A COMPARATIVE ANALYSIS OF KOKKOS AND SYCL AS HETEROGENEOUS PARALLEL PROGRAMMING MODELS FOR C++ APPLICATIONS

Jeff Hammond, Michael Kinsner, James Brodman
Intel Corporation

IWOCL DHPCC++ 2019 (13 May 2019)
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The PowerPoint C++ compiler is very lax about syntax – the code you see on the slides was derived from working code but has been modified for aesthetic appeal and may contain errors.

Hanlon’s Razor (blame stupidity, not malice).
SYCL: Reactive and Proactive Motivation

Reactive to OpenCL Pros and Cons:

• OpenCL has a well-defined, portable execution model.
• OpenCL is prohibitively verbose for many application developers.
• OpenCL remains a C API and only recently supported C++ kernels.
• Disjoint host and kernel source code is awkward.

Proactive about Future C++:

• SYCL is based on purely modern C++ and should feel familiar to C++11 users.
• SYCL expected to run ahead of C++Next regarding heterogeneity and parallelism.
• Not held back by C99 or C++03 compatibility goals.
Kokkos: Motivation and Goals

• DOE wants/needs to run applications across a wide range of architectures:
  • CPU w/ big or small cores (e.g. Intel® Xeon® and Xeon Phi™)
  • GPU w/ and w/o unified memory (e.g. LLNL Sierra and ORNL Titan)
  • No common programming model across all platforms due to inconsistent vendor support for OpenMP* and OpenCL*

• **Goal: write one implementation which:**
  • *compiles and runs on multiple architectures*
  • *obtains performant memory access patterns across architectures*
  • *can leverage architecture-specific features where possible.*

The goal text above is taken verbatim from the Kokkos SC15 tutorial.
Kokkos will support both of these machines...
PARALLEL EXECUTION MODEL
Parallel execution – where to run by default?

Default:

`cl::sycl::host_selector()`

“...selects a SYCL device based on an implementation defined heuristic. Must select a host device if no other suitable OpenCL device can be found.”

Default:

Kokkos::initialize(..)

“...initializes the default execution space Kokkos::DefaultExecutionSpace.”

The default depends on the Kokkos configuration. Kokkos documents the rule as:

ROCm > CUDA > OpenMP > Threads

(the priority of other cases is presumably documented in the source code)
Available devices:

- `cl::sycl::host_selector`{}
- `cl::sycl::cpu_selector`{}
- `cl::sycl::gpu_selector`{}
- `cl::sycl::accelerator_selector`{}

Available devices:

- Kokkos::Threads
- Kokkos::OpenMP
- Kokkos::OpenMPTarget
- Kokkos::Cuda
- Kokkos::ROCm
- Kokkos::HPX
- Kokkos::Qthreads
Parallel execution – example

queue q(cpu_selector{});

buffer<double,1> d_A { h_A, range<1>(n) };

q.submit([&](handler& h) {
    auto A = d_A.get_access<RW>(h);
    h.parallel_for<>(range<1>{n}, [=] (item<1> i){
        A[i]++;
    });
});
q.wait();

namespace K = Kokkos;
K::initialize(argc, argv);
typedef K::OpenMP Space;
typedef K::View<double*, Space> vector;
vector A("A", n);

auto range = K::RangePolicy<Space>(0,n);
K::parallel_for(range, KOKKOS_LAMBDA(int i) {
    A[i]++;
});
fence();
Array allocation parameters

SYCL buffer class parameters:
- Datatype
- Dimensions (1,2,3)
- Allocator

Accessors control access permissions.

Kokkos view class parameters:
- Datatype (built-in or struct of built-in)
- Dimensions (0,1,2,3,4,5,6,7,8)
- Space (optional)

Views can be const (assign from non-const view).

The Space may constrain the access rules (e.g. GPU cannot access host data unless UVM supported).

https://github.com/kokkos/kokkos/wiki/View
Accessing and moving data

SYCL data movement between host\(\rightleftharpoons\)device(s) usually implicit based on DAG deps, but explicit available for tuning

**Implicit:**
- DAG dependence triggers data movement prior to kernel launch

**Explicit:**
- `cl::sycl::handler::copy(..)` requires source to be at least as big as target.
- `cl::sycl::handler::update_host(..)`

“Kokkos never performs a hidden deep copy.”

Kokkos::deep_copy (out, in) but there are strict rules on what can be copied:

1. Identical memory layout and padding (likely different for host and device, e.g. OpenMP and CUDA)
2. HostMirror b = create_mirror(a)
3. HostMirror b = create_mirror_view(a)

2 always copies but 3 is a no-op when a is host memory.

https://github.com/kokkos/kokkos/wiki/View
COMPUTE PRIMITIVES
Parallel for and nested loops

// SYCL supports 1..3 dimensions

h.parallel_for<range<2>{n,n}, [=] (item<2> it) {
    id<2> ij{it[0],it[1]};
    id<2> ji{it[1],it[0]};
    B[ij] = A[ji];
});

h.parallel_for<range<2>{n,n}, [=] (item<2> it) {
    B[it[0] * n + it[1]] = A[it[1] * n + it[0]];
});

// MDRP = MDRangePolicy

// MDRP supports 2 to 6 dimensions

auto policy = K::MDRP<K::Rank<2>>({0,0},{n,n},{t,t});

K::parallel_for(policy, KOKKOS_LAMBDA(int i, int j) {
    B(i,j) = A(j,i);
});

I haven’t figured out which one I’m supposed to use, because the performance of the former has been much worse in some of my experiments...

Kokkos supports tiling and access pattern (row or column major), but it’s not clear how useful these are...

https://github.com/kokkos/kokkos/wiki/Kokkos::MDRangePolicy
Other parallel patterns

Like OpenCL* and CUDA* C/C++, SYCL assumes the user or a library implements patterns like reduce and scan.

Intel is working on a language extension...

Khronos SYCL parallel STL is a library solution:

namespace pstl = std::experimental::parallel;

cl::sycl::queue q;
pstl::sycl::sycl_execution_policy<> snp(q);
int result = pstl::reduce(snp, v.begin(), v.end());

K::parallel_reduce – reductions with built-in and custom reduction operators.

K::parallel_scan – prefix sum.

Kokkos built-in reductions include everything that MPI_Reduce supports, even the dumb stuff (prod).

Example:

double out(0);
K::parallel_reduce(n, [=] (int i, double &tmp) {
    tmp += ...;
}, out);

https://github.com/KhronosGroup/SyclParallelSTL
https://github.com/kokkos/kokkos/wiki/Data-Parallelism
NESTED PARALLELISM

This is where it all started for us 😊
# Kokkos vs SYCL

<table>
<thead>
<tr>
<th>Kokkos Name</th>
<th>SYCL Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thread team</td>
<td>Work-group</td>
</tr>
<tr>
<td>Thread league</td>
<td>Global range</td>
</tr>
<tr>
<td>Team scratch pad memory</td>
<td>Local memory</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Kokkos Construct</th>
<th>SYCL Construct</th>
</tr>
</thead>
<tbody>
<tr>
<td>parallel_for( TeamPolicy )</td>
<td>parallel_for_work_group(#wg, wg_size)</td>
</tr>
<tr>
<td>parallel_for( TeamThreadRange )</td>
<td>parallel_for_work_item(flex_range)</td>
</tr>
<tr>
<td>parallel_for( ThreadVectorRange )</td>
<td>parallel_for_sub_group</td>
</tr>
<tr>
<td>Barrier not implicit on ParFor( TeamThreadRange)</td>
<td>Implicit barrier at PFWI boundaries</td>
</tr>
<tr>
<td>single( PerTeam ) – execute λ once per team</td>
<td>Code at PFWG scope</td>
</tr>
<tr>
<td>single( PerThread ) – execute λ in single vec lane</td>
<td>Code at PFSG scope</td>
</tr>
</tbody>
</table>
Kokkos: nested parallelism

// TTR = TeamThreadRange
// TVR = ThreadVectorRange

typedef typename K::TeamPolicy<>::member_type tm;

struct foo {
    void operator() ( const tm& thread) const {
        int i = thread.league_rank();
        K::parallel_for(K::TTR(thread,jmax), [=] (const int& j) {
            K::parallel_for(K::TVR(thread,kmax), [=] (const int& k) {
                printf("foo %d %d %d
", i, j, k);
            });
        });
    }
};

const K::TeamPolicy<> policy( imax , K::AUTO , 1);
K::parallel_for( policy , foo() );
SYCL: nested parallelism

```c
q.submit([&](cl::sycl::handler& h) {
  h.parallel_for_work_group<class foo>(
      cl::sycl::nd_range<1>(imax*jmax,jmax),
      [=] (cl::sycl::group<1> g) {
        g.parallel_for_work_item( [=] (cl::sycl::h_item<1> i) {
          printf("foo g=%zu i=%zu\n", g.get_id(0), i.get_global_id());
        });
    });
});
```

```c
foo g=0 i=1
foo g=0 i=2
foo g=0 i=0
foo g=1 i=4
foo g=1 i=5
foo g=1 i=3
foo g=2 i=7
foo g=2 i=6
foo g=2 i=8
foo g=3 i=10
foo g=3 i=11
foo g=3 i=9
```

```c
int imax = 4;
int jmax = 3;
int kmax = 2;
```
using namespace cl::sycl;

q.submit([&](handler& h) {
    h.parallel_for_work_group<class bar>(
        nd_range<2>({imax*kmax,jmax*kmax}, {kmax,kmax}),
        [=] (group<2> g) {
            g.parallel_for_work_item( [=] (h_item<2> i) {
                printf("bar g[0]=%zu g[1]=%zu i[0]=%zu i[1]=%zu\n",
                    g.get_id(0), g.get_id(1),
                    i.get_global_id(0), i.get_global_id(1));
            });
        });
});
CONCLUSIONS
• Application developers should be giving Kokkos a serious look if they want to support all three major HPC accelerator platforms.

• SYCL needs to learn from Kokkos:
  • Reductions are first-class methods in HPC – they must be in the language.
  • Data/memory management needs to be more transparent (education?).
  • Move beyond OpenCL/CUDA thinking and support dimensions >3.

• SYCL compiler helps make device lambda usage better.
  • There is a Kokkos compiler effort but it isn’t the primary implementation.

• Kokkos@SYCL is a natural next step.
  • SYCL@Kokkos might be an interesting reference implementation...