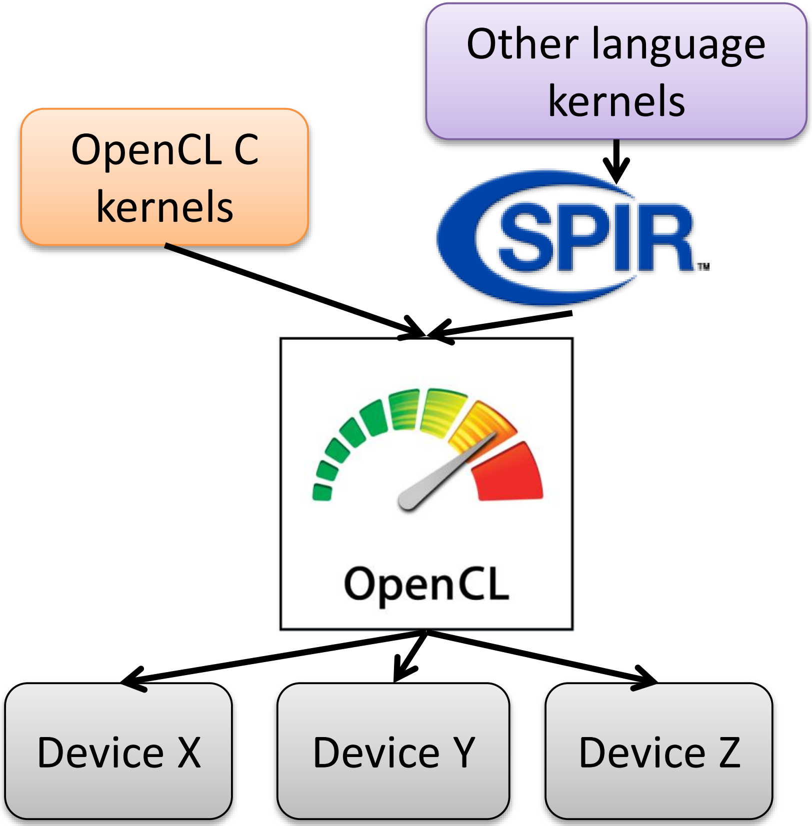
SYCL™ for OpenCL™

Andrew Richards, CEO Codeplay & Chair SYCL Working group

GDC, March 2014

Where is OpenCL today?

- OpenCL: supported by a very wide range of platforms
  - Huge industry adoption
- Provides a C-based kernel language
- NEW: SPIR provides ability to build other languages on top
- Now, we need to provide languages and libraries
- Topic for today: C++



OpenCL and the OpenCL logo are trademarks of Apple Inc.

SYCL for OpenCL

- Pronounced ‘sickle’ to go with ‘spear’ (SPIR)
- Royalty-free, cross-platform C++ programming layer
  - Builds on concepts portability & efficiency of OpenCL
  - Ease of use and flexibility of C++
- Single-source C++ development
  - C++ template functions can contain host & device code
  - Construct complex reusable algorithm templates that use OpenCL for acceleration

SYCL Roadmap

- Today
  - Releasing a provisional specification to enable feedback
  - Developers can provide input into standardization process
  - Feedback via Khronos forums
- Next steps
  - Full specification, based on feedback
  - Conformance testsuite to ensure compatibility between implementations
  - Release of implementations

What we want to achieve

- We want to enable a C++ on OpenCL ecosystem
  - With C++ libraries supported on OpenCL
  - C++ tools supported on OpenCL
  - Aim to achieve long-term support for OpenCL features with C++
  - Good performance of C++ software on OpenCL
  - Multiple sources of implementations
  - Enable future innovation

Where can I get SYCL?

Codeplay is working on an implementation

It's an open, royalty-free standard

Anyone can implement it

Simple example

Does everything* expected of an OpenCL program: compilation, startup, shutdown, host fall-back, queue-based parallelism, efficient data movement.

* (this sample doesn't catch exceptions)

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

int main ()
{
    int result; // this is where we will write our result

    {  // by sticking all the SYCL work in a {} block, we ensure
       // all SYCL tasks must complete before exiting the block

                       //  create a queue to work on
        cl::sycl::queue myQueue;

         // wrap our result variable in a buffer
        cl::sycl::buffer<int> resultBuf (&result, 1);

         // create some ‘commands’ for our ‘queue’
        cl::sycl::command_group (myQueue, [&] ()
        {
            // request access to our buffer
            auto writeResult = resultBuf.access<cl::sycl::access:write_only> ();

            // enqueue a single, simple task
            single_task(kernel_lambda<class simple_test>([=] ()
            {
                writeResult [0] = 1234;
            }
        }); // end of our commands for this queue

    } // end scope, so we wait for the queue to complete

    printf (“Result = %d\n”, result);
}
```

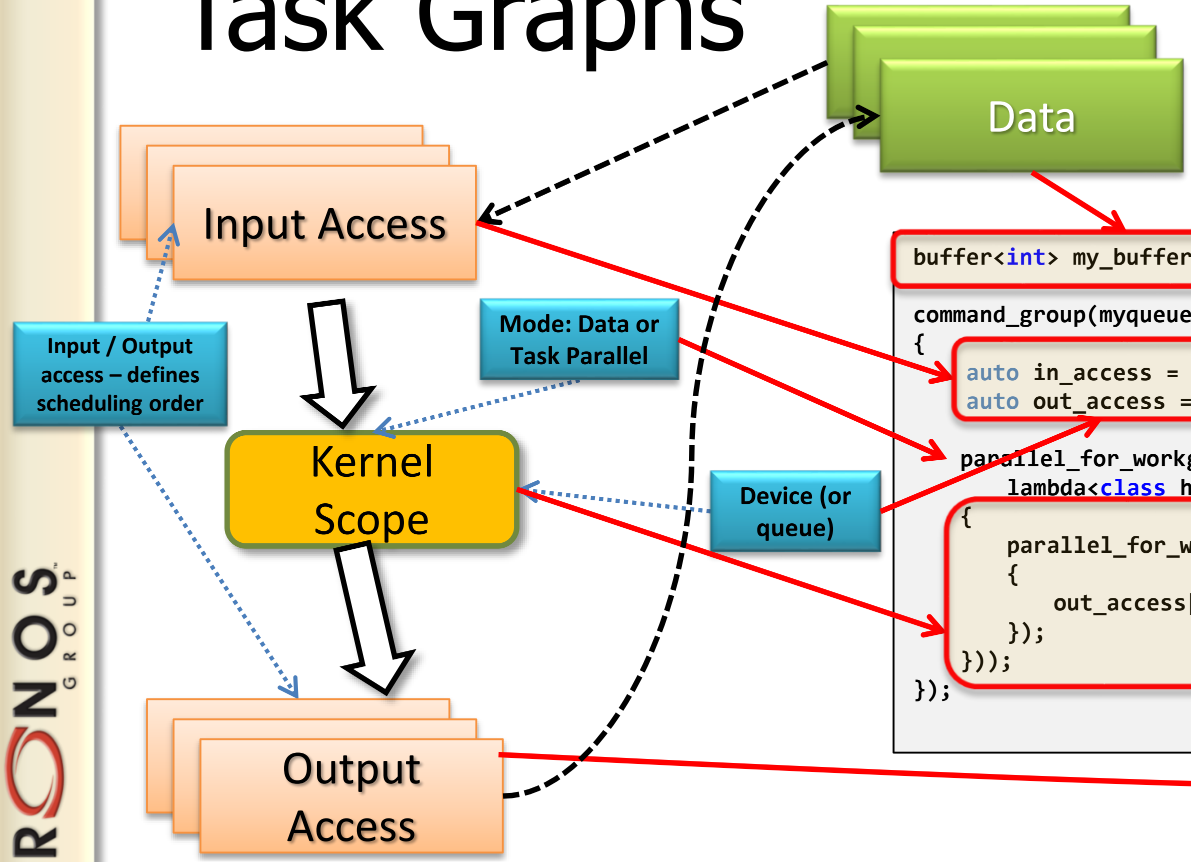
FEATURES OF SYCL

Default synchronization

- Uses C++ RAII
  - Simple to use
  - Clear, obvious rules
  - Common in C++

```
int my_array [20];

{
    cl::sycl::buffer my_buffer (my_array, 20); // creates the buffer
    // my_array is now taken over by the SYCL system and its contents undefined

    {
        auto my_access = my_buffer.get_access<cl::sycl::access::read_write,
                                              cl::sycl::access::host_buffer> ();
        /* The host now has access to the buffer via my_access.
           This is a synchronizing operation - it blocks until access is ready.
           Access is released when my_access is destroyed
           */
    }
    // access to my_buffer is now free to other threads/queues
}
/* my_buffer is destroyed. Waits for all threads/queues to complete work on
   my_buffer. Then writes any modified contents of my_buffer back to
   my_array, if necessary.
   */
```

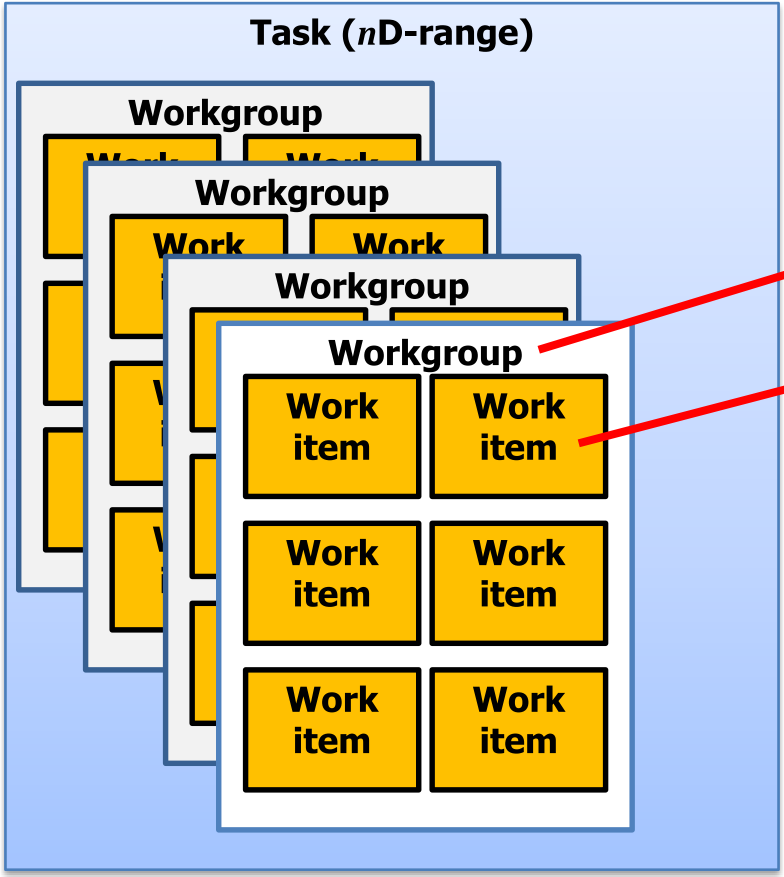
Task Graphs



SYCL separates data storage (buffers) from data access (accessors). This allows easy, safe, efficient scheduling

```
buffer<int> my_buffer(data, 10);

command_group(myqueue, [&]()
{
    auto in_access = my_buffer.access<cl::sycl::access:read_only>();
    auto out_access = my_buffer.access<cl::sycl::access:write_only>();

    parallel_for_workgroup(nd_range(range(size), range(groupsize)),
        lambda<class hierarchical>([=](group_id group)
    {
        parallel_for_workitem(group, [=](tile_id tile)
        {
            out_access[tile.global()] = in_access[tile.global()] * 2;
        });
    }));
});
```

Hierarchical Data Parallelism




```
buffer<int> my_buffer(data, 10);

command_group(my_queue, [&]()
{
    auto in_access = my_buffer.access<cl::sycl::access:read_only>();
    auto out_access = my_buffer.access<cl::sycl::access:write_only>();

    parallel_for_workgroup(nd_range(range(size), range(groupsize)),
        lambda<class hierarchical>([=](group_id group)
    {
        parallel_for_workitem(group, [=](tile_id tile)
        {
            out_access[tile] = in_access[tile] * 2;
        });
    }));
});
```

Advantages:

1. **Easy to understand the concept of work-groups**
2. **Performance-portable between CPU and GPU**
3. **No need to think about barriers (automatically deduced)**
4. **Easier to compose components & algorithms**
    - **e.g. *Kernel fusion***

Single source

- Developers want to write templates, like:

```
parallel_sort<MyClass> (myData);
```

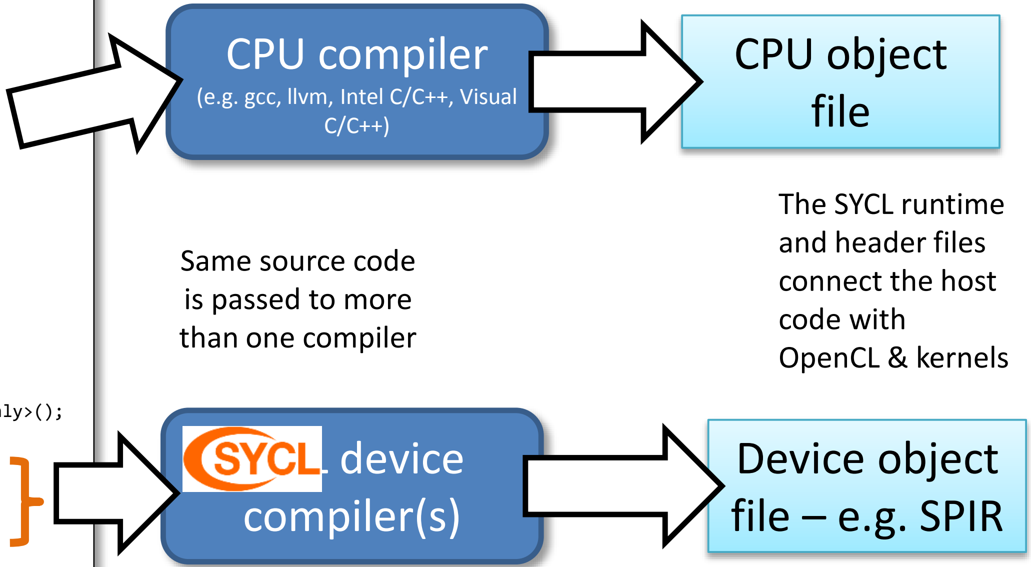
- This requires a single template function that includes both host and device code
  - The host code ensures the right data is in the right place
  - Type-checking (and maybe conversions) required

Choose your own host compiler

- Why?
  - Developers use a lot of CPU-compiler-specific features (OS integration, for example) - *SYCL supports this*
  - The kind of developer that wants to accelerate code with OpenCL will often use CPU-specific optimizations, intrinsic functions etc. - *SYCL supports this*
  - For example, a developer will think it reasonable to accelerate CPU code with OpenMP and GPU code with OpenCL, but want to share source between the 2. - *SYCL supports this*
- OpenCL C supports this approach, but without single source
  - SYCL additionally allows single source

Choose your own host compiler

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

int main()
{
  int result; // this is where we will write our result

  { // by sticking all the SYCL work in a {} block, we ensure
    // all SYCL tasks must complete before exiting the block

    //  create a queue to work on
    cl::sycl::queue myQueue;

    // wrap our result variable in a buffer
    cl::sycl::buffer<int> resultBuf(&result, 1);

    // create some ‘commands’ for our ‘queue’
    cl::sycl::command_group(myQueue, [&]()
    {
      // request access to our buffer
      auto writeResult = resultBuf.access<cl::sycl::access:write_only>();

        // enqueue a single, simple task
      cl::sycl::single_task(kernel_lambda<class simple_test>([=]()
      {
        writeResult[0] = 1234;
      }
    }); // end of our commands for this queue

  } // end scope, so we wait for the queue to complete

  printf(“Result = %d\n”, result);
}
```



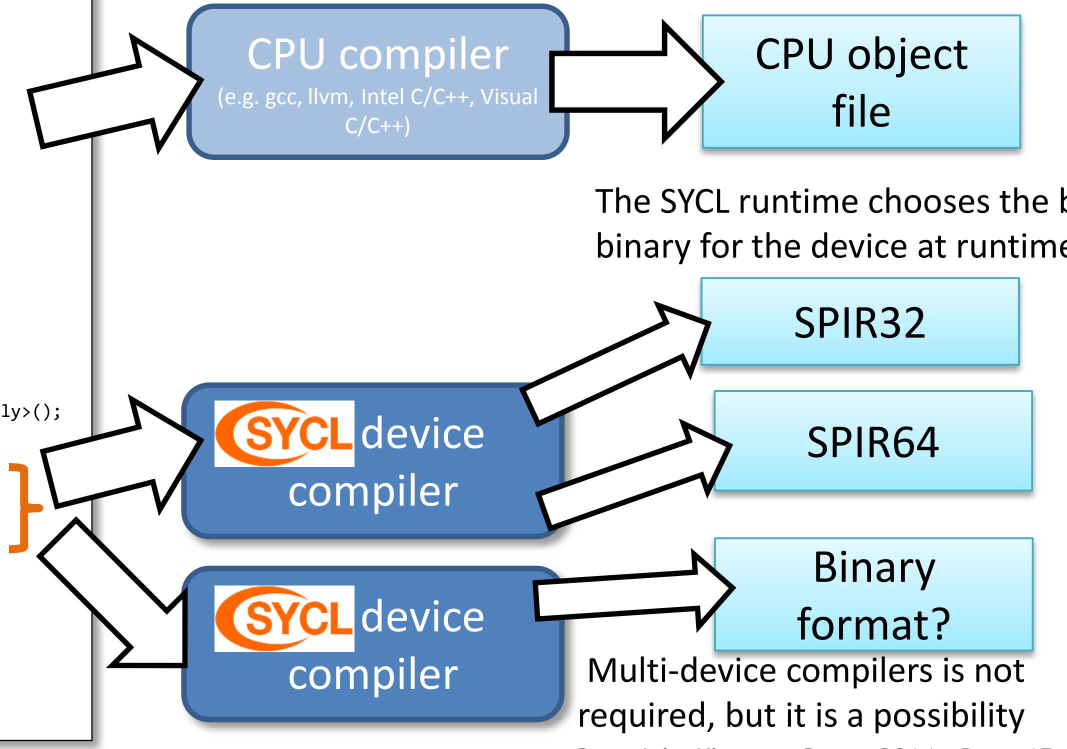
Same source code is passed to more than one compiler

The SYCL runtime and header files connect the host code with OpenCL & kernels

SYCL can be implemented multiple ways, including as a single compiler, but the multi-compiler option is a possible implementation of the specification

Support multiple device compilers

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

int main()
{
  int result; // this is where we will write our result

  { // by sticking all the SYCL work in a {} block, we ensure
    // all SYCL tasks must complete before exiting the block

    //  create a queue to work on
    cl::sycl::queue myQueue;

    // wrap our result variable in a buffer
    cl::sycl::buffer<int> resultBuf(&result, 1);

    // create some ‘commands’ for our ‘queue’
    cl::sycl::command_group(myQueue, [&]()
    {
      // request access to our buffer
      auto writeResult = resultBuf.access<cl::sycl::access:write_only>();

        // enqueue a single, simple task
      cl::sycl::single_task(kernel_lambda<class simple_test>([=]()
      {
        writeResult[0] = 1234;
      }
    }); // end of our commands for this queue

  } // end scope, so we wait for the queue to complete

  printf(“Result = %d\n”, result);
}
```

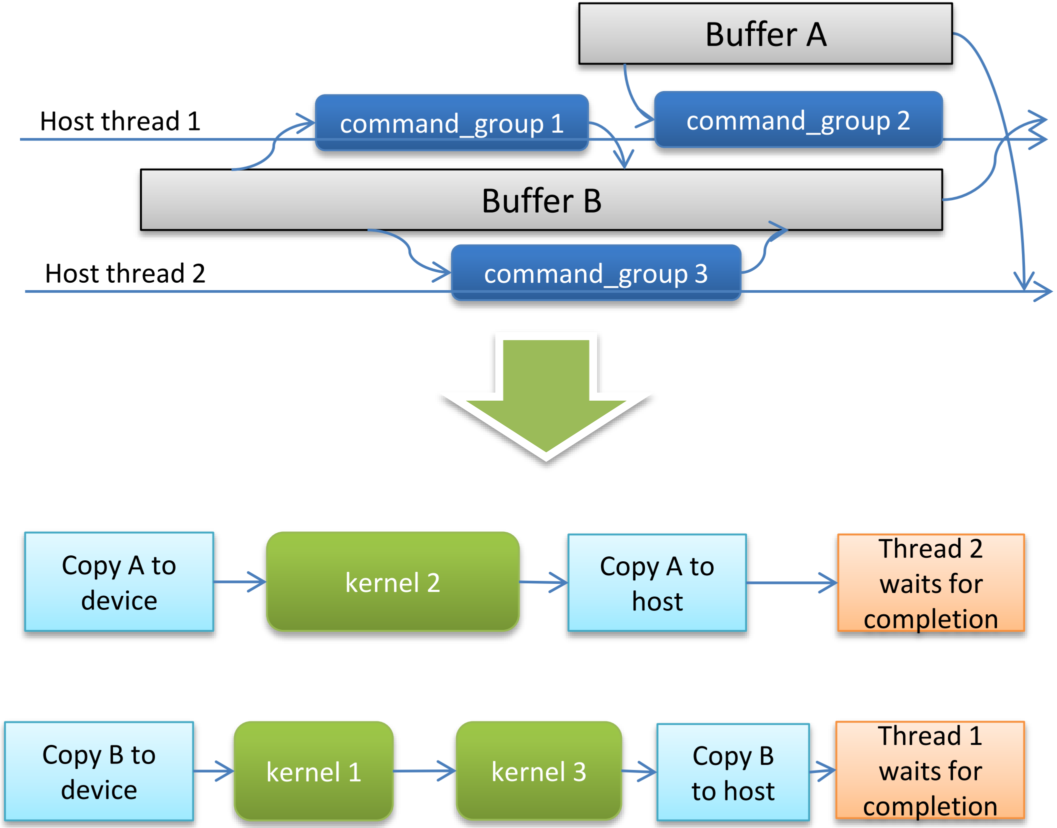


Can use a common library

- Can use #ifdefs to implement common libraries differently on different compilers/devices
  - e.g. defining domain-specific maths functions that use OpenCL C features on device and CPU-specific intrinsics on host
  - Or, define your own `parallel_for` templates that use (for example) OpenMP on host and OpenCL on device
  - The C++ code that calls the library function is shared across platforms, but the library is compiled differently depending on host/device

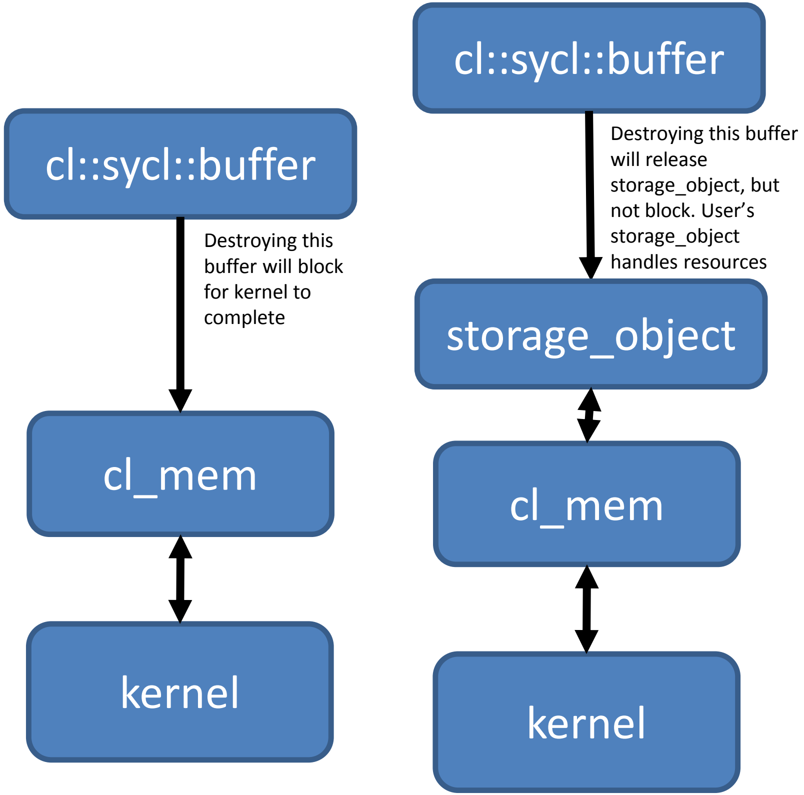
Asynchronous operation

- A `command_group` is:
  - an atomic operation that includes all memory object creation, copying, mapping, and execution of kernels
  - enqueued, non-blocking
  - scheduling dependencies tracked automatically
  - thread-safe
- Only blocks on return of data to host



Low-latency error-handling

- We use exception-handling to catch errors
- We use the standard C++ RAII approach
  - However, some developers require destructors to return immediately, even on error.
  - But the error-causing code may be asynchronously running. So such a developer needs to leave code running and resources released later. We support with `*storage objects*'



Relationship to core OpenCL

- Built on top of OpenCL
- Runs kernels on OpenCL devices

- Can construct SYCL objects from OpenCL objects and OpenCL objects obtained from SYCL objects

OpenCL/OpenGL interop

- Built directly on top of OpenCL interop extension
  - SYCL uses the same structures, macros, enums etc
- Lets developers share OpenGL images/textures etc with SYCL as well as OpenCL
- Only runs on OpenCL devices that support one of the CL/GL interop extensions
- Users can query a device for extension support first

The specification

An overview of the specification itself

The specification itself

- http://www.khronos.org/**opencl/sycl**

Structure

(Similar to OpenCL structure)

- Section 1: Introduction
- Section 2: SYCL Architecture
  - Very similar to OpenCL architecture
- Section 3: SYCL Programming Interface
  - This is the C++ interface that works across host and device
- Section 4: Support of non-core OpenCL features
- Section 5: Device compiler
  - This is the C++ compiler that compiles kernels
- Appendix A: Glossary

Architecture 1

- SYCL has *queues* and *command-groups*
  - Queues are identical to OpenCL C
  - Command-groups enqueue multiple OpenCL commands to handle data movement, access, synchronization etc
- SYCL has *buffers* and *images*
  - Built on top of OpenCL buffers and images, but abstracts away the different queues, devices, platforms maps, copying etc.
  - Can create SYCL buffers/images from OpenCL buffers/images, or obtain OpenCL buffers/images from SYCL buffers/images (but need to specify context).

Architecture 2

- In SYCL, access to data is defined by *accessors*
  - Users constructs within command-groups: used to define types of access and create data movement and synchronization commands
- Error handling
  - Synchronous errors handled by C++ exceptions
  - Asynchronous errors handled via user-supplied error-handler based on C++14 proposal [n3711]

Architecture: kernels

- Kernels can be:
  - Single task: A non-data-parallel task
  - Basic data parallel: NDRange with no workgroup
  - Work-group data parallel: NDRange with workgroup
  - Hierarchical data parallel: compiler feature to express workgroups in more template-friendly form
- Restrictions on language features *in kernels*, no:
  - function pointers, virtual methods, exceptions, RTTI …
- Vector classes can work efficiently on host & device
- OpenCL C kernel library available in kernels

Architecture: advanced features

- Storage objects
  - used to define complex ownership/synchronization
- All OpenCL C features supported in kernels
  - (but maybe in a namespace)
  - Including swizzles
- All host compiler features supported in host code
- Wrappers for: programs, kernels, samplers, events
  - Allows linking OpenCL C kernels with SYCL kernels

SYCL Programming Interface

- Defined as a C++ templated class library
- Some classes host-only, some (e.g. accessors, vectors) host-and-device
- Only uses standard C++ features, so code written to this library sharable between host and device.
- Classes have methods to construct from OpenCL C objects and obtain OpenCL C objects wherever possible
- Events, buffers, images work across multiple devices and contexts

SYCL Extensions

- Defines how OpenCL device extensions (e.g. CL/GL interop) are available within SYCL
- Availability is based on device support
- Host can also support extensions
- Queries are provided to allow users to query for device and host support for extensions
- OpenCL extensions not in the SYCL spec are still usable within SYCL due to deep OpenCL integration and interop

SYCL Device Compiler

- Defines the language features available in kernels
- Supports restricted standard C++11 feature-set
  - Restricted by capabilities of OpenCL 1.2 devices
  - Would be enhanced for OpenCL 2.0 in the future
- Defines how OpenCL kernel language features are available within SYCL
  - Users using OpenCL kernel language features need to ensure their code is compilable for host. May need `#ifdef`

What now?

- We are releasing this *provisional* specification to get feedback from developers
  - So please give feedback! Khronos forums are best place
  - http://www.khronos.org/**opencl/sycl**
- Next steps
  - Full specification, based on feedback
  - Conformance test suite to ensure compatibility between implementations
  - Release of implementations