *event_wait_list* is `NULL`, *num_events_in_wait_list* must be 0. If *event_wait_list* is not `NULL`, the list of events pointed to by *event_wait_list* must be valid and *num_events_in_wait_list* must be greater than 0. The events specified in *event_wait_list* act as synchronization points. The context associated with events in *event_wait_list* and *command_queue* must be the same. The memory associated with *event_wait_list* can be reused or freed after the function returns.
- *event* returns an event object that identifies this command and can be used to query or wait for this command to complete. If *event* is `NULL` or the enqueue is unsuccessful, no event will be

created and therefore it will not be possible to query the status of this command or to wait for this command to complete. If *event_wait_list* and *event* are not **NULL**, *event* must not refer to an element of the *event_wait_list* array.

clEnqueueTask is equivalent to calling **clEnqueueNDRangeKernel** with *work_dim* set to 1, *global_work_offset* set to **NULL**, *global_work_size[0]* set to 1, and *local_work_size[0]* set to 1.

clEnqueueTask returns **CL_SUCCESS** if the kernel-instance was successfully queued. Otherwise, it returns one of the following errors:

- **CL_INVALID_PROGRAM_EXECUTABLE** if there is no successfully built program executable available for device associated with *command_queue*.
- **CL_INVALID_COMMAND_QUEUE** if *command_queue* is not a valid host command-queue.
- **CL_INVALID_KERNEL** if *kernel* is not a valid kernel object.
- **CL_INVALID_CONTEXT** if context associated with *command_queue* and *kernel* are not the same or if the context associated with *command_queue* and events in *event_wait_list* are not the same.
- **CL_INVALID_KERNEL_ARGS** if the kernel argument values have not been specified.
- **CL_INVALID_WORK_GROUP_SIZE** if a work-group size is specified for *kernel* in the program source and it is not (1, 1, 1).
- **CL_INVALID_WORK_GROUP_SIZE** if the required number of sub-groups is specified for *kernel* in the program source and is not consistent with a work-group size of (1, 1, 1).
- **CL_MISALIGNED_SUB_BUFFER_OFFSET** if a sub-buffer object is specified as the value for an argument that is a buffer object and the *offset* specified when the sub-buffer object is created is not aligned to **CL_DEVICE_MEM_BASE_ADDR_ALIGN** value for device associated with *queue*. This error code is **missing before** version 1.1.
- **CL_INVALID_IMAGE_SIZE** if an image object is specified as an argument value and the image dimensions (image width, height, specified or compute row and/or slice pitch) are not supported by device associated with *queue*.
- **CL_IMAGE_FORMAT_NOT_SUPPORTED** if an image object is specified as an argument value and the image format (image channel order and data type) is not supported by device associated with *queue*.
- **CL_OUT_OF_RESOURCES** if there is a failure to queue the execution instance of *kernel* on the command-queue because of insufficient resources needed to execute the kernel. See how this error code is used with **clEnqueueNDRangeKernel** for examples.
- **CL_MEM_OBJECT_ALLOCATION_FAILURE** if there is a failure to allocate memory for data store associated with image or buffer objects specified as arguments to *kernel*.
- **CL_INVALID_EVENT_WAIT_LIST** if *event_wait_list* is **NULL** and *num_events_in_wait_list* > 0, or *event_wait_list* is not **NULL** and *num_events_in_wait_list* is 0, or if event objects in *event_wait_list* are not valid events.
- **CL_INVALID_OPERATION** if SVM pointers are passed as arguments to a kernel and the device does not support SVM or if system pointers are passed as arguments to a kernel and/or stored inside SVM allocations passed as kernel arguments and the device does not support fine grain system SVM allocations.

- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

To enqueue a command to execute a native C/C++ function not compiled using the OpenCL compiler, call the function

```
cl_int clEnqueueNativeKernel(
    cl_command_queue command_queue,
    void (CL_CALLBACK* user_func)(void*),
    void* args,
    size_t cb_args,
    cl_uint num_mem_objects,
    const cl_mem* mem_list,
    const void** args_mem_loc,
    cl_uint num_events_in_wait_list,
    const cl_event* event_wait_list,
    cl_event* event);
```

- *command_queue* is a valid host command-queue. A native user function can only be executed on a command-queue created on a device that has **CL_EXEC_NATIVE_KERNEL** capability set in **CL_DEVICE_EXECUTION_CAPABILITIES** as specified in the [Device Queries](#) table.
- *user_func* is a pointer to a host-callable user function. It is the application's responsibility to ensure that the host-callable user function is thread-safe.
- *args* is a pointer to the args list that *user_func* should be called with.
- *cb_args* is the size in bytes of the args list that *args* points to.
- *num_mem_objects* is the number of buffer objects that are passed in *args*.
- *mem_list* is a list of valid buffer objects, if *num_mem_objects* > 0. The buffer object values specified in *mem_list* are memory object handles (**cl_mem** values) returned by [clCreateBuffer](#) or [clCreateBufferWithProperties](#), or **NULL**.
- *args_mem_loc* is a pointer to appropriate locations that *args* points to where memory object handles (**cl_mem** values) are stored. Before the user function is executed, the memory object handles are replaced by pointers to global memory.
- *event_wait_list*, *num_events_in_wait_list* and *event* are as described in [clEnqueueNDRangeKernel](#).

The data pointed to by *args* and *cb_args* bytes in size will be copied and a pointer to this copied region will be passed to *user_func*. The copy needs to be done because the memory objects (**cl_mem** values) that *args* may contain need to be modified and replaced by appropriate pointers to global memory. When [clEnqueueNativeKernel](#) returns, the memory region pointed to by *args* can be reused by the application.

[clEnqueueNativeKernel](#) returns **CL_SUCCESS** if the user function execution instance was successfully queued. Otherwise, it returns one of the following errors:

- **CL_INVALID_COMMAND_QUEUE** if *command_queue* is not a valid host command-queue.
- **CL_INVALID_CONTEXT** if context associated with *command_queue* and events in *event_wait_list* are not the same.
- **CL_INVALID_VALUE** if *user_func* is **NULL**.
- **CL_INVALID_VALUE** if *args* is a **NULL** value and *cb_args* > 0, or if *args* is a **NULL** value and *num_mem_objects* > 0.
- **CL_INVALID_VALUE** if *args* is not **NULL** and *cb_args* is 0.
- **CL_INVALID_VALUE** if *num_mem_objects* > 0 and *mem_list* or *args_mem_loc* are **NULL**.
- **CL_INVALID_VALUE** if *num_mem_objects* = 0 and *mem_list* or *args_mem_loc* are not **NULL**.
- **CL_INVALID_OPERATION** if the device associated with *command_queue* cannot execute the native kernel.
- **CL_INVALID_MEM_OBJECT** if one or more memory objects specified in *mem_list* are not valid or are not buffer objects.
- **CL_OUT_OF_RESOURCES** if there is a failure to queue the execution instance of *kernel* on the command-queue because of insufficient resources needed to execute the kernel.
- **CL_MEM_OBJECT_ALLOCATION_FAILURE** if there is a failure to allocate memory for data store associated with buffer objects specified as arguments to *kernel*.
- **CL_INVALID_EVENT_WAIT_LIST** if *event_wait_list* is **NULL** and *num_events_in_wait_list* > 0, or *event_wait_list* is not **NULL** and *num_events_in_wait_list* is 0, or if event objects in *event_wait_list* are not valid events.
- **CL_INVALID_OPERATION** if SVM pointers are passed as arguments to a kernel and the device does not support SVM or if system pointers are passed as arguments to a kernel and/or stored inside SVM allocations passed as kernel arguments and the device does not support fine grain system SVM allocations.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.



The total number of read-only images specified as arguments to a kernel cannot exceed **CL_DEVICE_MAX_READ_IMAGE_ARGS**. Each image array argument to a kernel declared with the **read_only** qualifier counts as one image. The total number of write-only images specified as arguments to a kernel cannot exceed **CL_DEVICE_MAX_WRITE_IMAGE_ARGS**. Each image array argument to a kernel declared with the **write_only** qualifier counts as one image.

The total number of read-write images specified as arguments to a kernel cannot exceed **CL_DEVICE_MAX_READ_WRITE_IMAGE_ARGS**. Each image array argument to a kernel declared with the **read_write** qualifier counts as one image.

5.11. Event Objects

An event object can be used to track the execution status of a command. The API calls that enqueue commands to a command-queue create a new event object that is returned in the *event* argument. In case of an error enqueueing the command in the command-queue the event argument does not return an event object.

The execution status of an enqueued command at any given point in time can be one of the following:

- **CL_QUEUED**: Indicates that the command has been enqueued in a command-queue. This is the initial state of all events except user events.
- **CL_SUBMITTED**: The initial state for all user events. For all other events, indicates that the command has been submitted by the host to the device.
- **CL_RUNNING**: Indicates that the device has started executing this command. In order for the execution status of an enqueued command to change from **CL_SUBMITTED** to **CL_RUNNING**, all events that this command is waiting on must have completed successfully i.e. their execution status must be **CL_COMPLETE**.
- **CL_COMPLETE**: Indicates that the command has successfully completed.
- An Error Code: A negative integer value indicating that the command was abnormally terminated. Abnormal termination may occur for a number of reasons, such as a bad memory access.



A command is considered to be complete if its execution status is **CL_COMPLETE** or is a negative integer value.

If the execution of a command is terminated, the command-queue associated with this terminated command, and the associated context (and all other command-queues in this context) may no longer be available. The behavior of OpenCL API calls that use this context (and command-queues associated with this context) are now considered to be implementation-defined. The user registered callback function specified when context is created can be used to report appropriate error information.

To create a user event object, call the function

```
cl_event clCreateUserEvent(  
    cl_context context,  
    cl_int* errcode_ret);
```



clCreateUserEvent is missing before version 1.1.

- *context* must be a valid OpenCL context.
- *errcode_ret* will return an appropriate error code. If *errcode_ret* is **NULL**, no error code is returned.

User events allow applications to enqueue commands that wait on a user event to finish before the command is executed by the device.

clCreateUserEvent returns a valid non-zero event object and *errcode_ret* is set to **CL_SUCCESS** if the user event object is created successfully. Otherwise, it returns a **NULL** value with one of the following error values returned in *errcode_ret*:

- **CL_INVALID_CONTEXT** if *context* is not a valid context.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

The initial execution status for the user event object is **CL_SUBMITTED**.

To set the execution status of a user event object, call the function

```
cl_int clSetUserEventStatus(  
    cl_event event,  
    cl_int execution_status);
```



clSetUserEventStatus is missing before version 1.1.

- *event* is a user event object created using **clCreateUserEvent**.
- *execution_status* specifies the new execution status to be set and can be **CL_COMPLETE** or a negative integer value to indicate an error. A negative integer value causes all enqueued commands that wait on this user event to be terminated. **clSetUserEventStatus** can only be called once to change the execution status of *event*.

If there are enqueued commands with user events in the *event_wait_list* argument of **clEnqueue*** commands, the user must ensure that the status of these user events being waited on are set using **clSetUserEventStatus** before any OpenCL APIs that release OpenCL objects except for event objects are called; otherwise the behavior is undefined.

For example, the following code sequence will result in undefined behavior of **clReleaseMemObject**.



```
ev1 = clCreateUserEvent(ctx, NULL);  
clEnqueueWriteBuffer(cq, buf1, CL_FALSE, ..., 1, &ev1, NULL);  
clEnqueueWriteBuffer(cq, buf2, CL_FALSE, ...);  
clReleaseMemObject(buf2);  
clSetUserEventStatus(ev1, CL_COMPLETE);
```

The following code sequence, however, works correctly.

```

ev1 = clCreateUserEvent(ctx, NULL);
clEnqueueWriteBuffer(cq, buf1, CL_FALSE, ..., 1, &ev1, NULL);
clEnqueueWriteBuffer(cq, buf2, CL_FALSE, ...);
clSetUserEventStatus(ev1, CL_COMPLETE);
clReleaseMemObject(buf2);

```

clSetUserEventStatus returns **CL_SUCCESS** if the function was executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_EVENT** if *event* is not a valid user event object.
- **CL_INVALID_VALUE** if the *execution_status* is not **CL_COMPLETE** or a negative integer value.
- **CL_INVALID_OPERATION** if the *execution_status* for *event* has already been changed by a previous call to **clSetUserEventStatus**.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

To wait for events to complete, call the function

```

cl_int clWaitForEvents(
    cl_uint num_events,
    const cl_event* event_list);

```

- *num_events* is the number of events in *event_list*.
- *event_list* is a pointer to a list of event object handles.

This function waits on the host thread for commands identified by event objects in *event_list* to complete. A command is considered complete if its execution status is **CL_COMPLETE** or a negative value. The events specified in *event_list* act as synchronization points.

clWaitForEvents returns **CL_SUCCESS** if the execution status of all events in *event_list* is **CL_COMPLETE**. Otherwise, it returns one of the following errors:

- **CL_INVALID_VALUE** if *num_events* is zero or *event_list* is **NULL**.
- **CL_INVALID_CONTEXT** if events specified in *event_list* do not belong to the same context.
- **CL_INVALID_EVENT** if event objects specified in *event_list* are not valid event objects.
- **CL_EXEC_STATUS_ERROR_FOR_EVENTS_IN_WAIT_LIST** if the execution status of any of the events in *event_list* is a negative integer value. This error code is **missing before** version 1.1.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

To return information about an event object, call the function

```
cl_int clGetEventInfo(  
    cl_event event,  
    cl_event_info param_name,  
    size_t param_value_size,  
    void* param_value,  
    size_t* param_value_size_ret);
```

- *event* specifies the event object being queried.
- *param_name* specifies the information to query. The list of supported *param_name* types and the information returned in *param_value* by **clGetEventInfo** is described in the [Event Object Queries](#) table.
- *param_value* is a pointer to memory where the appropriate result being queried is returned. If *param_value* is **NULL**, it is ignored.
- *param_value_size* is used to specify the size in bytes of memory pointed to by *param_value*. This size must be \geq size of return type as described in the [Event Object Queries](#) table.
- *param_value_size_ret* returns the actual size in bytes of data being queried by *param_name*. If *param_value_size_ret* is **NULL**, it is ignored.

Table 36. List of supported *param_names* by **clGetEventInfo**

Event Info	Return Type	Description
CL_EVENT_COMMAND_QUEUE	cl_command_queue	Return the command-queue associated with <i>event</i> . For user event objects, a NULL value is returned.
CL_EVENT_CONTEXT	cl_context	Return the context associated with <i>event</i> .
missing before version 1.1.		
CL_EVENT_COMMAND_TYPE	cl_command_type	Return the command type associated with <i>event</i> as described in the Event Command Types table.

Event Info	Return Type	Description
CL_EVENT_COMMAND_EXECUTION_STATUS ^[19]	cl_int	<p>Return the execution status of the command identified by event. Valid values are:</p> <p>CL_QUEUED (command has been enqueued in the command-queue),</p> <p>CL_SUBMITTED (enqueued command has been submitted by the host to the device associated with the command-queue),</p> <p>CL_RUNNING (device is currently executing this command),</p> <p>CL_COMPLETE (the command has completed), or</p> <p>Error code given by a negative integer value. (command was abnormally terminated - this may be caused by a bad memory access etc.). These error codes come from the same set of error codes that are returned from the platform or runtime API calls as return values or <code>errcode_ret</code> values.</p>
CL_EVENT_REFERENCE_COUNT ^[20]	cl_uint	Return the <i>event</i> reference count.

Table 37. List of supported event command types

Events Created By	Event Command Type
clEnqueueNDRangeKernel	CL_COMMAND_NDRANGE_KERNEL
clEnqueueTask	CL_COMMAND_TASK
clEnqueueNativeKernel	CL_COMMAND_NATIVE_KERNEL
clEnqueueReadBuffer	CL_COMMAND_READ_BUFFER
clEnqueueWriteBuffer	CL_COMMAND_WRITE_BUFFER
clEnqueueCopyBuffer	CL_COMMAND_COPY_BUFFER
clEnqueueReadImage	CL_COMMAND_READ_IMAGE
clEnqueueWriteImage	CL_COMMAND_WRITE_IMAGE
clEnqueueCopyImage	CL_COMMAND_COPY_IMAGE
clEnqueueCopyBufferToImage	CL_COMMAND_COPY_BUFFER_TO_IMAGE
clEnqueueCopyImageToBuffer	CL_COMMAND_COPY_IMAGE_TO_BUFFER
clEnqueueMapBuffer	CL_COMMAND_MAP_BUFFER
clEnqueueMapImage	CL_COMMAND_MAP_IMAGE
clEnqueueUnmapMemObject	CL_COMMAND_UNMAP_MEM_OBJECT

Events Created By	Event Command Type
clEnqueueMarker, clEnqueueMarkerWithWaitList	CL_COMMAND_MARKER missing before version 1.1.
clEnqueueReadBufferRect	CL_COMMAND_READ_BUFFER_RECT missing before version 1.1.
clEnqueueWriteBufferRect	CL_COMMAND_WRITE_BUFFER_RECT missing before version 1.1.
clEnqueueCopyBufferRect	CL_COMMAND_COPY_BUFFER_RECT missing before version 1.1.
clCreateUserEvent	CL_COMMAND_USER missing before version 1.1.
clEnqueueBarrier, clEnqueueBarrierWithWaitList	CL_COMMAND_BARRIER missing before version 1.2.
clEnqueueMigrateMemObjects	CL_COMMAND_MIGRATE_MEM_OBJECTS missing before version 1.2.
clEnqueueFillBuffer	CL_COMMAND_FILL_BUFFER missing before version 1.2.
clEnqueueFillImage	CL_COMMAND_FILL_IMAGE missing before version 1.2.
clEnqueueSVMFree	CL_COMMAND_SVM_FREE missing before version 2.0.
clEnqueueSVMMemcpy	CL_COMMAND_SVM_MEMCPY missing before version 2.0.
clEnqueueSVMMemFill	CL_COMMAND_SVM_MEMFILL missing before version 2.0.
clEnqueueSVMMap	CL_COMMAND_SVM_MAP missing before version 2.0.
clEnqueueSVMUnmap	CL_COMMAND_SVM_UNMAP missing before version 2.0.

Events Created By	Event Command Type
<code>clEnqueueSVMigrateMem</code>	<code>CL_COMMAND_SVM_MIGRATE_MEM</code> missing before version 3.0. Prior to OpenCL 3.0, implementations should return <code>CL_COMMAND_MIGRATE_MEM_OBJECTS</code> , but may return an implementation-defined event command type for <code>clEnqueueSVMigrateMem</code> .

Using `clGetEventInfo` to determine if a command identified by *event* has finished execution (i.e. `CL_EVENT_COMMAND_EXECUTION_STATUS` returns `CL_COMPLETE`) is not a synchronization point. There are no guarantees that the memory objects being modified by command associated with *event* will be visible to other enqueued commands.

`clGetEventInfo` returns `CL_SUCCESS` if the function is executed successfully. Otherwise, it returns one of the following errors:

- `CL_INVALID_VALUE` if *param_name* is not valid, or if size in bytes specified by *param_value_size* is < size of return type as described in the [Kernel Argument Queries](#) table and *param_value* is not `NULL`.
- `CL_INVALID_VALUE` if information to query given in *param_name* cannot be queried for *event*.
- `CL_INVALID_EVENT` if *event* is not a valid event object.
- `CL_OUT_OF_RESOURCES` if there is a failure to allocate resources required by the OpenCL implementation on the device.
- `CL_OUT_OF_HOST_MEMORY` if there is a failure to allocate resources required by the OpenCL implementation on the host.

To register a user callback function for a specific command execution status, call the function

```
cl_int clSetEventCallback(
    cl_event event,
    cl_int command_exec_callback_type,
    void (CL_CALLBACK* pfn_notify)(cl_event event, cl_int event_command_status, void
*user_data),
    void* user_data);
```



`clSetEventCallback` is missing before version 1.1.

- *event* is a valid event object.
- *command_exec_callback_type* specifies the command execution status for which the callback is registered. The command execution callback values for which a callback can be registered are: `CL_SUBMITTED`, `CL_RUNNING`, or `CL_COMPLETE` ^[21]. There is no guarantee that the callback functions registered for various execution status values for an event will be called in the exact order that the execution status of a command changes. Furthermore, it should be noted that receiving a

call back for an event with a status other than `CL_COMPLETE`, in no way implies that the memory model or execution model as defined by the OpenCL specification has changed. For example, it is not valid to assume that a corresponding memory transfer has completed unless the event is in a state `CL_COMPLETE`.

- *pfn_event_notify* is the event callback function that can be registered by the application. This callback function may be called asynchronously by the OpenCL implementation. It is the application's responsibility to ensure that the callback function is thread-safe. The parameters to this callback function are:
 - *event* is the event object for which the callback function is invoked.
 - *event_command_status* is equal to the *command_exec_callback_type* used while registering the callback. Refer to the [Event Object Queries](#) table for the command execution status values. If the callback is called as the result of the command associated with event being abnormally terminated, an appropriate error code for the error that caused the termination will be passed to *event_command_status* instead.
 - *user_data* is a pointer to user supplied data.
- *user_data* will be passed as the *user_data* argument when *pfn_notify* is called. *user_data* can be `NULL`.

The registered callback function will be called when the execution status of command associated with *event* changes to an execution status equal to or past the status specified by *command_exec_status*.

Each call to [clSetEventCallback](#) registers the specified user callback function on a callback stack associated with *event*. The order in which the registered user callback functions are called is undefined.

All callbacks registered for an event object must be called before the event object is destroyed. Callbacks should return promptly.

Behavior is undefined when calling expensive system routines, OpenCL APIs to create contexts or command-queues, or blocking OpenCL APIs in an event callback. Rather than calling a blocking OpenCL API in an event callback, applications may call a non-blocking OpenCL API, then register a completion callback for the non-blocking OpenCL API with the remainder of the work.

Because commands in a command-queue are not required to begin execution until the command-queue is flushed, callbacks that enqueue commands on a command-queue should either call [clFlush](#) on the queue before returning, or arrange for the command-queue to be flushed later.

[clSetEventCallback](#) returns `CL_SUCCESS` if the function is executed successfully. Otherwise, it returns one of the following errors:

- `CL_INVALID_EVENT` if *event* is not a valid event object.
- `CL_INVALID_VALUE` if *pfn_event_notify* is `NULL` or if *command_exec_callback_type* is not `CL_SUBMITTED`, `CL_RUNNING`, or `CL_COMPLETE`.
- `CL_OUT_OF_RESOURCES` if there is a failure to allocate resources required by the OpenCL implementation on the device.

- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

To retain an event object, call the function

```
cl_int clRetainEvent(  
    cl_event event);
```

- *event* is the event object to be retained.

The *event* reference count is incremented. The OpenCL commands that return an event perform an implicit retain.

clRetainEvent returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_EVENT** if *event* is not a valid event object.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

To release an event object, call the function

```
cl_int clReleaseEvent(  
    cl_event event);
```

- *event* is the event object to be released.

The *event* reference count is decremented.

The event object is deleted once the reference count becomes zero, the specific command identified by this event has completed (or terminated) and there are no commands in the command-queues of a context that require a wait for this event to complete. Using this function to release a reference that was not obtained by creating the object or by calling **clRetainEvent** causes undefined behavior.



Developers should be careful when releasing their last reference count on events created by **clCreateUserEvent** that have not yet been set to status of **CL_COMPLETE** or an error. If the user event was used in the *event_wait_list* argument passed to a **clEnqueue*** API or another application host thread is waiting for it in **clWaitForEvents**, those commands and host threads will continue to wait for the event status to reach **CL_COMPLETE** or error, even after the application has released the object. Since in this scenario the application has released its last reference count to the user event, it would be in principle no longer valid for the application to change the status of the event to unblock all the other machinery. As a result the waiting tasks will wait forever, and associated events, **cl_mem** objects, command-

queues and contexts are likely to leak. In-order command-queues caught up in this deadlock may cease to do any work.

clReleaseEvent returns **CL_SUCCESS** if the function is executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_EVENT** if *event* is not a valid event object.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

5.12. Markers, Barriers and Waiting for Events

To enqueue a marker command which waits for events or commands to complete, call the function

```
cl_int clEnqueueMarkerWithWaitList(  
    cl_command_queue command_queue,  
    cl_uint num_events_in_wait_list,  
    const cl_event* event_wait_list,  
    cl_event* event);
```



clEnqueueMarkerWithWaitList is [missing before](#) version 1.2.

- *command_queue* is a valid host command-queue.
- *event_wait_list* and *num_events_in_wait_list* specify events that need to complete before this particular command can be executed.
- *event* returns an event object that identifies this command and can be used to query or wait for this command to complete. If *event* is **NULL** or the enqueue is unsuccessful, no event will be created and therefore it will not be possible to query the status of this command or to wait for this command to complete. If *event_wait_list* and *event* are not **NULL**, *event* must not refer to an element of the *event_wait_list* array.

If *event_wait_list* is **NULL**, *num_events_in_wait_list* must be 0. If *event_wait_list* is not **NULL**, the list of events pointed to by *event_wait_list* must be valid and *num_events_in_wait_list* must be greater than 0. The events specified in *event_wait_list* act as synchronization points. The context associated with events in *event_wait_list* and *command_queue* must be the same. The memory associated with *event_wait_list* can be reused or freed after the function returns.

If *event_wait_list* is **NULL**, then this particular command waits until all previous enqueued commands to *command_queue* have completed.

The marker command either waits for a list of events to complete, or if the list is empty it waits for all commands previously enqueued in *command_queue* to complete before it completes. This command returns an *event* which can be waited on, i.e. this event can be waited on to insure that all events either in the *event_wait_list* or all previously enqueued commands, queued before this

command to *command_queue*, have completed.

clEnqueueMarkerWithWaitList returns **CL_SUCCESS** if the function is successfully executed. Otherwise, it returns one of the following errors:

- **CL_INVALID_COMMAND_QUEUE** if *command_queue* is not a valid host command-queue.
- **CL_INVALID_CONTEXT** if context associated with *command_queue* and events in *event_wait_list* are not the same.
- **CL_INVALID_EVENT_WAIT_LIST** if *event_wait_list* is **NULL** and *num_events_in_wait_list* > 0, or *event_wait_list* is not **NULL** and *num_events_in_wait_list* is 0, or if event objects in *event_wait_list* are not valid events.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

To enqueue a marker command which waits for previous commands to complete, call the function

```
cl_int clEnqueueMarker(  
    cl_command_queue command_queue,  
    cl_event* event);
```



clEnqueueMarker is deprecated by version 1.2.

- *command_queue* is a valid host command-queue.
- *event* returns an event object that identifies this command and can be used to query or wait for this command to complete. If *event* is **NULL** or the enqueue is unsuccessful, no event will be created and therefore it will not be possible to query the status of this command or to wait for this command to complete. If *event_wait_list* and *event* are not **NULL**, *event* must not refer to an element of the *event_wait_list* array.

The marker command waits for all commands previously enqueued in *command_queue* to complete before it completes. This command returns an *event* which can be waited on, i.e. this event can be waited on to insure that all previously enqueued commands, queued before this command to *command_queue*, have completed.

clEnqueueMarker returns **CL_SUCCESS** if the function is successfully executed. Otherwise, it returns one of the following errors:

- **CL_INVALID_COMMAND_QUEUE** if *command_queue* is not a valid host command-queue.
- **CL_INVALID_VALUE** if *event* is **NULL**.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

To enqueue a wait for a specific event or a list of events to complete before any future commands queued in a command-queue are executed, call the function

```
cl_int clEnqueueWaitForEvents(  
    cl_command_queue command_queue,  
    cl_uint num_events,  
    const cl_event* event_list);
```



clEnqueueWaitForEvents is deprecated by version 1.2.

- *command_queue* is a valid host command-queue.
- *event_list* and *num_events* specify events that need to complete before this particular command can be executed.

The events specified in *event_list* act as synchronization points. The context associated with events in *event_list* and *command_queue* must be the same. The memory associated with *event_list* can be reused or freed after the function returns.

clEnqueueWaitForEvents returns **CL_SUCCESS** if the function is successfully executed. Otherwise, it returns one of the following errors:

- **CL_INVALID_COMMAND_QUEUE** if *command_queue* is not a valid host command-queue.
- **CL_INVALID_CONTEXT** if context associated with *command_queue* and events in *event_list* are not the same.
- **CL_INVALID_VALUE** if *num_events* is 0 or *event_list* is **NULL**.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

To enqueue a barrier command which waits for events or commands to complete, call the function

```
cl_int clEnqueueBarrierWithWaitList(  
    cl_command_queue command_queue,  
    cl_uint num_events_in_wait_list,  
    const cl_event* event_wait_list,  
    cl_event* event);
```



clEnqueueBarrierWithWaitList is missing before version 1.2.

- *command_queue* is a valid host command-queue.
- *event_wait_list* and *num_events_in_wait_list* specify events that need to complete before this particular command can be executed.
- If *event_wait_list* is **NULL**, *num_events_in_wait_list* must be 0. If *event_wait_list* is not **NULL**, the list

of events pointed to by *event_wait_list* must be valid and *num_events_in_wait_list* must be greater than 0. The events specified in *event_wait_list* act as synchronization points. The context associated with events in *event_wait_list* and *command_queue* must be the same. The memory associated with *event_wait_list* can be reused or freed after the function returns.

- *event* returns an event object that identifies this command and can be used to query or wait for this command to complete. If *event* is **NULL** or the enqueue is unsuccessful, no event will be created and therefore it will not be possible to query the status of this command or to wait for this command to complete. If *event_wait_list* and *event* are not **NULL**, *event* must not refer to an element of the *event_wait_list* array.

If *event_wait_list* is **NULL**, then this particular command waits until all previous enqueued commands to *command_queue* have completed.

The barrier command either waits for a list of events to complete, or if the list is empty it waits for all commands previously enqueued in *command_queue* to complete before it completes. This command blocks command execution, that is, any following commands enqueued after it do not execute until it completes. This command returns an *event* which can be waited on, i.e. this event can be waited on to insure that all events either in the *event_wait_list* or all previously enqueued commands, queued before this command to *command_queue*, have completed.

clEnqueueBarrierWithWaitList returns **CL_SUCCESS** if the function is successfully executed. Otherwise, it returns one of the following errors:

- **CL_INVALID_COMMAND_QUEUE** if *command_queue* is not a valid host command-queue.
- **CL_INVALID_CONTEXT** if context associated with *command_queue* and events in *event_wait_list* are not the same.
- **CL_INVALID_EVENT_WAIT_LIST** if *event_wait_list* is **NULL** and *num_events_in_wait_list* > 0, or *event_wait_list* is not **NULL** and *num_events_in_wait_list* is 0, or if event objects in *event_wait_list* are not valid events.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

To enqueue a barrier command which waits for commands to complete, call the function

```
cl_int clEnqueueBarrier(  
    cl_command_queue command_queue);
```



clEnqueueBarrier is deprecated by version 1.2.

- *command_queue* is a valid host command-queue.

The barrier command waits for all commands previously enqueued in *command_queue* to complete before it completes. This command blocks command execution, that is, any following commands enqueued after it do not execute until it completes. The barrier command is a synchronization

point.

clEnqueueBarrier returns **CL_SUCCESS** if the function is successfully executed. Otherwise, it returns one of the following errors:

- **CL_INVALID_COMMAND_QUEUE** if *command_queue* is not a valid host command-queue.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

5.13. Out-of-order Execution of Kernels and Memory Object Commands

The OpenCL functions that are submitted to a command-queue are enqueued in the order the calls are made but can be configured to execute in-order or out-of-order. The *properties* argument in **clCreateCommandQueueWithProperties** or **clCreateCommandQueue** can be used to specify the execution order.

If the **CL_QUEUE_OUT_OF_ORDER_EXEC_MODE_ENABLE** property of a command-queue is not set, the commands enqueued to a command-queue execute in-order. For example, if an application calls **clEnqueueNDRangeKernel** to execute kernel A followed by a **clEnqueueNDRangeKernel** to execute kernel B, the application can assume that kernel A finishes first and then kernel B is executed. If the memory objects output by kernel A are inputs to kernel B then kernel B will see the correct data in memory objects produced by execution of kernel A. If the **CL_QUEUE_OUT_OF_ORDER_EXEC_MODE_ENABLE** property of a command-queue is set, then there is no guarantee that kernel A will finish before kernel B starts execution.

Applications can configure the commands enqueued to a command-queue to execute out-of-order by setting the **CL_QUEUE_OUT_OF_ORDER_EXEC_MODE_ENABLE** property of the command-queue. This can be specified when the command-queue is created. In out-of-order execution mode there is no guarantee that the enqueued commands will finish execution in the order they were queued. As there is no guarantee that kernels will be executed in-order, i.e. based on when the **clEnqueueNDRangeKernel** or **clEnqueueTask** calls are made within a command-queue, it is therefore possible that an earlier **clEnqueueNDRangeKernel** call to execute kernel A identified by event A may execute and/or finish later than a **clEnqueueNDRangeKernel** call to execute kernel B which was called by the application at a later point in time. To guarantee a specific order of execution of kernels, a wait on a particular event (in this case event A) can be used. The wait for event A can be specified in the *event_wait_list* argument to **clEnqueueNDRangeKernel** for kernel B.

In addition, a marker (**clEnqueueMarker** or **clEnqueueMarkerWithWaitList**) or a barrier (**clEnqueueBarrier** or **clEnqueueBarrierWithWaitList**) command can be enqueued to the command-queue. The marker command ensures that previously enqueued commands identified by the list of events to wait for (or all previous commands) have finished. A barrier command is similar to a marker command, but additionally guarantees that no later-enqueued commands will execute until the waited-for commands have executed.

Similarly, commands to read, write, copy or map memory objects that are enqueued after `clEnqueueNDRangeKernel`, `clEnqueueTask` or `clEnqueueNativeKernel` commands are not guaranteed to wait for kernels scheduled for execution to have completed (if the `CL_QUEUE_OUT_OF_ORDER_EXEC_MODE_ENABLE` property is set). To ensure correct ordering of commands, the event object returned by `clEnqueueNDRangeKernel`, `clEnqueueTask` or `clEnqueueNativeKernel` can be used to enqueue a wait for event or a barrier command can be enqueued that must complete before reads or writes to the memory object(s) occur.

5.14. Profiling Operations on Memory Objects and Kernels

This section describes the profiling of OpenCL functions that are enqueued as commands to a command-queue. Profiling of OpenCL commands can be enabled by using a command-queue created with the `CL_QUEUE_PROFILING_ENABLE` flag set in the `CL_QUEUE_PROPERTIES` bitfield in the *properties* argument to `clCreateCommandQueueWithProperties`, or in the *properties* argument to `clCreateCommandQueue`. When profiling is enabled, the event objects that are created from enqueueing a command store a timestamp for each of their state transitions.

To return profiling information for a command associated with an event when profiling is enabled, call the function

```
cl_int clGetEventProfilingInfo(
    cl_event event,
    cl_profiling_info param_name,
    size_t param_value_size,
    void* param_value,
    size_t* param_value_size_ret);
```

- *event* specifies the event object.
- *param_name* specifies the profiling data to query. The list of supported *param_name* types and the information returned in *param_value* by `clGetEventProfilingInfo` is described in the [Event Profiling Queries](#) table.
- *param_value* is a pointer to memory where the appropriate result being queried is returned. If *param_value* is `NULL`, it is ignored.
- *param_value_size* is used to specify the size in bytes of memory pointed to by *param_value*. This size must be \geq size of return type as described in the [Event Profiling Queries](#) table.
- *param_value_size_ret* returns the actual size in bytes of data being queried by *param_name*. If *param_value_size_ret* is `NULL`, it is ignored.

Table 38. List of supported *param_names* by `clGetEventProfilingInfo`

Event Profiling Info	Return Type	Description
CL_PROFILING_COMMAND_QUEUED	cl_ulong	A 64-bit value that describes the current device time counter in nanoseconds when the command identified by event is enqueued in a command-queue by the host.
CL_PROFILING_COMMAND_SUBMIT	cl_ulong	A 64-bit value that describes the current device time counter in nanoseconds when the command identified by event that has been enqueued is submitted by the host to the device associated with the command-queue.
CL_PROFILING_COMMAND_START	cl_ulong	A 64-bit value that describes the current device time counter in nanoseconds when the command identified by event starts execution on the device.
CL_PROFILING_COMMAND_END	cl_ulong	A 64-bit value that describes the current device time counter in nanoseconds when the command identified by event has finished execution on the device.
CL_PROFILING_COMMAND_COMPLETE missing before version 2.0.	cl_ulong	A 64-bit value that describes the current device time counter in nanoseconds when the command identified by event and any child commands enqueued by this command on the device have finished execution.

The unsigned 64-bit values returned can be used to measure the time in nano-seconds consumed by OpenCL commands.

OpenCL devices are required to correctly track time across changes in device frequency and power states. The `CL_DEVICE_PROFILING_TIMER_RESOLUTION` specifies the resolution of the timer i.e. the number of nanoseconds elapsed before the timer is incremented.

`clGetEventProfilingInfo` returns `CL_SUCCESS` if the function is executed successfully and the profiling information has been recorded. Otherwise, it returns one of the following errors:

- `CL_PROFILING_INFO_NOT_AVAILABLE` if the `CL_QUEUE_PROFILING_ENABLE` flag is not set for the command-queue, if the execution status of the command identified by *event* is not `CL_COMPLETE` or if *event* is a user event object. Prior to OpenCL 3.0, implementations may return `CL_PROFILING_INFO_NOT_AVAILABLE` for an event created by `clEnqueueSVMFree`.
- `CL_INVALID_VALUE` if *param_name* is not valid, or if size in bytes specified by *param_value_size* is < size of return type as described in the [Event Profiling Queries](#) table and *param_value* is not `NULL`.
- `CL_INVALID_EVENT` if *event* is a not a valid event object.
- `CL_OUT_OF_RESOURCES` if there is a failure to allocate resources required by the OpenCL implementation on the device.
- `CL_OUT_OF_HOST_MEMORY` if there is a failure to allocate resources required by the OpenCL implementation on the host.

5.15. Flush and Finish

To flush commands to a device, call the function

```
cl_int clFlush(  
    cl_command_queue command_queue);
```

- *command_queue* is the command-queue to flush.

All previously queued OpenCL commands in *command_queue* are issued to the device associated with *command_queue*. **clFlush** only guarantees that all queued commands to *command_queue* will eventually be submitted to the appropriate device. There is no guarantee that they will be complete after **clFlush** returns.

Any blocking commands queued in a command-queue and **clReleaseCommandQueue** perform an implicit flush of the command-queue. These blocking commands are **clEnqueueReadBuffer**, **clEnqueueReadBufferRect**, **clEnqueueReadImage**, with *blocking_read* set to **CL_TRUE**; **clEnqueueWriteBuffer**, **clEnqueueWriteBufferRect**, **clEnqueueWriteImage** with *blocking_write* set to **CL_TRUE**; **clEnqueueMapBuffer**, **clEnqueueMapImage** with *blocking_map* set to **CL_TRUE**; **clEnqueueSVMMemcpy** with *blocking_copy* set to **CL_TRUE**; **clEnqueueSVMMap** with *blocking_map* set to **CL_TRUE** or **clWaitForEvents**.

To use event objects that refer to commands enqueued in a command-queue as event objects to wait on by commands enqueued in a different command-queue, the application must call a **clFlush** or any blocking commands that perform an implicit flush of the command-queue where the commands that refer to these event objects are enqueued.

clFlush returns **CL_SUCCESS** if the function call was executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_COMMAND_QUEUE** if *command_queue* is not a valid host command-queue.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

To wait for completion of commands on a device, call the function

```
cl_int clFinish(  
    cl_command_queue command_queue);
```

- *command_queue* is the command-queue to wait for.

All previously queued OpenCL commands in *command_queue* are issued to the associated device, and the function blocks until all previously queued commands have completed. **clFinish** does not return until all previously queued commands in *command_queue* have been processed and completed. **clFinish** is also a synchronization point.

clFinish returns **CL_SUCCESS** if the function call was executed successfully. Otherwise, it returns one of the following errors:

- **CL_INVALID_COMMAND_QUEUE** if *command_queue* is not a valid host command-queue.
- **CL_OUT_OF_RESOURCES** if there is a failure to allocate resources required by the OpenCL implementation on the device.
- **CL_OUT_OF_HOST_MEMORY** if there is a failure to allocate resources required by the OpenCL implementation on the host.

[1] Only out-of-order device queues are supported.

[2] The application must create a default device queue if any kernels containing calls to **get_default_queue** are enqueued. There can only be one default device queue for each device within a context. If a default device queue has already been created, calling **clCreateCommandQueueWithProperties** with **CL_QUEUE_PROPERTIES** set to **CL_QUEUE_ON_DEVICE** and **CL_QUEUE_ON_DEVICE_DEFAULT** will return the default device queue that has already been created and increment its reference count by 1.

[3] The reference count returned should be considered immediately stale. It is unsuitable for general use in applications. This feature is provided for identifying memory leaks.

[4] Note that reading and writing 2D image arrays from a kernel with **image_array_size** equal to one may perform worse than 2D images.

[5] To create a 2D image from a buffer object that share the data store between the image and buffer object.

[6] To create an image object from another image object that share the data store between these image objects.

[7] This allows creation of a sRGB view of the image from a linear RGB view or vice-versa, i.e. the pixels stored in the image can be accessed as linear RGB or sRGB values.

[8] Support for the **CL_DEPTH** image channel order is required only for 2D images and 2D image arrays.

[9] Support for reading from the **CL_sRGBA** image channel order is optional for 1D image buffers. Support for writing to the **CL_sRGBA** image channel order is optional for all image types.

[10] The map count returned should be considered immediately stale. It is unsuitable for general use in applications. This feature is provided for debugging.

[11] The reference count returned should be considered immediately stale. It is unsuitable for general use in applications. This feature is provided for identifying memory leaks.

[12] The reference count returned should be considered immediately stale. It is unsuitable for general use in applications. This feature is provided for identifying memory leaks.

[13] As per the definition of **-cl-denorms-are-zero**, the inclusion of this option with **-cl-unsafe-math-optimizations** means that the implementation may flush denormal numbers to zero but is not required to.

[14] The reference count returned should be considered immediately stale. It is unsuitable for general use in applications. This feature is provided for identifying memory leaks.

[15] Implementations are encouraged to favor this option as it makes it more likely that errors will be managed by applications.

[16] The reference count returned should be considered immediately stale. It is unsuitable for general use in applications. This feature is provided for identifying memory leaks.

[17] **CL_KERNEL_ARG_TYPE_CONST** is returned if the argument is a pointer and the referenced type is declared with the **const** qualifier. For example, a kernel argument declared as **global int const *x** returns **CL_KERNEL_ARG_TYPE_CONST** but a kernel argument declared as **global int * const x** does not.

Similarly, **CL_KERNEL_ARG_TYPE_RESTRICT** will be returned if the pointer type is marked **restrict**. For example, **global int * restrict x** returns **CL_KERNEL_ARG_TYPE_RESTRICT**.

CL_KERNEL_ARG_TYPE_VOLATILE is returned for **CL_KERNEL_ARG_TYPE_QUALIFIER** if the argument is a pointer and the referenced type is declared with the **volatile** qualifier. For example, a kernel argument declared as **global int volatile *x** returns **CL_KERNEL_ARG_TYPE_VOLATILE** but a kernel argument declared as **global int * volatile x** does not.

[18] **CL_KERNEL_ARG_TYPE_CONST** is returned for **CL_KERNEL_ARG_TYPE_QUALIFIER** if the argument is declared with the **constant** address space qualifier.

[19] The error code values are negative, and event state values are positive. The event state values are ordered from the largest value **CL_QUEUED** for the first or initial state to the smallest value (**CL_COMPLETE** or negative integer value) for the last or complete state. The value of **CL_COMPLETE** and **CL_SUCCESS** are the same.

[20] The reference count returned should be considered immediately stale. It is unsuitable for general use in applications. This feature is provided for identifying memory leaks.

[21] The callback function registered for a *command_exec_callback_type* value of **CL_COMPLETE** will be called when the command has

completed successfully or is abnormally terminated.

Chapter 6. Associated OpenCL specification

6.1. SPIR-V Intermediate Language

OpenCL 2.1 and 2.2 require support for the SPIR-V intermediate language that allows offline compilation to a binary format that may be consumed by the [clCreateProgramWithIL](#) interface.

The OpenCL specification includes a specification for the SPIR-V intermediate language as a cross-platform input language. In addition, platform vendors may support their own IL if this is appropriate. The OpenCL runtime will return a list of supported IL versions using the `CL_DEVICE_IL_VERSION` or `CL_DEVICE_ILS_WITH_VERSION` parameter to the [clGetDeviceInfo](#) query.

6.2. Extensions to OpenCL

In addition to the specification of core features, OpenCL provides a number of extensions to the API, kernel language or intermediate representation. These features are defined in the OpenCL extension specification document.

Extensions defined against earlier versions of the OpenCL specifications, whether the API or language specification, are defined in the matching versions of the extension specification document.

6.3. The OpenCL C Kernel Language

The OpenCL C kernel language is not defined in the OpenCL unified specification. The OpenCL C kernel languages are instead defined in the OpenCL 1.0, OpenCL 1.1, OpenCL 1.2, OpenCL C 2.0 Kernel Language, and OpenCL C 3.0 Kernel Language specifications. When OpenCL devices support one or more versions of the OpenCL C kernel language (see `CL_DEVICE_OPENCL_C_VERSION` and `CL_DEVICE_OPENCL_C_ALL_VERSIONS`), OpenCL program objects may be created by passing OpenCL C source strings to [clCreateProgramWithSource](#).

Chapter 7. OpenCL Embedded Profile

The OpenCL specification describes the feature requirements for desktop platforms. This section describes the OpenCL embedded profile that allows us to target a subset of the OpenCL specification for handheld and embedded platforms. The optional extensions defined in the OpenCL Extension Specification apply to both profiles.

The OpenCL embedded profile has the following restrictions until version 2.0 (i.e. the optionality described below was [deprecated by](#) version 2.0):

1. Support for 3D images is optional.

If `CL_DEVICE_IMAGE3D_MAX_WIDTH`, `CL_DEVICE_IMAGE3D_MAX_HEIGHT` and `CL_DEVICE_IMAGE3D_MAX_DEPTH` are zero, calls to `clCreateImage` or `clCreateImageWithProperties` will fail to create the 3D image, and the `errcode_ret` argument will return `CL_INVALID_OPERATION`. Declaring arguments of type `image3d_t` in a kernel will result in a compilation error.

If `CL_DEVICE_IMAGE3D_MAX_WIDTH`, `CL_DEVICE_IMAGE3D_MAX_HEIGHT` and `CL_DEVICE_IMAGE3D_MAX_DEPTH` are greater than zero 0, calls to `clCreateImage` and `clCreateImageWithProperties` will behave as described for full profile implementations, and the `image3d_t` data type can be used in a kernel.

2. Support for 2D image array writes is optional. If the `cles_khr_2d_image_array_writes` extension is supported by the embedded profile, writes to 2D image arrays are supported.
3. Image and image arrays created with an `image_channel_data_type` value of `CL_FLOAT` or `CL_HALF_FLOAT` can only be used with samplers that use a filter mode of `CL_FILTER_NEAREST`. The values returned by `read_imagef`^[1] for 2D and 3D images if `image_channel_data_type` value is `CL_FLOAT` or `CL_HALF_FLOAT` and sampler with `filter_mode = CL_FILTER_LINEAR` are undefined.

Furthermore, the OpenCL embedded profile has the following restrictions for all versions:

1. 64 bit integers i.e. long, along including the appropriate vector data types and operations on 64-bit integers are optional. The `cles_khr_int64`^[2] extension string will be reported if the embedded profile implementation supports 64-bit integers. If double precision is supported i.e. `CL_DEVICE_DOUBLE_FP_CONFIG` is not zero, then `cles_khr_int64` must also be supported.
2. The mandated minimum single precision floating-point capability given by `CL_DEVICE_SINGLE_FP_CONFIG` is `CL_FP_ROUND_TO_ZERO` or `CL_FP_ROUND_TO_NEAREST`. If `CL_FP_ROUND_TO_NEAREST` is supported, the default rounding mode will be round to nearest even; otherwise the default rounding mode will be round to zero.
3. The single precision floating-point operations (addition, subtraction and multiplication) shall be correctly rounded. Zero results may always be positive 0.0. The accuracy of division and sqrt are given in the OpenCL C and OpenCL SPIR-V Environment specifications.

If `CL_FP_INF_NAN` is not set in `CL_DEVICE_SINGLE_FP_CONFIG`, and one of the operands or the result of addition, subtraction, multiplication or division would signal the overflow or invalid exception (see IEEE 754 specification), the value of the result is implementation-defined. Likewise, single precision comparison operators (`<`, `>`, `<=`, `>=`, `==`, `!=`) return implementation-defined values when one or more operands is a NaN.

In all cases, conversions (see the OpenCL C and OpenCL SPIR-V Environment specifications) shall be correctly rounded as described for the FULL_PROFILE, including those that consume or produce an INF or NaN. The built-in math functions shall behave as described for the FULL_PROFILE, including edge case behavior, but with slightly different accuracy rules. Edge case behavior and accuracy rules are described in the OpenCL C and OpenCL SPIR-V Environment specifications.

Note



If addition, subtraction and multiplication have default round to zero rounding mode, then **fract**, **fma** and **fdim** shall produce the correctly rounded result for round to zero rounding mode.

This relaxation of the requirement to adhere to IEEE 754 requirements for basic floating-point operations, though extremely undesirable, is to provide flexibility for embedded devices that have lot stricter requirements on hardware area budgets.

4. Denormalized numbers for the half data type which may be generated when converting a float to a half using variants of the **vstore_half** function or when converting from a half to a float using variants of the **vload_half** function can be flushed to zero. The OpenCL SPIR-V Environment Specification for details.
5. The precision of conversions from **CL_UNORM_INT8**, **CL_SNORM_INT8**, **CL_UNORM_INT16**, **CL_SNORM_INT16**, **CL_UNORM_INT_101010**, and **CL_UNORM_INT_101010_2** to float is ≤ 2 ulp for the embedded profile instead of ≤ 1.5 ulp as defined in the full profile. The exception cases described in the full profile and given below apply to the embedded profile.

For **CL_UNORM_INT8**

- 0 must convert to 0.0f and
- 255 must convert to 1.0f

For **CL_UNORM_INT16**

- 0 must convert to 0.0f and
- 65535 must convert to 1.0f

For **CL_SNORM_INT8**

- -128 and -127 must convert to -1.0f,
- 0 must convert to 0.0f and
- 127 must convert to 1.0f

For **CL_SNORM_INT16**

- -32768 and -32767 must convert to -1.0f,
- 0 must convert to 0.0f and
- 32767 must convert to 1.0f

For `CL_UNORM_INT_101010`

- 0 must convert to 0.0f and
- 1023 must convert to 1.0f

For `CL_UNORM_INT_101010_2`

- 0 must convert to 0.0f and
- 1023 must convert to 1.0f (for RGB)
- 3 must convert to 1.0f (for A)

`CL_PLATFORM_PROFILE` defined in the [OpenCL Platform Queries](#) table will return the string `EMBEDDED_PROFILE` if the OpenCL implementation supports the embedded profile only.

The minimum maximum values specified in the [OpenCL Device Queries](#) table that have been modified for the OpenCL embedded profile are listed in the [OpenCL Embedded Device Queries](#) table.

Table 39. List of supported `param_names` by `clGetDeviceInfo` for embedded profile

Device Info	Return Type	Description
<code>CL_DEVICE_MAX_READ_IMAGE_ARGS</code>	<code>cl_uint</code>	Max number of image objects arguments of a kernel declared with the <code>read_only</code> qualifier. The minimum value is 8 if <code>CL_DEVICE_IMAGE_SUPPORT</code> is <code>CL_TRUE</code> , the value is 0 otherwise.
<code>CL_DEVICE_MAX_WRITE_IMAGE_ARGS</code>	<code>cl_uint</code>	Max number of image objects arguments of a kernel declared with the <code>write_only</code> qualifier. The minimum value is 8 if <code>CL_DEVICE_IMAGE_SUPPORT</code> is <code>CL_TRUE</code> , the value is 0 otherwise.
<code>CL_DEVICE_MAX_READ_WRITE_IMAGE_ARGS</code>	<code>cl_uint</code>	Max number of image objects arguments of a kernel declared with the <code>write_only</code> or <code>read_write</code> qualifier. The minimum value is 8 if <code>CL_DEVICE_IMAGE_SUPPORT</code> is <code>CL_TRUE</code> , the value is 0 otherwise.
<code>CL_DEVICE_IMAGE2D_MAX_WIDTH</code>	<code>size_t</code>	Max width of 2D image in pixels. The minimum value is 2048 if <code>CL_DEVICE_IMAGE_SUPPORT</code> is <code>CL_TRUE</code> , the value is 0 otherwise.
<code>CL_DEVICE_IMAGE2D_MAX_HEIGHT</code>	<code>size_t</code>	Max height of 2D image in pixels. The minimum value is 2048 if <code>CL_DEVICE_IMAGE_SUPPORT</code> is <code>CL_TRUE</code> , the value is 0 otherwise.
<code>CL_DEVICE_IMAGE3D_MAX_WIDTH</code>	<code>size_t</code>	Max width of 3D image in pixels. The minimum value is 2048 if <code>CL_DEVICE_IMAGE_SUPPORT</code> is <code>CL_TRUE</code> , the value is 0 otherwise.
<code>CL_DEVICE_IMAGE3D_MAX_HEIGHT</code>	<code>size_t</code>	Max height of 3D image in pixels. The minimum value is 2048 if <code>CL_DEVICE_IMAGE_SUPPORT</code> is <code>CL_TRUE</code> , the value is 0 otherwise.

Device Info	Return Type	Description
CL_DEVICE_IMAGE3D_MAX_DEPTH	size_t	Max depth of 3D image in pixels. The minimum value is 2048 if CL_DEVICE_IMAGE_SUPPORT is CL_TRUE, the value is 0 otherwise.
CL_DEVICE_IMAGE_MAX_BUFFER_SIZE	size_t	Max number of pixels for a 1D image created from a buffer object. The minimum value is 2048 if CL_DEVICE_IMAGE_SUPPORT is CL_TRUE, the value is 0 otherwise.
CL_DEVICE_IMAGE_MAX_ARRAY_SIZE	size_t	Max number of images in a 1D or 2D image array. The minimum value is 256 if CL_DEVICE_IMAGE_SUPPORT is CL_TRUE, the value is 0 otherwise.
CL_DEVICE_MAX_SAMPLERS	cl_uint	Maximum number of samplers that can be used in a kernel. The minimum value is 8 if CL_DEVICE_IMAGE_SUPPORT is CL_TRUE, the value is 0 otherwise.
CL_DEVICE_MAX_PARAMETER_SIZE	size_t	Max size in bytes of all arguments that can be passed to a kernel. The minimum value is 256 bytes for devices that are not of type CL_DEVICE_TYPE_CUSTOM. A maximum of 255 arguments can be passed to a kernel.

Device Info	Return Type	Description
CL_DEVICE_SINGLE_FP_CONFIG	cl_device_fp_config	<p>Describes single precision floating-point capability of the device. This is a bit-field that describes one or more of the following values:</p> <p>CL_FP_DENORM - denorms are supported</p> <p>CL_FP_INF_NAN - INF and quiet NaNs are supported.</p> <p>CL_FP_ROUND_TO_NEAREST - round to nearest even rounding mode supported</p> <p>CL_FP_ROUND_TO_ZERO - round to zero rounding mode supported</p> <p>CL_FP_ROUND_TO_INF - round to positive and negative infinity rounding modes supported</p> <p>CL_FP_FMA - IEEE754-2008 fused multiply-add is supported.</p> <p>CL_FP_CORRECTLY_ROUNDED_DIVIDE_SQRT - divide and sqrt are correctly rounded as defined by the IEEE754 specification.</p> <p>CL_FP_SOFT_FLOAT - Basic floating-point operations (such as addition, subtraction, multiplication) are implemented in software.</p> <p>The mandated minimum floating-point capability is: CL_FP_ROUND_TO_ZERO or CL_FP_ROUND_TO_NEAREST for devices that are not of type CL_DEVICE_TYPE_CUSTOM.</p>
CL_DEVICE_MAX_CONSTANT_BUFFER_SIZE	cl_ulong	<p>Max size in bytes of a constant buffer allocation. The minimum value is 1 KB for devices that are not of type CL_DEVICE_TYPE_CUSTOM.</p>
CL_DEVICE_MAX_CONSTANT_ARGS	cl_uint	<p>Max number of arguments declared with the <code>__constant</code> qualifier in a kernel. The minimum value is 4 for devices that are not of type CL_DEVICE_TYPE_CUSTOM.</p>
CL_DEVICE_LOCAL_MEM_SIZE	cl_ulong	<p>Size of local memory arena in bytes. The minimum value is 1 KB for devices that are not of type CL_DEVICE_TYPE_CUSTOM.</p>

Device Info	Return Type	Description
CL_DEVICE_COMPILER_AVAILABLE	cl_bool	<p>Is CL_FALSE if the implementation does not have a compiler available to compile the program source.</p> <p>Is CL_TRUE if the compiler is available. This can be CL_FALSE for the embedded platform profile only.</p>
CL_DEVICE_LINKER_AVAILABLE	cl_bool	<p>Is CL_FALSE if the implementation does not have a linker available. Is CL_TRUE if the linker is available.</p> <p>This can be CL_FALSE for the embedded platform profile only.</p> <p>This must be CL_TRUE if CL_DEVICE_COMPILER_AVAILABLE is CL_TRUE.</p>
CL_DEVICE_QUEUE_ON_DEVICE_MAX_SIZE	cl_uint	The max. size of the device queue in bytes. The minimum value is 64 KB for the embedded profile
CL_DEVICE_PRINTF_BUFFER_SIZE	size_t	Maximum size in bytes of the internal buffer that holds the output of printf calls from a kernel. The minimum value for the EMBEDDED profile is 1 KB.

If **CL_DEVICE_IMAGE_SUPPORT** specified in the [OpenCL Device Queries](#) table is **CL_TRUE**, the values assigned to **CL_DEVICE_MAX_READ_IMAGE_ARGS**, **CL_DEVICE_MAX_WRITE_IMAGE_ARGS**, **CL_DEVICE_IMAGE2D_MAX_WIDTH**, **CL_DEVICE_IMAGE2D_MAX_HEIGHT**, **CL_DEVICE_IMAGE3D_MAX_WIDTH**, **CL_DEVICE_IMAGE3D_MAX_HEIGHT**, **CL_DEVICE_IMAGE3D_MAX_DEPTH**, and **CL_DEVICE_MAX_SAMPLERS** by the implementation must be greater than or equal to the minimum values specified in the [OpenCL Embedded Device Queries](#) table.

If **CL_DEVICE_IMAGE_SUPPORT** specified in the [OpenCL Device Queries](#) table is **CL_TRUE**, the minimum list of supported image formats for either reading or writing in a kernel for embedded profile devices is:

Table 40. Minimum list of supported image formats for reading or writing (embedded profile)

num_channels	channel_order	channel_data_type
4	CL_RGBA	CL_UNORM_INT8 CL_UNORM_INT16 CL_SIGNED_INT8 CL_SIGNED_INT16 CL_SIGNED_INT32 CL_UNSIGNED_INT8 CL_UNSIGNED_INT16 CL_UNSIGNED_INT32 CL_HALF_FLOAT CL_FLOAT

For embedded profiles devices that support reading from and writing to the same image object from the same kernel instance (see `CL_DEVICE_MAX_READ_WRITE_IMAGE_ARGS`) there is no required minimum list of supported image formats.

[1] And `read_imageh`, if the `cl_khr_fp16` extension is supported.

[2] Note that the performance of 64-bit integer arithmetic can vary significantly between embedded devices.

Appendix A: Host environment and thread safety

Shared OpenCL Objects

This section describes which objects can be shared across multiple command-queues created within a host process.

OpenCL memory objects, program objects and kernel objects are created using a context and can be shared across multiple command-queues created using the same context. Event objects can be created when a command is queued to a command-queue. These event objects can be shared across multiple command-queues created using the same context.

The application needs to implement appropriate synchronization across threads on the host processor to ensure that the changes to the state of a shared object (such as a command-queue object, memory object, program or kernel object) happen in the correct order (deemed correct by the application) when multiple command-queues in multiple threads are making changes to the state of a shared object.

A command-queue can cache changes to the state of a memory object on the device associated with the command-queue. To synchronize changes to a memory object across command-queues, the application must do the following:

In the command-queue that includes commands that modify the state of a memory object, the application must do the following:

- Get appropriate event objects for commands that modify the state of the shared memory object.
- Call the **clFlush** (or **clFinish**) API to issue any outstanding commands from this command-queue.

In the command-queue that wants to synchronize to the latest state of a memory object, commands queued by the application must use the appropriate event objects that represent commands that modify the state of the shared memory object as event objects to wait on. This is to ensure that commands that use this shared memory object complete in the previous command-queue before the memory objects are used by commands executing in this command-queue.

The results of modifying a shared resource in one command-queue while it is being used by another command-queue are undefined.

Multiple Host Threads

All OpenCL API calls are thread-safe ^[1] except those that modify the state of **cl_kernel** objects: **clSetKernelArg**, **clSetKernelArgSVMPointer**, **clSetKernelExecInfo** and **clCloneKernel**. **clSetKernelArg**, **clSetKernelArgSVMPointer**, **clSetKernelExecInfo** and **clCloneKernel** are safe to call from any host thread, and safe to call re-entrantly so long as concurrent calls to any combination of these API calls operate on different **cl_kernel** objects. The state of the **cl_kernel** object is undefined if **clSetKernelArg**, **clSetKernelArgSVMPointer**, **clSetKernelExecInfo** or

clCloneKernel are called from multiple host threads on the same **cl_kernel** object at the same time ^[2]. Please note that there are additional limitations as to which OpenCL APIs may be called from [OpenCL callback functions](#).

The behavior of OpenCL APIs called from an interrupt or signal handler is implementation-defined

The OpenCL implementation should be able to create multiple command-queues for a given OpenCL context and multiple OpenCL contexts in an application running on the host processor.

Global constructors and destructors

The execution order of global constructors and destructors is left undefined by the C and C++ standards. It is therefore not possible to know the relative execution order of an OpenCL implementation's global constructors and destructors with respect to an OpenCL application's or library's.

The behavior of OpenCL API functions called from global constructors or destructors is therefore implementation-defined.

[1] Please refer to the OpenCL glossary for the OpenCL definition of thread-safe. This definition may be different from usage of the term in other contexts.

[2] There is an inherent race condition in the design of OpenCL that occurs between setting a kernel argument and using the kernel with **clEnqueueNDRangeKernel**. Another host thread might change the kernel arguments between when a host thread sets the kernel arguments and then enqueues the kernel, causing the wrong kernel arguments to be enqueued. Rather than attempt to share **cl_kernel** objects among multiple host threads, applications are strongly encouraged to make additional **cl_kernel** objects for kernel functions for each host thread.

Appendix B: Portability

OpenCL is designed to be portable to other architectures and hardware designs. OpenCL has used at its core a C99 based programming language and follows rules based on that heritage. Floating-point arithmetic is based on the **IEEE-754** and **IEEE-754-2008** standards. The memory objects, pointer qualifiers and weakly ordered memory are designed to provide maximum compatibility with discrete memory architectures implemented by OpenCL devices. Command-queues and barriers allow for synchronization between the host and OpenCL devices. The design, capabilities and limitations of OpenCL are very much a reflection of the capabilities of underlying hardware.

Unfortunately, there are a number of areas where idiosyncrasies of one hardware platform may allow it to do some things that do not work on another. By virtue of the rich operating system resident on the CPU, on some implementations the kernels executing on a CPU may be able to call out to system services whereas the same calls on the GPU will likely fail for now. Since there is some advantage to having these services available for debugging purposes, implementations can use the OpenCL extension mechanism to implement these services.

Likewise, the heterogeneity of computing architectures might mean that a particular loop construct might execute at an acceptable speed on the CPU but very poorly on a GPU, for example. CPUs are designed in general to work well on latency sensitive algorithms on single threaded tasks, whereas common GPUs may encounter extremely long latencies, potentially orders of magnitude worse. Developers interested in writing portable code may need to test their software on a diversity of hardware designs to make sure that key algorithms are structured in a way that works well on a diversity of hardware. We suggest favoring more work-items over fewer. It is anticipated that over the coming months and years experience will produce a set of best practices that will help foster a uniformly favorable experience on a diversity of computing devices.

Of somewhat more concern is the topic of endianness. Since a majority of devices supported by the initial implementation of OpenCL are little-endian, developers need to make sure that their kernels are tested on both big-endian and little-endian devices to ensure source compatibility with OpenCL devices now and in the future. The endian attribute qualifier is supported by the SPIR-V IL to allow developers to specify whether the data uses the endianness of the host or the OpenCL device. This allows the OpenCL compiler to do appropriate endian-conversion on load and store operations from or to this data.

We also describe how endianness can leak into an implementation causing kernels to produce unintended results:

When a big-endian vector machine (e.g. AltiVec, CELL SPE) loads a vector, the order of the data is retained. That is both the order of the bytes within each element and the order of the elements in the vector are the same as in memory. When a little-endian vector machine (e.g. SSE) loads a vector, the order of the data in register (where all the work is done) is reversed. **Both** the order of the bytes within each element and the order of the elements with respect to one another in the vector are reversed.

Memory:

uint4 a =

0x00010203	0x04050607	0x08090A0B	0x0C0D0E0F
------------	------------	------------	------------

In register (big-endian):

uint4 a =

0x00010203	0x04050607	0x08090A0B	0x0C0D0E0F
------------	------------	------------	------------

In register (little-endian):

uint4 a =

0x0F0E0D0C	0x0B0A0908	0x07060504	0x03020100
------------	------------	------------	------------

This allows little-endian machines to use a single vector load to load little-endian data, regardless of how large each piece of data is in the vector. That is the transformation is equally valid whether that vector was a `uchar16` or a `ulong2`. Of course, as is well known, little-endian machines actually ^[1] store their data in reverse byte order to compensate for the little-endian storage format of the array elements:

Memory (big-endian):

uint4 a =

0x00010203	0x04050607	0x08090A0B	0x0C0D0E0F
------------	------------	------------	------------

Memory (little-endian):

uint4 a =

0x03020100	0x07060504	0x0B0A0908	0x0F0E0D0C
------------	------------	------------	------------

Once that data is loaded into a vector, we end up with this:

In register (big-endian):

uint4 a =

0x00010203	0x04050607	0x08090A0B	0x0C0D0E0F
------------	------------	------------	------------

In register (little-endian):

uint4 a =

0x0C0D0E0F	0x08090A0B	0x04050607	0x00010203
------------	------------	------------	------------

That is, in the process of correcting the endianness of the bytes within each element, the machine ends up reversing the order that the elements appear in the vector with respect to each other within the vector. 0x00010203 appears at the left of the big-endian vector and at the right of the little-endian vector.

When the host and device have different endianness, the developer must ensure that kernel argument values are processed correctly. The implementation may or may not automatically convert endianness of kernel arguments. Developers should consult vendor documentation for guidance on how to handle kernel arguments in these situations.

OpenCL provides a consistent programming model across architectures by numbering elements according to their order in memory. Concepts such as **even/odd** and **high/low** follow accordingly. Once the data is loaded into registers, we find that element 0 is at the left of the big-endian vector and element 0 is at the right of the little-endian vector:

```
float x[4];
float4 v = vload4( 0, x );
```

Big-endian:

```
v contains { x[0], x[1], x[2], x[3] }
```

Little-endian:

```
v contains { x[3], x[2], x[1], x[0] }
```

The compiler is aware that this swap occurs and references elements accordingly. So long as we refer to them by a numeric index such as **.s0123456789abcdef** or by descriptors such as **.xyzw**, **.hi**, **.lo**, **.even** and **.odd**, everything works transparently. Any ordering reversal is undone when the data is stored back to memory. The developer should be able to work with a big-endian programming model and ignore the element ordering problem in the vector ... for most problems. This mechanism relies on the fact that we can rely on a consistent element numbering. Once we change numbering system, for example by conversion-free casting (using **as_type_n**) a vector to another vector of the same size but a different number of elements, then we get different results on different implementations depending on whether the system is big-endian, or little-endian or indeed has no vector unit at all. (Thus, the behavior of bitcasts to vectors of different numbers of elements is implementation-defined, see section 6.4.4 of OpenCL C specification.)

An example follows:

```
float x[4] = { 0.0f, 1.0f, 2.0f, 3.0f };
float4 v = vload4( 0, x );
uint4 y = as_uint4(v);      // legal, portable
ushort8 z = as_ushort8(v);  // legal, not portable
                             // element size changed
```

Big-endian:

```
v contains { 0.0f, 1.0f, 2.0f, 3.0f }
y contains { 0x00000000, 0x3f800000,
```

```

                                0x40000000, 0x40400000 }
z contains { 0x0000, 0x0000, 0x3f80, 0x0000,
                                0x4000, 0x0000, 0x4040, 0x0000 }
z.z is 0x3f80

```

Little-endian:

```

v contains { 3.0f, 2.0f, 1.0f, 0.0f }
y contains { 0x40400000, 0x40000000,
                                0x3f800000, 0x00000000 }
z contains { 0x4040, 0x0000, 0x4000, 0x0000,
                                0x3f80, 0x0000, 0x0000, 0x0000 }
z.z is 0

```

Here, the value in **z.z** is not the same between big- and little-endian vector machines

OpenCL could have made it illegal to do a conversion free cast that changes the number of elements in the name of portability. However, while OpenCL provides a common set of operators drawing from the set that are typically found on vector machines, it can not provide access to everything every ISA may offer in a consistent uniform portable manner. Many vector ISAs provide special purpose instructions that greatly accelerate specific operations such as DCT, SAD, or 3D geometry. It is not intended for OpenCL to be so heavy handed that time-critical performance sensitive algorithms can not be written by knowledgeable developers to perform at near peak performance. Developers willing to throw away portability should be able to use the platform-specific instructions in their code. For this reason, OpenCL is designed to allow traditional vector C language programming extensions, such as the AltiVec C Programming Interface or the Intel C programming interfaces (such as those found in `emmintrin.h`) to be used directly in OpenCL with OpenCL data types as an extension to OpenCL. As these interfaces rely on the ability to do conversion-free casts that change the number of elements in the vector to function properly, OpenCL allows them too.

As a general rule, any operation that operates on vector types in segments that are not the same size as the vector element size may break on other hardware with different endianness or different vector architecture.

Examples might include:

- Combining two `uchar8`'s containing high and low bytes of a `ushort`, to make a `ushort8` using `.even` and `.odd` operators (please use `upsample()` for this)
- Any bitcast that changes the number of elements in the vector. (Operations on the new type are non-portable.)
- Swizzle operations that change the order of data using chunk sizes that are not the same as the element size

Examples of operations that are portable:

- Combining two `uint8`'s to make a `uchar16` using `.even` and `.odd` operators. For example to interleave left and right audio streams.

- Any bitcast that does not change the number of elements (e.g. `(float4) uint4`)— we define the storage format for floating-point types)
- Swizzle operations that swizzle elements of the same size as the elements of the vector.

OpenCL has made some additions to C to make application behavior more dependable than C. Most notably in a few cases OpenCL defines the behavior of some operations that are undefined in C99:

- OpenCL provides `convert_` functions for conversion between all types. C99 does not define what happens when a floating-point type is converted to an integer type and the floating-point value lies outside the representable range of the integer type after rounding. When the `sat` variant of the conversion is used, the float shall be converted to the nearest representable integer value. Similarly, OpenCL also makes recommendations about what should happen with NaN. Hardware manufacturers that provide the saturated conversion in hardware may use the saturated conversion hardware for both the saturated and non-saturated versions of the OpenCL `convert_` functions. OpenCL does not define what happens for the non-saturated conversions when floating-point operands are outside the range representable integers after rounding.
- The format of `half`, `float`, and `double` types is defined to be the binary16, binary32 and binary64 formats in the draft IEEE-754 standard. (The latter two are identical to the existing IEEE-754 standard.) You may depend on the positioning and meaning of the bits in these types.
- OpenCL defines behavior for oversized shift values. Shift operations that shift greater than or equal to the number of bits in the first operand reduce the shift value modulo the number of bits in the element. For example, if we shift an `int4` left by 33 bits, OpenCL treats this as shift left by $33\%32 = 1$ bit.
- A number of edge cases for math library functions are more rigorously defined than in C99. Please see *section 7.5* of the OpenCL C specification.

[1] Note that we are talking about the programming model here. In reality, little endian systems might choose to simply address their bytes from "the right" or reverse the "order" of the bits in the byte. Either of these choices would mean that no big swap would need to occur in hardware.

Appendix C: Application Data Types

This section documents the provided host application types and constant definitions. The documented material describes the commonly defined data structures, types and constant values available to all platforms and architectures. The addition of these details demonstrates our commitment to maintaining a portable programming environment and potentially deters changes to the supplied headers.

Supported Application Scalar Data Types

The following application scalar types are provided for application convenience.

```
cl_char
cl_uchar
cl_short
cl_ushort
cl_int
cl_uint
cl_long
cl_ulong
cl_half
cl_float
cl_double
```

Supported Application Vector Data Types

Application vector types are unions used to create vectors of the above application scalar types. The following application vector types are provided for application convenience.

```
cl_char<n>
cl_uchar<n>
cl_short<n>
cl_ushort<n>
cl_int<n>
cl_uint<n>
cl_long<n>
cl_ulong<n>
cl_half<n>
cl_float<n>
cl_double<n>
```

n can be 2, 3, 4, 8 or 16.

The application scalar and vector data types are defined in the **cl_platform.h** header file.

Alignment of Application Data Types

The user is responsible for ensuring that pointers passed into and out of OpenCL kernels are natively aligned relative to the data type of the parameter as defined in the kernel language and SPIR-V specifications. This implies that OpenCL buffers created with `CL_MEM_USE_HOST_PTR` need to provide an appropriately aligned host memory pointer that is aligned to the data types used to access these buffers in a kernel(s), that SVM allocations must correctly align and that pointers into SVM allocations must also be correctly aligned. The user is also responsible for ensuring image data passed is aligned to the granularity of the data representing a single pixel (e.g. `image_num_channels * sizeof(image_channel_data_type)`) except for `CL_RGB` and `CL_RGBx` images where the data must be aligned to the granularity of a single channel in a pixel (i.e. `sizeof(image_channel_data_type)`). This implies that OpenCL images created with `CL_MEM_USE_HOST_PTR` must align correctly. The image alignment value can be queried using the `CL_DEVICE_IMAGE_BASE_ADDRESS_ALIGNMENT` query. In addition, source pointers for `clEnqueueWriteImage` and other operations that copy to the OpenCL runtime, as well as destination pointers for `clEnqueueReadImage` and other operations that copy from the OpenCL runtime must follow the same alignment rules.

OpenCL makes no requirement about the alignment of OpenCL application defined data types outside of buffers and images, except that the underlying vector primitives (e.g. `__cl_float4`) where defined shall be directly accessible as such using appropriate named fields in the `cl_type` union (see [Vector Components](#)). Nevertheless, it is recommended that the `cl_platform.h` header should attempt to naturally align OpenCL defined application data types (e.g. `cl_float4`) according to their type.

Vector Literals

Application vector literals may be used in assignments of individual vector components. Literal usage follows the convention of the underlying application compiler.

```
cl_float2 foo = { .s[1] = 2.0f };
cl_int8 bar = {{ 2, 4, 6, 8, 10, 12, 14, 16 }};
```

Vector Components

The components of application vector types can be addressed using the `<vector_name>.s[<index>]` notation.

For example:

```
foo.s[0] = 1.0f; // Sets the 1st vector component of foo
pos.s[6] = 2;    // Sets the 7th vector component of bar
```

In some cases vector components may also be accessed using the following notations. These notations are not guaranteed to be supported on all implementations, so their use should be accompanied by a check of the corresponding preprocessor symbol.

Named vector components notation

Vector data type components may be accessed using the `.sN`, `.sn` or `.xyzw` field naming convention, similar to how they are used within the OpenCL C language. Use of the `.xyzw` field naming convention only allows accessing of the first 4 component fields. Support of these notations is identified by the `CL_HAS_NAMED_VECTOR_FIELDS` preprocessor symbol. For example:

```
#ifdef CL_HAS_NAMED_VECTOR_FIELDS
    cl_float4 foo;
    cl_int16 bar;
    foo.x = 1.0f; // Set first component
    foo.s0 = 1.0f; // Same as above
    bar.z = 3;    // Set third component
    bar.se = 11;  // Same as bar.s[0xe]
    bar.sD = 12;  // Same as bar.s[0xd]
#endif
```

Vector data type components may also be accessed using the `.rgba` field naming convention, similar to how they are used within the OpenCL C 3.0 language. Use of the `.rgba` field naming convention only allows accessing of the first 4 component fields. Support of these notations is identified by the `CL_HAS_NAMED_RGBA_VECTOR_FIELDS` preprocessor symbol. For example:

```
#ifdef CL_HAS_NAMED_RGBA_VECTOR_FIELDS
    cl_float4 foo;
    cl_int16 bar;
    foo.r = 1.0f; // Set first component
    bar.b = 3;    // Set third component
#endif
```

Unlike the OpenCL C language type usage of named vector fields, only one component field may be accessed at a time. This restriction prevents the ability to swizzle or replicate components as is possible with the OpenCL C language types. Attempting to access beyond the number of components for a type also results in a failure.

```
foo.xy    // illegal - illegal field name combination
bar.s1234 // illegal - illegal field name combination
foo.s7    // illegal - no component s7
```

High/Low vector component notation

Vector data type components may be accessed using the `.hi` and `.lo` notation similar to that supported within the language types. Support of this notation is identified by the `CL_HAS_HI_LO_VECTOR_FIELDS` preprocessor symbol. For example:

```
#ifdef CL_HAS_HI_LO_VECTOR_FIELDS
    cl_float4 foo;
```

```

    cl_float2 new_hi = 2.0f, new_lo = 4.0f;
    foo.hi = new_hi;
    foo.lo = new_lo;
#endif

```

Native vector type notation

Certain native vector types are defined for providing a mapping of vector types to architecturally built-in vector types. Unlike the above described application vector types, these native types are supported on a limited basis depending on the supporting architecture and compiler.

These types are not unions, but rather convenience mappings to the underlying architectures' built-in vector types. The native types share the name of their application counterparts but are preceded by a double underscore "__".

For example, `__cl_float4` is the native built-in vector type equivalent of the `cl_float4` application vector type. The `__cl_float4` type may provide direct access to the architectural built-in `__m128` or vector float type, whereas the `cl_float4` is treated as a union.

In addition, the above described application data types may have native vector data type members for access convenience. The native components are accessed using the `.vN` sub-vector notation, where `N` is the number of elements in the sub-vector. In cases where the native type is a subset of a larger type (more components), the notation becomes an index based array of the sub-vector type.

Support of the native vector types is identified by a `__CL_TYPEN__` preprocessor symbol matching the native type name. For example:

```

#ifdef __CL_FLOAT4__ // Check for native cl_float4 type
    cl_float8 foo;
    __cl_float4 bar; // Use of native type
    bar = foo.v4[1]; // Access the second native float4 vector
#endif

```

Implicit Conversions

Implicit conversions between application vector types are not supported.

Explicit Casts

Explicit casting of application vector types (`cl_typen`) is not supported. Explicit casting of native vector types (`__cl_typen`) is defined by the external compiler.

Other operators and functions

The behavior of standard operators and function on both application vector types (`cl_typen`) and native vector types (`__cl_typen`) is defined by the external compiler.

Application constant definitions

In addition to the above application type definitions, the following literal definitions are also available.

CL_CHAR_BIT	Bit width of a character
CL_SCHAR_MAX	Maximum value of a type <code>cl_char</code>
CL_SCHAR_MIN	Minimum value of a type <code>cl_char</code>
CL_CHAR_MAX	Maximum value of a type <code>cl_char</code>
CL_CHAR_MIN	Minimum value of a type <code>cl_char</code>
CL_UCHAR_MAX	Maximum value of a type <code>cl_uchar</code>
CL_SHRT_MAX	Maximum value of a type <code>cl_short</code>
CL_SHRT_MIN	Minimum value of a type <code>cl_short</code>
CL_USHRT_MAX	Maximum value of a type <code>cl_ushort</code>
CL_INT_MAX	Maximum value of a type <code>cl_int</code>
CL_INT_MIN	Minimum value of a type <code>cl_int</code>
CL_UINT_MAX	Maximum value of a type <code>cl_uint</code>
CL_LONG_MAX	Maximum value of a type <code>cl_long</code>
CL_LONG_MIN	Minimum value of a type <code>cl_long</code>
CL_ULONG_MAX	Maximum value of a type <code>cl_ulong</code>
CL_FLT_DIG	Number of decimal digits of precision for the type <code>cl_float</code>
CL_FLT_MANT_DIG	Number of digits in the mantissa of type <code>cl_float</code>
CL_FLT_MAX_10_EXP	Maximum positive integer such that 10 raised to this power minus one can be represented as a normalized floating-point number of type <code>cl_float</code>
CL_FLT_MAX_EXP	Maximum exponent value of type <code>cl_float</code>
CL_FLT_MIN_10_EXP	Minimum negative integer such that 10 raised to this power minus one can be represented as a normalized floating-point number of type <code>cl_float</code>
CL_FLT_MIN_EXP	Minimum exponent value of type <code>cl_float</code>
CL_FLT_RADIX	Base value of type <code>cl_float</code>
CL_FLT_MAX	Maximum value of type <code>cl_float</code>
CL_FLT_MIN	Minimum value of type <code>cl_float</code>

<code>CL_CHAR_BIT</code>	Bit width of a character
<code>CL_FLT_EPSILON</code>	Minimum positive floating-point number of type <code>cl_float</code> such that $1.0 + \text{CL_FLT_EPSILON} \neq 1$ is true.
<code>CL_DBL_DIG</code> missing before version 1.2. Also see extension <code>cl_khr_fp64</code> .	Number of decimal digits of precision for the type <code>cl_double</code>
<code>CL_DBL_MANT_DIG</code> missing before version 1.2. Also see extension <code>cl_khr_fp64</code> .	Number of digits in the mantissa of type <code>cl_double</code>
<code>CL_DBL_MAX_10_EXP</code> missing before version 1.2. Also see extension <code>cl_khr_fp64</code> .	Maximum positive integer such that 10 raised to this power minus one can be represented as a normalized floating-point number of type <code>cl_double</code>
<code>CL_DBL_MAX_EXP</code> missing before version 1.2. Also see extension <code>cl_khr_fp64</code> .	Maximum exponent value of type <code>cl_double</code>
<code>CL_DBL_MIN_10_EXP</code> missing before version 1.2. Also see extension <code>cl_khr_fp64</code> .	Minimum negative integer such that 10 raised to this power minus one can be represented as a normalized floating-point number of type <code>cl_double</code>
<code>CL_DBL_MIN_EXP</code> missing before version 1.2. Also see extension <code>cl_khr_fp64</code> .	Minimum exponent value of type <code>cl_double</code>
<code>CL_DBL_RADIX</code> missing before version 1.2. Also see extension <code>cl_khr_fp64</code> .	Base value of type <code>cl_double</code>
<code>CL_DBL_MAX</code> missing before version 1.2. Also see extension <code>cl_khr_fp64</code> .	Maximum value of type <code>cl_double</code>
<code>CL_DBL_MIN</code> missing before version 1.2. Also see extension <code>cl_khr_fp64</code> .	Minimum value of type <code>cl_double</code>

<code>CL_CHAR_BIT</code>	Bit width of a character
<code>CL_DBL_EPSILON</code> missing before version 1.2. Also see extension <code>cl_khr_fp64</code> .	Minimum positive floating-point number of type <code>cl_double</code> such that <code>1.0 + CL_DBL_EPSILON != 1</code> is true.
<code>CL_NAN</code> missing before version 1.1.	Macro expanding to a value representing NaN
<code>CL_HUGE_VALF</code> missing before version 1.1.	Largest representative value of type <code>cl_float</code>
<code>CL_HUGE_VAL</code> missing before version 1.1.	Largest representative value of type <code>cl_double</code>
<code>CL_MAXFLOAT</code> missing before version 1.1.	Maximum value of type <code>cl_float</code>
<code>CL_INFINITY</code> missing before version 1.1.	Macro expanding to a value representing infinity

These literal definitions are defined in the `cl_platform.h` header.

Appendix D: Checking for Memory Copy Overlap

The following code describes how to determine if there is overlap between the source and destination rectangles specified to `clEnqueueCopyBufferRect` provided the source and destination buffers refer to the same buffer object.

```
unsigned int
check_copy_overlap(const size_t src_origin[],
                  const size_t dst_origin[],
                  const size_t region[],
                  const size_t row_pitch,
                  const size_t slice_pitch )
{
    const size_t slice_size = (region[1] - 1) * row_pitch + region[0];
    const size_t block_size = (region[2] - 1) * slice_pitch + slice_size;
    const size_t src_start = src_origin[2] * slice_pitch
                             + src_origin[1] * row_pitch
                             + src_origin[0];
    const size_t src_end = src_start + block_size;
    const size_t dst_start = dst_origin[2] * slice_pitch
                             + dst_origin[1] * row_pitch
                             + dst_origin[0];
    const size_t dst_end = dst_start + block_size;

    /* No overlap if dst ends before src starts or if src ends
     * before dst starts.
     */
    if( (dst_end <= src_start) || (src_end <= dst_start) ){
        return 0;
    }

    /* No overlap if region[0] for dst or src fits in the gap
     * between region[0] and row_pitch.
     */
    {
        const size_t src_dx = src_origin[0] % row_pitch;
        const size_t dst_dx = dst_origin[0] % row_pitch;

        if( ((dst_dx >= src_dx + region[0]) &&
              (dst_dx + region[0] <= src_dx + row_pitch)) ||
            ((src_dx >= dst_dx + region[0]) &&
              (src_dx + region[0] <= dst_dx + row_pitch)) )
        {
            return 0;
        }
    }
}
```

```

/* No overlap if region[1] for dst or src fits in the gap
 * between region[1] and slice_pitch.
 */
{
    const size_t src_dy =
        (src_origin[1] * row_pitch + src_origin[0]) % slice_pitch;
    const size_t dst_dy =
        (dst_origin[1] * row_pitch + dst_origin[0]) % slice_pitch;

    if( ((dst_dy >= src_dy + slice_size) &&
        (dst_dy + slice_size <= src_dy + slice_pitch)) ||
        ((src_dy >= dst_dy + slice_size) &&
        (src_dy + slice_size <= dst_dy + slice_pitch)) ) {
        return 0;
    }
}

/* Otherwise src and dst overlap. */
return 1;
}

```

Appendix E: Changes to OpenCL

Changes to the OpenCL API and OpenCL C specifications between successive versions are summarized below.

Summary of changes from OpenCL 1.0 to OpenCL 1.1

The following features are added to the OpenCL 1.1 platform layer and runtime (*sections 4 and 5*):

- Following queries to *table 4.3*
 - `CL_DEVICE_NATIVE_VECTOR_WIDTH_CHAR`, `CL_DEVICE_NATIVE_VECTOR_WIDTH_SHORT`, `CL_DEVICE_NATIVE_VECTOR_WIDTH_INT`, `CL_DEVICE_NATIVE_VECTOR_WIDTH_LONG`, `CL_DEVICE_NATIVE_VECTOR_WIDTH_FLOAT`, `CL_DEVICE_NATIVE_VECTOR_WIDTH_DOUBLE`, `CL_DEVICE_NATIVE_VECTOR_WIDTH_HALF`
 - `CL_DEVICE_HOST_UNIFIED_MEMORY`
 - `CL_DEVICE_OPENCL_C_VERSION`
- `CL_CONTEXT_NUM_DEVICES` to the list of queries specified to `clGetContextInfo`.
- Optional image formats: `CL_Rx`, `CL_RGx`, and `CL_RGBx`.
- Support for sub-buffer objects ability to create a buffer object that refers to a specific region in another buffer object using `clCreateSubBuffer`.
- `clEnqueueReadBufferRect`, `clEnqueueWriteBufferRect` and `clEnqueueCopyBufferRect` APIs to read from, write to and copy a rectangular region of a buffer object respectively.
- `clSetMemObjectDestructorCallback` API to allow a user to register a callback function that will be called when the memory object is deleted and its resources freed.
- Options that [control the OpenCL C version](#) used when building a program executable.
- `CL_KERNEL_PREFERRED_WORK_GROUP_SIZE_MULTIPLE` to the list of queries specified to `clGetKernelWorkGroupInfo`.
- Support for user events. User events allow applications to enqueue commands that wait on a user event to finish before the command is executed by the device. Following new APIs are added - `clCreateUserEvent` and `clSetUserEventStatus`.
- `clSetEventCallback` API to register a callback function for a specific command execution status.

The following modifications are made to the OpenCL 1.1 platform layer and runtime (*sections 4 and 5*):

- Following queries in *table 4.3*
 - The minimum FULL_PROFILE value for `CL_DEVICE_MAX_PARAMETER_SIZE` increased from 256 to 1024 bytes
 - The minimum FULL_PROFILE value for `CL_DEVICE_LOCAL_MEM_SIZE` increased from 16 KB to 32 KB.
- The *global_work_offset* argument in `clEnqueueNDRangeKernel` can be a non-NULL value.
- All API calls except `clSetKernelArg` are thread-safe.

The following features are added to the OpenCL C programming language (*section 6*) in OpenCL 1.1:

- 3-component vector data types.
- New built-in functions
 - **get_global_offset** work-item function defined in *section 6.15.1*.
 - **minmag**, **maxmag** math functions defined in *section 6.15.2*.
 - **clamp** integer function defined in *section 6.15.3*.
 - (vector, scalar) variant of integer functions **min** and **max** in *section 6.12.3*.
 - **async_work_group_strided_copy** defined in *section 6.15.11*.
 - **vec_step**, **shuffle** and **shuffle2** defined in *section 6.15.13*.
- **cl_khr_byte_addressable_store** extension is a core feature.
- **cl_khr_global_int32_base_atomics**, **cl_khr_global_int32_extended_atomics**, **cl_khr_local_int32_base_atomics** and **cl_khr_local_int32_extended_atomics** extensions are core features. The built-in atomic function names are changed to use the **atomic_** prefix instead of **atom_**.
- Macros **CL_VERSION_1_0** and **CL_VERSION_1_1**.

The following features in OpenCL 1.0 are deprecated (see glossary) in OpenCL 1.1:

- The **clSetCommandQueueProperty** API is deprecated, which simplifies implementations and possibly improves performance by enforcing that command-queue properties are invariant. Applications are encouraged to create multiple command-queues with different properties versus modifying the properties of a single command-queue.
- The **-cl-strict-aliasing** build option has been deprecated. It is no longer required after defining type-based aliasing rules.
- The **cl_khr_select_fprounding_mode** extension is deprecated and its use is no longer recommended.

The following new extensions are added to *section 9* in OpenCL 1.1:

- **cl_khr_gl_event** for creating a CL event object from a GL sync object.
- **cl_khr_d3d10_sharing** for sharing memory objects with Direct3D 10.

The following modifications are made to the OpenCL ES Profile described in *section 10* in OpenCL 1.1:

- 64-bit integer support is optional.

Summary of changes from OpenCL 1.1 to OpenCL 1.2

The following features are added to the OpenCL 1.2 platform layer and runtime (*sections 4 and 5*):

- Custom devices and built-in kernels are supported. **clCreateProgramWithBuiltInKernels** has been added to allow creation of a **cl_program** using built-in kernels.

- Device partitioning that allows a device to be partitioned based on a number of partitioning schemes supported by the device. This is done by using **clCreateSubDevices** to create a new **cl_device_id** based on a partitioning.
- **clCompileProgram** and **clLinkProgram** to allow handling these aspects **clBuildProgram** separately.
- Extend **cl_mem_flags** to describe how the host accesses the data in a **cl_mem** object.
- **clEnqueueFillBuffer** and **clEnqueueFillImage** to support filling a buffer with a pattern or an image with a color.
- Add **CL_MAP_WRITE_INVALIDATE_REGION** to **cl_map_flags**. Appropriate clarification to the behavior of **CL_MAP_WRITE** has been added to the spec.
- New image types: 1D image, 1D image from a buffer object, 1D image array and 2D image arrays.
- **clCreateImage** to create an image object.
- **clEnqueueMigrateMemObjects** API that allows a developer to have explicit control over the location of memory objects or to migrate a memory object from one device to another.
- Support separate compilation and linking of programs.
- Additional queries to get the number of kernels and kernel names in a program have been added to **clGetProgramInfo**.
- Additional queries to get the compile and link status and options have been added to **clGetProgramBuildInfo**.
- **clGetKernelArgInfo** API that returns information about the arguments of a kernel.
- **clEnqueueMarkerWithWaitList** and **clEnqueueBarrierWithWaitList** APIs.
- **clUnloadPlatformCompiler** to request that a single platform's compiler is unloaded. This is compatible with the **cl_khr_icd** extension if that is supported, unlike **clUnloadCompiler**.

The following features are added to the OpenCL C programming language (*section 6*) in OpenCL 1.2:

- Double-precision is now an optional core feature instead of an extension.
- New built in image types: **image1d_t**, **image1d_buffer_t**, **image1d_array_t**, and **image2d_array_t**.
- New built-in functions
 - Functions to read from and write to a 1D image, 1D and 2D image arrays described in *sections 6.15.15.2, 6.15.15.3 and 6.15.15.4*.
 - Sampler-less image read functions described in *section 6.15.15.3*.
 - **popcount** integer function described in *section 6.15.3*.
 - **printf** function described in *section 6.15.14*.
- Storage class specifiers **extern** and **static** as described in *section 6.10*.
- Macros **CL_VERSION_1_2** and **__OPENCL_C_VERSION__**.

The following APIs in OpenCL 1.1 are deprecated (see glossary) in OpenCL 1.2:

- The **clEnqueueMarker**, **clEnqueueBarrier** and **clEnqueueWaitForEvents** APIs are deprecated to simplify the API. The **clEnqueueMarkerWithWaitList** and **clEnqueueBarrierWithWaitList** APIs provide equivalent functionality and support explicit event wait lists.
- The **clCreateImage2D**, **clCreateImage3D**, **clCreateFromGLTexture2D** and **clCreateFromGLTexture3D** APIs are deprecated to simplify the API. The **clCreateImage** and **clCreateFromGLTexture** APIs provide equivalent functionality and support additional image types and properties.
- **clUnloadCompiler** and **clGetExtensionFunctionAddress** APIs are deprecated. The **clUnloadPlatformCompiler** and **clGetExtensionFunctionAddressForPlatform** APIs provide equivalent functionality and are compatible with the **cl_khr_icd** extension.

The following queries are deprecated (see glossary) in OpenCL 1.2:

- The **CL_DEVICE_MIN_DATA_TYPE_ALIGN_SIZE** query is deprecated. The minimum data type alignment can be derived from **CL_DEVICE_MEM_BASE_ADDR_ALIGN**.

Summary of changes from OpenCL 1.2 to OpenCL 2.0

The following features are added to the OpenCL 2.0 platform layer and runtime (*sections 4 and 5*):

- Shared virtual memory. The associated API additions are:
 - **clSetKernelArgSVMPointer** to control which shared virtual memory (SVM) pointer to associate with a kernel instance.
 - **clSVMAlloc**, **clSVMFree** and **clEnqueueSVMFree** to allocate and free memory for use with SVM.
 - **clEnqueueSVMMap** and **clEnqueueSVMUnmap** to map and unmap to update regions of an SVM buffer from host.
 - **clEnqueueSVMMemcpy** and **clEnqueueSVMMemFill** to copy or fill SVM memory regions.
- Device queues used to enqueue kernels on the device.
 - **clCreateCommandQueueWithProperties** is added to allow creation of a command-queue with properties that affect both host command-queues and device queues.
- Pipes.
 - **clCreatePipe** and **clGetPipeInfo** have been added to the API for host side creation and querying of pipes.
- Images support for 2D image from buffer, depth images and sRGB images.
- **clCreateSamplerWithProperties**.

The following modifications are made to the OpenCL 2.0 platform layer and runtime (*sections 4 and 5*):

- All API calls except **clSetKernelArg**, **clSetKernelArgSVMPointer** and **clSetKernelExecInfo** are thread-safe. Note that this statement does not imply that other API calls were not thread-safe in earlier versions of the specification.

The following features are added to the OpenCL C programming language (*section 6*) in OpenCL 2.0:

- Clang Blocks.
- Kernels enqueueing kernels to a device queue.
- Program scope variables in global address space.
- Generic address space.
- C1x atomics.
- New built-in functions (sections 6.15.10, 6.15.12, and 6.15.16).
- Support images with the `read_write` qualifier.
- 3D image writes are a core feature.
- The `CL_VERSION_2_0` and `NULL` macros.
- The `opencl_unroll_hint` attribute.

The following APIs are deprecated (see glossary) in OpenCL 2.0:

- The `clCreateCommandQueue` API has been deprecated to simplify the API. The `clCreateCommandQueueWithProperties` API provides equivalent functionality and supports specifying additional command-queue properties.
- The `clCreateSampler` API has been deprecated to simplify the API. The `clCreateSamplerWithProperties` API provides equivalent functionality and supports specifying additional sampler properties.
- The `clEnqueueTask` API has been deprecated to simplify the API. The `clEnqueueNDRangeKernel` API provides equivalent functionality.

The following queries are deprecated (see glossary) in OpenCL 2.0:

- The `CL_DEVICE_HOST_UNIFIED_MEMORY` query is deprecated. This query was purely informational and had different meanings for different implementations. Its use is no longer recommended.
- The `CL_IMAGE_BUFFER` query has been deprecated to simplify the API. The `CL_MEM_ASSOCIATED_MEMOBJECT` query provides equivalent functionality.
- The `CL_DEVICE_QUEUE_PROPERTIES` query has been deprecated and replaced by `CL_DEVICE_QUEUE_ON_HOST_PROPERTIES`.
- Atomics and Fences
 - The Explicit Memory Fence Functions defined in section 6.12.9 of the OpenCL 1.2 specification have been deprecated to simplify the programming language. The **`atomic_work_item_fence`** function provides equivalent functionality. The deprecated functions are still described in section 6.15.9 of this specification.
 - The Atomic Functions defined in section 6.12.11 of the OpenCL 1.2 specification have been deprecated to simplify the programming language. The **`atomic_fetch`** and **`atomic_modify`** functions provide equivalent functionality. The deprecated functions are still described in section 6.15.12.8 of this specification.

Summary of changes from OpenCL 2.0 to OpenCL 2.1

The following features are added to the OpenCL 2.1 platform layer and runtime (*sections 4 and 5*):

- **clGetKernelSubGroupInfo** API call.
- **CL_KERNEL_MAX_NUM_SUB_GROUPS**, **CL_KERNEL_COMPILE_NUM_SUB_GROUPS** additions to table 5.21 of the API specification.
- **clCreateProgramWithIL** API call.
- **clGetHostTimer** and **clGetDeviceAndHostTimer** API calls.
- **clEnqueueSVMigrateMem** API call.
- **clCloneKernel** API call.
- **clSetDefaultDeviceCommandQueue** API call.
- **CL_PLATFORM_HOST_TIMER_RESOLUTION** added to table 4.1 of the API specification.
- **CL_DEVICE_IL_VERSION**, **CL_DEVICE_MAX_NUM_SUB_GROUPS**, **CL_DEVICE_SUB_GROUP_INDEPENDENT_FORWARD_PROGRESS** added to table 4.3 of the API specification.
- **CL_PROGRAM_IL** to table 5.17 of the API specification.
- **CL_QUEUE_DEVICE_DEFAULT** added to table 5.2 of the API specification.
- Added table 5.22 to the API specification with the enums: **CL_KERNEL_MAX_SUB_GROUP_SIZE_FOR_NDRANGE**, **CL_KERNEL_SUB_GROUP_COUNT_FOR_NDRANGE** and **CL_KERNEL_LOCAL_SIZE_FOR_SUB_GROUP_COUNT**

The following modifications are made to the OpenCL 2.1 platform layer and runtime (*sections 4 and 5*):

- All API calls except **clSetKernelArg**, **clSetKernelArgSVMPointer**, **clSetKernelExecInfo** and **clCloneKernel** are thread-safe. Note that this statement does not imply that other API calls were not thread-safe in earlier versions of the specification.

Note that the OpenCL C kernel language is not updated for OpenCL 2.1. The OpenCL 2.0 kernel language will still be consumed by OpenCL 2.1 runtimes.

The SPIR-V and OpenCL SPIR-V Environment specifications have been added.

Summary of changes from OpenCL 2.1 to OpenCL 2.2

The following changes have been made to the OpenCL 2.2 execution model (*section 3*)

- Added the third prerequisite (executing non-trivial constructors for program scope global variables).

The following features are added to the OpenCL 2.2 platform layer and runtime (*sections 4 and 5*):

- **clSetProgramSpecializationConstant** API call
- **clSetProgramReleaseCallback** API call
- Queries for **CL_PROGRAM_SCOPE_GLOBAL_CTORS_PRESENT** and **CL_PROGRAM_SCOPE_GLOBAL_DTORS_PRESENT**

The following modifications are made to the OpenCL 2.2 platform layer and runtime (section 4 and 5):

- Modified description of `CL_DEVICE_MAX_CLOCK_FREQUENCY` query.
- Added a new error code `CL_MAX_SIZE_RESTRICTION_EXCEEDED` to `clSetKernelArg` API call

Added definition of Deprecation and Specialization constants to the glossary.

Summary of changes from OpenCL 2.2 to OpenCL 3.0

OpenCL 3.0 is a major revision that breaks backwards compatibility with previous versions of OpenCL, see [OpenCL 3.0 Backwards Compatibility](#) for details.

OpenCL 3.0 adds new queries to determine optional capabilities for a device:

- `CL_DEVICE_ATOMIC_MEMORY_CAPABILITIES` and `CL_DEVICE_ATOMIC_FENCE_CAPABILITIES` to determine the atomic memory and atomic fence capabilities of a device.
- `CL_DEVICE_NON_UNIFORM_WORK_GROUP_SUPPORT` to determine if a device supports non-uniform work-group sizes.
- `CL_DEVICE_WORK_GROUP_COLLECTIVE_FUNCTIONS_SUPPORT` to determine whether a device supports optional work-group collective functions, such as broadcasts, scans, and reductions.
- `CL_DEVICE_GENERIC_ADDRESS_SPACE_SUPPORT` to determine whether a device supports the generic address space.
- `CL_DEVICE_DEVICE_ENQUEUE_CAPABILITIES` to determine the device-side enqueue capabilities of a device.
- `CL_DEVICE_PIPE_SUPPORT` to determine whether a device supports pipe memory objects.
- `CL_DEVICE_PREFERRED_WORK_GROUP_SIZE_MULTIPLE` to determine the preferred work-group size multiple for a device.

OpenCL 3.0 adds new queries to conveniently and precisely describe supported features and versions:

- `CL_PLATFORM_NUMERIC_VERSION` to describe the platform version as a numeric value.
- `CL_PLATFORM_EXTENSIONS_WITH_VERSION` to describe supported platform extensions and their supported version.
- `CL_DEVICE_NUMERIC_VERSION` to describe the device version as a numeric value.
- `CL_DEVICE_EXTENSIONS_WITH_VERSION` to describe supported device extensions and their supported version.
- `CL_DEVICE_ILS_WITH_VERSION` to describe supported intermediate languages (ILs) and their supported version.
- `CL_DEVICE_BUILT_IN_KERNELS_WITH_VERSION` to describe supported built-in kernels and their supported version.

OpenCL 3.0 adds a new API to register a function that will be called when a context is destroyed,

enabling an application to safely free user data associated with a context callback function.

- **clSetContextDestructorCallback**

OpenCL 3.0 adds two new APIs to support creating buffer and image memory objects with additional properties. Although no new properties are added in OpenCL 3.0, these APIs enable new buffer and image extensions to be added easily and consistently:

- **clCreateBufferWithProperties**
- **clCreateImageWithProperties**

OpenCL 3.0 adds new queries for the properties arrays specified when creating buffers, images, pipes, samplers, and command-queues:

- **CL_MEM_PROPERTIES**
- **CL_PIPE_PROPERTIES**
- **CL_SAMPLER_PROPERTIES**
- **CL_QUEUE_PROPERTIES_ARRAY**

Program initialization and clean-up kernels are not supported in OpenCL 3.0 due to implementation complexity and lack of demand. The following APIs and queries for program initialization and clean-up kernels are deprecated in OpenCL 3.0:

- **CL_PROGRAM_SCOPE_GLOBAL_CTORS_PRESENT**
- **CL_PROGRAM_SCOPE_GLOBAL_DTORS_PRESENT**
- **clSetProgramReleaseCallback**

OpenCL 3.0 adds the OpenCL 3.0 C kernel language, which includes feature macros to describe OpenCL C language support. Please refer to the OpenCL C specification for details.

Scalar input arguments to the **any** and **all** built-in functions have been deprecated in the OpenCL 3.0 C kernel language. These functions behaved inconsistently with the C language's use of scalar integers as logical values.

OpenCL 3.0 adds new queries to determine supported OpenCL C language versions and supported OpenCL C features:

- **CL_DEVICE_OPENCL_C_ALL_VERSIONS** to determine the set of OpenCL C language versions supported by a device.
- **CL_DEVICE_OPENCL_C_FEATURES** to determine optional OpenCL C language features supported by a device.

OpenCL 3.0 adds an event command type to identify events associated with the OpenCL 2.1 command **clEnqueueSVMMigrateMem**:

- **CL_COMMAND_SVM_MIGRATE_MEM**

OpenCL 3.0 adds a new query to determine the latest version of the conformance test suite that the

device has fully passed in accordance with the official conformance process:

- `CL_DEVICE_LATEST_CONFORMANCE_VERSION_PASSED`

Summary of changes from OpenCL 3.0

The first non-provisional version of the OpenCL 3.0 specifications was **v3.0.5**.

Changes from **v3.0.5**:

- Fixed the calculation in "mapping work-items onto an ND-range".
- Added new extensions:
 - `cl_khr_extended_versioning`
 - `cl_khr_subgroup_extended_types`
 - `cl_khr_subgroup_non_uniform_vote`
 - `cl_khr_subgroup_ballot`
 - `cl_khr_subgroup_non_uniform_arithmetic`
 - `cl_khr_subgroup_shuffle`
 - `cl_khr_subgroup_shuffle_relative`
 - `cl_khr_subgroup_clustered_reduce`

Changes from **v3.0.6**:

- Removed erroneous condition for `CL_INVALID_KERNEL_ARGS`.
- Fixed the spelling of `-cl-no-signed-zeros`.
- Clarified the table structure in the backwards compatibility appendix.
- Clarified that `-cl-unsafe-math-optimizations` also implies `-cl-denorms-are-zero`.
- Added new extensions:
 - `cl_khr_extended_bit_ops`
 - `cl_khr_pci_bus_info`
 - `cl_khr_spirv_extended_debug_info`
 - `cl_khr_spirv_linkonce_odr`
 - `cl_khr_suggested_local_work_size`

Changes from **v3.0.7**:

- Clarified optionality support for double-precision literals.
- Removed unnecessary phrase from sub-group mask function descriptions.
- Added `input_slice_pitch` error condition for read and write image APIs.
- Added new extension:
 - `cl_khr_integer_dot_product`

Changes from **v3.0.8**:

- Added a missing error condition for **clGetKernelSuggestedLocalWorkSizeKHR**.
- Clarified requirements for **CL_DEVICE_DOUBLE_FP_CONFIG** prior to OpenCL 2.0.
- Clarified the behavior of ballot operations for remainder sub-groups.
- Added new extensions:
 - **cl_khr_integer_dot_product** (version 2)
 - **cl_khr_semaphore** (provisional)
 - **cl_khr_external_semaphore** (provisional)
 - **cl_khr_external_semaphore_dx_fence** (provisional)
 - **cl_khr_external_semaphore_opaque_fd** (provisional)
 - **cl_khr_external_semaphore_sync_fd** (provisional)
 - **cl_khr_external_semaphore_win32** (provisional)
 - **cl_khr_external_memory** (provisional)
 - **cl_khr_external_memory_dma_buf** (provisional)
 - **cl_khr_external_memory_dx** (provisional)
 - **cl_khr_external_memory_opaque_fd** (provisional)
 - **cl_khr_external_memory_win32** (provisional)

Changes from **v3.0.9**:

- Relaxed memory object acquire error checking requirements for OpenGL, EGL, and DirectX interop extensions.
- Added a missing error condition for **clGetSemaphoreHandleForTypeKHR**.
- Clarified that **clCompileProgram** is valid for programs created from SPIR.
- Documented the possible state of a kernel object after a failed call to **clSetKernelArg**.
- Added new extensions:
 - **cl_khr_async_copy_fence** (final)
 - **cl_khr_extended_async_copies** (final)
 - **cl_khr_expect_assume**
 - **cl_khr_command_buffer** (provisional)

Changes from **v3.0.10**:

- Added a requirement for implementations supporting device-side enqueue to also support program scope global variables.
- Added missing device scope atomic feature guards to several atomic function overloads.
- Added a possible error condition for **clGetEventProfilingInfo** for pre-OpenCL 3.0 devices.
- Added several missing error conditions for **clGetKernelSubGroupInfo**.

- Clarified the expected return value for the of `CL_IMAGE_ROW_PITCH` and `CL_IMAGE_SLICE_PITCH` queries.
- Updated descriptions of the extended async copies functions to remove references to nonexistent function arguments.
- Clarified that the extended versioning extension is a core OpenCL 3.0 feature.
- Clarified sub-group clustered reduction behavior when the cluster size is not an integer constant or a power of two.
- Added new extensions:
 - `cl_khr_subgroup_rotate`
 - `cl_khr_work_group_uniform_arithmetic`

Changes from **v3.0.11**:

- Added a definition for a valid object and requirements for testing for valid objects.
- Added a maximum limit for the number of arguments supported by a kernel.
- Clarified requirements for comparability and uniqueness of object handles.
- Clarified behavior for invalid device-side enqueue `cl_event_t` handles.
- Clarified `cl_khr_command_buffer` interactions with other extensions.
- Specified error behavior when a command buffer is finalized multiple times.
- Added new extension:
 - `cl_khr_command_buffer_mutable_dispatch` (provisional)

Changes from **v3.0.12**:

- Fixed the accuracy requirements description for half-precision math functions (those prefixed by `half_`).
- Clarified that the semaphore type must always be provided when creating a semaphore.
- Removed an unnecessary and contradictory error condition when creating a semaphore.
- Added an issue regarding non-linear image import to the `cl_khr_external_memory` extension.
- Added missing calls to `clBuildProgram` to the `cl_khr_command_buffer` and `cl_khr_command_buffer_mutable_dispatch` sample code.
- Fixed a copy-paste error in the extensions quick reference appendix.
- Fixed typos and improved formatting consistency in the extensions spec.

Changes from **v3.0.13**:

- Corrected the precision for `cross` and `dot` to be based on `HALF_EPSILON` in `cl_khr_fp16`, see [#893](#).
- Added a context query for command-buffers to `cl_khr_command_buffer`, see [#899](#).
- Updated the semaphore wait and signal rules for binary semaphores in `cl_khr_semaphore`, see [#882](#).
- Removed redundant error conditions from `cl_khr_external_semaphore` and

`cl_khr_external_memory`, see [#903](#) and [#904](#).

- Added new extension:
 - `cl_khr_command_buffer_multi_device` (provisional)

Changes from **v3.0.14**:

- Clarified which error code should be returned when calling `clCreateBuffer` with a pointer to an SVM allocation that is too small, see [#879](#).
- Improved capitalization and hyphenation consistency throughout the specs, see [#902](#).
- Clarified that SVM is optional for all OpenCL 3.0 devices, see [#913](#).
- Clarified that `clSetCommandQueueProperty` is only required for OpenCL 1.0 devices and may return an error otherwise, see [#980](#).
- Clarified that the application must ensure the free function passed to `clEnqueueSVMFree` is thread safe, see [#1016](#).
- Clarified that the application must ensure the user function passed to `clEnqueueNativeKernel` is thread safe, see [#1026](#).
- `cl_khr_command_buffers` (provisional):
 - Removed the "invalid" command buffer state, see [#885](#).
 - Added support for recording SVM memory copies and memory fills in a command buffer, see [#915](#).
- `cl_khr_command_buffer_multi_device` (provisional):
 - Clarified that the sync devices query should only return root devices, see [#925](#).
- `cl_khr_external_memory` (provisional):
 - Disallowed specifying a device handle list without also specifying an external memory handle, see [#922](#).
 - Added a query to determine the handle types an implementation will assume have a linear memory layout, see [#940](#).
 - Added an external memory-specific device handle list enum, see [#956](#).
 - Clarified that implementations may acquire information about an image from an external memory handle when the image is created, see [#970](#).
- `cl_khr_external_semaphore` (provisional):
 - Added the ability to re-import "sync fd" handles into an existing semaphore, see [#939](#).
 - Clarified that a semaphore may only export one handle type, and that a semaphore created from an external handle cannot also export a handle, see [#975](#).
 - Clarified that `cl_khr_external_semaphore` requires support for `cl_khr_semaphore`, see [#976](#).
 - Added a query to determine if a semaphore may export an external handle, see [#997](#).
- `cl_khr_semaphore` (provisional):
 - Added an semaphore-specific device handle list enum, see [#956](#).
 - Restricted semaphores to a single associated device, see [#996](#).

- `cl_khr_subgroup_rotate`:
 - Clarified that only rotating within a subgroup is supported, see [#967](#).

Appendix F: Error Codes

This section lists OpenCL error codes and their meanings.

Error Code	Brief Description
CL_SUCCESS	This is a special error code to indicate that the API executed successfully, without errors.
CL_BUILD_PROGRAM_FAILURE	Returned when clBuildProgram failed to build the specified program.
CL_COMPILE_PROGRAM_FAILURE	Returned when clCompileProgram failed to compile the specified program.
missing before version 1.2.	
CL_COMPILER_NOT_AVAILABLE	Returned when compiling or building a program from source or IL when CL_DEVICE_COMPILER_AVAILABLE is CL_FALSE .
CL_DEVICE_NOT_FOUND	Returned when no devices were found that match the specified device type.
CL_DEVICE_NOT_AVAILABLE	Returned when attempting to use a device when CL_DEVICE_AVAILABLE is CL_FALSE .
CL_DEVICE_PARTITION_FAILED	Returned when device partitioning is supported but the device could not be further partitioned.
missing before version 1.2.	
CL_EXEC_STATUS_ERROR_FOR_EVENTS_IN_WAIT_LIST	Returned by blocking APIs when an event in the event wait list has a negative value, indicating it is in an error state.
missing before version 1.1.	
CL_IMAGE_FORMAT_MISMATCH	Returned when attempting to copy images that do not use the same image format.
CL_IMAGE_FORMAT_NOT_SUPPORTED	Returned when attempting to create or use an image format that is not supported.
CL_INVALID_ARG_INDEX	Returned when attempting to get or set a kernel argument using an invalid index for the specified kernel.
CL_INVALID_ARG_SIZE	Returned when the specified size of a kernel argument does not match the size of the kernel argument.
CL_INVALID_ARG_VALUE	Returned when attempting to set a kernel argument that is not valid.
CL_INVALID_BINARY	Returned when a program binary is not valid for a device.
CL_INVALID_BUFFER_SIZE	Returned when attempting to create a buffer or a sub-buffer with an invalid size.
CL_INVALID_BUILD_OPTIONS	Returned when build options passed to clBuildProgram are not valid.

Error Code	Brief Description
CL_INVALID_COMMAND_QUEUE	Returned when the specified command-queue is not a valid command-queue .
CL_INVALID_COMPILER_OPTIONS missing before version 1.2.	Returned when compiler options passed to clCompileProgram are not valid.
CL_INVALID_CONTEXT	Returned when a specified context is not a valid context , or when mixing objects from multiple contexts.
CL_INVALID_DEVICE	Returned when a specified device is not a valid device .
CL_INVALID_DEVICE_PARTITION_COUNT missing before version 1.2.	Returned when the requested device partitioning using CL_DEVICE_PARTITION_BY_COUNTS is not valid.
CL_INVALID_DEVICE_QUEUE missing before version 2.0.	Returned when setting a device queue kernel argument to a value that is not a valid device command-queue.
CL_INVALID_DEVICE_TYPE	Returned when the requested device type is not a valid value.
CL_INVALID_EVENT	Returned when a specified event object is not a valid event object .
CL_INVALID_EVENT_WAIT_LIST	Returned when the specified event wait list or number of events in the wait list is not valid.
CL_INVALID_GLOBAL_OFFSET	Returned when the specified global offset and global work size exceeds the limits of the device.
CL_INVALID_GLOBAL_WORK_SIZE	Returned when the specified global work size exceeds the limits of the device.
CL_INVALID_HOST_PTR	Returned when the specified host pointer is not valid for the specified flags.
CL_INVALID_IMAGE_DESCRIPTOR missing before version 1.2.	Returned when the specified image descriptor is NULL or specifies invalid values.
CL_INVALID_IMAGE_FORMAT_DESCRIPTOR	Returned when the specified image format descriptor is NULL or specifies invalid value.
CL_INVALID_IMAGE_SIZE	Returned when the specified image dimensions exceed the maximum dimensions for a device or all devices in a context.
CL_INVALID_KERNEL	Returned when the specified kernel is not a valid kernel object .
CL_INVALID_KERNEL_ARGS	Returned when enqueueing a kernel when some kernel arguments have not been set or are invalid.

Error Code	Brief Description
CL_INVALID_KERNEL_DEFINITION	Returned when creating a kernel for multiple devices where the number of kernel arguments or kernel argument types are not the same for all devices.
CL_INVALID_KERNEL_NAME	Returned when creating a kernel when no kernel with the specified name exists in the program object.
CL_INVALID_LINKER_OPTIONS missing before version 1.2.	Returned when build options passed to clLinkProgram are not valid.
CL_INVALID_MEM_OBJECT	Returned when a specified memory object is not a valid memory object .
CL_INVALID_OPERATION	This is a generic error code that is returned when the requested operation is not a valid operation.
CL_INVALID_PIPE_SIZE missing before version 2.0.	Returned when attempting to create a pipe with an invalid packet size or number of packets.
CL_INVALID_PLATFORM	Returned when the specified platform is not a valid platform .
CL_INVALID_PROGRAM	Returned when a specified program is not a valid program object .
CL_INVALID_PROGRAM_EXECUTABLE	Returned when the specified program is valid but has not been successfully built.
CL_INVALID_PROPERTY missing before version 1.1.	Returned when a specified property name is invalid, when the value for a property name is invalid, or when the same property name is specified more than once.
CL_INVALID_QUEUE_PROPERTIES	Returned when specified queue properties are valid but are not supported by the device.
CL_INVALID_SAMPLER	Returned when a specified sampler is not a valid sampler object .
CL_INVALID_SPEC_ID missing before version 2.2.	Returned when the specified specialization constant ID is not valid for the specified program.
CL_INVALID_VALUE	This is a generic error that is returned when a specified value is not a valid value.
CL_INVALID_WORK_DIMENSION	Returned by clEnqueueNDRangeKernel when the specified work dimension is not valid.
CL_INVALID_WORK_GROUP_SIZE	Returned by clEnqueueNDRangeKernel when the specified total work-group size is not valid for the specified kernel or device.

Error Code	Brief Description
CL_INVALID_WORK_ITEM_SIZE	Returned by clEnqueueNDRangeKernel when the specified work-group size in one dimension is not valid for the device.
CL_KERNEL_ARG_INFO_NOT_AVAILABLE missing before version 1.2.	Returned by clGetKernelArgInfo when kernel argument information is not available for the specified kernel.
CL_LINK_PROGRAM_FAILURE missing before version 1.2.	Returned by clLinkProgram when there is a failure to link the specified binaries or libraries.
CL_LINKER_NOT_AVAILABLE missing before version 1.2.	Returned by clLinkProgram when CL_DEVICE_LINKER_AVAILABLE is CL_FALSE.
CL_MAP_FAILURE	Returned when there is a failure to map the specified region into the host address space.
CL_MEM_COPY_OVERLAP	Returned when copying from one region of a memory object to another where the source and destination regions overlap.
CL_MEM_OBJECT_ALLOCATION_FAILURE	Returned when there is a failure to allocate memory for a memory object.
CL_MISALIGNED_SUB_BUFFER_OFFSET missing before version 1.1.	Returned when a sub-buffer object is created or used that is not aligned to CL_DEVICE_MEM_BASE_ADDR_ALIGN for the device.
CL_OUT_OF_HOST_MEMORY	This is a generic error that is returned when memory could not be allocated on the host.
CL_OUT_OF_RESOURCES	This is a generic error that is returned when resources could not be allocated on the device.
CL_MAX_SIZE_RESTRICTION_EXCEEDED missing before version 2.2.	Returned when the size of the specified kernel argument value exceeds the maximum size defined for the kernel argument.
CL_PROFILING_INFO_NOT_AVAILABLE	Returned by clGetEventProfilingInfo when the command associated with the specified event was not enqueued into a command-queue with CL_QUEUE_PROFILING_ENABLE.

Appendix G: Other Miscellaneous Enums

This section lists other miscellaneous OpenCL enumerants and their meanings.

Enumerant	Brief Description
CL_TRUE	Indicates a boolean "true" value.
CL_FALSE	Indicates a boolean "false" value.
CL_NONE	Indicates that none of the other enumerations or conditions are applicable.
CL_BLOCKING missing before version 1.2.	Alias of CL_TRUE that can be used to improve the readability of calls to enqueue functions that can block.
CL_NON_BLOCKING missing before version 1.2.	Alias of CL_FALSE that can be used to improve the readability of calls to enqueue function that can block.

Appendix H: OpenCL 3.0 Backwards Compatibility

OpenCL 3.0 breaks backwards compatibility with earlier versions of OpenCL by making some features that were previously required for FULL_PROFILE or EMBEDDED_PROFILE devices optional. This appendix describes the features that were previously required that are now optional, how to detect whether an optional feature is supported, and expected behavior when an optional feature is not supported.



Informally, in the tables below the first row usually describes a feature detection mechanism ("May return this value indicating that the feature is not supported") and subsequent rows usually describe behavior when a feature is not supported ("Returns this value if the feature is not supported").

Shared Virtual Memory

Shared Virtual Memory (SVM) is optional for devices supporting OpenCL 3.0. When Shared Virtual Memory is not supported:

API	Behavior
clGetDeviceInfo , passing CL_DEVICE_SVM_CAPABILITIES	May return 0 , indicating that <i>device</i> does not support Shared Virtual Memory.
clGetMemObjectInfo , passing CL_MEM_USES_SVM_POINTER	Returns CL_FALSE if no devices in the context associated with <i>memobj</i> support Shared Virtual Memory.
clSVMAlloc	Returns NULL if no devices in <i>context</i> support Shared Virtual Memory.
clSVMFree	Is a NOP if no devices in <i>context</i> support Shared Virtual Memory.
clEnqueueSVMFree , clEnqueueSVMMemcpy , clEnqueueSVMMemFill , clEnqueueSVMMap , clEnqueueSVMUnmap , clEnqueueSVMMigrateMem	Returns CL_INVALID_OPERATION if the device associated with <i>command_queue</i> does not support Shared Virtual Memory.
clSetKernelArgSVMPointer , clSetKernelExecInfo	Returns CL_INVALID_OPERATION if no devices in the context associated with <i>kernel</i> support Shared Virtual Memory.

Memory Consistency Model

Some aspects of the OpenCL memory consistency model are optional for devices supporting OpenCL 3.0. New device queries were added to [clGetDeviceInfo](#) to allow capabilities to be precisely reported. When the full memory consistency model is not supported:

API	Behavior
clGetDeviceInfo , passing <code>CL_DEVICE_ATOMIC_MEMORY_CAPABILITIES</code>	<p>May return:</p> <p><code>CL_DEVICE_ATOMIC_ORDER_RELAXED</code> <code>CL_DEVICE_ATOMIC_SCOPE_WORK_GROUP</code></p> <p>indicating that <i>device</i> does not support the full memory consistency model for atomic memory operations.</p> <p>Note that a device that provides the same level of capabilities as an OpenCL 2.x device would be expected to return:</p> <p><code>CL_DEVICE_ATOMIC_ORDER_RELAXED</code> <code>CL_DEVICE_ATOMIC_ORDER_ACQ_REL</code> <code>CL_DEVICE_ATOMIC_ORDER_SEQ_CST</code> <code>CL_DEVICE_ATOMIC_SCOPE_WORK_GROUP</code> <code>CL_DEVICE_ATOMIC_SCOPE_DEVICE</code> <code>CL_DEVICE_ATOMIC_SCOPE_ALL_DEVICES</code></p>
clGetDeviceInfo , passing <code>CL_DEVICE_ATOMIC_FENCE_CAPABILITIES</code>	<p>May return:</p> <p><code>CL_DEVICE_ATOMIC_ORDER_RELAXED</code> <code>CL_DEVICE_ATOMIC_ORDER_ACQ_REL</code> <code>CL_DEVICE_ATOMIC_SCOPE_WORK_GROUP</code></p> <p>indicating that <i>device</i> does not support the full memory consistency model for atomic fence operations.</p> <p>Note that a device that provides the same level of capabilities as an OpenCL 2.x device would be expected to return:</p> <p><code>CL_DEVICE_ATOMIC_ORDER_RELAXED</code> <code>CL_DEVICE_ATOMIC_ORDER_ACQ_REL</code> <code>CL_DEVICE_ATOMIC_ORDER_SEQ_CST</code> <code>CL_DEVICE_ATOMIC_SCOPE_WORK_ITEM</code> <code>CL_DEVICE_ATOMIC_SCOPE_WORK_GROUP</code> <code>CL_DEVICE_ATOMIC_SCOPE_DEVICE</code> <code>CL_DEVICE_ATOMIC_SCOPE_ALL_DEVICES</code></p>

OpenCL C compilers supporting atomics orders or scopes beyond the mandated minimum will define some or all of following feature macros as appropriate:

`__opencl_c_atomic_order_acq_rel` — Indicating atomic operations support acquire-release orderings.

`__opencl_c_atomic_order_seq_cst` — Indicating atomic operations and fences support acquire sequentially consistent orderings.

`__opencl_c_atomic_scope_device` — Indicating atomic operations and fences support device-wide memory ordering constraints.

`__opencl_c_atomic_scope_all_devices` — Indicating atomic operations and fences support all-device memory ordering constraints, across any host threads and all devices that can share SVM memory with each other and the host process.

Device-Side Enqueue

Device-side enqueue and on-device queues are optional for devices supporting OpenCL 3.0. When device-side enqueue is not supported:

API	Behavior
<code>clGetDeviceInfo</code> , passing <code>CL_DEVICE_DEVICE_ENQUEUE_CAPABILITIES</code>	May return <code>0</code> , indicating that <i>device</i> does not support device-side enqueue and on-device queues.
<code>clGetDeviceInfo</code> , passing <code>CL_DEVICE_QUEUE_ON_DEVICE_PROPERTIES</code>	Returns <code>0</code> if <i>device</i> does not support device-side enqueue and on-device queues.
<code>clGetDeviceInfo</code> , passing <code>CL_DEVICE_QUEUE_ON_DEVICE_PREFERRED_SIZE</code> , <code>CL_DEVICE_QUEUE_ON_DEVICE_MAX_SIZE</code> , <code>CL_DEVICE_MAX_ON_DEVICE_QUEUES</code> , or <code>CL_DEVICE_MAX_ON_DEVICE_EVENTS</code>	Returns <code>0</code> if <i>device</i> does not support device-side enqueue and on-device queues.
<code>clGetCommandQueueInfo</code> , passing <code>CL_QUEUE_SIZE</code>	Returns <code>CL_INVALID_COMMAND_QUEUE</code> since <i>command_queue</i> cannot be a valid device command-queue.
<code>clGetCommandQueueInfo</code> , passing <code>CL_QUEUE_DEVICE_DEFAULT</code>	Returns <code>NULL</code> if the device associated with <i>command_queue</i> does not support on-device queues.
<code>clGetEventProfilingInfo</code> , passing <code>CL_PROFILING_COMMAND_COMPLETE</code>	Returns a value equivalent to passing <code>CL_PROFILING_COMMAND_END</code> if the device associated with <i>event</i> does not support device-side enqueue.
<code>clSetDefaultDeviceCommandQueue</code>	Returns <code>CL_INVALID_OPERATION</code> if <i>device</i> does not support on-device queues.

When device-side enqueue is supported but a replaceable default on-device queue is not supported:

API	Behavior
<code>clGetDeviceInfo</code> , passing <code>CL_DEVICE_DEVICE_ENQUEUE_CAPABILITIES</code>	May omit <code>CL_DEVICE_QUEUE_REPLACEABLE_DEFAULT</code> , indicating that <i>device</i> does not support a replaceable default on-device queue.
<code>clSetDefaultDeviceCommandQueue</code>	Returns <code>CL_INVALID_OPERATION</code> if <i>device</i> does not support a replaceable default on-device queue.

OpenCL C compilers supporting device-side enqueue and on-device queues will define the feature macro `__opencl_c_device_enqueue`. OpenCL C compilers that define the feature macro `__opencl_c_device_enqueue` must also define the feature macro `__opencl_c_generic_address_space`

because some OpenCL C functions for device-side enqueue accept pointers to the generic address space. OpenCL C compilers that define the feature macro `__opencl_c_device_enqueue` must also define the feature macro `__opencl_c_program_scope_global_variables` because an implementation of blocks may interact with program scope variables in global address space as part of ABI.

Pipes

Pipe memory objects are optional for devices supporting OpenCL 3.0. When pipes are not supported:

API	Behavior
<code>clGetDeviceInfo</code> , passing <code>CL_DEVICE_PIPE_SUPPORT</code>	May return <code>CL_FALSE</code> , indicating that <i>device</i> does not support pipes.
<code>clGetDeviceInfo</code> , passing <code>CL_DEVICE_MAX_PIPE_ARGS</code> , <code>CL_DEVICE_PIPE_MAX_ACTIVE_RESERVATIONS</code> , or <code>CL_DEVICE_PIPE_MAX_PACKET_SIZE</code>	Returns <code>0</code> if <i>device</i> does not support pipes.
<code>clCreatePipe</code>	Returns <code>CL_INVALID_OPERATION</code> if no devices in <i>context</i> support pipes.
<code>clGetPipeInfo</code>	Returns <code>CL_INVALID_MEM_OBJECT</code> since <i>pipe</i> cannot be a valid pipe object.

OpenCL C compilers supporting pipes will define the feature macro `__opencl_c_pipes`. OpenCL C compilers that define the feature macro `__opencl_c_pipes` must also define the feature macro `__opencl_c_generic_address_space` because some OpenCL C functions for pipes accept pointers to the generic address space.

Program Scope Global Variables

Program scope global variables are optional for devices supporting OpenCL 3.0. When program scope global variables are not supported:

API	Behavior
<code>clGetDeviceInfo</code> , passing <code>CL_DEVICE_MAX_GLOBAL_VARIABLE_SIZE</code>	May return <code>0</code> , indicating that <i>device</i> does not support program scope global variables.
<code>clGetDeviceInfo</code> , passing <code>CL_DEVICE_GLOBAL_VARIABLE_PREFERRED_TOTAL_SIZE</code>	Returns <code>0</code> if <i>device</i> does not support program scope global variables.
<code>clGetProgramBuildInfo</code> , passing <code>CL_PROGRAM_BUILD_GLOBAL_VARIABLE_TOTAL_SIZE</code>	Returns <code>0</code> if <i>device</i> does not support program scope global variables.

OpenCL C compilers supporting program scope global variables will define the feature macro `__opencl_c_program_scope_global_variables`.

Non-Uniform Work-groups

Support for non-uniform work-groups is optional for devices supporting OpenCL 3.0. When non-uniform work-groups are not supported:

API	Behavior
clGetDeviceInfo , passing <code>CL_DEVICE_NON_UNIFORM_WORK_GROUP_SUPPORT</code>	May return <code>CL_FALSE</code> , indicating that <i>device</i> does not support non-uniform work-groups.
clEnqueueNDRangeKernel	Behaves as though non-uniform work-groups were not enabled for <i>kernel</i> , if the device associated with <i>command_queue</i> does not support non-uniform work-groups.

Read-Write Images

Read-write images, that may be read from and written to in the same kernel, are optional for devices supporting OpenCL 3.0. When read-write images are not supported:

API	Behavior
clGetDeviceInfo , passing <code>CL_DEVICE_MAX_READ_WRITE_IMAGE_ARGS</code>	May return <code>0</code> , indicating that <i>device</i> does not support read-write images.
clGetSupportedImageFormats , passing <code>CL_MEM_KERNEL_READ_AND_WRITE</code>	Returns an empty set (such as <i>num_image_formats</i> equal to <code>0</code>), indicating that no image formats are supported for reading and writing in the same kernel, if no devices in <i>context</i> support read-write images.

OpenCL C compilers supporting read-write images will define the feature macro `__opencl_c_read_write_images`.

Creating 2D Images from Buffers

Creating a 2D image from a buffer is optional for devices supporting OpenCL 3.0. When creating a 2D image from a buffer is not supported:

API	Behavior
clGetDeviceInfo , passing <code>CL_DEVICE_IMAGE_PITCH_ALIGNMENT</code> or <code>CL_DEVICE_IMAGE_BASE_ADDRESS_ALIGNMENT</code>	May return <code>0</code> , indicating that <i>device</i> does not support creating a 2D image from a Buffer.
clGetDeviceInfo , passing <code>CL_DEVICE_EXTENSIONS</code>	Will not describe support for the <code>cl_khr_image2d_from_buffer</code> extension if <i>device</i> does not support creating a 2D image from a buffer.

API	Behavior
clCreateImage or clCreateImageWithProperties , passing <i>image_type</i> equal to CL_MEM_OBJECT_IMAGE2D and <i>mem_object</i> not equal to NULL	Returns CL_INVALID_OPERATION if no devices in <i>context</i> support creating a 2D image from a buffer.

sRGB Images

All of the sRGB image channel orders (such as **CL_sRGBA**) are optional for devices supporting OpenCL 3.0. When sRGB images are not supported:

API	Behavior
clGetSupportedImageFormats	Will not return any image formats with <i>image_channel_order</i> equal to an sRGB image channel order if no devices in <i>context</i> support sRGB images.

Depth Images

The **CL_DEPTH** image channel order is optional for devices supporting OpenCL 3.0. When depth images are not supported:

API	Behavior
clGetSupportedImageFormats	Will not return any image formats with <i>image_channel_order</i> equal to CL_DEPTH if no devices in <i>context</i> support depth images.

Device and Host Timer Synchronization

Synchronizing the device and host timers is optional for platforms supporting OpenCL 3.0. When device and host timer synchronization is not supported:

API	Behavior
clGetPlatformInfo , passing CL_PLATFORM_HOST_TIMER_RESOLUTION	May return 0 , indicating that <i>platform</i> does not support device and host timer synchronization.
clGetDeviceAndHostTimer , clGetHostTimer	Returns CL_INVALID_OPERATION if the platform associated with <i>device</i> does not support device and host timer synchronization.

Intermediate Language Programs

Creating programs from an intermediate language (such as SPIR-V) is optional for devices supporting OpenCL 3.0. When intermediate language programs are not supported:

API	Behavior
clGetDeviceInfo , passing <code>CL_DEVICE_IL_VERSION</code> or <code>CL_DEVICE_ILS_WITH_VERSION</code>	May return an empty string and empty array, indicating that <i>device</i> does not support intermediate language programs.
clGetProgramInfo , passing <code>CL_PROGRAM_IL</code>	Returns an empty buffer (such as <i>param_value_size_ret</i> equal to 0) if no devices in the context associated with <i>program</i> support intermediate language programs.
clCreateProgramWithIL	Returns <code>CL_INVALID_OPERATION</code> if no devices in <i>context</i> support intermediate language programs.
clSetProgramSpecializationConstant	Returns <code>CL_INVALID_OPERATION</code> if no devices associated with <i>program</i> support intermediate language programs.
clGetKernelSubGroupInfo , passing <code>CL_KERNEL_COMPILE_NUM_SUB_GROUPS</code>	Returns 0 if <i>device</i> does not support intermediate language programs, since there is currently no way to require a number of sub-groups per work-group for programs created from source.

Sub-groups

Sub-groups are optional for devices supporting OpenCL 3.0. When sub-groups are not supported:

API	Behavior
clGetDeviceInfo , passing <code>CL_DEVICE_MAX_NUM_SUB_GROUPS</code>	May return 0, indicating that <i>device</i> does not support sub-groups.
clGetDeviceInfo , passing <code>CL_DEVICE_SUB_GROUP_INDEPENDENT_FORWARD_PROGRESS</code>	Returns <code>CL_FALSE</code> if <i>device</i> does not support sub-groups.
clGetDeviceInfo , passing <code>CL_DEVICE_EXTENSIONS</code>	Will not describe support for the <code>cl_khr_subgroups</code> extension if <i>device</i> does not support sub-groups.
clGetKernelSubGroupInfo	Returns <code>CL_INVALID_OPERATION</code> if <i>device</i> does not support sub-groups.

OpenCL C compilers supporting sub-groups will define the feature macro `__opencl_c_subgroups`.

Program Initialization and Clean-Up Kernels

Program initialization and clean-up kernels are not supported in OpenCL 3.0, and the APIs and queries for program initialization and clean-up kernels are deprecated in OpenCL 3.0. When program initialization and clean-up kernels are not supported:

API	Behavior
clGetProgramInfo , passing <code>CL_PROGRAM_SCOPE_GLOBAL_CTORS_PRESENT</code> or <code>CL_PROGRAM_SCOPE_GLOBAL_DTORS_PRESENT</code>	Returns <code>CL_FALSE</code> if no devices in the context associated with <i>program</i> support program initialization and clean-up kernels.
clSetProgramReleaseCallback	Returns <code>CL_INVALID_OPERATION</code> if no devices in the context associated with <i>program</i> support program initialization and clean-up kernels.

3D Image Writes

Kernel built-in functions for writing to 3D image objects are optional for devices supporting OpenCL 3.0. When writing to 3D image objects is not supported:

API	Behavior
clGetDeviceInfo , passing <code>CL_DEVICE_EXTENSIONS</code>	Will not describe support for the <code>cl_khr_3d_image_writes</code> extension if <i>device</i> does not support writing to 3D image objects.
clGetSupportedImageFormats , passing <code>CL_MEM_OBJECT_IMAGE3D</code> and one of <code>CL_MEM_WRITE_ONLY</code> , <code>CL_MEM_READ_WRITE</code> , or <code>CL_MEM_KERNEL_READ_AND_WRITE</code>	Returns an empty set (such as <i>num_image_formats</i> equal to 0), indicating that no image formats are supported for writing to 3D image objects, if no devices in <i>context</i> support writing to 3D image objects.

OpenCL C compilers supporting writing to 3D image objects will define the feature macro `__opengl_c_3d_image_writes`.

Work-group Collective Functions

Work-group collective functions for broadcasts, scans, and reductions are optional for devices supporting OpenCL 3.0. When work-group collective functions are not supported:

API	Behavior
clGetDeviceInfo , passing <code>CL_DEVICE_WORK_GROUP_COLLECTIVE_FUNCTIONS_SUPPORT</code>	May return <code>CL_FALSE</code> , indicating that <i>device</i> does not support work-group collective functions.

OpenCL C compilers supporting work-group collective functions will define the feature macro `__opengl_c_work_group_collective_functions`.

Generic Address Space

Support for the generic address space is optional for devices supporting OpenCL 3.0. When the generic address space is not supported:

API	Behavior
<code>clGetDeviceInfo</code> , passing <code>CL_DEVICE_GENERIC_ADDRESS_SPACE_SUPPORT</code>	May return <code>CL_FALSE</code> , indicating that <i>device</i> does not support the generic address space.

OpenCL C compilers supporting the generic address space will define the feature macro `__opencl_c_generic_address_space`.

Language Features that Were Already Optional

Some OpenCL C language features were already optional before OpenCL 3.0, the API mechanisms for querying these have not changed.

New feature macros for these optional features have been added to OpenCL C to provide a consistent mechanism for using optional features in OpenCL C 3.0. OpenCL C compilers supporting images will define the feature macro `__opencl_c_images`. OpenCL C compilers supporting the `double` type will define the feature macro `__opencl_c_fp64`. OpenCL C compilers supporting the `long`, `unsigned long` and `ulong` types will define the feature macro `__opencl_c_int64`, note that compilers for FULL_PROFILE devices must support these types and define the macro unconditionally.

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