DPC++ Reference

Intel

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CHAPTER

ONE

INTRODUCTION

Obtaining high compute performance on today's modern computer architectures requires code that is optimized, power efficient, and scalable. The demand for high performance continues to increase due to needs in AI, video analytics, data analytics, as well as in traditional high performance computing (HPC).

Modern workload diversity has resulted in a need for architectural diversity; no single architecture is best for every workload. A mix of scalar, vector, matrix, and spatial (SVMS) architectures deployed in CPU, GPU, AI, and FPGA *accelerators* is required to extract best performance.

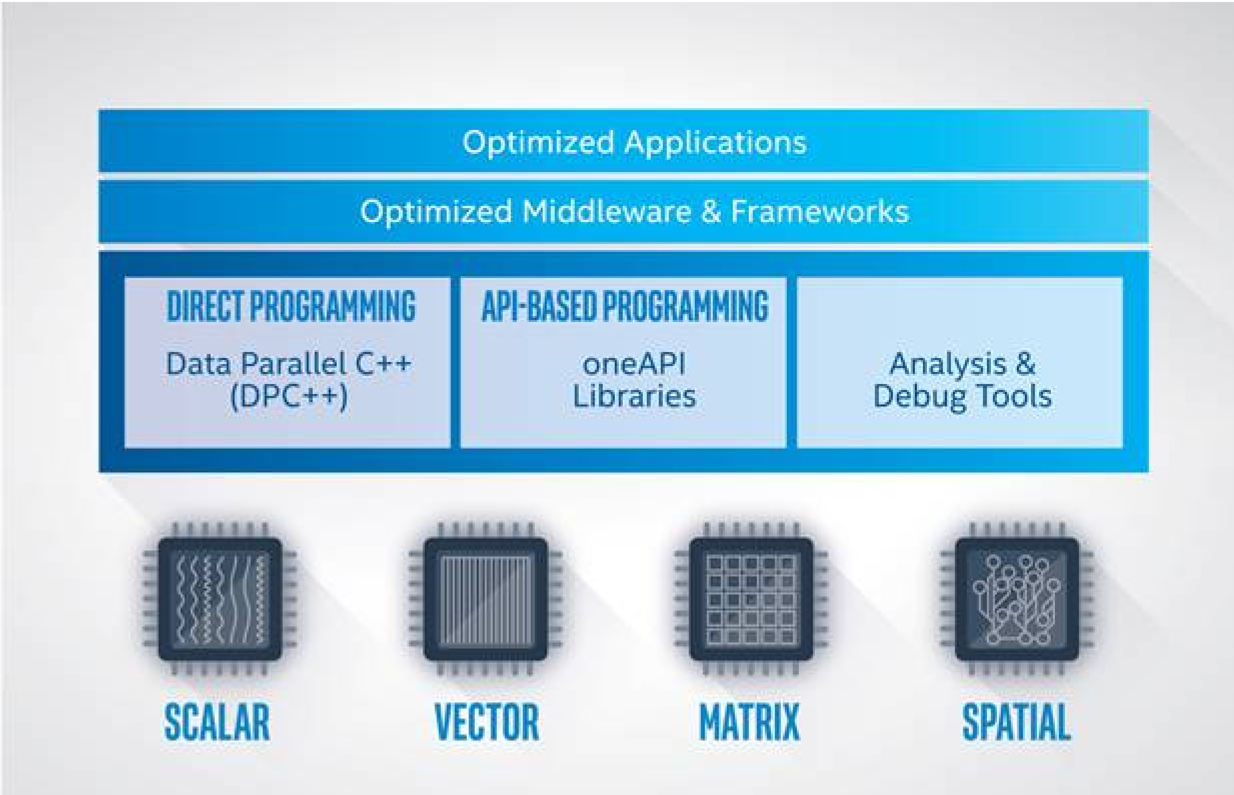
Today, coding for CPUs and accelerators requires different languages, libraries, and tools. There is limited application code reusability across different target architectures.

oneAPI is a cross-industry initiative for an open, standards-based unified programming model that creates a common developer experience across compute accelerator architectures. Its objective is to deliver an efficient, performant programming model that eliminates the need for developers to maintain separate code bases, languages, tools, and workflows for each architecture.

1.1 Overview

oneAPI consists of Data Parallel C++ (DPC++) and a core set of libraries for compute-intensive domains. DPC++ programs accelerate a sequential computation by distributing work across the processing elements in a device. DPC++ uses a data parallel programming model. The data is distributed across a set of processing elements, and each processing element operates on the data in parallel. By using a data parallel programming model, the developer is able to scale the parallelism with the size of the data.

A developer can either use DPC++ to explicitly parallelize an algorithm, or use a parallel implementation from a oneAPI library. oneAPI makes it possible to target CPU, GPU, or FPGA with a single implementation by providing consistent interfaces. However, some devices may not implement all features. Achieving best performance often requires the programmer to tune the code for the target architecture. oneAPI libraries are written to achieve best performance on all supported architectures without end user tuning.



As shown in the figure above, applications that take advantage of the oneAPI programming model can execute on multiple target hardware platforms ranging from CPU to FPGA.

1.2 Data Parallel C++ (DPC++)

DPC++ is the heart of oneAPI. DPC++ programs are written in ISO C++ and use the Khronos* SYCL* parallel programming model to distribute computation across processing elements in a device. DPC++ extends SYCL with features for performance and productivity.

DPC++ is *single source* – device and host code can be included in the same source file. A DPC++ compiler generates code for both the host and device. Any C++ compiler can compile programs that only use the host subset of DPC++.

In this guide, it is safe to assume that anything that mentions SYCL is also applicable to DPC++. Anything specific to DPC++ will be explicitly mentioned.

1.3 Structure of This Document

This document consists of the following sections:

- *Programming Model* describes the high-level concepts for the DPC++ programming model and the execution model that it depends upon.
- *Interface* provides a detailed explanation of the classes that make up the programming model.

1.4 How to Use This Document

This document is a reference manual for DPC++. It is intended to be the document to consult when you are coding an algorithm in DPC++ and need to understand the detailed functionality, usage of an API, or some other aspect of DPC++.

If you want to learn DPC++, the oneAPI online training is more appropriate. The ultimate sources for DPC++ information are the oneAPI Specification and the SYCL Specification. The specifications are written for implementors of oneAPI elements and SYCL compilers/runtimes. The descriptions are more precise, but may be difficult to understand if you are not already an expert in other aspects of DPC++.

1.5 Related Documentation

The following documents are useful starting points for developers getting started with oneAPI projects. This document assumes you already have a basic understanding of the oneAPI programming model concepts.

- oneAPI
- SYCL
- SYCL Specification

CHAPTER

TWO

PROGRAMMING MODEL

DPC++ defines a parallel programming model for distributing a computation across a *host* and *processing element*s of a heterogenous system. The parallel programming model is an extension of Khronos* SYCL*. Every SYCL program is also a DPC++ program, but the reverse is not true when an application uses DPC++ extensions. The base language of DPC++ and SYCL is C++, with no extensions. All DPC++ functionality is invoked via interfaces defined by a set of C++ classes, which are introduced in this section and described in detail in *Interface*.

2.1 Anatomy of a DPC++ Program

We start with a DPC++ example application to illustrate basic DPC++ concepts. We continue by breaking down the DPC++ programming model into 4 areas as follows.

The following example uses the oneAPI programming model to add 2 vectors. When compiled and executed, the sample program computes the 1024 element vector add in parallel on the accelerator. This assumes the accelerator has multiple compute elements capable of executing in parallel. This sample illustrates the models that software developers need to employ in their program. We identify sections of code by line number and discuss their role, highlighting their relation to the programming and execution models.

Note: This sample code is intended to illustrate the models that comprise the oneAPI program model; it is not intended to be a typical program.

```
#include <CL/sycl.hpp>
using namespace sycl;

const int SIZE = 10;

void show_platforms() {
  auto platforms = platform::get_platforms();

  for (auto &platform : platforms) {
    std::cout << "Platform: "
              << platform.get_info<info::platform::name>()
              << std::endl;

    auto devices = platform.get_devices();
    for (auto &device : devices ) {
      std::cout << "  Device: "
                << device.get_info<info::device::name>()
                << std::endl;
    }
```

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```
  }
}

void vec_add(int *a, int *b, int *c) {
  range<1> a_size{SIZE};

  buffer<int> a_buf(a, a_size);
  buffer<int> b_buf(b, a_size);
  buffer<int> c_buf(c, a_size);

  queue q;

  q.submit([&](handler &h) {
      auto c_res = c_buf.get_access<access::mode::write>(h);
      auto a_in = a_buf.get_access<access::mode::read>(h);
      auto b_in = b_buf.get_access<access::mode::read>(h);

      h.parallel_for(a_size,
                     [=](id<1> idx) {
                       c_res[idx] = a_in[idx] + b_in[idx];
                     });
    });
}

int main() {
  int a[SIZE], b[SIZE], c[SIZE];

  for (int i = 0; i < SIZE; ++i) {
    a[i] = i;
    b[i] = i;
    c[i] = i;
  }

  show_platforms();
  vec_add(a, b, c);

  for (int i = 0; i < SIZE; i++) std::cout << c[i] << std::endl;
  return 0;
}
```

With the following output:

```
Platform: Intel(R) FPGA Emulation Platform for OpenCL(TM)
  Device: Intel(R) FPGA Emulation Device
Platform: Intel(R) OpenCL
  Device: Intel(R) Core(TM) i5-7300U CPU @ 2.60GHz
Platform: Intel(R) CPU Runtime for OpenCL(TM) Applications
  Device: Intel(R) Core(TM) i5-7300U CPU @ 2.60GHz
Platform: SYCL host platform
  Device: SYCL host device
0
2
4
6
8
10
12
```

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```
14
16
18
```

DPC++ is *single source*, which means the *host code* and the *device code* can be placed in the same file and compiled with a single invocation of the compiler. Therefore, when examining a DPC++ program, the first step is to understand the delineation between host code and device code. DPC++ programs have 3 different scopes.

- *kernel scope*: Function that executes on the device
- *command group scope*: Kernel function and host code to launch it on the device
- *application scope*: Code that executes on the host

Application scope includes all program lines not in the command group scope. The application scope is responsible for creating DPC++ queues that are connected to devices (line 32), allocating data that can be accessed from the device (lines 28-30), and submit tasks to the queues (line 34).

Kernel scope is the body of the lambda function found on lines 40-42. Each invocation of the kernel function adds a single element of the `a` and `b` vectors.

```
39                            c_res[idx] = a_in[idx] + b_in[idx];
40                          });
41     });
42 }
```

Command group scope can be found on lines 34-43. A command group contains a single kernel function and code to coordinate the passing of data and control between the host and the device. Lines 35-37 create accessors, which enable the kernel to access the data in the buffers created on lines 28-30. The `parallel_for` on line 39 launches an instance of the kernel on every element of an index space and passes the coordinates of the point in the index space to the function. The index space is defined on line 26. It is a one-dimensional space that ranges from 0 to 1023.

```
34       auto a_in = a_buf.get_access<access::mode::read>(h);
35       auto b_in = b_buf.get_access<access::mode::read>(h);
36
37       h.parallel_for(a_size,
38                         [=](id<1> idx) {
39                           c_res[idx] = a_in[idx] + b_in[idx];
40                         });
41     });
42 }
43
```

Now we walk through line by line. Every DPC++ program must include sycl.hpp (line 3). All types are in the `cl::sycl` namespace and the line 4 namespace command is a convenience.

Lines 8-23 illustrate the use of the **platform model** by enumerating all the platforms available on the system and the devices contained in the platform.

Lines 28-30 and 35-37 show the role of the **memory model**. Device and host do not access the same memory by default. The memory model defines the rules for access. Lines 47 allocates memory on the host for the vectors. Lines 28-30 wrap buffers around that memory. Kernels read/write buffer data via the accessors that are created on lines 35-37. The accessor on line 35 gives the kernel write access to buffer names as *c_device*, and the accessors on lines 36 & 37 give the kernel read access to the other buffers.

```
28   buffer<int> c_buf(c, a_size);
29
30   queue q;
```

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```
31
32   q.submit([&](handler &h) {
33       auto c_res = c_buf.get_access<access::mode::write>(h);
34       auto a_in = a_buf.get_access<access::mode::read>(h);
35       auto b_in = b_buf.get_access<access::mode::read>(h);
36
37       h.parallel_for(a_size,
```

Lines 32-34 demonstrate the use of the **application execution model**. A command group is submitted to a queue on line 34. The SYCL runtime launches the kernel function in the command group on the device connected to the queue when the requirements of the command group are met. For this example, the accessors create the requirement that the buffers be accessible on the device. Queueing the command group triggers the copying of the data contained in the buffer from host memory to the device. The runtime launches the kernel when the data movements complete.

Lines 40-42 illustrate the function of **kernel execution model**. The `parallel_for` launches an instance of the kernel function for every point in the index space denoted by `a_size`. The instances are distributed among the processing elements of the device.

DPC++ uses C++ scopes and object models to concisely express synchronization. The vectors start in host memory. When the host memory for the vector is passed to the buffer constructor on lines 28-30, the buffers take *ownership* of the host memory and any use of the original host memory is undefined. When the destructor for the buffer runs because the containing scope ends, the runtime ensures that kernel accessing the buffer has ended and syncs the data back to the original host memory.

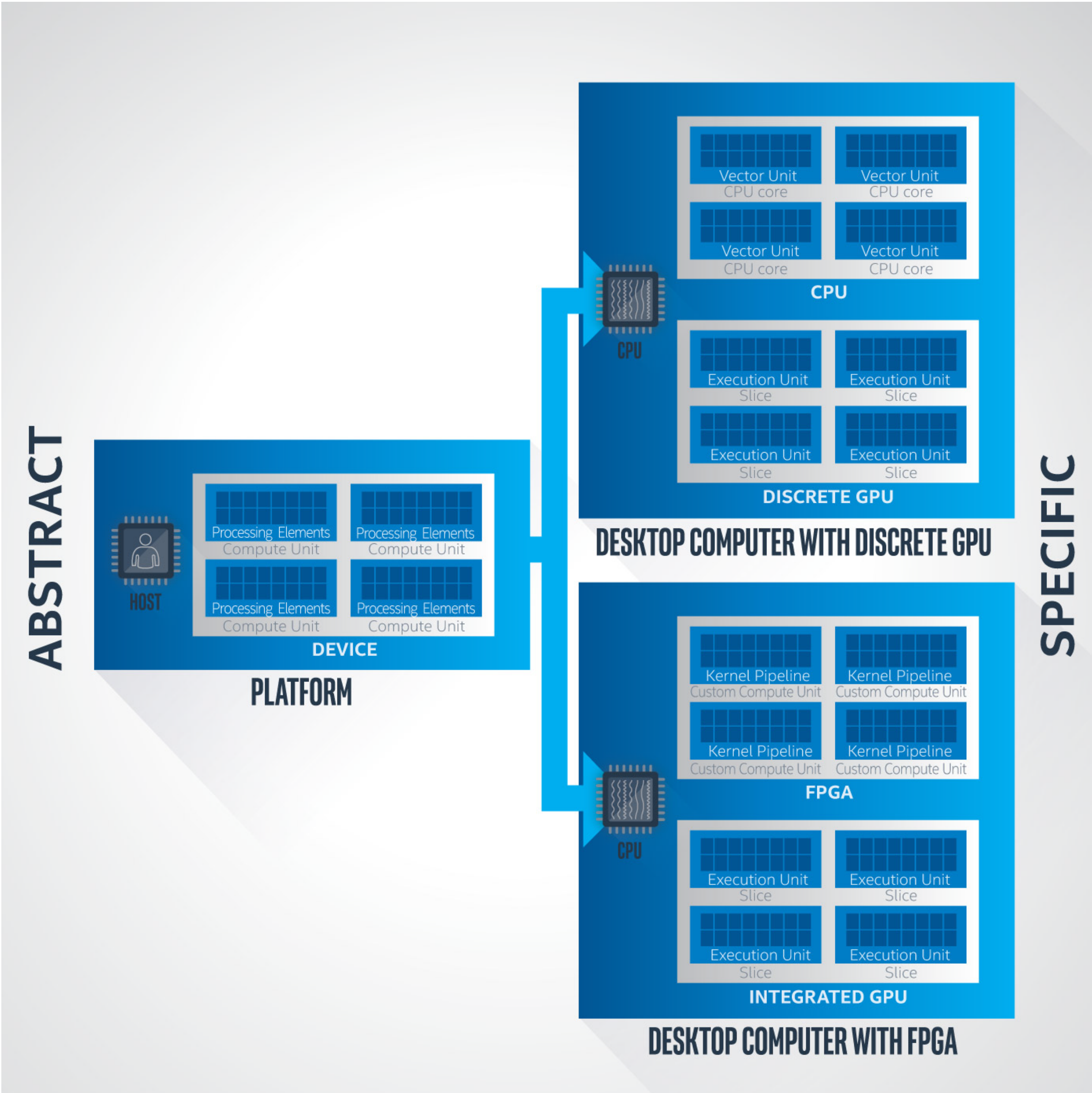
The next sections discuss in more details those four models: Platform model, Execution model, Memory model, and Kernel model.

2.2 Platform Model

The platform model for oneAPI is based upon the SYCL* platform model. It specifies a host controlling one or more devices. A host is the computer, typically a CPU-based system executing the primary portion of a program, specifically the application scope and the command group scope. The host coordinates and controls the compute work that is performed on the devices. A device is an accelerator, a specialized component containing compute resources that can quickly execute a subset of operations typically more efficiently than the CPUs in the system. Each device contains one or more compute units that can execute several operations in parallel. Each compute unit contains one or more *processing elements* that serve as the individual engine for computation.

A system can instantiate and execute several platforms simultaneously, which is desirable because a particular platform may only target a subset of the available hardware resources on a system. However, a system typically includes one platform comprised of one or more supported devices, and the compute resources made available by those devices.

The following figure illustrates the relationships of the components in the platform model. One host communicates with one or more devices. Each device can contain one or more compute units. Each compute unit can contain one or more processing elements.



The platform model is general enough to be mapped to several different types of devices, demonstrating the portability of DPC++ programs. The hierarchy on the device is also general and can be mapped to several different types of accelerators from FPGAs to GPUs and ASICs as long as these devices support the minimal requirements of the DPC++ programming model.

See also:

- *Runtime Classes*

2.3 Execution Model

The execution model is based upon the SYCL* execution model. It defines and specifies how code, termed kernels, execute on the host and the devices. We explain the execution model in 2 parts, *application execution model* and *kernel execution model*.

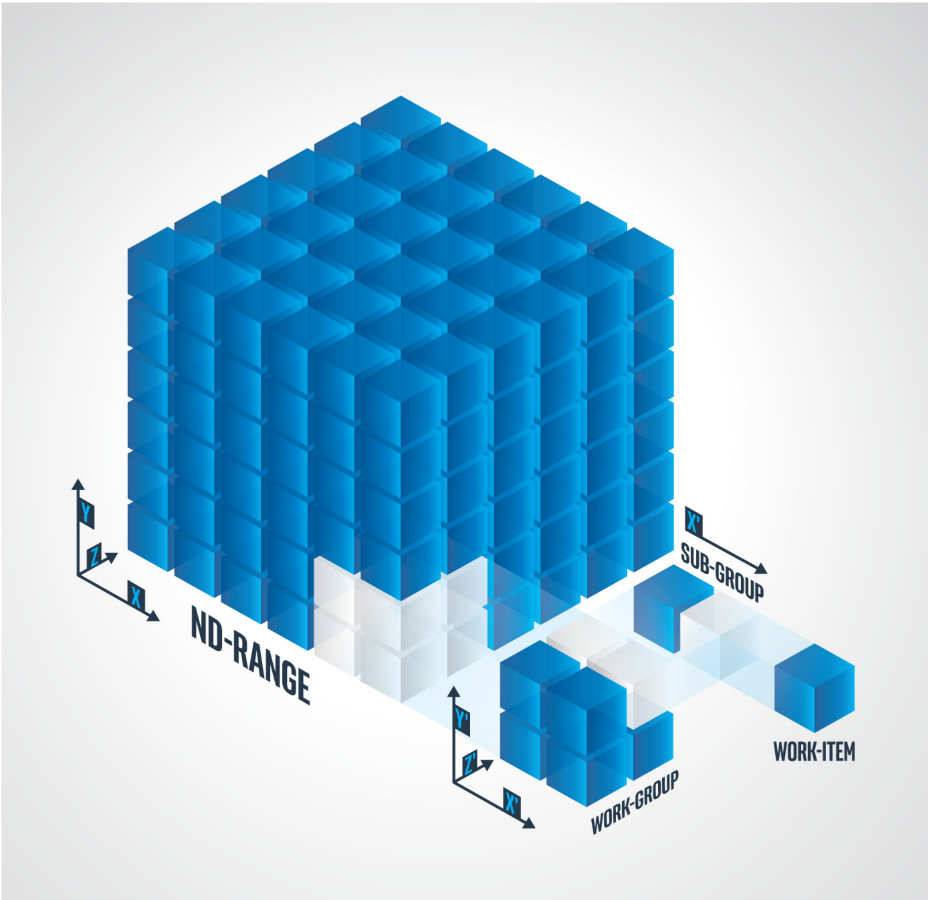
2.3.1 Application Execution Model

The application execution model coordinates execution and data management between the host and devices via command groups. The command groups, which are groupings of commands like kernel invocation and accessors, are submitted to queues for execution. Accessors, which are formally part of the memory model, also communicate ordering requirements of execution. A program employing the execution model declares and instantiates *queue*s. Queues can execute with an in-order or out-of-order policy controllable by the program.

2.3.2 Kernel Execution Model

The device execution model specifies how computation is accomplished on the accelerator. Compute ranging from small one-dimensional data to large multidimensional data sets are allocated across a hierarchy of *nd-range*, *work-group*, *sub-group*, and *work-item*, which are all specified when the work is submitted to the command queue. It is important to note that the actual kernel code represents the work that is executed for one work-item. The code outside of the kernel controls just how much parallelism is executed; the amount and distribution of the work is controlled by specification of the sizes of the ND-range and work-group.

The following figure depicts the relationship between an ND-range, work-group, sub-group, and work-item. The total amount of work is specified by the ND-range size. The grouping of the work is specified by the work-group size. The example shows the ND-range size of X * Y * Z, work-group size of X' * Y' * Z', and subgroup size of X'. Therefore, there are X * Y * Z work-items. There are (X * Y * Z) / (X' * Y' * Z') work-groups and (X * Y * Z) / X' subgroups.



When kernels are executed, the location of a particular work-item in the larger ND-range, work-group, or sub-group is important. For example, if the work-item is assigned to compute on specific pieces of data, a method of specification is necessary. Unique identification of the work-item is provided via intrinsic functions such as those in the `nd_item` class (`global_id`, `work_group_id`, and `local_id`).

The following code sample launches a kernel and displays the relationships of the previously discussed `ND-range`, `work-group`, and `work-item`.

```
#include <CL/sycl.hpp>
#include <iostream>
#include <iomanip>

const int N = 6;
const int M = 2;

using namespace sycl;

int main() {
  queue q;
  buffer<int,2> buf(range<2>(N,N));

  q.submit([&](handler &h){
      auto bufacc = buf.get_access<access::mode::read_write>(h);
      h.parallel_for(nd_range<2>(range<2>(N,N), range<2>(M,M)),
                     [=](nd_item<2> item){
                       int i = item.get_global_id(0);
```

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```
19                         int j = item.get_global_id(1);
20                         bufacc[i][j] = i + j;
21                       });
22     });
23 
24   auto bufacc1 = buf.get_access<access::mode::read>();
25   for(int i = 0; i < N; i++){
26     for(int j = 0; j < N; j++)
27       std::cout << std::setw(10) << bufacc1[i][j] << "  ";
28     std::cout<<"\n";
29   }
30   return 0;
31 }
```

With the following output:

```
         0          1          2          3          4          5
         1          2          3          4          5          6
         2          3          4          5          6          7
         3          4          5          6          7          8
         4          5          6          7          8          9
         5          6          7          8          9         10
```

ND-Range Parallelism Example

The following discusses the relationships in the use of the ND-range in the previous code sample.

- Line 16 is the `nd-range` declaration. `nd_range<2>` specifies a two-dimensional index space.
- The first argument, `range<2>(N,N)`, defines a `N` by `N` global index space shape.
- The second argument, `range<2>(M,M)` defines a `M` by `M` local work-group shape.
- Lines 18 & 19 extract the coordinates of the work item in the index space

The `sub-group` is an extension to the SYCL execution model and sits hierarchically between the `work_group` and `work_item`. The `sub_group` was created to align with typical hardware resources that contain a vector unit to execute several similar operations in parallel and in lock step.

See also:

- *Expressing parallelism*

2.4 Memory Model

The memory model for oneAPI is based upon the SYCL* memory model. It defines how the host and devices interact with memory. It coordinates the allocation and management of memory between the host and devices. The memory model is an abstraction that aims to generalize across and be adaptable to the different possible host and device configurations. In this model, memory resides upon and is owned by either the host or the device and is specified by declaring a memory object. There are two different types of memory objects, *buffers* and *images*. Interaction of these memory objects between the host and device is accomplished via an *accessor*, which communicates the desired location of access, such as host or device, and the particular mode of access, such as read or write.

Consider a case where memory is allocated on the host through a traditional malloc call. Once the memory is allocated on the host, a buffer object is created, which enables the host allocated memory to be communicated to the device. The `buffer` class communicates the type and number of items of that type to be communicated to the device for computation. Once a buffer is created on the host, the type of access allowed on the device is communicated via an `accessor` object, which specifies the type of access to the buffer. The general steps are summarized as:

1. Instantiate a `buffer` or `image` object.

   The host or device memory for the `buffer` or `image` is allocated as part of the instantiation or relies on previously allocated memory on the host.

2. Instantiate an `accessor` object.

   The `accessor` specifies the required location of access, such as host or device, and the particular mode of access, such as read or write. It represents dependencies between uses of memory objects.

The following code sample exercises different memory objects and accessors. The highlighted lines are discussed below.

```
1  #include <CL/sycl.hpp>
2
3  using namespace sycl;
4
5  const int SIZE = 64;
6
7  int main() {
8    std::array<int, SIZE> a, c;
9    std::array<sycl::float4, SIZE> b;
10   for (int i = 0; i<SIZE; ++i) {
11     a[i] = i;
12     b[i] = (float)-i;
13     c[i] = i;
14   }
15
16   {
17     range<1> a_size{SIZE};
18     queue q;
19
20     buffer<int>  a_device(a.data(), a_size);
21     buffer<int>  c_device(c.data(), a_size);
22     image<2>  b_device(b.data(),image_channel_order::rgba,
23                        image_channel_type::fp32, range<2>(8, 8));
24
25     q.submit([&](handler &h) {
26         accessor<int, 1, access::mode::discard_write,
27                  access::target::global_buffer> c_res(c_device, h);
28         accessor<int, 1, access::mode::read,
29                  access::target::constant_buffer> a_res(a_device, h);
30         accessor<float4, 2, access::mode::write,
31                  access::target::image> b_res(b_device, h);
32
33         float4 init = {0.f, 0.f, 0.f, 0.f};
34
35         h.parallel_for(a_size,[=](id<1> idx) {
36             c_res[idx] = a_res[idx];
37             b_res.write(int2(0,0), init);
38           });
39       });
40   }
41   return 0;
42 }
```

- Lines 8 and 9 contain the host allocations of arrays `a`, `b`, & `c`. The declaration of `b` is as a `float4` because it will be accessed as an image on the device side.

- Lines 26 and 27 create an accessor for `c_device` that has an access mode of `discard_write` and a target of `global_buffer`.
- Lines 28 and 29 create an accessor for `a_device` that has an access mode of `read` and a target of `constant_buffer`.
- Lines 30 and 31 create an accessor for `b_device` that has an access mode of `write` and a target of `image`.

The accessors specify where and how the kernel accesses these memory objects. The runtime is responsible for placing the memory objects in the correct location. Therefore, the runtime may copy data between host and device to meet the requirements of the accessor target.

Designate accessor targets to optimize the locality of access for a particular algorithm. For example, private memory can be used for data that is only accessed by a single work item. Not all combinations of access targets and access modes are compatible. For details, see the SYCL Specification.

2.4.1 Memory Objects

Memory objects are either buffers or images.

- *Buffers* object - a one, two, or three dimensional array of elements. Buffers can be accessed via lower level C++ pointer types. For further information on buffers, see the SYCL Specification.
- *Images* object - a formatted opaque memory object stored in a type specific and optimized fashion. Access occurs through built-in functions. Image objects typically pertain to pictures comprised of pixels stored in a format such as RGB (red, green, blue intensity). For further information on images, see the SYCL Specification.

See also:

- *Data access*

2.4.2 Accessors

Accessors provide access to buffers and images in the host or inside the kernel and also communicate data dependencies between the application and different kernels. The accessor communicates the data type, size, target, and access mode. To enable good performance, pay particular attention to the target because the accessor specifies the memory type from the choices in the SYCL memory model.

The targets associated with buffers are:

- global_buffer
- host_buffer
- constant_buffer
- local

The targets associated with images are:

- image
- host_image
- image_array

Image access must also specify a channel order to communicate the format of the data being read. For example, an image may be specified as a `float4`, but accessed with a channel order of RGBA.

The access mode impacts correctness as well as performance and is one of `read`, `write`, `read_write`, `discard_write`, `discard_read_write`, or `atomic`. Mismatches in access mode and actual memory operations such as a `write` to a `buffer` with access mode `read` can result in compiler diagnostics as well as erroneous program state. The `discard_write` and `discard_read_write` access modes can provide performance benefits for some implementations. For further details on accessors, see the SYCL Specification.

See also:

- *Accessors*

2.4.3 Synchronization

It is possible to access a `buffer` without employing an `accessor`, however it should be the rare case. To do so safely, a `mutex_class` should be passed when a `buffer` is instantiated. For further details on this method, see the SYCL Specification.

Access Targets

Target	Description
`host_buffer`	Access the buffer on the host.
`global_buffer`	Access the buffer through global memory on the device.
`constant_buffer`	Access the buffer from constant memory on the device. This may enable some optimization.
`local`	Access the buffer from local memory on the device.
`image`	Access the image.
`image_array`	Access an array of images.
`host_image`	Access the image on the host.

Access Modes

Memory Access Mode	Description
`read`	Read-only
`write`	Write-only
`read_write`	Read and write
`discard_write`	Write-only access. Previous value is discarded.
`discard_read_write`	Read and write. Previous value is discarded.
`atomic`	Provide atomic, one at a time, access.

See also:

- *Buffers*
- *Images*

2.4.4 Unified Shared Memory

Unified shared memory provides a pointer-based alternative to the buffer and accessor programming model. It provides both explicit and implicit models for managing memory. In the explicit model, programmers are responsible for specifying when data should be copied between memory allocations on the host and allocations on a device. In the implicit model, the underlying runtime and device drivers are responsible for automatically migrating memory between the host and a device.

Since unified shared memory does not rely on accessors, dependencies between operations must be specified using events. Programmers may either explicitly wait on event objects or use the `depends_on` method inside a command group to specify a list of events that must complete before a task may begin.

2.4.5 Memory Types

Memory Type	Description
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.
Global Memory	Accessible to all work-items in all work-groups. Read/write, may be cached, persistent across kernel invocations.
Local Memory	Shared between work-items in a single work-group and inaccessible to work-items in other work-groups.
Private Memory	A region of memory private to a work-item. Variables defined in one work-item's private memory are not visible to another work-item.

See also:

- *Multipointer*

See also:

- *Data access*

2.5 Kernel Programming Model

The device code can specify the amount of parallelism to request through several mechanisms.

- `single_task` – execute a single instance of the kernel with a single work item.
- `parallel_for` – execute a kernel in parallel across a range of processing elements. Typically, this version of parallel_for is employed on “embarrassingly parallel” workloads.
- `parallel_for_work_group` – execute a kernel in parallel across a hierarchical range of processing elements using local memory and barriers.

The following code sample shows two combinations of invoking kernels:

1. single_task and C++ lambda (lines 32-34)
2. parallel_for and functor (lines 8-16 and line 46)

```
1  #include <array>
2  #include <CL/sycl.hpp>
3
4  const int SIZE = 1024;
5
6  using namespace sycl;
7
8  class Vassign {
9    accessor<int, 1, access::mode::read_write,
10            access::target::global_buffer> access;
11
12 public:
13   Vassign(accessor<int, 1, access::mode::read_write,
14           access::target::global_buffer> &access_) : access(access_) {}
15   void operator()(id<1> id) { access[id] = 1; }
16 };
17
18 int main() {
19   std::array<int, SIZE> a;
20
21   for (int i = 0; i<SIZE; ++i) {
22     a[i] = i;
23   }
24
25   {
26     range<1> a_size{SIZE};
27     buffer<int>  a_device(a.data(), a_size);
28     queue q;
29
30     q.submit([&](handler &h) {
31         auto a_in = a_device.get_access<access::mode::write>(h);
32         h.single_task([=]() {
33             a_in[0] = 2;
34           });
35       });
36   }
37
38   {
39     range<1> a_size{SIZE};
40     buffer<int>  a_device(a.data(), a_size);
41     queue q;
```

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```
    q.submit([&](handler &h) {
        auto a_in = a_device.get_access<access::mode::read_write,
                                        access::target::global_buffer>(h);
        Vassign F(a_in);
        h.parallel_for(range<1>(SIZE), F);
      });
  }
}

```

2.6 Error Handling

C++ exception handling is the basis for handling error conditions in the programming model. Some restrictions on exceptions are in place due to the asynchronous nature of host and device execution. For example, it is not possible to throw an exception in kernel scope and catch it (in the traditional sense) in application scope. Instead, there are a set of restrictions and expectations in place when performing error handling. These include:

- At application scope, the full C++ exception handling mechanisms and capability are valid as long as there is no expectation that exceptions can cross to kernel scope.
- At the command group scope, exceptions are asynchronous with respect to the application scope. During command group construction, an `async_handler` can be declared to handle any exceptions occurring during execution in the command group.

See also:

- *Exceptions*

2.7 Fall Back

Typically, a command group is submitted and executed on the designated command queue; however, there may be cases where the command queue is unable to execute the group. In these cases, it is possible to specify a fall back command queue for the command group to be executed upon. This capability is handled by the runtime. This fallback mechanism is detailed in the SYCL Specification.

The following code fails due to the size of the workgroup when executed on Intel Processor Graphics, such as Intel HD Graphics 530. The SYCL specification allows specifying a secondary queue as a parameter to the submit function and this secondary queue is used if the device kernel runs into issues with submission to the first device.

```
#include<CL/sycl.hpp>
#include<iostream>

const int N = 1024;
const int M = 32;

using namespace sycl;

int main(){
  cpu_selector cpuSelector;
  queue cpuQueue(cpuSelector);
  queue defaultqueue;
  buffer<int,2> buf(range<2>(N,N));

```

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```
  defaultqueue.submit([&](handler &h){
      auto bufacc = buf.get_access<access::mode::read_write>(h);
      h.parallel_for(nd_range<2>(range<2>(N,N), range<2>(M,M)),
                       [=](nd_item<2> i){
                         id<2> ind = i.get_global_id();
                         bufacc[ind[0]][ind[1]] = ind[0]+ind[1];
                       });
    }, cpuQueue);
  auto bufacc1 = buf.get_access<access::mode::read>();
  for(int i = 0; i < N; i++){
    for(int j = 0; j < N; j++){
      if(bufacc1[i][j] != i+j){
        std::cout<<"Wrong result\n";
        return 1;
      }
    }
  }
  std::cout<<"Correct results\n";
  return 0;
}
```

See also:

- *queue*

CHAPTER

THREE

LANGUAGE

The host code can be compiled by C++11 and later compilers and take advantage of supported C++11 and later language features. The device code requires a compiler that accepts all C++03 language features and the following C++11 features:

- Lamdba expressions
- Variadic templates
- Alias templates
- rvalue references
- std::function, std::string, std::vector

In addition, the device code cannot use the following features:

- Virtual Functions
- Virtual Inheritance
- Exceptions handling – throws and catches between host and device
- Run Time Type Information (RTTI)
- Object management employing new and delete operators

The device code is specified via one of three language constructs: lambda expression, functor, or kernel class. The separation of host code and device code via these language constructs is natural and accomplished without language extensions. These different forms of expressing kernels give the developer flexibility in enmeshing the host code and device code. For example:

- To put the kernel code in line with the host code, consider employing a lambda expression.
- To have the device code separate from the host code, but still maintain the single source property, consider employing a functor.
- To port code from OpenCL programs or to ensure a more rigid separation between host and device code, consider employing the kernel class.

3.1 Keywords

SYCL does not add any keywords to the C++ language.

3.2 Preprocessor Directives and Macros

Standard C++ preprocessing directives and macros are supported by the compiler. In addition, the SYCL Specification defines the SYCL specific preprocessor directives and macros.

The following preprocessor macros are supported by the compiler.

Macro	Value	Description
`SYCL_DUMP_IMAGES`	`true` or `false`	Instructs the runtime to dump the device image
`SYCL_USE_KERNEL_SPV`	<device binary>	Employ device binary to fulfill kernel launch request
`SYCL_PROGRAM_BUILD_OPTIONS`	<options>	Used to pass additional options for device program building.

3.3 Standard Library Classes Required for the Interface

The SYCL specification documents a facility to enable vendors to provide custom optimized implementations. Implementations require aliases for several STL interfaces. These are summarized as follows:

CHAPTER

FOUR

INTERFACE

For further details on SYCL, see the SYCL Specification.

Tip: If you are unfamiliar with C++ templates and lambda functions, consult a C++ language references to gain a basic understanding before continuing.

4.1 Header File

A single header file must be included:

```
#include "CL/sycl.hpp"
```

4.2 Namespaces

Unless otherwise noted, all symbols should be prefixed with the `sycl` namespace. `buffer` is `sycl::buffer`, and `info::device::name` is `sycl::info::device::name`.

4.3 Common Interface

In this section, we define methods that are common to multiple classes.

4.3.1 By-value Semantics

Types: id, range, item, nd_item, h_item, group and nd_range.

Classes with reference semantics support the following methods.

```
class T {
  T(const T &rhs);
  T(T &&rhs);
  T &operator=(const T &rhs);
  T &operator=(T &&rhs);
  ~T();
  friend bool operator==(const T &lhs, const T &rhs) { /* ... */ }
  friend bool operator!=(const T &lhs, const T &rhs) { /* ... */ }
};
```

4.3.2 Reference Semantics

Classes: device, context, queue, program, kernel, event, buffer, image, sampler, accessor and stream

Classes with reference semantics support the following methods. An instance that is constructed as a copy of another instance must behave as-if it were the same instance.

```
class T {
public:
  T(const T &rhs);
  T(T &&rhs);
  T &operator=(const T &rhs);
  T &operator=(T &&rhs);
  ~T();
  friend bool operator==(const T &lhs, const T &rhs) { /* ... */ }
  friend bool operator!=(const T &lhs, const T &rhs) { /* ... */ }
};
```

4.3.3 property_list

```
class property_list;
```

Member and nonmember functions

property_list

```
template <typename... propertyTN>
property_list(propertyTN... props);
```

4.3.4 param_traits

```
template <typename T, T param>
class param_traits;
```

Namespace

```
info
```

Member types

return_type	

4.4 Runtime Classes

4.4.1 Device selectors

Devices selectors allow the SYCL runtime to choose the device.

A device selector can be passed to *queue*, *platform*, and other constructors to control the selection of a device. A program may use *Built-in Device Selectors* or define its own *device_selector* for full control.

device_selector

```
class device_selector;
```

Abstract class for device selectors.

This is the base class for the *Built-in Device Selectors*. To define a custom device selector, create a derived class that defines the () operator.

Member and nonmember functions

(constructors)

```
device_selector();
device_selector(const device_selector &rhs);
```

Construct a device_selector.

A device selector can be created from another by passing `rhs`.

select_device

```
device select_device() const;
```

Returns the device with the highest score as determined by calling *operator()*.

Exceptions

Throws a runtime error if all devices have a negative score.

operator=

```
device_selector &operator=(const device_selector &rhs);
```

Create a device selector by copying another one.

operator()

```
virtual int operator()(const device &device) const = 0;
```

Scoring function for devices.

All derived device selectors must define this operator. *select_device* calls this operator for every device, and selects the device with highest score. Return a negative score if a device should not be selected.

Built-in Device Selectors

SYCL provides built-in device selectors for convenience. They use *device_selector* as a base class.

default_selector	Selects device according to implementation-defined heuristic or host device if no device can be found.
gpu_selector	Select a GPU
accelerator_selector	Select an accelerator
cpu_selector	Select a CPU device
host_selector	Select the host device

Create a device selector by copying another one.

See also:

SYCL Specification Section 4.6.1.1

Example

```
#include <CL/sycl.hpp>

using namespace sycl;

int main() {
  device d;

  try {
    d = device(gpu_selector());
  } catch (exception const& e) {
    std::cout << "Cannot select a GPU\n" << e.what() << "\n";
    std::cout << "Using a CPU device\n";
    d = device(cpu_selector());
  }

  std::cout << "Using " << d.get_info<sycl::info::device::name>();
}
```

Output on a system without a GPU:

```
Cannot select a GPU
No device of requested type available. Please check https://software.intel.com/en-us/
↪articles/intel-oneapi-dpcpp-compiler-system-requirements-beta -1 (CL_DEVICE_NOT_
↪FOUND)
```

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```
Using a CPU device
Using Intel(R) Core(TM) i5-7300U CPU @ 2.60GHz
```

4.4.2 Platforms

platform

```
class platform;
```

Abstraction for SYCL platform.

A platform contains 1 or more SYCL devices, or a host device.

See also:

SYCL Specification Section 4.6.2

Member and nonmember functions

Example

Enumerate the platforms and the devices they contain.

```
#include <CL/sycl.hpp>

int main() {
  auto platforms = sycl::platform::get_platforms();

  for (auto &platform : platforms) {
    std::cout << "Platform: "
              << platform.get_info<sycl::info::platform::name>()
              << std::endl;

    auto devices = platform.get_devices();
    for (auto &device : devices ) {
      std::cout << "  Device: "
                << device.get_info<sycl::info::device::name>()
                << std::endl;
    }
  }

  return 0;
}
```

Output:

```
Platform: Intel(R) FPGA Emulation Platform for OpenCL(TM)
  Device: Intel(R) FPGA Emulation Device
Platform: Intel(R) OpenCL
  Device: Intel(R) Core(TM) i5-7300U CPU @ 2.60GHz
Platform: Intel(R) CPU Runtime for OpenCL(TM) Applications
  Device: Intel(R) Core(TM) i5-7300U CPU @ 2.60GHz
Platform: SYCL host platform
  Device: SYCL host device
```

(constructors)

```
platform();
explicit platform(cl_platform_id platformID);
explicit platform(const device_selector &deviceSelector);
```

Construct a SYCL platform instance.

The default constructor creates a host platform. When passed a `cl_platform_id`, an OpenCL|trade| platform is used to construct the platform. The `cl_platform_id` is retained and available via *get*. When passed a *device_selector*, a platform is constructed that includes the preferred device.

get

```
cl_platform_id get() const;
```

Returns the OpenCL device associated with the platform.

Only call this when the platform constructor was passed a `cl_platform_id`.

get_devices

```
vector_class<device> get_devices(
   info::device_type = info::device_type::all) const;
```

Return vector of SYCL devices associated with the platform and filtered by the *device_type*.

Example

See *platform-example*.

get_info

```
template< info::platform param >
typename info::param_traits<info::platform, param>::return_type get_info() const;
```

Returns information about the platform as determined by `param`.

See *Platform Info* for details.

Example

See *platform-example*.

has_extension

```
bool has_extension(const string_class &extension) const;
```

Returns True if the platform has `extension`.

is_host

```
bool is_host() const;
```

Returns True if the platform contains a SYCL host device

get_platforms

```
static vector_class<platform> get_platforms();
```

Returns a vector_class containing SYCL platforms bound to the system.

Example

See *platform-example*.

Platform Info

```
enum class platform : unsigned int {
  profile,
  version,
  name,
  vendor,
  extensions
};
```

Namespace

```
info
```

Used as a template parameter for *get_info* to determine the type of information.

Descriptor	Return type	Description
profile	string_class	OpenCL profile
version	string_class	OpenCL software driver version
name	string_class	Device name of the platform
vendor	string_class	Vendor name
extensions	vector_class<string_class>	Extension names supported by the platform

4.4.3 Contexts

context

```
class context;
```

A context encapsulates a single SYCL platform and a collection of SYCL devices associated with the platform.

A context may include a subset of the devices provided by the platform. The same platform may be associated with more than one context, but a device can only be part of a single context.

See also:

SYCL Specification Section 4.6.3

Member and nonmember functions

(constructors)

```
explicit context(const property_list &propList = {});
context(async_handler asyncHandler,
        const property_list &propList = {});
context(const device &dev, const property_list &propList = {});
context(const device &dev, async_handler asyncHandler,
        const property_list &propList = {});
context(const platform &plt, const property_list &propList = {});
context(const platform &plt, async_handler asyncHandler,
        const property_list &propList = {});
context(const vector_class<device> &deviceList,
        const property_list &propList = {});
context(const vector_class<device> &deviceList,
        async_handler asyncHandler, const property_list &propList = {});
context(cl_context clContext, async_handler asyncHandler = {});
```

Construct a context.

The parameters to the constructor allow control of the devices and platforms associated with the context. The constructor uses the *default selector* when no platforms or devices are supplied.

Parameters

propList See *Context Properties*.

asyncHandler Called to report asynchronous SYCL exceptions for this context

dev Constructed context contains device

deviceList Constructed context contains devices

plt Constructed context contains platform

clContext Constructed context contains cl_context

Constructs a context

get

```
cl_context get() const;
```

Returns cl_context that was passed in constructor.

is_host

```
bool is_host() const;
```

Returns True if this context is a host context.

get_platform

```
platform get_platform() const;
```

Return platform associated with this context.

get_devices

```
vector_class<device> get_devices() const;
```

Returns vector of devices associated with this context.

get_info

```
template <info::context param>
typename info::param_traits<info::context, param>::return_type get_info() const;
```

Returns information about the context as determined by `param`. See *Context Info* for details.

has_property

```
template <typename propertyT>
bool has_property() const;
```

Template parameters

propertyT	

Returns True if the property type was passed to the constructor.

get_property

```
template <typename propertyT>
propertyT get_property() const;
```

Template parameters

propertyT	

Returns copy of property of passed to the constructor.

Context Info

```
enum class context : int {
  reference_count,
  platform,
  devices
};
```

Namespace

```
info
```

Used as a template parameter for *get_info* to determine the type of information.

Descriptor	Return type	Description
reference_count	cl_uint	Reference count of the underlying cl_context
platform	platform	SYCL platform for the context
devices	vector_class<device>	SYCL devices associated with this platform

Context Properties

SYCL does not define any properties for *context*.

4.4.4 Devices

device

```
class device;
```

An abstract class representing various models of SYCL devices. A device could be a GPU, CPU, or other type of accelerator. Devices execute kernel functions.

See also:

SYCL Specification Section 4.6.4

Member and nonmember functions

(constructors)

```
device();
explicit device(cl_device_id deviceId);
explicit device(const device_selector &deviceSelector);
```

Construct a device.

The default constructor creates a host device. A device can also be constructed from an OpenCL|trade| device or may be chosen by a *Device selectors*.

Parameters

deviceID	OpenCL device id
deviceSelector	Device selector

get

```
cl_device_id get() const;
```

Return the cl_device_id of the underlying OpenCL platform.

is_host

```
bool is_host() const;
```

Returns True if the device is a host device, False otherwise.

is_cpu

```
bool is_cpu() const;
```

Returns True if the device is a CPU, False otherwise.

is_gpu

```
bool is_gpu() const;
```

Returns True if the device is a GPU, False otherwise.

is_accelerator

```
bool is_accelerator() const;
```

Returns True if the device is an accelerator, False otherwise.

get_platform

```
platform get_platform() const;
```

Returns the platform that contains the device.

get_info

```
template <info::device param>
typename info::param_traits<info::device, param>::return_type
get_info() const;
```

Returns information about the device as determined by `param`. See *Device Info* for details.

Example

See *Example*.

has_extension

```
bool has_extension(const string_class &extension) const;
```

Returns True if device supports the extension.

create_sub_devices

```
Available only when:
 prop == info::partition_property::partition_equally

template <info::partition_property prop>
vector_class<device> create_sub_devices(size_t nbSubDev) const;

Available only when:
 prop == info::partition_property::partition_by_counts

template <info::partition_property prop>
vector_class<device> create_sub_devices(const vector_class<size_t> &counts)
 ↪const;

Available only when:
 prop == info::partition_property::partition_by_affinity_domain
```

```
template <info::partition_property prop>
vector_class<device> create_sub_devices(info::affinity_domain affinityDomain)␣
↪const;
```

Divide into sub-devices, according to the requested partition property.

Template parameters

prop	See *partition_property*

Parameters

nbSubDev	Number of subdevices
counts	Vector of sizes for the subdevices
affinityDomain	See *partition_affinity_domain*

Exceptions

feature_not_supported When device does not support the *partition_property* specified by the `prop` template argument.

get_devices

```
static vector_class<device> get_devices(
    info::device_type deviceType = info::device_type::all);
```

Returns vector of devices associated with deviceType.

See *device_type*

Device Info

device

```
enum class device : int {
  device_type,
  vendor_id,
  max_compute_units,
  max_work_item_dimensions,
  max_work_item_sizes,
  max_work_group_size,
  preferred_vector_width_char,
  preferred_vector_width_short,
  preferred_vector_width_int,
  preferred_vector_width_long,
  preferred_vector_width_float,
  preferred_vector_width_double,
  preferred_vector_width_half,
  native_vector_width_char,
```

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```
native_vector_width_short,
native_vector_width_int,
native_vector_width_long,
native_vector_width_float,
native_vector_width_double,
native_vector_width_half,
max_clock_frequency,
address_bits,
max_mem_alloc_size,
image_support,
max_read_image_args,
max_write_image_args,
image2d_max_height,
image2d_max_width,
image3d_max_height,
image3d_max_width,
image3d_max_depth,
image_max_buffer_size,
image_max_array_size,
max_samplers,
max_parameter_size,
mem_base_addr_align,
half_fp_config,
single_fp_config,
double_fp_config,
global_mem_cache_type,
global_mem_cache_line_size,
global_mem_cache_size,
global_mem_size,
max_constant_buffer_size,
max_constant_args,
local_mem_type,
local_mem_size,
error_correction_support,
host_unified_memory,
profiling_timer_resolution,
is_endian_little,
is_available,
is_compiler_available,
is_linker_available,
execution_capabilities,
queue_profiling,
built_in_kernels,
platform,
name,
vendor,
driver_version,
profile,
version,
opencl_c_version,
extensions,
printf_buffer_size,
preferred_interop_user_sync,
parent_device,
partition_max_sub_devices,
partition_properties,
partition_affinity_domains,
```

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```
  partition_type_property,
  partition_type_affinity_domain,
  reference_count
}
```

Namespace

```
info
```

Used as a template parameter for *get_info* to determine the type of information.

Descriptor	Return type	Description
device_type		
vendor_id		
max_compute_units		
max_work_item_dimensions		
max_work_item_sizes		
max_work_group_size		
preferred_vector_width_char		
preferred_vector_width_short		
preferred_vector_width_int		
preferred_vector_width_long		
preferred_vector_width_float		
preferred_vector_width_double		
preferred_vector_width_half		
native_vector_width_char		
native_vector_width_short		
native_vector_width_int		
native_vector_width_long		
native_vector_width_float		
native_vector_width_double		
native_vector_width_half		
max_clock_frequency		
address_bits		
max_mem_alloc_size		
image_support		
max_read_image_args		
max_write_image_args		
image2d_max_height		
image2d_max_width		
image3d_max_height		
image3d_max_width		
image3d_max_depth		
image_max_buffer_size		
image_max_array_size		
max_samplers		
max_parameter_size		
mem_base_addr_align		
half_fp_config	*fp_config*	

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Table 1 – continued from previous page

Descriptor	Return type	Description
single_fp_config	*fp_config*	
double_fp_config	*fp_config*	
global_mem_cache_type	*global_mem_cache_type*	
global_mem_cache_line_size		
global_mem_cache_size		
global_mem_size		
max_constant_buffer_size		
max_constant_args		
local_mem_type	*local_mem_type*	
local_mem_size		
error_correction_support		
host_unified_memory		
profiling_timer_resolution		
is_endian_little		
is_available		
is_compiler_available		
is_linker_available		
execution_capabilities	*execution_capability*	
queue_profiling		
built_in_kernels		
platform		
name		
vendor		
driver_version		
profile		
version		
opencl_c_version		
extensions		
printf_buffer_size		
preferred_interop_user_sync		
parent_device		
partition_max_sub_devices		
partition_properties		
partition_affinity_domains		
partition_type_property		
partition_type_affinity_domain		
reference_count		

device_type

```
enum class device_type : unsigned int {
  cpu,          // Maps to OpenCL CL_DEVICE_TYPE_CPU
  gpu,          // Maps to OpenCL CL_DEVICE_TYPE_GPU
  accelerator,  // Maps to OpenCL CL_DEVICE_TYPE_ACCELERATOR
  custom,       // Maps to OpenCL CL_DEVICE_TYPE_CUSTOM
  automatic,    // Maps to OpenCL CL_DEVICE_TYPE_DEFAULT
  host,
  all           // Maps to OpenCL CL_DEVICE_TYPE_ALL
};
```

See *get_devices*

partition_property

```
enum class partition_property : int {
  no_partition,
  partition_equally,
  partition_by_counts,
  partition_by_affinity_domain
};
```

See *create_sub_devices*

partition_affinity_domain

```
enum class partition_affinity_domain : int {
  not_applicable,
  numa,
  L4_cache,
  L3_cache,
  L2_cache,
  L1_cache,
  next_partitionable
};
```

See *create_sub_devices*

local_mem_type

```
enum class local_mem_type : int { none, local, global };
```

See *get_info*

fp_config

```
enum class fp_config : int {
  denorm,
  inf_nan,
  round_to_nearest,
  round_to_zero,
  round_to_inf,
  fma,
  correctly_rounded_divide_sqrt,
  soft_float
};
```

See *get_info*

global_mem_cache_type

```
enum class global_mem_cache_type : int { none, read_only, read_write };
```

See *get_info*

execution_capability

```
enum class execution_capability : unsigned int {
  exec_kernel,
  exec_native_kernel
};
```

See *get_info*

4.4.5 Queues

queue

```
class queue;
```

Queues connect a host program to a single device. Programs submit tasks to a device via the queue and may monitor the queue for completion. A program initiates the task by submitting a *Command group function object* to a queue. The command group defines a kernel function, the prerequisites to execute the kernel function, and an invocation of the kernel function on an index space. After submitting the command group, a program may use the queue to monitor the completion of the task for completion and errors.

See also:

SYCL Specification Section 4.6.5

Member and nonmember functions

(constructors)

```
explicit queue(const property_list &propList = {});
explicit queue(const async_handler &asyncHandler,
               const property_list &propList = {});
explicit queue(const device_selector &deviceSelector,
               const property_list &propList = {});
explicit queue(const device_selector &deviceSelector,
               const async_handler &asyncHandler,
               const property_list &propList = {});
explicit queue(const device &syclDevice, const property_list &propList = {});
explicit queue(const device &syclDevice, const async_handler &asyncHandler,
               const property_list &propList = {});
explicit queue(const context &syclContext,
               const device_selector &deviceSelector,
               const property_list &propList = {});
explicit queue(const context &syclContext,
               const device_selector &deviceSelector,
```

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```
                const async_handler &asyncHandler,
                const property_list &propList = {});
explicit queue(const context &syclContext,
                const device &syclDevice,
                const property_list &propList = {});
explicit queue(const context &syclContext, const device &syclDevice,
                const async_handler &asyncHandler,
                const property_list &propList = {});
explicit queue(cl_command_queue clQueue, const context& syclContext,
                const async_handler &asyncHandler = {});
```

Construct a queue.

Constructing a queue selects the device attached to the queue. The program may control the device by passing a cl_command_queue, *device*, or a *device_selector*. If none are provided, the constructor uses the *default_selector* to select a device. The constructor implicitly creates the *context*, *platform*, and *device* as needed.

The SYCL runtime executes the tasks asynchronously. Programs may catch asynchronous errors that occur during execution by constructing the queue with an `asyncHandler` and calling *wait_and_throw*.

Parameters

propList	See *Queue Properties*
asyncHandler	Called for asynchronous exceptions, see *async_handler*
deviceSelector	Selects device for queue
syclDevice	Device for queue
syclContext	Associate queue with the context
clQueue	Assocate queue with OpenCL|trade| queue

Exceptions

invalid_object_error If `syclContext` does not encapsulate `syclDevice`.

get

```
cl_command_queue get() const;
```

Return OpenCL queue associated with SYCL queue.

get_context

```
context get_context() const;
```

Returns context associated with queue.

get_device

```
device get_device() const;
```

Returns device associated with queue.

is_host

```
bool is_host() const;
```

Returns True if queue executes on host device.

get_info

```
template <info::queue param>
typename info::param_traits<info::queue, param>::return_type get_info() const;
```

Returns information about the queue as determined by `param`. See *queue* for details.

submit

```
template <typename T>
event submit(T cgf);
template <typename T>
event submit(T cgf, const queue &secondaryQueue);
```

Template parameters

T	

Parameters

cgf	Command group function object
secondaryQueue	On error, runtime resubmits command group to the secondary queue.

Submit a command group function object to the queue for asynchronous execution.

Returns an *event*, which may be used for synchronizing enqueued tasks. See *Command group function object* for more information on the `cgf` parameter.

In most cases, the `T` template parameter is not provided because it is inferred from the type of `cgf`.

Exceptions

The runtime resubmits the command group to the secondary queue if an error occurs executing on the primary queue.

wait

```
void wait();
```

Wait for all enqueued tasks to complete.

wait_and_throw

```
void wait_and_throw();
```

Wait for all enqueued tasks and pass asynchronous errors to handler provided in *(constructors)*.

throw_asynchronous

```
void throw_asynchronous();
```

Passes any asynchronous errors to handler provided in *(constructors)*.

Queue Info

```
enum class queue : int {
  context,
  device,
  reference_count,
};
```

Namespace

```
info
```

Used as a template parameter for *get_info* to determine the type of information.

Descriptor	Return type	Description
context	context	SYCL context associated with the queue
device	device	SYCL device associated with the queue
reference_count	cl_uint	Reference count of the queue

Queue Properties

Namespace

```
property::queue
```

Queue properties are specified in the queue constructor.

enable_profiling SYCL runtime captures profiling information for command groups submitted to the queue.

4.4.6 Events

event

```
class event;
```

Events support the explicit control of scheduling of kernels, and querying status of a running kernel. Operations like *submit* that queue a kernel for execution may accept an event to wait on and return an event associated with the queued kernel.

See also:

SYCL Specification Section 4.6.6

Member and nonmember functions

(constructors)

```
event();
event(cl_event clEvent, const context& syclContext);
```

Construct an event.

cl_event_get

```
cl_event get();
```

Returns OpenCL|trade| event associated with this event.

is_host

```
bool is_host() const;
```

Returns True if this a host event

get_wait_list

```
vector_class<event> get_wait_list();
```

Returns vector of events that this events waits on.

wait

```
void wait();
```

Wait for the associated command to complete.

wait

```
static void wait(const vector_class<event> &eventList);
```

Wait for vector of events to complete.

wait_and_throw

```
void wait_and_throw();
```

Wait for an event to complete, and pass asynchronous errors to handler associated with the command.

wait_and_throw

```
static void wait_and_throw(const vector_class<event> &eventList);
```

Wait for a vector of events to complete, and pass asynchronous errors to handlers associated with the commands.

get_info

```
template <info::event param>
typename info::param_traits<info::event, param>::return_type get_info() const;
```

Returns information about the queue as determined by `param`. See *Event Info* for details.

get_profiling_info

```
template <info::event_profiling param>
typename info::param_traits<info::event_profiling, param>::return_type get_profiling_
↪info() const;
```

Returns information about the queue as determined by `param`. See *Event profiling info* for details.

Event info

```
enum class event: int {
  command_execution_status,
  reference_count
};
```

Namespace

```
info
```

Used as a template parameter for *get_info* to determine the type of information.

Descriptor	Return type	Description
command_execution_status	info::event_command_status	See *event_command_status*
reference_count	cl_uint	Reference count of the event

event_command_status

```
enum class event_command_status : int {
  submitted,
  running,
  complete
};
```

Event profiling info

```
enum class event_profiling : int {
  command_submit,
  command_start,
  command_end
};
```

Namespace

```
info
```

Used as a template parameter for *get_profiling_info* to determine the type of information.

Descriptor	Return type	Description
command_submit	cl_ulong	Time in nanoseconds when *command_group* was submitted
command_start	cl_ulong	Time in nanoseconds when *command_group* started execution
command_end	cl_ulong	Time in nanoseconds when *command_group* finished execution

4.5 Data access

4.5.1 Buffers

buffer

```
template <typename T, int dimensions = 1,
          typename AllocatorT = cl::sycl::buffer_allocator>
class buffer;
```

Template parameters

T	Type of data in buffer
dimensions	Dimensionality of data: 1, 2, or 3
AllocatorT	Allocator for buffer data

Buffers are containers for data that can be read/written by both kernel and host. Data in a buffer cannot be directly via pointers. Instead, a program creates an *Buffer accessor* that references the buffer. The accessor provides array-like interfaces to read/write actual data. Accessors indicate when they read or write data. When a program creates an accessor for a buffer, the SYCL runtime copies the data to where it is needed, either the host or the device. If the accessor is part of a device command group, then the runtime delays execution of the kernel until the data movement is complete. If the host creates an accessor, it will pause until the data is available on the host. As a result data and kernels can execute asynchronously and in parallel, only requiring the program to specify the data dependencies.

Initialization

Buffers can be automatically initialized via host data, iterator, or as a slice of another buffer. The constructor determines the initialization method.

Write back

The destructor for a buffer can optionally write the data back to host memory, either by pointer or iterator. *set_final_data* and *set_write_back* control the write back of data.

Memory allocation

The SYCL runtimes uses the default allocator for buffer memory allocation, unless the constructor provides an allocator.

Member types

value_type	type of buffer element
reference	reference type of buffer element
const_reference	const reference type of buffer element
allocator_type	type of allocator for buffer data

See also:

SYCL Specification Section 4.7.2

Member and nonmember functions

(constructors)

```
buffer(const range<dimensions> &bufferRange,
       const property_list &propList = {});
buffer(const range<dimensions> &bufferRange, AllocatorT allocator,
       const property_list &propList = {});
buffer(T hostData, const range<dimensions> &bufferRange,
       const property_list &propList = {});
buffer(T *hostData, const range<dimensions> &bufferRange,
       AllocatorT allocator, const property_list &propList = {});
buffer(const T *hostData, const range<dimensions> &bufferRange,
       const property_list &propList = {});
buffer(const T *hostData, const range<dimensions> &bufferRange,
       AllocatorT allocator, const property_list &propList = {});
buffer(const shared_ptr_class<T> &hostData,
       const range<dimensions> &bufferRange, AllocatorT allocator,
       const property_list &propList = {});
buffer(const shared_ptr_class<T> &hostData,
       const range<dimensions> &bufferRange,
       const property_list &propList = {});
buffer(buffer<T, dimensions, AllocatorT> b, const id<dimensions> &baseIndex,
       const range<dimensions> &subRange);

*Available only when:
 dimensions == 1

template <class InputIterator>
buffer<T, 1>(InputIterator first, InputIterator last, AllocatorT allocator,
             const property_list &propList = {});
template <class InputIterator>
buffer<T, 1>(InputIterator first, InputIterator last,
             const property_list &propList = {});
buffer(cl_mem clMemObject, const context &syclContext,
       event availableEvent = {});
```

Construct a buffer.

Buffers can be initialized by a host data pointer. While the buffer exists, it *owns* the host data and direct access of the host data pointer during that time is undefined. The SYCL runtime performs a write back of the buffer data back to the host data pointer when the buffer is destroyed. Buffers can also be initialized as a slice of another buffer, by specifying the origin of the data and the dimensions.

A constructor can also accept cl_mem or iterators to initialize a buffer.

Template parameters

InputIterator	type of iterator used to initialize the buffer

Parameters

bufferRange	*range* specifies the dimensions of the buffer
allocator	Allocator for buffer data
propList	See *Buffer properties*
hostData	Pointer to host memory to hold data
first	Iterator to initialize buffer
last	Iterator to initialize buffer
b	Buffer used to initialize this buffer
baseIndx	Origin of sub-buffer
subRange	Dimensions of sub-buffer

get_range

```
range<dimensions> get_range() const;
```

Returns the dimensions of the buffer.

get_count

```
size_t get_count() const;
```

Returns the total number of elements in the buffer.

get_size

```
size_t get_size() const;
```

Returns the size of the buffer storage in bytes.

get_allocator

```
AllocatorT get_allocator() const;
```

Returns the allocator provided to the buffer.

get_access

```
template <access::mode mode, access::target target = access::target::global_buffer>
accessor<T, dimensions, mode, target> get_access(
    handler &commandGroupHandler);
template <access::mode mode>
accessor<T, dimensions, mode, access::target::host_buffer> get_access();
template <access::mode mode, access::target target = access::target::global_buffer>
accessor<T, dimensions, mode, target> get_access(
    handler &commandGroupHandler, range<dimensions> accessRange,
    id<dimensions> accessOffset = {});
template <access::mode mode>
accessor<T, dimensions, mode, access::target::host_buffer> get_access(
  range<dimensions> accessRange, id<dimensions> accessOffset = {});
```

Returns a accessor to the buffer.

Template parameters

mode	See *mode*
target	See *target*

Parameters

commandGroupHandler	Command group that uses the accessor
accessRange	Dimensions of the sub-buffer that is accessed
accessOffset	Origin of the sub-buffer that is accessed

set_final_data

```
template <typename Destination = std::nullptr_t>
void set_final_data(Destination finalData = nullptr);
```

Template parameters

Destination	std::weak_ptr<T> or output iterator

Parameters

finalData	Indicates where data is copied at destruction time

Set the final data location. Final data controls the location for write back when the buffer is destroyed.

set_write_back

```
void set_write_back(bool flag = true);
```

Parameters

flag	True to force write back

Set the write back.

is_sub_buffer

```
bool is_sub_buffer() const;
```

Returns True if this is a sub-buffer.

reinterpret

```
template <typename ReinterpretT, int ReinterpretDim>
buffer<ReinterpretT, ReinterpretDim, AllocatorT>
reinterpret(range<ReinterpretDim> reinterpretRange) const;
```

Template parameters

ReinterpretT	Type of new buffer element
ReinterpretDim	Dimensions of new buffer

Parameters

ReinterpretRange	Dimensionality of new buffer

Creates a new buffer with the requested element type and dimensionality, containing the data of the passed buffer or sub-buffer.

Exceptions

errc::invalid_object_error Size in bytes of new buffer does not match original buffer.

Buffer properties

use_host_ptr

```
class use_host_ptr;
```

Namespace

```
property::buffer
```

Use the provided host pointer and do not allocate new data on the host.

Member and nonmember functions

(constructors)

```
use_host_ptr();
```

use_mutex

```
class use_mutex;
```

Namespace

```
property::buffer
```

Adds the requirement that the memory owned by the SYCL buffer can be shared with the application via a std::mutex provided to the property.

Member and nonmember functions

(constructors)

```
use_mutex();
```

get_mutex_ptr

```
mutex_class *get_mutex_ptr() const;
```

context_bound

```
context_bound;
```

Namespace

```
property::buffer
```

The buffer can only be associated with a single SYCL context provided to the property.

Member and nonmember functions

(constructors)

```
use_mutex();
```

get_context

```
context get_context() const;
```

4.5.2 Images

image

```
template <int dimensions = 1,
          typename AllocatorT = cl::sycl::image_allocator>
class image;
```

Template parameters

dimensions	
AllocatorT	

See also:

SYCL Specification Section 4.7.3

Member and nonmember functions

(constructors)

```
image(image_channel_order order, image_channel_type type,
      const range<dimensions> &range, const property_list &propList = {});
image(image_channel_order order, image_channel_type type,
      const range<dimensions> &range, AllocatorT allocator,
      const property_list &propList = {});
image(void hostPointer, image_channel_order order,
      image_channel_type type, const range<dimensions> &range,
      const property_list &propList = {});
image(void *hostPointer, image_channel_order order,
      image_channel_type type, const range<dimensions> &range,
      AllocatorT allocator, const property_list &propList = {});
image(const void *hostPointer, image_channel_order order,
      image_channel_type type, const range<dimensions> &range,
      const property_list &propList = {});
image(const void *hostPointer, image_channel_order order,
      image_channel_type type, const range<dimensions> &range,
      AllocatorT allocator, const property_list &propList = {});
image(shared_ptr_class<void> &hostPointer, image_channel_order order,
      image_channel_type type, const range<dimensions> &range,
      const property_list &propList = {});
image(shared_ptr_class<void> &hostPointer, image_channel_order order,
      image_channel_type type, const range<dimensions> &range,
      AllocatorT allocator, const property_list &propList = {});
image(cl_mem clMemObject, const context &syclContext,
      event availableEvent = {});

*Available only when:
 dimensions > 1

image(image_channel_order order, image_channel_type type,
      const range<dimensions> &range, const range<dimensions - 1> &pitch,
      const property_list &propList = {});
image(image_channel_order order, image_channel_type type,
      const range<dimensions> &range, const range<dimensions - 1> &pitch,
      AllocatorT allocator, const property_list &propList = {});
image(void *hostPointer, image_channel_order order,
      image_channel_type type, const range<dimensions> &range,
      range<dimensions - 1> &pitch, const property_list &propList = {});
image(void *hostPointer, image_channel_order order,
      image_channel_type type, const range<dimensions> &range,
      range<dimensions - 1> &pitch, AllocatorT allocator,
      const property_list &propList = {});
image(shared_ptr_class<void> &hostPointer, image_channel_order order,
      image_channel_type type, const range<dimensions> &range,
      const range<dimensions - 1> &pitch, const property_list &propList = {});
image(shared_ptr_class<void> &hostPointer, image_channel_order order,
      image_channel_type type, const range<dimensions> &range,
      const range<dimensions - 1> &pitch, AllocatorT allocator,
      const property_list &propList = {});
```

Parameters

order	
type	
range	
propList	See *Image properties*
allocator	
pitch	
hostPointer	
syclContext	
clMemObject	
availableEvent	

get_range

```
range<dimensions> get_range() const;
```

get_pitch

```
range<dimensions-1> get_pitch() const;
```

Available only when dimensions > 1

get_count

```
size_t get_count() const;
```

get_size

```
size_t get_size() const;
```

get_allocator

```
AllocatorT get_allocator() const;
```

get_access

```
template <typename dataT, access::mode accessMode>
accessor<dataT, dimensions, accessMode, access::target::image>
get_access(handler & commandGroupHandler);
template <typename dataT, access::mode accessMode>
accessor<dataT, dimensions, accessMode, access::target::host_image>
get_access();
```

Template parameters

dataT	
accessMode	

Parameters

commandGroupHandler	

set_final_data

```
template <typename Destination = std::nullptr_t>
void set_final_data(Destination finalData = nullptr);
```

Description

Template parameters

Destination	

Parameters

finalData	

set_write_back

```
void set_write_back(bool flag = true);
```

Parameters

flag	

Image properties

use_host_ptr

```
class use_host_ptr;
```

Namespace

```
property::image
```

Description

Member and nonmember functions

(constructors)

```
use_host_ptr();
```

Description

use_mutex

```
class use_mutex;
```

Namespace

```
property::image
```

Description

Member and nonmember functions

(constructors)

```
use_mutex();
```

Description

get_mutex_ptr

```
mutex_class *get_mutex_ptr() const;
```

Description

context_bound

```
context_bound;
```

Namespace

```
property::image
```

Description

Member and nonmember functions

(constructors)

```
use_mutex();
```

Description

get_context

```
context get_context() const;
```

Description

Image_channel_order

```
enum class image_channel_order : unsigned int {
  a,
  r,
  rx,
  rg,
  rgx,
  ra,
  rgb,
  rgbx,
  rgba,
  argb,
  bgra,
  intensity,
  luminance,
  abgr
}
```

Image_channel_type

```
enum class image_channel_type : unsigned int {
  snorm_int8,
  snorm_int16,
  unorm_int8,
  unorm_int16,
  unorm_short_565,
  unorm_short_555,
  unorm_int_101010,
  signed_int8,
  signed_int16,
  signed_int32,
  unsigned_int8,
  unsigned_int16,
  unsigned_int32,
  fp16,
  fp32
}
```

4.5.3 Accessors

An accessor provides access to the data managed by a buffer or image, or to shared local memory allocated by the runtime.

Buffer accessors

Buffer accessor

```
template <typename dataT, int dimensions, access::mode accessmode,
          access::target accessTarget = access::target::global_buffer,
          access::placeholder isPlaceholder = access::placeholder::false_t>
class accessor;
```

Description

Template parameters

dataT	Type of buffer element
dimensions	Number of buffer dimensions
accessmode	See *mode*
accessTarget	See *target*
isPlaceholder	True if accessor is a placeholder

Member types

value_type	Type of buffer element
reference	Type of reference to buffer element
const_reference	Type of const reference to buffer element

See also:

SYCL Specification Section 4.7.6.9

Member and nonmember functions

(constructors)

```
Available only when:
 ((isPlaceholder == access::placeholder::false_t && accessTarget ==␣
↪access::target::host_buffer)
  || (isPlaceholder == access::placeholder::true_t
      && (accessTarget == access::target::global_buffer
          || accessTarget == access::target::constant_buffer)))
 && dimensions == 0

template <typename AllocatorT>
accessor(buffer<dataT, 1, AllocatorT> &bufferRef,
         const property_list &propList = {});

Available only when:
 (isPlaceholder == access::placeholder::false_t
  && (accessTarget == access::target::global_buffer
      || accessTarget == access::target::constant_buffer))
 && dimensions == 0

template <typename AllocatorT>
accessor(buffer<dataT, 1, AllocatorT> &bufferRef,
         handler &commandGroupHandlerRef, const property_list &propList = {});

Available only when:
 ((isPlaceholder == access::placeholder::false_t
   && accessTarget == access::target::host_buffer)
  || (isPlaceholder == access::placeholder::true_t
      && (accessTarget == access::target::global_buffer
          || accessTarget == access::target::constant_buffer)))
 && dimensions > 0

template <typename AllocatorT>
accessor(buffer<dataT, dimensions, AllocatorT> &bufferRef,
         const property_list &propList = {});
template <typename AllocatorT>
accessor(buffer<dataT, dimensions, AllocatorT> &bufferRef,
         range<dimensions> accessRange, const property_list &propList = {});
template <typename AllocatorT>
accessor(buffer<dataT, dimensions, AllocatorT> &bufferRef,
```

```
        range<dimensions> accessRange, id<dimensions> accessOffset,
        const property_list &propList = {});

Available only when:
 (isPlaceholder == access::placeholder::false_t
  && (accessTarget == access::target::global_buffer
      || accessTarget == access::target::constant_buffer))
  && dimensions > 0

template <typename AllocatorT>
accessor(buffer<dataT, dimensions, AllocatorT> &bufferRef,
         handler &commandGroupHandlerRef, const property_list &propList = {});
template <typename AllocatorT>
accessor(buffer<dataT, dimensions, AllocatorT> &bufferRef,
         handler &commandGroupHandlerRef, range<dimensions> accessRange,
         const property_list &propList = {});
template <typename AllocatorT>
accessor(buffer<dataT, dimensions, AllocatorT> &bufferRef,
         handler &commandGroupHandlerRef, range<dimensions> accessRange,
         id<dimensions> accessOffset, const property_list &propList = {});
```

Construct an accessor for a buffer.

Programs typically find it more convenient to use *get_access* to create an accessor for a buffer.

Template parameters

AllocatorT	Type of allocator for buffer element

Parameters

bufferRef	Associate accessor with this buffer
commandGroupHandlerRef	Associate accessor with this handler
propList	*Buffer accessor properties*
accessRange	Dimensions of data to be accessed
accessOffset	Coordinates of origin of data

is_placeholder

```
constexpr bool is_placeholder() const;
```

Return True if this is a placeholder accessor.

get_size

```
size_t get_size() const;
```

Returns size in bytes of the buffer region that this accesses.

get_count

```
size_t get_count() const;
```

Returns number elements that this accesses.

get_range

```
Available only when:
 dimensions > 0

range<dimensions> get_range() const;
```

Template parameters

dimensions	number of dimensions

Returns dimensions of the asssociated buffer or range that was provided when the accessor was created.

get_offset

```
Available only when:
 dimensions > 0

id<dimensions> get_offset() const;
```

Template parameters

dimensions	number of dimensions

Returns coordinates of the origin of the buffer or offset that was provided when the accessor was created.

operator ()

```
Available only when:
 accessMode == access::mode::write
  || accessMode == access::mode::read_write
  || accessMode == access::mode::discard_write
  || accessMode == access::mode::discard_read_write

operator dataT &() const;

Available only when:
 accessMode == access::mode::read

operator dataT() const;

Available only when:
 accessMode == access::mode::atomic

operator atomic<dataT, access::address_space::global_space> () const;
```

Returns reference or value of element in the associated buffer.

The variants of this operator are only available when *dimensions == 0*, which means that a buffer contains a single element.

operator[]

```
Reference variants
dataT &operator[](size_t index) const;
dataT &operator[](id<dimensions> index) const;

Value variants
dataT operator[](size_t index) const;
dataT operator[](id<dimensions> index) const;

Atomic variants
atomic<dataT, access::address_space::global_space> operator[](
  size_t index) const;
atomic<dataT, access::address_space::global_space> operator[](
  id<dimensions> index) const;

Single dimension in multi-dimensional buffer
__unspecified__ &operator[](size_t index) const;
```

Returns reference or value of element in the associated buffer at the requested index.

One dimensional buffers are indexed by a data of type size_t. Multi-dimensional buffers may be indexed by a data of type `id<dimensions>`, or by a sequence of *[]*, 1 per dimension. For example `a[1][2]`. The operator returns a reference when the accessor allows writes, which requires that accessMode be one of `access::mode::write`, `accessMode == access::mode::read_write`, `accessMode == access::mode::discard_write`, or `accessMode == access::mode::discard_read_write`. The operator returns an atomic if the accessMode is `access::mode::atomic`.

get_pointer

```
Available only when:
 accessTarget == access::target::host_buffer

dataT *get_pointer() const;

Available only when:
 accessTarget == access::target::global_buffer

global_ptr<dataT> get_pointer() const;

Available only when:
 accessTarget == access::target::constant_buffer

constant_ptr<dataT> get_pointer() const;
```

Returns pointer to memory in a host buffer.

Buffer accessor properties

SYCL does not define any properties for the buffer specialization of an accessor.

Local accessor

```
template <typename dataT, int dimensions, access::mode accessmode,
          access::target accessTarget = access::target::global_buffer,
          access::placeholder isPlaceholder = access::placeholder::false_t>
class accessor;
```

Description

Template parameters

dataT	
dimensions	
accessmode	
accessTarget	
isPlaceholder	

Member types

value_type	
reference	
const_reference	

See also:

SYCL Specification Section 4.7.6.11

Member and nonmember functions

(constructors)

```
Available only when:
 dimensions == 0

accessor(handler &commandGroupHandlerRef, const property_list &propList = {});


Available only when:
 dimensions > 0

accessor(range<dimensions> allocationSize, handler &commandGroupHandlerRef,
         const property_list &propList = {});
```

get_size

```
size_t get_size() const;
```

Returns

get_count

```
size_t get_count() const;
```

Returns

get_range

```
range<dimensions> get_range() const;
```

Template parameters

dimensions	

Returns

get_pointer

```
local_ptr<dataT> get_pointer() const;
```

Available only when: accessTarget == access::target::local

operator[]

```
Available only when:
 accessMode == access::mode::read_write && dimensions > 0

dataT &operator[](id<dimensions> index) const;

Available only when:
 accessMode == access::mode::read_write && dimensions == 1

dataT &operator[](size_t index) const

Available only when:
 accessMode == access::mode::atomic && dimensions > 0

atomic<dataT, access::address_space::local_space> operator[](
  id<dimensions> index) const;

Available only when:
 accessMode == access::mode::atomic && dimensions == 1

atomic<dataT, access::address_space::local_space> operator[](
  size_t index) const;

Available only when:
 dimensions > 1

__unspecified__ &operator[](size_t index) const;
```

operator ()

```
Available only when:
 accessMode == access::mode::read_write && dimensions == 0

operator dataT &() const;

Available only when:
 accessMode == access::mode::atomic && dimensions == 0

operator atomic<dataT,access::address_space::local_space> () const;
```

Image accessor

```
template <typename dataT, int dimensions, access::mode accessmode,
          access::target accessTarget = access::target::global_buffer,
          access::placeholder isPlaceholder = access::placeholder::false_t>
class accessor;
```

Description

Template parameters

dataT	
dimensions	
accessmode	
accessTarget	
isPlaceholder	

Member types

value_type	
reference	
const_reference	

See also:

SYCL Specification Section 4.7.6.12

Member and nonmember functions

(constructors)

```
Available only when:
 accessTarget == access::target::host_image

template <typename AllocatorT>
accessor(image<dimensions, AllocatorT> &imageRef,
         const property_list &propList = {});

Available only when:
 accessTarget == access::target::image

template <typename AllocatorT>
accessor(image<dimensions, AllocatorT> &imageRef,
         handler &commandGroupHandlerRef, const property_list &propList = {});

Available only when:
 accessTarget == access::target::image_array && dimensions < 3

template <typename AllocatorT>
accessor(image<dimensions + 1, AllocatorT> &imageRef,
         handler &commandGroupHandlerRef, const property_list &propList = {});
```

get_count

```
size_t get_count() const;
```

get_range

```
Available only when:
 (accessTarget != access::target::image_array)

range<dimensions> get_range() const;

Available only when:
 (accessTarget == access::target::image_array)

range<dimensions+1> get_range() const;
```

Template parameters

dimensions	

read

```
Available only when:
 (accessTarget == access::target::image && accessMode == access::mode::read)
 || (accessTarget ==
      access::target::host_image && (accessMode ==
      access::mode::read || accessMode == access::mode::read_write))

template <typename coordT>
dataT read(const coordT &coords) const;

Available only when:
 (accessTarget == access::target::image && accessMode == access::mode::read)
 || (accessTarget ==
      access::target::host_image && (accessMode ==
      access::mode::read || accessMode == access::mode::read_write))

template <typename coordT>
dataT read(const coordT &coords, const sampler &smpl) const;
```

Template parameters

coordT	

operator[]

```
*Available only when:
 accessTarget == access::target::image_array && dimensions < 3*

__image_array_slice__ operator[](size_t index) const;
```

mode

```
enum class mode {
  read = 1024,
  write,
  read_write,
  discard_write,
  discard_read_write,
  atomic
};
```

Namespace

```
access
```

target

```
enum class target {
  global_buffer = 2014,
  constant_buffer,
  local,
  image,
  host_buffer,
  host_image,
  image_array
};
```

Namespace

```
access
```

4.5.4 Multipointer

access::address_space

```
enum class address_space : int {
    global_space,
    local_space,
    constant_space,
    private_space
};
```

See also:

SYCL Specification Section 4.7.7

multi_ptr

```
template <typename ElementType, access::address_space Space> class multi_ptr;

template <access::address_space Space> class multi_ptr<VoidType, Space>;
```

Template parameters

ElementType	
Space	

Member types

element_type	
difference_type	
pointer_t	
const_pointer_t	
reference_t	
const_reference_t	

Nonmember data

address_space	

See also:

SYCL Specification Section 4.7.7.1

Member and nonmember functions

(constructors)

```
multi_ptr();
multi_ptr(const multi_ptr&);
multi_ptr(multi_ptr&&);
multi_ptr(pointer_t);
multi_ptr(ElementType*);
multi_ptr(std::nullptr_t);
```

operator=

```
multi_ptr &operator=(const multi_ptr&);
multi_ptr &operator=(multi_ptr&&);
multi_ptr &operator=(pointer_t);
multi_ptr &operator=(ElementType*);
multi_ptr &operator=(std::nullptr_t);


Available only when:
 Space == global_space

template <int dimensions, access::mode Mode, access::placeholder␣
↪isPlaceholder>
multi_ptr(accessor<ElementType, dimensions, Mode, access::target::global_
↪buffer, isPlaceholder>);

Available only when:
 Space == local_space

template <int dimensions, access::mode Mode, access::placeholder␣
↪isPlaceholder>
multi_ptr(accessor<ElementType, dimensions, Mode, access::target::local,␣
↪isPlaceholder>);

Available only when:
 Space == constant_space

template <int dimensions, access::mode Mode, access::placeholder␣
↪isPlaceholder>
multi_ptr(accessor<ElementType, dimensions, Mode, access::target::constant_
↪buffer, isPlaceholder>);
```

Template parameters

dimensions	
Mode	
isPlaceholder	

operator*

```
friend ElementType& operator*(const multi_ptr& mp);
```

operator->

```
ElementType* operator->() const;
```

get

```
pointer_t get() const;
```

Returns

Returns the underlying OpenCL C pointer

(Implicit conversions)

```
Implicit conversion to the underlying pointer type

operator ElementType*() const;

Implicit conversion to a multi_ptr<void>.  Only available
 when ElementType is not const-qualified

operator multi_ptr<void, Space>() const;

Implicit conversion to a multi_ptr<const void>. Only
 available when ElementType is const-qualified

operator multi_ptr<const void, Space>() const;

Implicit conversion to multi_ptr<const ElementType, Space>

operator multi_ptr<const ElementType, Space>() const;
```

(Arithmetic operators)

```
friend multi_ptr& operator++(multi_ptr& mp);
friend multi_ptr operator++(multi_ptr& mp, int);
friend multi_ptr& operator--(multi_ptr& mp);
friend multi_ptr operator--(multi_ptr& mp, int);
friend multi_ptr& operator+=(multi_ptr& lhs, difference_type r);
friend multi_ptr& operator-=(multi_ptr& lhs, difference_type r);
friend multi_ptr operator+(const multi_ptr& lhs, difference_type r);
friend multi_ptr operator-(const multi_ptr& lhs, difference_type r);
```

prefetch

```
void prefetch(size_t numElements) const;
```

(Relational operators)

```
friend bool operator==(const multi_ptr& lhs, const multi_ptr& rhs);
friend bool operator!=(const multi_ptr& lhs, const multi_ptr& rhs);
friend bool operator<(const multi_ptr& lhs, const multi_ptr& rhs);
friend bool operator>(const multi_ptr& lhs, const multi_ptr& rhs);
friend bool operator<=(const multi_ptr& lhs, const multi_ptr& rhs);
friend bool operator>=(const multi_ptr& lhs, const multi_ptr& rhs);

friend bool operator==(const multi_ptr& lhs, std::nullptr_t);
friend bool operator!=(const multi_ptr& lhs, std::nullptr_t);
friend bool operator<(const multi_ptr& lhs, std::nullptr_t);
friend bool operator>(const multi_ptr& lhs, std::nullptr_t);
friend bool operator<=(const multi_ptr& lhs, std::nullptr_t);
friend bool operator>=(const multi_ptr& lhs, std::nullptr_t);

friend bool operator==(std::nullptr_t, const multi_ptr& rhs);
friend bool operator!=(std::nullptr_t, const multi_ptr& rhs);
friend bool operator<(std::nullptr_t, const multi_ptr& rhs);
friend bool operator>(std::nullptr_t, const multi_ptr& rhs);
friend bool operator<=(std::nullptr_t, const multi_ptr& rhs);
friend bool operator>=(std::nullptr_t, const multi_ptr& rhs);
```

4.5.5 private_memory

```
template <typename T, int Dimensions = 1>
class private_memory;
```

See also:

SYCL Specification Section 4.10.7.3

Member and nonmember functions

(constructors)

```
private_memory(const group<Dimensions> &);
```

(operators)

```
T &operator()(const h_item<Dimensions> &id);
```

4.5.6 Samplers

See also:

SYCL Specification Section 4.7.8

address_mode

```
enum class addressing_mode: unsigned int {
    mirrored_repeat,
    repeat,
    clamp_to_edge,
    clamp,
    none
};
```

filtering_mode

```
enum class filtering_mode: unsigned int {
   nearest,
   linear
};
```

coordinate_normalization_mode

```
enum class coordinate_normalization_mode : unsigned int {
   normalized,
   unnormalized
};
```

sampler

```
class sampler;
```

(constructors)

```
sampler(coordinate_normalization_mode normalizationMode,
        addressing_mode addressingMode, filtering_mode filteringMode,
        const property_list &propList = {});

sampler(cl_sampler clSampler, const context &syclContext);
```

get_address_mode

```
addressing_mode get_addressing_mode() const;
```

get_filtering_mode

```
filtering_mode get_filtering_mode() const;
```

get_coordinate_normalization_mode

```
coordinate_normalization_mode get_coordinate_normalization_mode() const;
```

4.6 Unified shared memory (USM)

4.6.1 malloc_device

Since SYCL 2020

```
void* sycl::malloc_device(size_t num_bytes,
                          const sycl::device& dev,
                          const sycl::context& ctxt);
void* sycl::aligned_alloc_device(size_t alignment,
                                 size_t num_bytes,
                                 const sycl::device& dev,
                                 const sycl::context& ctxt);
template <typename T>
T* sycl::malloc_device(size_t count,
                       const sycl::device& dev,
                       const sycl::context& ctxt);
template <typename T>
T* sycl::aligned_alloc_device(size_d alignment,
                              size_t count,
                              const sycl::device& dev,
                              const sycl::context& ctxt);
```

Parameters

alignment	alignment of allocated data
num_bytes	allocation size in bytes
count	number of elements
dev	See *device*
ctxt	See *context*

Returns a pointer to memory that resides on the device.

The host may not reference the memory. To access the data on the host, the device must copy it to host-accessible memory.

Deallocate with *free*.

See also:

SYCL Specification Section 4.8.5.1

4.6.2 malloc_host

Since SYCL 2020

```
void* sycl::malloc_host(size_t num_bytes, const sycl::context& ctxt);
template <typename T>
void* sycl::aligned_alloc_host(size_t alignment, size_t num_bytes, const␣
↪sycl::context& ctxt);
T* sycl::malloc_host(size_t count, const sycl::context& ctxt);
T* sycl::aligned_alloc_host(size_t alignment, size_t count, const sycl::context&␣
↪ctxt);
```

Parameters

alignment	alignment of allocated data
num_bytes	allocation size in bytes
count	number of elements
dev	See *device*
ctxt	See *context*

Returns a pointer to memory that resides on the host.

Host and device may reference the memory.

Deallocate with *free*.

See also:

SYCL Specification Section 4.8.5.2

4.6.3 malloc_shared

Since SYCL 2020

```
void* sycl::malloc_shared(size_t num_bytes,
                          const sycl::device& dev,
                          const sycl::context& ctxt);
void* sycl::aligned_alloc_ahared(size_t alignment,
                              size_t num_bytes,
                              const sycl::device& dev,
                              const sycl::context& ctxt);
template <typename T>
T* sycl::malloc_shared(size_t count,
                       const sycl::device& dev,
                       const sycl::context& ctxt);
template <typename T>
T* sycl::aligned_alloc_ahared(size_t alignment,
                           size_t count,
                           const sycl::device& dev,
                           const sycl::context& ctxt);
```

Parameters

alignment	alignment of allocated data
num_bytes	allocation size in bytes
count	number of elements
dev	See *device*
ctxt	See *context*

Returns a pointer to memory that may reside on host or device.

The SYCL runtime may migrate the data between host and device to optimize access.

Deallocate with *free*.

See also:

SYCL Specification Section 4.8.5.2

4.6.4 free

Since SYCL 2020

```
void free(void* ptr, sycl::context& context);
```

Free memory allocated by *malloc_device*, *malloc_host*, or *malloc_shared*.

See also:

SYCL Specification Section 4.8.5.4

4.6.5 usm_allocator

Since SYCL 2020

```
template <typename T, usm::alloc AllocKind, size_t Alignment = 0>
class usm_allocator;
```

Allocator suitable for use with a C++ standard library container.

A `usm_allocator` enables using USM allocation for standard library containers. It is typically passed as template parameter when declaring standard library containers (e.g. vector).

Template parameters

T	Type of allocated element
AllocKind	Type of allocation, see o
Alignment	Alignment of the allocation

Example

```
#include <vector>

#include <CL/sycl.hpp>

using namespace sycl;

const int size = 10;

int main() {
  queue q;

  // USM allocator for data of type int in shared memory
  typedef usm_allocator<int, usm::alloc::shared> vec_alloc;
  // Create allocator for device associated with q
  vec_alloc myAlloc(q);
  // Create std vectors with the allocator
  std::vector<int, vec_alloc >
    a(size, myAlloc),
    b(size, myAlloc),
    c(size, myAlloc);

  // Get pointer to vector data for access in kernel
  auto A = a.data();
  auto B = b.data();
  auto C = c.data();

  for (int i = 0; i < size; i++) {
    a[i] = i;
    b[i] = i;
    c[i] = i;
  }

  q.submit([&](handler &h) {
      h.parallel_for(range<1>(size),
```

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```
                          [=](id<1> idx) {
                            C[idx] = A[idx] + B[idx];
                          });
      }).wait();

  for (int i = 0; i < size; i++) std::cout << c[i] << std::endl;
  return 0;
}
```

Member types

value_type	

See also:

SYCL Specification Section 4.8.4

Member and nonmember functions

(constructors)

```
usm_allocator(const context &ctxt, const device &dev) noexcept;
usm_allocator(const queue &q) noexcept;
usm_allocator(const usm_allocator &other) noexcept;
template <class U>
usm_allocator(usm_allocator<U, AllocKind, Alignment> const &) noexcept;
```

allocate

```
T *allocate(size_t Size);
```

Allocates memory

deallocate

```
void deallocate(T *Ptr, size_t size);
```

Deallocates memory

construct

```
template <
    usm::alloc AllocT = AllocKind,
    typename std::enable_if<AllocT != usm::alloc::device, int>::type = 0,
    class U, class... ArgTs>
void construct(U *Ptr, ArgTs &&... Args);
template <
    usm::alloc AllocT = AllocKind,
    typename std::enable_if<AllocT == usm::alloc::device, int>::type = 0,
    class U, class... ArgTs>
void construct(U *Ptr, ArgTs &&... Args);
```

Constructs an object on memory pointed by Ptr.

destroy

```
template <
    usm::alloc AllocT = AllocKind,
    typename std::enable_if<AllocT != usm::alloc::device, int>::type = 0>
void destroy(T *Ptr);

/// Throws an error when trying to destroy a device allocation
/// on the host
template <
    usm::alloc AllocT = AllocKind,
    typename std::enable_if<AllocT == usm::alloc::device, int>::type = 0>
void destroy(T *Ptr);
```

Destroys an object.

(operators)

```
template <class T, usm::alloc AllocKindT, size_t AlignmentT, class U,
          usm::alloc AllocKindU, size_t AlignmentU>
bool operator==(const usm_allocator<T, AllocKindT, AlignmentT> &,
                const usm_allocator<U, AllocKindU, AlignmentU> &) noexcept;
template <class T, class U, usm::alloc AllocKind, size_t Alignment = 0>
bool operator!=(const usm_allocator<T, AllocKind, Alignment> &allocT,
                const usm_allocator<U, AllocKind, Alignment> &allocU) noexcept;
```

Allocators only compare equal if they are of the same USM kind, alignment, context, and device (when kind is not host).

4.6.6 alloc

Since SYCL 2020

```
enum class alloc {
  host,
  device,
  shared,
  unknown
};
```

Namespace

```
usm
```

Identifies type of USM memory in calls to USM-related API.

host Resides on host and also accessible by device

device Resides on device and only accessible by device

shared SYCL runtime may move data between host and device. Accessible by host and device.

See also:

SYCL Specification Section 4.8.3

4.7 Expressing parallelism

4.7.1 range

```
template <int dimensions = 1>
class range;
```

The range is an abstraction that describes the number of elements in each dimension of buffers and index spaces. It can contain 1, 2, or 3 numbers, dependending on the dimensionality of the object it describes.

Template parameters

dimensions	Number of dimensions

See also:

SYCL Specification Section 4.10.1.1

Member and nonmember functions

(constructors)

```
range(size_t dim0);
range(size_t dim0, size_t dim1);
range(size_t dim0, size_t dim1, size_t dim2);
```

Constructs a 1, 2, or 3 dimensional range.

get

```
size_t get(int dimension) const;
```

Returns the range of a single dimension.

operator[]

```
size_t &operator[](int dimension);
size_t operator[](int dimension) const;
```

Returns the range of a single dimension.

size

```
size_t size() const;
```

Returns the size of a range by multiplying the range of the individual dimensions.

For a buffer, it is the number of elements in the buffer.

Arithmetic Operators

```
OP is: +, -, *, /, %, <<, >>, &, |, ^, &&, ||, <, >, <=, >=

friend range operatorOP(const range &lhs, const range &rhs)
friend range operatorOP(const range &lhs, const size_t &rhs)
friend range operatorOP(const size_t &lhs, const range &rhs)

OP is: +=, -=, *=, /=, %=, <<=, >>=, &=, |=, ^=

friend range & operatorOP(const range &lhs, const range &rhs)
friend range & operatorOP(const range &lhs, const size_t &rhs)
```

Arithmetical and relational operations on ranges.

4.7.2 group

```
template <int dimensions = 1>
class group;
```

Template parameters

dimensions	

See also:

SYCL Specification Section 4.10.1.7

Member and nonmember functions

get_id

```
id<dimensions> get_id() const;
size_t get_id(int dimension) const;
```

get_global_range

```
range<dimensions> get_global_range() const;
size_t get_global_range(int dimension) const;
```

get_local_range

```
range<dimensions> get_local_range() const;
size_t get_local_range(int dimension) const;
```

get_group_range

```
range<dimensions> get_group_range() const;
size_t get_group_range(int dimension) const;
```

get_linear_id

```
size_t get_linear_id() const;
```

parallel_for_work_item

```
template<typename workItemFunctionT>
void parallel_for_work_item(workItemFunctionT func) const;
template<typename workItemFunctionT>
void parallel_for_work_item(range<dimensions> logicalRange,
  workItemFunctionT func) const;
```

mem_fence

```
template <access::mode accessMode = access::mode::read_write>
void mem_fence(access::fence_space accessSpace =
  access::fence_space::global_and_local) const;
```

async_work_group_copy

```
template <typename dataT>
device_event async_work_group_copy(local_ptr<dataT> dest,
  global_ptr<dataT> src, size_t numElements) const;
template <typename dataT>
device_event async_work_group_copy(global_ptr<dataT> dest,
  local_ptr<dataT> src, size_t numElements) const;
template <typename dataT>
device_event async_work_group_copy(local_ptr<dataT> dest,
  global_ptr<dataT> src, size_t numElements, size_t srcStride) const;
template <typename dataT>
device_event async_work_group_copy(global_ptr<dataT> dest,
  local_ptr<dataT> src, size_t numElements, size_t destStride) const;
```

wait_for

```
template <typename... eventTN>
void wait_for(eventTN... events) const;
```

operator[]

```
size_t operator[](int dimension) const;
```

4.7.3 id

```
template <int dimensions = 1>
class id;
```

The `id` is an abstraction that describes the location of a point in a *range*. Examples includes use as an index in an *Buffer accessor* and as an argument to a kernel function in a *parallel_for* to identify the work item.

See also:

SYCL Specification Section 4.10.1.3

Member and nonmember functions

(constructors)

```
id();
id(size_t dim0);
id(size_t dim0, size_t dim1);
id(size_t dim0, size_t dim1, size_t dim2);

id(const range<dimensions> &range);
id(const item<dimensions> &item);
```

Construct an `id`.

An `id` can be 0, 1, 2, or 3 dimensions. An `id` constructed from a *range* uses the `range` values. An `id` constructed from an *item* uses the `id` contained in the `item`.

get

```
size_t get(int dimension) const;
```

Returns the value for dimension `dimension`.

(operators)

```
size_t &operator[](int dimension);
size_t operator[](int dimension) const;

*OP is:
 +, -, \*, /, %, <<, >>, &, |, ^, &&, ||, <, >, <=, >=*

friend id operatorOP(const id &lhs, const id &rhs);
friend id operatorOP(const id &lhs, const size_t &rhs);

*OP is:
 +=, -=, \*=, /=, %=, <<=, >>=, &=, |=, ^=*

friend id &operatorOP(id &lhs, const id &rhs);
friend id &operatorOP(id &lhs, const size_t &rhs);

*OP is:
 +, -, \*, /, %, <<, >>, &, |, ^, &&, ||, <, >, <=, >=*

 friend id operatorOP(const size_t &lhs, const id &rhs);
```

Relational, arithmetic, and indexing operators on an `id`.

4.7.4 item

```
template <int dimensions = 1, bool with_offset = true>
class item;
```

Similar to an *id*, the `item` describes the location of a point in a `range`. It can be used as an argument to a kernel function in a *parallel_for* to identify the work item. The `item` carries more information than than *id*, such as the `range` of an index space. The interface does not include a constructor because only the SYCL runtime needs to construct an `item`.

Template parameters

dimensions	Number of dimensions in index space
with_offset	True if item has offset

See also:

SYCL Specification Section 4.10.1.4

Member and nonmember functions

get_id

```
id<dimensions> get_id() const;
size_t get_id(int dimension) const;
```

Returns *id* associated with `item`.

get_range

```
range<dimensions> get_range() const;
size_t get_range(int dimension) const;
```

Returns *range* associated with `item`.

get_offset

```
*Only available when:
 with_offset is true*

id<dimensions> get_offset() const;
```

Returns offset associated with `item`.

get_linear_id

```
size_t get_linear_id() const;
```

Returns the linear id, suitable for mapping the `id` to a 1 dimensional array.

operator[]

```
size_t operator[](int dimension) const;
```

Returns id for dimension `dimension`.

operator()

```
operator item<dimensions, true>() const;
```

Returns item with offset set to 0.

Only available when `with_offset` is False.

4.7.5 h_item

```
template <int dimensions>
class h_item;
```

See also:

SYCL Specification Section 4.10.1.6

Member and nonmember functions

get_global

```
item<dimensions, false> get_global() const;
```

get_local

```
item<dimensions, false> get_local() const;
```

get_logical_local

```
item<dimensions, false> get_logical_local() const;
```

get_physical_local

```
item<dimensions, false> get_physical_local() const;
```

get_global_range

```
range<dimensions> get_global_range() const;
size_t get_global_range(int dimension) const;
```

get_global_id

```
id<dimensions> get_global_id() const;
size_t get_global_id(int dimension) const;
```

get_local_range

```
range<dimensions> get_local_range() const;
size_t get_local_range(int dimension) const;
```

get_local_id

```
id<dimensions> get_local_id() const;
size_t get_local_id(int dimension) const;
```

get_logical_local_range

```
range<dimensions> get_logical_local_range() const;
size_t get_logical_local_range(int dimension) const;
```

get_logical_local_id

```
id<dimensions> get_logical_local_id() const;
size_t get_logical_local_id(int dimension) const;
```

get_physical_local_range

```
range<dimensions> get_physical_local_range() const;
size_t get_physical_local_range(int dimension) const;
```

get_physical_local_id

```
id<dimensions> get_physical_local_id() const;
size_t get_physical_local_id(int dimension) const;
```

4.7.6 nd_item

```
template <int dimensions = 1>
class nd_item;
```

The `nd_item` describes the location of a point in an *nd_range*.

An `nd_item` is typically passed to a kernel function in a *parallel_for*. It addition to containing the `id` of the work item in the work group and global space, the `nd_item` also contains the *nd_range* defining the index space.

See also:

SYCL Specification Section 4.10.1.5

Member and nonmember functions

get_global_id

```
id<dimensions> get_global_id() const;
size_t get_global_id(int dimension) const;
```

Returns global *id* for the requested dimensions.

get_global_linear_id

```
size_t get_global_linear_id() const;
```

Returns global id mapped to a linear space.

get_local_id

```
id<dimensions> get_local_id() const;
size_t get_local_id(int dimension) const;
```

Returns id for the point in the work group.

get_local_linear_id

```
size_t get_local_linear_id() const;
```

Returns linear id for point in the work group.

get_group

```
group<dimensions> get_group() const;
size_t get_group(int dimension) const;
```

Returns *group* associated with the item.

get_group_linear_id

```
size_t get_group_linear_id() const;
```

Returns linear id for group in workspace.

get_group_range

```
range<dimensions> get_group_range() const;
size_t get_group_range(int dimension) const;
```

Returns the number of groups in every dimension.

get_global_range

```
range<dimensions> get_global_range() const;
size_t get_global_range(int dimension) const;
```

Returns the *range* of the index space.

get_local_range

```
range<dimensions> get_local_range() const;
size_t get_local_range(int dimension) const;
```

Returns the position of the work item in the work group.

get_offset

```
id<dimensions> get_offset() const;
```

Returns the offset provided to the *parallel_for*.

get_nd_range

```
nd_range<dimensions> get_nd_range() const;
```

Returns the *nd_range* provided to the *parallel_for*.

barrier

```
void barrier(access::fence_space accessSpace =
  access::fence_space::global_and_local) const;
```

Executes a work group barrier.

mem_fence

```
template <access::mode accessMode = access::mode::read_write>
void mem_fence(access::fence_space accessSpace =
  access::fence_space::global_and_local) const;
```

Executes a work group memory fence.

async_work_group_copy

```
template <typename dataT>
device_event async_work_group_copy(local_ptr<dataT> dest,
  global_ptr<dataT> src, size_t numElements) const;
template <typename dataT>
device_event async_work_group_copy(global_ptr<dataT> dest,
  local_ptr<dataT> src, size_t numElements) const;
template <typename dataT>
device_event async_work_group_copy(local_ptr<dataT> dest,
  global_ptr<dataT> src, size_t numElements, size_t srcStride) const;
template <typename dataT>
device_event async_work_group_copy(global_ptr<dataT> dest,
  local_ptr<dataT> src, size_t numElements, size_t destStride) const;
```

Copies elements from a source local to the destination asynchronously.

Returns an event that indicates when the operation has completed.

wait_for

```
template <typename... eventTN>
void wait_for(eventTN... events) const;
```

Wait for asynchronous events to complete.

4.7.7 nd_range

```
template <int dimensions = 1>
class nd_range;
```

The `nd_range` defines the index space for a work group as well as the global index space. It is passed to *parallel_for* to execute a kernel on a set of work items.

Template parameters

dimensions	Number of dimensions

See also:

SYCL Specification Section 4.10.1.2

Member and nonmember functions

(constructors)

```
nd_range(range<dimensions> globalSize, range<dimensions> localSize,
         id<dimensions> offset = id<dimensions>());
```

Construct an `nd_range`.

Parameters

globalSize	dimensions of the entire index space
localSize	dimensions of the work group
offset	Origin of the index space

get_global_range

```
range<dimensions> get_global_range() const;
```

Returns a *range* defining the index space.

get_local_range

```
range<dimensions> get_local_range() const;
```

Returns a *range* defining the index space of a work group.

get_group_range

```
range<dimensions> get_group_range() const;
```

Returns a *range* defining the number of work groups in every dimension.

get_offset

```
id<dimensions> get_offset() const;
```

Returns a *id* defining the offset.

4.7.8 device_event

```
class device_event;
```

See also:

SYCL Specification Section 4.7.8

Member and nonmember functions

wait

```
void wait();
```

4.7.9 Command groups

Command group function object

command_group

```
class command_group;
```

Member and nonmember functions

(constructors)

```
template <typename functorT>
command_group(queue &primaryQueue, const functorT &lambda);
template <typename functorT>
command_group(queue &primaryQueue, queue &secondaryQueue,
              const functorT &lambda);
```

events

```
event start_event();
event kernel_event();
event complete_event();
```

4.7.10 Invoking kernels

handler

```
class handler;
```

The `handler` defines the interface to invoke kernels by submitting commands to a queue.

A `handler` can only be constructed by the SYCL runtime and is passed as an argument to the command group function. The command group function is an argument to *submit*.

See also:

SYCL Specification Section 4.10.4

Member and nonmember functions

require

```
template <typename dataT, int dimensions, access::mode accessMode,
  access::target accessTarget>
void require(accessor<dataT, dimensions, accessMode, accessTarget,
             access::placeholder::true_t> acc);
```

Adds a requirement before a device may execute a kernel.

set_arg

```
template <typename T>
void set_arg(int argIndex, T && arg);
```

Sets a kernel argument.

set_args

```
template <typename... Ts>
void set_args(Ts &&... args);
```

Sets all kernel arguments.

single_task

```
template <typename KernelName, typename KernelType>
void single_task(KernelType kernelFunc);

void single_task(kernel syclKernel);
```

Defines and invokes a kernel function.

parallel_for

```
template <typename KernelName, typename KernelType, int dimensions>
void parallel_for(range<dimensions> numWorkItems, KernelType kernelFunc);

template <typename KernelName, typename KernelType, int dimensions>
void parallel_for(range<dimensions> numWorkItems,
                  id<dimensions> workItemOffset, KernelType kernelFunc);

template <typename KernelName, typename KernelType, int dimensions>
void parallel_for(nd_range<dimensions> ndRange, KernelType kernelFunc);

template <int dimensions>
void parallel_for(range<dimensions> numWorkItems, kernel syclKernel);

template <int dimensions>
void parallel_for(range<dimensions> numWorkItems,
                  id<dimensions> workItemOffset, kernel syclKernel);

template <int dimensions>
void parallel_for(nd_range<dimensions> ndRange, kernel syclKernel);
```

Invokes a kernel function for a *range* or *nd_range*.

Parameters

numWorkItems	Range for work items
workItemOffset	Offset into range for work items
kernelFunc	Kernel function
syclKernel	See *kernel*
ndRange	See *nd_range*

parallel_for_work_group

```
template <typename KernelName, typename WorkgroupFunctionType, int dimensions>
void parallel_for_work_group(range<dimensions> numWorkGroups,
                             WorkgroupFunctionType kernelFunc);

template <typename KernelName, typename WorkgroupFunctionType, int dimensions>
void parallel_for_work_group(range<dimensions> numWorkGroups,
                             range<dimensions> workGroupSize,
                             WorkgroupFunctionType kernelFunc);
```

Outer invocation in a hierarchical invocation of a kernel.

The kernel function is executed once per work group.

copy

```
template <typename T_src, int dim_src, access::mode mode_src, access::target tgt_src,
          access::placeholder isPlaceholder, typename T_dest>
void copy(accessor<T_src, dim_src, mode_src, tgt_src, isPlaceholder> src,
          shared_ptr_class<T_dest> dest);
template <typename T_src,
          typename T_dest, int dim_dest, access::mode mode_dest, access::target tgt_
→dest,
          access::placeholder isPlaceholder>
void copy(shared_ptr_class<T_src> src,
          accessor<T_dest, dim_dest, mode_dest, tgt_dest, isPlaceholder> dest);
template <typename T_src, int dim_src, access::mode mode_src,
          access::target tgt_src, access::placeholder isPlaceholder,
          typename T_dest>
void copy(accessor<T_src, dim_src, mode_src, tgt_src, isPlaceholder> src,
          T_dest *dest);
template <typename T_src,
          typename T_dest, int dim_dest, access::mode mode_dest,
          access::target tgt_dest, access::placeholder isPlaceholder>
void copy(const T_src *src,
          accessor<T_dest, dim_dest, mode_dest, tgt_dest, isPlaceholder> dest);
template <typename T_src, int dim_src, access::mode mode_src,
          access::target tgt_src, access::placeholder isPlaceholder_src,
          typename T_dest, int dim_dest, access::mode mode_dest, access::target tgt_
→dest,
          access::placeholder isPlaceholder_dest>
void copy(accessor<T_src, dim_src, mode_src, tgt_src, isPlaceholder_src> src,
          accessor<T_dest, dim_dest, mode_dest, tgt_dest, isPlaceholder_dest> dest);
```

Copies memory from `src` to `dest`.

`copy` invokes the operation on a *device*. The source, destination, or both source and destination are *Accessors*. Source or destination can be a pointer or a `shared_ptr`.

Template parameters

T_src	Type of source data elements
dim_src	Dimensionality of source accessor data
T_dest	Type of element for destination data
dim_dest	Dimensionality of destination accessor data
mode_src	Mode for source accessor
mode_dest	Mode for destination accessor
tgt_src	Target for source accessor
tgt_dest	Target for destination accessor
isPlaceholder_src	Placeholder value for source accessor
isPlaceholder_dest	Placeholder value for destination accessor

Parameters

src	source of copy
dest	destination of copy

update_host

```
template <typename T, int dim, access::mode mode,
          access::target tgt, access::placeholder isPlaceholder>
void update_host(accessor<T, dim, mode, tgt, isPlaceholder> acc);
```

Template parameters

T	Type of element associated with accessor
dim	Dimensionality of accessor
mode	Access mode for accessor
tgt	Target for accessor
isPlaceholder	Placeholder value for accessor

Updates host copy of data associated with accessor.

fill

```
template <typename T, int dim, access::mode mode,
          access::target tgt, access::placeholder isPlaceholder>
void fill(accessor<T, dim, mode, tgt, isPlaceholder> dest, const T& src);
```

Template parameters

T	Type of element associated with accessor
dim	Dimensionality of accessor
mode	Access mode for accessor
tgt	Target for accessor
isPlaceholder	Placeholder value for accessor

Parameters

dest	Destination of fill operation
src	Value to fill

Fill the destination of the memory associated with the accessor with the value in `src`.

4.7.11 Kernel

kernel

```
class kernel;
```

Abstraction of a kernel object.

See also:

SYCL Specification Section 4.12

Member and nonmember functions

(constructors)

```
kernel(cl_kernel clKernel, const context& syclContext);
```

Constructs a SYCL kernel instance from an OpenCL kernel.

get

```
cl_kernel get() const;
```

Returns OpenCL kernel associated with the SYCL kernel.

is_host

```
bool is_host() const;
```

Return true if this SYCL kernel is a host kernel.

get_context

```
context get_context() const;
```

Returns context associated with the kernel.

get_program

```
program get_program() const;
```

Returns program that this kernel is part of.

get_info

```
template <info::kernel param>
typename info::param_traits<info::kernel, param>::return_type
get_info() const;
```

Template parameters

param	See *info::kernel*

Returns information about the kernel

get_work_group_info

```
template <info::kernel_work_group param>
typename info::param_traits<info::kernel_work_group, param>::return_type
get_work_group_info(const device &dev) const;
```

Template parameters

param	See *info::kernel_work_group*

Returns information about the work group

info::kernel

```
enum class kernel: int {
    function_name,
    num_args,
    context,
    program,
    reference_count,
    attributes
};
```

info::kernel_work_group

```
enum class kernel_work_group: int {
    global_work_size,
    work_group_size,
    compile_work_group_size,
    preferred_work_group_size_multiple,
    private_mem_size
};
```

4.7.12 Program

info::program

```
enum class program: int {
    context,
    devices,
    reference_count
};
```

program_state

```
enum class program_state {
    none,
    compiled,
    linked
};
```

program

```
class program;
```

(constructors)

```
explicit program(const context &context,
                 const property_list &propList = {});
program(const context &context, vector_class<device> deviceList,
        const property_list &propList = {});
program(vector_class<program> &programList,
        const property_list &propList = {});
program(vector_class<program> &programList, string_class linkOptions,
        const property_list &propList = {});
program(const context &context, cl_program clProgram);
```

get

```
cl_program get() const;
```

is_host

```
bool is_host() const;
```

compile_with_kernel_type

```
template <typename kernelT>
void build_with_kernel_type(string_class buildOptions = "");
```

build_with_source

```
void build_with_source(string_class kernelSource,
                       string_class buildOptions = "");
```

link

```
void link(string_class linkOptions = "");
```

has_kernel

```
template <typename kernelT>
bool has_kernel<kernelT>() const;

bool has_kernel(string_class kernelName) const;
```

get_kernel

```
template <typename kernelT>
kernel get_kernel<kernelT>() const;

kernel get_kernel(string_class kernelName) const;
```

get_info

```
template <info::program param>
typename info::param_traits<info::program, param>::return_type
get_info() const;
```

get_binaries

```
vector_class<vector_class<char>> get_binaries() const;
```

get_context

```
context get_context() const;
```

get_devices

```
vector_class<device> get_devices() const;
```

get_compile_options

```
string_class get_compile_options() const;
```

get_link_options

```
string_class get_link_options() const;
```

get_build_options

```
string_class get_build_options() const;
```

get_state

```
program_state get_state() const;
```

4.8 Error handling

4.8.1 Exceptions

exception

```
class exception;
```

See also:

SYCL Specification Section 4.15.2

Member and nonmember functions

Container for an exception that occurs during execution. Synchronous API's throw exceptions that may be caught with C++ exception handling methods. The SYCL runtime holds exceptions that occur during asynchronous operations until *wait_and_throw* or *throw_asynchronous* is called. They runtime delivers the exception as a list to the *async_handler* associated with the *queue*.

what

```
const char *what() const;
```

Returns string that describes the error that triggered the exception.

has_context

```
bool has_context() const;
```

Returns true if error has an associated *context*.

get_context

```
context get_context() const;
```

Returns *context* associated with this error.

get_cl_code

```
cl_int get_cl_code() const;
```

Returns OpenCL error code if the error is an OpenCL error, otherwise `CL_SUCCESS`.

exception_list

```
class exception_list;
```

An exContainer for a list of asychronous exceptions that occur in the same queue. Re

Member types

value_type	
reference	
const_reference	
size_type	
iterator	
const_iterator	

Member and nonmember functions

size

```
size_type size() const;
```

Returns number of elements in the list.

begin

```
iterator begin() const;
```

Returns an iterator to the beginning of the list of exceptions.

end

```
iterator end() const;
```

Returns an iterator to the beginning of the list of exceptions.

Derived exceptions

runtime_error

```
class runtime_error : public exception;
```

kernel_error

```
class kernel_error : public runtime_error;
```

Error that occured before or while enqueuing the SYCL kernel.

accessor_error

```
class accessor_error : public runtime_error;
```

Error regarding *Accessors*.

nd_range_error

```
class nd_range_error : public runtime_error;
```

Error regarding the *nd_range* for a SYCL kernel.

event_error

```
class event_error : public runtime_error;
```

Error regarding an *event*.

invalid_parameter_error

```
class invalid_parameter_error : public runtime_error;
```

Error regarding parameters to a SYCL kernel, including captured parameters to a lambda.

device_error

```
class device_error : public exception;
```

compile_program_error

```
class compile_program_error : public device_error;
```

Error while compiling a SYCL kernel.

link_program_error

```
class link_program_error : public device_error;
```

Error linking a SYCL kernel to a SYCL device.

invalid_object_error

```
class invalid_object_error : public device_error;
```

Error regarding memory objects used inside a kernel.

memory_allocation_error

```
class memory_allocation_error : public device_error;
```

Error regarding memory allocation on the SYCL device.

platform_error

```
class platform_error : public device_error;
```

Error triggered by the *platform*.

profililng_error

```
class profiling_error : public device_error;
```

Error triggered while profiling is enabled.

featured_non_supported

```
class feature_not_supported : public device_error;
```

Optional feature or extension is not available on the *device*.

async_handler

```
void handler(exception_list e);
```

Parameters

e	List of asynchronous exceptions. See *exception_list*

The SYCL runtime delivers asynchronous exceptions by invoking an `async_handler`. The handler is passed to a *queue* constructor. The SYCL runtime delivers asynchronous exceptions to the handler when *wait_and_throw* or *throw_asynchronous* is called.

4.9 Data types

4.9.1 Scalar types

byte

OpenCL types

4.9.2 Vector types

rounding_mode

```
enum class rounding_mode {
    automatic,
    rte,
    rtz,
    rtp,
    rtn
};
```

elem

```
struct elem {
    static constexpr int x = 0;
    static constexpr int y = 1;
    static constexpr int z = 2;
    static constexpr int w = 3;
    static constexpr int r = 0;
    static constexpr int g = 1;
    static constexpr int b = 2;
    static constexpr int a = 3;
    static constexpr int s0 = 0;
    static constexpr int s1 = 1;
    static constexpr int s2 = 2;
    static constexpr int s3 = 3;
    static constexpr int s4 = 4;
    static constexpr int s5 = 5;
    static constexpr int s6 = 6;
    static constexpr int s7 = 7;
    static constexpr int s8 = 8;
    static constexpr int s9 = 9;
    static constexpr int sA = 10;
    static constexpr int sB = 11;
    static constexpr int sC = 12;
    static constexpr int sD = 13;
    static constexpr int sE = 14;
    static constexpr int sF = 15;
};
```

vec

```
template <typename dataT, int numElements>
class vec;
```

Member types

element_type	
vector_t	

(constructors)

```
vec();
explicit vec(const dataT &arg);
template <typename... argTN>
vec(const argTN&... args);
vec(const vec<dataT, numElements> &rhs);
vec(vector_t openclVector);
```

Conversion functions

```
 operator vector_t() const;
```

Available when:
 numElements == 1

```
operator dataT() const;
```

get_count

```
size_t get_count() const;
```

get_size

```
size_t get_size() const;
```

convert

```
template <typename convertT, rounding_mode roundingMode = rounding_mode::automatic>
vec<convertT, numElements> convert() const;
```

as

```
template <typename asT>
asT as() const;
```

swizzle

```
template<int... swizzleIndexes>
__swizzled_vec__ swizzle() const;
```

swizzle access

```
__swizzled_vec__ x() const;
__swizzled_vec__ y() const;
__swizzled_vec__ z() const;

__swizzled_vec__ w() const;
__swizzled_vec__ r() const;
__swizzled_vec__ g() const;
__swizzled_vec__ b() const;
__swizzled_vec__ a() const;

__swizzled_vec__ s0() const;
__swizzled_vec__ s1() const;
__swizzled_vec__ s2() const;
__swizzled_vec__ s3() const;
__swizzled_vec__ s4() const;
__swizzled_vec__ s5() const;
__swizzled_vec__ s6() const;
__swizzled_vec__ s7() const;
__swizzled_vec__ s8() const;
__swizzled_vec__ s9() const;
__swizzled_vec__ sA() const;
__swizzled_vec__ sC() const;
__swizzled_vec__ sD() const;
__swizzled_vec__ sE() const;
__swizzled_vec__ sF() const;

__swizzled_vec__ lo() const;
__swizzled_vec__ hi() const;
__swizzled_vec__ odd() const;
__swizzled_vec__ even() const;
```

load

```
template <access::address_space addressSpace>
void load(size_t offset, multi_ptr<const dataT, addressSpace> ptr);
```

store

```
template <access::address_space addressSpace>
void load(size_t offset, multi_ptr<const dataT, addressSpace> ptr);
```

Arithmetic operators

```
friend vec operator+(const vec &lhs, const vec &rhs);
friend vec operator+(const vec &lhs, const dataT &rhs);
friend vec operator+(const dataT &lhs, const vec &rhs);

friend vec operator-(const vec &lhs, const vec &rhs);
friend vec operator-(const vec &lhs, const dataT &rhs);
friend vec operator-(const dataT &lhs, const vec &rhs);

friend vec operator*(const vec &lhs, const vec &rhs);
friend vec operator*(const vec &lhs, const dataT &rhs);
friend vec operator*(const dataT &lhs, const vec &rhs);

friend vec operator/(const vec &lhs, const vec &rhs);
friend vec operator/(const vec &lhs, const dataT &rhs);
friend vec operator/(const dataT &lhs, const vec &rhs);


friend vec &operator+=(vec &lhs, const vec &rhs);
friend vec &operator+=(vec &lhs, const dataT &rhs);

friend vec &operator-=(vec &lhs, const vec &rhs);
friend vec &operator-=(vec &lhs, const dataT &rhs);

friend vec &operator*=(vec &lhs, const vec &rhs);
friend vec &operator*=(vec &lhs, const dataT &rhs);

friend vec &operator/=(vec &lhs, const vec &rhs);
friend vec &operator/=(vec &lhs, const dataT &rhs);


friend vec &operator++(vec &lhs);
friend vec operator++(vec& lhs, int);

friend vec &operator--(vec &lhs);
friend vec operator--(vec& lhs, int);

friend vec<RET, numElements> operator&&(const vec &lhs, const vec &rhs);
friend vec<RET, numElements> operator&&(const vec& lhs, const dataT &rhs);
```

```
friend vec<RET, numElements> operator||(const vec &lhs, const vec &rhs);
friend vec<RET, numElements> operator||(const vec& lhs, const dataT &rhs);


friend vec<RET, numElements> operator==(const vec &lhs, const vec &rhs);
friend vec<RET, numElements> operator==(const vec &lhs, const dataT &rhs);
friend vec<RET, numElements> operator==(const dataT &lhs, const vec &rhs);

friend vec<RET, numElements> operator!=(const vec &lhs, const vec &rhs);
friend vec<RET, numElements> operator!=(const vec &lhs, const dataT &rhs);
friend vec<RET, numElements> operator!=(const dataT &lhs, const vec &rhs);

friend vec<RET, numElements> operator<(const vec &lhs, const vec &rhs);
friend vec<RET, numElements> operator<(const vec &lhs, const dataT &rhs);
friend vec<RET, numElements> operator<(const dataT &lhs, const vec &rhs);

friend vec<RET, numElements> operator>(const vec &lhs, const vec &rhs);
friend vec<RET, numElements> operator>(const vec &lhs, const dataT &rhs);
friend vec<RET, numElements> operator>(const dataT &lhs, const vec &rhs);

friend vec<RET, numElements> operator<=(const vec &lhs, const vec &rhs);
friend vec<RET, numElements> operator<=(const vec &lhs, const dataT &rhs);
friend vec<RET, numElements> operator<=(const dataT &lhs, const vec &rhs);

friend vec<RET, numElements> operator>=(const vec &lhs, const vec &rhs);
friend vec<RET, numElements> operator>=(const vec &lhs, const dataT &rhs);
friend vec<RET, numElements> operator>=(const dataT &lhs, const vec &rhs);

vec<dataT, numElements> &operator=(const vec<dataT, numElements> &rhs);
vec<dataT, numElements> &operator=(const dataT &rhs);

friend vec<RET, numElements> operator&&(const dataT &lhs, const vec &rhs);

friend vec<RET, numElements> operator||(const dataT &lhs, const vec &rhs);

Available only when:
 dataT != cl_float && dataT != cl_double && dataT != cl_half

friend vec operator<<(const vec &lhs, const vec &rhs);
friend vec operator<<(const vec &lhs, const dataT &rhs);
friend vec operator<<(const dataT &lhs, const vec &rhs);
friend vec operator>>(const vec &lhs, const vec &rhs);
friend vec operator>>(const vec &lhs, const dataT &rhs);
friend vec operator>>(const dataT &lhs, const vec &rhs);
friend vec &operator>>=(vec &lhs, const vec &rhs);
friend vec &operator>>=(vec &lhs, const dataT &rhs);
friend vec &operator<<=(vec &lhs, const vec &rhs);
friend vec &operator<<=(vec &lhs, const dataT &rhs);
friend vec operator&(const vec &lhs, const vec &rhs);
friend vec operator&(const vec &lhs, const dataT &rhs);
friend vec operator|(const vec &lhs, const vec &rhs);
friend vec operator|(const vec &lhs, const dataT &rhs);
friend vec operator^(const vec &lhs, const vec &rhs);
```

```
friend vec operator^(const vec &lhs, const dataT &rhs);
friend vec &operator&=(vec &lhs, const vec &rhs);
friend vec &operator&=(vec &lhs, const dataT &rhs);
friend vec &operator|=(vec &lhs, const vec &rhs);
friend vec &operator|=(vec &lhs, const dataT &rhs);
friend vec &operator^=(vec &lhs, const vec &rhs);
friend vec &operator^=(vec &lhs, const dataT &rhs);
friend vec &operator%=(vec &lhs, const vec &rhs);
friend vec &operator%=(vec &lhs, const dataT &rhs);
friend vec operator%(const vec &lhs, const vec &rhs);
friend vec operator%(const vec &lhs, const dataT &rhs);
friend vec operator%(const dataT &lhs, const vec &rhs);
friend vec operator~(const vec &v);
friend vec<RET, numElements> operator!(const vec &v);
friend vec operator&(const dataT &lhs, const vec &rhs);
friend vec operator|(const dataT &lhs, const vec &rhs);
friend vec operator^(const dataT &lhs, const vec &rhs);
```

4.10 Synchronization and atomics

4.10.1 Synchronization types

access::fence_space

```
enum class fence_space : char {
    local_space,
    global_space,
    global_and_local
};
```

memory_order

```
enum class memory_order : int {
    relaxed
};
```

atomic

```
template <typename T,
          access::address_space addressSpace = access::address_space::global_space
         >
class atomic;
```

(constructors)

```
template <typename pointerT>
atomic(multi_ptr<pointerT, addressSpace> ptr);
```

store

```
void store(T operand, memory_order memoryOrder = memory_order::relaxed);
```

load

```
T load(memory_order memoryOrder = memory_order::relaxed) const;
```

exchange

```
T exchange(T operand, memory_order memoryOrder = memory_order::relaxed);
```

compare_exchange_strong

```
Available only when:
 T != float

bool compare_exchange_strong(T &expected, T desired,
                             memory_order successMemoryOrder = memory_
↪order::relaxed,
                             memory_order failMemoryOrder = memory_
↪order::relaxed);
```

fetch_add

```
Available only when:
 T != float

T fetch_add(T operand, memory_order memoryOrder = memory_order::relaxed);
```

fetch_sub

```
Available only when:
 T != float

T fetch_sub(T operand, memory_order memoryOrder = memory_order::relaxed);
```

fetch_and

```
Available only when:
 T != float

T fetch_and(T operand, memory_order memoryOrder = memory_order::relaxed);
```

fetch_or

```
Available only when:
 T != float

T fetch_or(T operand, memory_order memoryOrder = memory_order::relaxed);
```

fetch_xor

```
Available only when:
 T != float

T fetch_xor(T operand, memory_order memoryOrder = memory_order::relaxed);
```

fetch_min

```
Available only when:
 T != float

T fetch_min(T operand, memory_order memoryOrder = memory_order::relaxed);
```

fetch_max

```
Available only when:
 T != float

T fetch_max(T operand, memory_order memoryOrder = memory_order::relaxed);
```

4.11 IO

4.11.1 Streams

stream_manipulator

```
enum class stream_manipulator {
    flush,
    dec,
    hex,
    oct,
    noshowbase,
```

(continues on next page)

(continued from previous page)

```
    showbase,
    noshowpos,
    showpos,
    endl,
    fixed,
    scientific,
    hexfloat,
    defaultfloat
 };
```

Stream manipulators

```
const stream_manipulator flush = stream_manipulator::flush;
const stream_manipulator dec = stream_manipulator::dec;
const stream_manipulator hex = stream_manipulator::hex;
const stream_manipulator oct = stream_manipulator::oct;
const stream_manipulator noshowbase = stream_manipulator::noshowbase;
const stream_manipulator showbase = stream_manipulator::showbase;
const stream_manipulator noshowpos = stream_manipulator::noshowpos;
const stream_manipulator showpos = stream_manipulator::showpos;
const stream_manipulator endl = stream_manipulator::endl;
const stream_manipulator fixed = stream_manipulator::fixed;
const stream_manipulator scientific = stream_manipulator::scientific;
const stream_manipulator hexfloat = stream_manipulator::hexfloat;
const stream_manipulator defaultfloat = stream_manipulator::defaultfloat;
__precision_manipulator__ setprecision(int precision);
__width_manipulator__ setw(int width);
```

Stream Class

```
class stream;
```

(constructors)

```
stream(size_t totalBufferSize, size_t workItemBufferSize, handler& cgh);
```

get_size

```
size_t get_size() const;
```

get_work_item_buffer_size

```
size_t get_work_item_buffer_size() const;
```

get_max_statement_size

```
size_t get_max_statement_size() const;
```

get_max_statement_size() has the same functionality as get_work_item_buffer_size(), and is provided for backward compatibility. get_max_statement_size() is a deprecated query.

operator<<

```
template <typename T>
const stream& operator<<(const stream& os, const T &rhs);
```

CHAPTER

FIVE

GLOSSARY

accelerator Specialized component containing compute resources that can quickly execute a subset of operations. Examples include CPU, FPGA, GPU. See also: *device*

accessor Interface to read and write data contained in a buffer, image, or local memory. Accessors implicitly define the data dependences when kernels and the host access a buffer. See *Accessors*.

application scope Code that executes on the host.

buffers Encapsulates data that is must be accessed by the device. See *Buffers*.

command group scope Code that acts as the interface between the host and device.

command queue Issues command groups concurrently.

compute unit A grouping of processing elements into a 'core' that contains shared elements for use between the processing elements and with faster access than memory residing on other compute units on the device.

device An accelerator or specialized component containing compute resources that can quickly execute a subset of operations. A CPU can be employed as a device, but when it is, it is being employed as an accelerator. Examples include CPU, FPGA, GPU. See also: *accelerator*

device code Code that executes on the device rather than the host. Device code is specified via lambda expression, functor, or kernel class.

fat binary Application binary that contains device code for multiple devices. The binary includes both the generic code (SPIR-V representation) and target specific executable code.

fat library Archive or library of object code that contains object code for multiple devices. The fat library includes both the generic object (SPIR-V representation) and target specific object code.

fat object File that contains object code for multiple devices. The fat object includes both the generic object (SPIR-V representation) and target specific object code.

host A CPU-based system (computer) that executes the primary portion of a program, specifically the application scope and command group scope.

host device A SYCL device that is always present and usually executes on the host CPU.

host code Code that is compiled by the host compiler and executes on the host rather than the device.

images Formatted opaque memory object that is accessed via built-in function. Typically pertains to pictures comprised of pixels stored in format like RGB.

kernel scope Code that executes on the device.

nd-range Short for N-Dimensional Range, a group of kernel instances, or work item, across one, two, or three dimensions.

processing element Individual engine for computation that makes up a compute unit.

single source Denotes that source code for device and host can be in the same file.

SPIR-V Binary intermediate language for representing graphical-shader stages and compute kernels.

sub-group Collection of work-items in a work-group. Arranging computations in sub-groups may enables the use of SIMD instructions.

work-group Collection of work-items that execute on a compute unit.

work-item Basic unit of computation for a single point in the index space processed by a kernel.

CHAPTER

SIX

NOTICES AND DISCLAIMERS

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