C++ and Khronos computing standards

OpenCL, SYCL (and Vulkan, OpenVX?)

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KHRONOS GROUP

Remember C++ ?

2-line description by Bjarne Stroustrup

- Direct mapping to hardware
- Zero-overhead abstraction

Modern Python/C/Modern C++/Old C++

- Python 3.11

```
v = [ 1, 2, 3, 5, 7 ]
print(v)
```

```
https://godbolt.org/z/Kq9vc1jhY
```

- C99 (also usable in C++)

```
#include <stdio.h>
int a[] = { 1, 2, 3, 5, 7 };
for (int i = 0;
     i < sizeof(a)/sizeof(a[0]);
     ++i)
  printf("%d ", a[i]);
```

- C++23

```
import std;
std::vector v { 1, 2, 3, 5, 7 };
std::println("{}", v);
```

- C++03

```
#include <iostream>
#include <vector>
std::vector<int> v;
v.push_back(1);
v.push_back(2);
v.push_back(3);
v.push_back(5);
v.push_back(7);
for (std::vector<int>::iterator i =
       v.begin(); i != v.end(); ++i)
  std::cout << *i << std::endl;
```

But...
No heterogeneous computing in C++

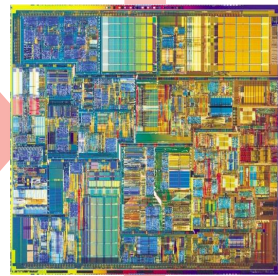
COLLADA

3D for the Web

- Real-time apps and games in-browser
- Efficiently delivering runtime 3D assets

WebGL glTF

NNEF OpenVX



OpenGL|SC OpenVG

Vulkan OpenGL|ES

OpenGL OpenXR

Vision and Neural Networks

- Tracking and odometry
- Scene analysis/understanding
- Neural Network inferencing

Real-time 2D/3D

- Virtual and Augmented Reality
- Cross-platform gaming and UI
- CG Visual Effects
- CAD and Product Design
- Safety-critical displays

SPIR SYCL

OpenCL

Parallel Computation

- Machine Learning acceleration
- Embedded vision processing
- High Performance Computing (HPC)

OpenCL and C++

Non-single source API

- Host C API to control the device with various C++ wrappers and other languages
  - Old Khronos C++ wrapper v1 (C++03)
  - Less old Khronos C++ wrapper v2 (C++11) `https://github.khronos.org/OpenCL-CLHPP` `https://github.com/KhronosGroup/OpenCL-Headers`
  - Boost.Compute https://github.com/boostorg/compute
  - + everybody developing own C++ (or other languages) wrappers
- Kernel source code or binary (SPIR or target)
  - Legacy OpenCL C source code
  - OpenCL C++ 1.0 for OpenCL 2.2
    - Inspired by SYCL 2.2 modernism but incompatible with legacy OpenCL C
  - Khronos-friendly-but-independent *C++ for OpenCL* in Clang/LLVM `https://clang.llvm.org/docs/OpenCLSupport.html` `https://www.khronos.org/opencl/assets/CXX_for_OpenCL.html`
- Split-source + JIT ⇝ easy meta-programming with strings

Vector addition with OpenCL C++ host API v2

```cpp
#include <iostream>
#include <iterator>

#define CL_HPP_ENABLE_EXCEPTIONS
#include <CL/cl2.hpp>

constexpr size_t N = 3;
using Vector = float[N];

int main() {
  Vector a = { 1, 2, 3 };
  Vector b = { 5, 6, 8 };
  Vector c;

  // The input read-only buffers for OpenCL on default context
  cl::Buffer buffer_a { std::begin(a), std::end(a), true };
  cl::Buffer buffer_b { std::begin(b), std::end(b), true };

  // The output buffer for OpenCL on default context
  cl::Buffer buffer_c { CL_MEM_WRITE_ONLY, sizeof(c) };

  // Construct an OpenCL program from the source file
  const char kernel_source[] = R"(
__kernel void vector_add(const __global float *a,
                         const __global float *b,
                         __global float *c) {
  c[get_global_id(0)] = a[get_global_id(0)] + b[get_global_id(0)];
}
)";

  // Compile and build the program
  cl::Program p { kernel_source, true };
  // Create the kernel functor taking 3 buffers as parameter
  cl::KernelFunctor<cl::Buffer, cl::Buffer, cl::Buffer> k
    { p, "vector_add" };

  // Call the kernel with N work-items on default command queue
  k(cl::EnqueueArgs(cl::NDRange(N)), buffer_a, buffer_b, buffer_c);

  // Get the output data from the accelerator
  cl::copy(buffer_c, std::begin(c), std::end(c));

  std::cout << std::endl << "Result:" << std::endl;
  for(auto e : c)
    std::cout << e << " ";
  std::cout << std::endl;
}
```

https://github.com/keryell/heterogeneous_examples/blob/main/vector_add/OpenCL-CLHPP/opencl_vector_add.cpp

SYCL 2020 ≡ heterogeneous simplicity with modern C++

```
#include <iostream>
#include <sycl/sycl.hpp>
constexpr int n = 32;

int main () {
  sycl::buffer<int> buf { n };
  sycl::queue {}.submit([&](auto &h) {
      sycl::accessor a { buf, h, sycl::write_only, sycl::no_init };
      h.parallel_for(n, [=](auto i) { a[i] = i; });
  });
  for (sycl::host_accessor a { buf }; auto e : a)
      std::cout << e << std::end;
}
```

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Abstract storage

- Host or device (remote) memory

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Code executed on device (“kernel”)

- “Single-source”
- Seamless integration in host code
- Type-safety
- Asynchronous execution

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Accessor

- Express access intention
- Implicit data flow graph
- Automatic data transfers across devices
- Overlap computation & communication

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Queue

- Direct work to specific accelerator
- Submission of a command group

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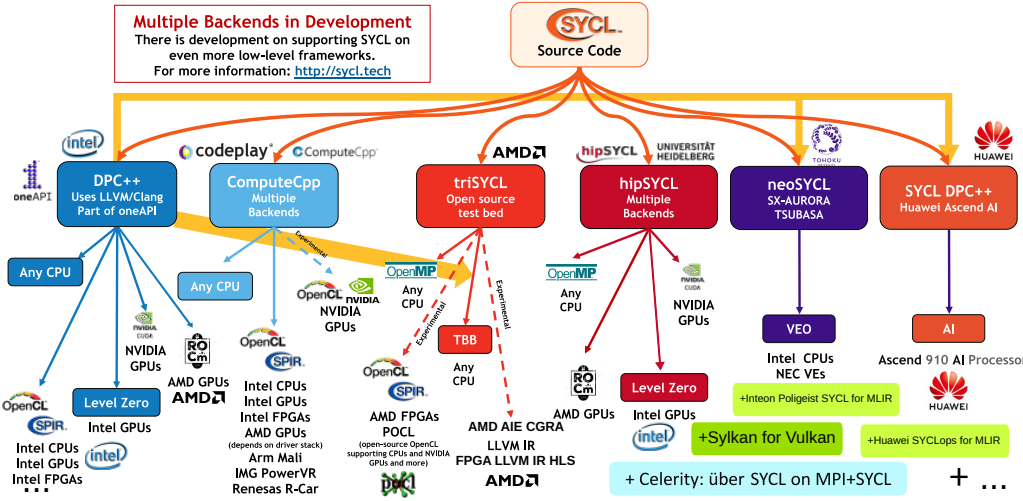
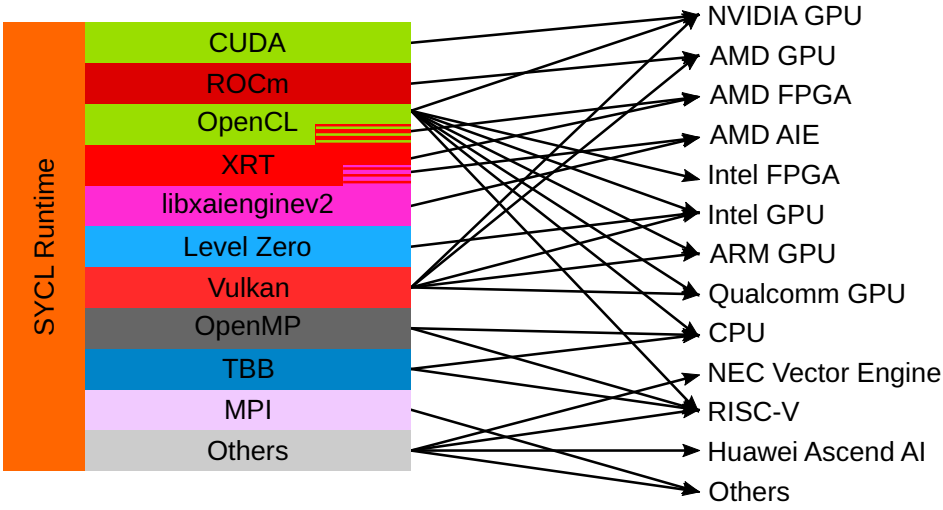
SYCL grew beyond OpenCL HLM



https://www.khronos.org/blog/sycl-2020-what-do-you-need-to-know

Some of the existing SYCL backends



Unique SYCL feature: interoperability with backends

- Porting existing code
  - Code already based on OpenCL/CUDA/OpenMP/HIP/... (or whatever backend)
  - Want to change just part of application to use SYCL
- Incorporating a backend module into a SYCL application
  - Application based on SYCL
  - Want to call some OpenCL/CUDA/OpenMP/HIP/... library (or whatever backend)
- Take advantage of backend-specific features
- Disadvantage: reduces portability!
  - Not all implementations may support your backend
- ⇝ Unique feature of SYCL!

Aksel ALPAY, Thomas APPLENCOURT, Gordon BROWN, Ronan KERYELL and Gregory LUECK. “Using interoperability mode in SYCL 2020.” In SYCLcon 2022: International Workshop on SYCL. Association for Computing Machinery, May 2022. doi:10.1145/3529538.3529997.

`https://www.iwocl.org/wp-content/uploads/39-presentation-iwocl-syclcon-2022-aksel.pdf`

`https://www.youtube.com/watch?v=XIPhuesdqYE`

SYCL interoperability as OpenCL C++ wrapper

```cpp
#include <cassert>
#include <cstdlib>
#include <sycl/sycl.hpp>
#include <CL/opencl.h>

constexpr int size = 4;

auto check_error(auto&& function) {
  cl_int err;
  auto ret = function(&err);
  if (err != CL_SUCCESS)
    std::exit(err);
  return ret;
};

int main() {
  sycl::buffer<int> a { size };
  sycl::buffer<int> b { size };
  sycl::buffer<int> c { size };

  {
    sycl::host_accessor a_a { a };
    sycl::host_accessor a_b { b };
    for (int i = 0; i < size; ++i) {
      a_a[i] = i;
      a_b[i] = i + 42;
    }
  }

  sycl::queue q;
  std::array kernel_source { R"(
      __kernel void vector_add(const __global float *a,
                               const __global float *b,
                               __global float *c) {
        c[get_global_id(0)] = a[get_global_id(0)] + b[get_global_id(0)];
      }
      )" };
  cl_context oc = sycl::get_native<sycl::backend::opencl>(q.get_context())
  auto program = check_error([&](auto err) {
    return clCreateProgramWithSource(oc, kernel_source.size(),
                                     kernel_source.data(), nullptr, err);
  });
  check_error([&](auto err) {
    return (*err =
              clBuildProgram(program, 0, nullptr, nullptr, nullptr, null
  });
  sycl::kernel k = sycl::make_kernel<sycl::backend::opencl>(
      check_error(
          [&](auto err) { return clCreateKernel(program, "vector_add", err
      q.get_context());

  q.submit([&](sycl::handler& cgh) {
    cgh.set_args(sycl::accessor { a, cgh, sycl::read_only },
                 sycl::accessor { b, cgh, sycl::read_only },
                 sycl::accessor { c, cgh, sycl::write_only, sycl::no_init
    cgh.parallel_for(size, k);
  });

  {
    sycl::host_accessor a_a { a };
    sycl::host_accessor a_b { b };
    sycl::host_accessor a_c { c };
    for (int i = 0; i < size; ++i)
      assert(a_c[i] == a_a[i] + a_b[i]);
  }
}
```

https://github.com/keryell/heterogeneous_examples/blob/main/vector_add/SYCL/vector_add_OpenCL_interoperability.cpp

Vulkan C++ wrapper

- `https://github.com/KhronosGroup/Vulkan-Hpp`

```
vk::Instance instance = vk::su::createInstance( AppName, EngineName );
vk::PhysicalDevice physicalDevice = instance.enumeratePhysicalDevices().front();
```

- Specific namespace for RAII (Resource Acquisition Is Initialization) API version ≈ SYCL objects

```
vk::raii::Context context;
vk::raii::Instance instance = vk::raii::su::makeInstance(context, AppName, EngineName);
vk::raii::PhysicalDevices physicalDevices { instance };
```

- C++20 designated initializers *à la* Python

```
vk::ApplicationInfo applicationInfo{ .pApplicationName   = AppName,
                                     .applicationVersion = 1,
                                     .pEngineName        = EngineName,
                                     .engineVersion      = 1,
                                     .apiVersion         = VK_API_VERSION_1_1 };
```

- C++20 modules are coming
- Other C++ wrappers available too (`https://github.com/andy-thomason/Vookoo`)

Culture

- OpenCL : mostly runtime API ⇝ no big C++ culture inside OpenCL WG ☹
  - Designing C++ API requires some cultural knowledge
  - Several vendor implementations are forks from initial Apple contribution
    - Do not benefit from open-source goodies
    - Huge technical debt, no portable IR,. . .
    - Require other producers to rely on LLVM IR or MLIR to OpenCL C backend
- SYCL is all about C++
  - Need to be close to Clang/LLVM upstream
    - Otherwise painful technical debt management
- Vulkan has some C++ culture in the host API

Conclusion

- Do we care about C++?
- Who wants to push C++ inside the OpenCL WG?
- C++ and API: large design space, depend on C++ version...
- Cultural? Market? Politics? Religious?
- Provide directions to programmers interested by C++ to pick an API?
- Just split-source vs single-source independent from C++ aspects?
  - Like CUDA Driver vs CUDA Runtime?
- Look also at Vulkan C++ which is split-source too?