EVALUATING THE PERFORMANCE OF THE HIPSYCL TOOLCHAIN FOR HPC KERNELS ON NVIDIA V100 GPUS

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HPC LEADERSHIP COMPUTING SYSTEMS

- Summit [1] – Oak Ridge National Laboratory
  - IBM CPUs
  - NVIDIA GPUs

- Aurora [2] – Argonne National Laboratory
  - Intel CPUs
  - Intel GPUs

  - AMD CPUs
  - AMD GPUs

- Increasing in diversity
TECHNOLOGIES USED IN THIS STUDY

  - Designed to work with C, C++, and Fortran.
  - Provides scalable programming by utilizing abstractions for the hierarch of thread groups, shared memories, and barrier synchronization.

  - Builds on the underlying concepts of OpenCL while including the strengths of single-source C++.
  - Includes hierarchical parallelism syntax and separation of data access from data storage.

  - Aksel Alpay - https://github.com/illuhad/hipSYCL
HIPSYCL

- Provides a SYCL 1.2.1 implementation built on top of NVIDIA CUDA / AMD HIP.

- Includes two components.
  - SYCL runtime on top of CUDA / HIP runtime.
  - Compiler plugin to compile SYCL using CUDA frontend of Clang.

- Building on top of CUDA allows us to use the NVIDIA performance analysis toolset.
OUR CONTRIBUTIONS

1. We implement a SYCL variant of the RAJA Performance Suite [7] and port two HPC mini-apps to CUDA and SYCL.

2. We collect performance data on the RAJA Performance Suite for the programming models and toolchains of interest.

3. We investigate significant performance differences found in the benchmark suite.

4. We analyze the performance of two HPC mini-apps of interest: an N-body mini-app and a Monte Carlo neutron transport mini-app.
BENCHMARKS

- RAJA Performance Suite
  - Collection of benchmark kernels of interest to the HPC community.
  - Provides many small kernels for collecting many data points.

- N-Body \cite{8}
  - Simple simulation application for a dynamical system of particles.

- XSBench \cite{9}
  - Computationally representative of Monte Carlo transport applications.
Collection of performance benchmarks with RAJA and non-RAJA variants. Checksums verified against serial execution.

- **Basic (simple)**
  - DAXBY, IF_QUAD, INIT3, INIT_VIEW1D, INIT_VIEW1D_OFFSET, MULADDSUB, NESTED_INIT, REDUCE3_INT, TRAP_INT

- **Stream (stream)**
  - ADD, COPY, DOT, MUL, TRIAD

- **LCALS (loop optimizations)**
  - DIFF_PREDICT, EOS, FIRST_DIFF, HYDRO_1D, HYDRO_2D, INT_PREDICT, PLANCKIAN

- **PolyBench (polyhedral optimizations)**
  - 2MM, 3MM, ADI, ATAX, FDTD_2D, FLOYD_ARSHALL, GEMM, GEMVER, GESUMMV, HEAT_3D, JACOBI_1D, JACOBI_2D, MVT

- **Apps (applications)**
  - DEL_DOT_VEC_2D, ENERGY, FIR, LTIMES, LTIMES_NOVIEW, PRESSURE, VOL3D
PORTING FOR COMPARABILITY

- Block size and grid size
- Indexing
- Memory management

Listing 1: CUDA Example

```c
const size_t block_size = 256;

#define DATA_SETUP_CU `
 Double a; `
 cudaMalloc(&a, iend); `
 cudaMempyc(&a, m_a, iend);

#define DATA_TEAROWN_CU `
 cudaMempyc(m_a, a, iend); `
 cudaFree(a);

__global__ void example(double a) {
    size_t i = blockIdx.x*blockDim.x + threadIdx.x;
    if (i < iend) {
        // EXAMPLE_BODY
    }
}

void EXAMPLE::runCudaVariant(VariantID vid) {
    const size_t t_iend = getRunSize();
    DATA_SETUP_CU;
    startTimer();
    for (size_t irep = 0; irep < num_reps; ++irep) {
        const size_t grid_size = block_size *
            DIVIDE_CEILING(iend, block_size);
        q.submit([&] (sycl::handler& h) {
            auto a =
                d_a.get_access<sycl::access::mode::read_write>(h);
            h.parallel_for<class EXAMPLE>(sycl::nd_range<1>,
                (grid_size, block_size),
                [=] (sycl::nd_item<1> item) {
                    size_t i = item.get_group(0) *
                        item.get_local_range().get(0) +
                        item.get_local_id(0);
                    if (i < iend) {
                        // EXAMPLE_BODY
                    }
                });
        });
    }
    stopTimer();
    DATA_TEAROWN_CU;
}
```

Listing 2: SYCL Example

```c
const size_t block_size = 256;

#define DATA_SETUP_SYCL `
 sycl::buffer<double> d_a(m_a, iend);

void EXAMPLE::runSyclVariant(VariantID vid) {
    // Buffer Scope
    const size_t t_iend = getRunSize();
    DATA_SETUP_SYCL;
    startTimer();
    for (size_t irep = 0; irep < num_reps; ++irep) {
        const size_t grid_size = block_size *
            DIVIDE_CEILING(iend, block_size);
        q.submit([&] (sycl::handler& h) {
            auto a =
                d_a.get_access<sycl::access::mode::read_write>(h);
            h.parallel_for<class EXAMPLE>(sycl::nd_range<1>,
                (grid_size, block_size),
                [=] (sycl::nd_item<1> item) {
                    size_t i = item.get_group(0) *
                        item.get_local_range().get(0) +
                        item.get_local_id(0);
                    if (i < iend) {
                        // EXAMPLE_BODY
                    }
                });
        });
    }
    stopTimer();
}
```
PORTING FOR COMPARABILITY

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- Indexing
- Memory management

Listing 1: CUDA Example

```c
const size_t block_size = 256;

#define DATA_SETUP_CUDA
  double a;
  cudaMalloc(&a, iend);
  cudaMemcpy(a, m_a, iend);
#endif

#define DATA_TEAROWN_CUDA
  cudaFree(a);
#endif

_global_ void example(double a) {
  size_t i = blockIdx.x * blockDim.x + threadIdx.x;
  if (i < iend) {
    EXAMPLE_BODY
  }
}

void EXAMPLE::runCudaVariant(VariantID vid) {
  const size_t iend = getRunSize();
  DATA_SETUP_CUDA;
  startTimer();

  for (size_t i = 0; i < iend; ++i) {
    const size_t grid_size = DIVIDE_CEILING(iend, block_size);
    example<<<grid_size, block_size>>>(a, iend);
  }

  stopTimer();
  DATA_TEAROWN_CUDA;
}
```

Listing 2: SYCL Example

```c
const size_t block_size = 256;

#define DATA_SETUP_SYCL
  sycl::buffer<double> d_a(m_a, iend);
#endif

void EXAMPLE::runSyclVariant(VariantID vid) {
  // Buffer Scope
  const size_t iend = getRunSize();
  DATA_SETUP_SYCL;
  startTimer();

  for (size_t i = 0; i < iend; ++i) {
    const size_t grid_size = block_size * DIVIDE_CEILING(iend, block_size);
    auto a = d_a.get_access<sycl::access::mode::read_write>(h);
    h.parallel_for<class EXAMPLE>(sycl::nd_range<1>,
      (grid_size, block_size),
      [=](sycl::nd_item<1> item) {
        size_t i = item.get_group(0) * item.get_local_range().get(0) +
          item.get_local_id(0);
        if (i < iend) {
          EXAMPLE_BODY
        }
      });
  }
  // Buffer Destruction
  stopTimer();
}
PORTING FOR COMPARABILITY

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- Indexing
- Memory management

Listing 1: CUDA Example

```c
const size_t block_size = 256;

#define DATA_SETUP_CUDA
 Double a; //
 cudaMalloc(&a, iend); //
 cudaHmemcpy(a, m_a, iend);
#endif

#define DATA_TEAROWN_CUDA
 cudaHmemcpy(m_a, a, iend); //
 cudaFree(a);

global void example(double a)
{
    size_t i = blockIdx.x * blockDim.x + threadIdx.x;
    if (i < iend) {
        EXAMPLE_BODY
    }
}

void EXAMPLE::runCudaVariant(VariantID vid) {
    const size_t t iend = getRunSize();
    DATA_SETUP_CUDA;
    startTimer();

    for (size_t irep = 0; irep < num_reps; ++irep) {
        const size_t grid_size = block_size *
            DIVIDE_CEILING(iend, block_size);
        <<<grid_size, block_size>>> (a, iend);
    }

    stopTimer();
    DATA_TEAROWN_CUDA;
}
```

Listing 2: SYCL Example

```c
const size_t block_size = 256;

#define DATA_SETUP_SYCL
 sycl::buffer<double> d_a(m_a, iend);
#endif

void EXAMPLE::runSyclVariant(VariantID vid) {
    // Buffer Scope
    const size_t t iend = getRunSize();
    DATA_SETUP_SYCL;
    startTimer();

    for (size_t t irep = 0; irep < num_reps; ++irep) {
        const size_t grid_size = block_size *
            DIVIDE_CEILING(iend, block_size);
        sycl::range<1> (grid_size, block_size);

        for (sycl::nd_item<> i) {
            auto a =
                d_a.get_access<sycl::access::mode::read_write>(i);

            size_t i = i.item.get_group(0) *
                i.item.get_local_range().get(0) +
                i.item.get_local_id(0);

            if (i < iend) {
                EXAMPLE_BODY
            }
        }
    }

    stopTimer();
}
```
PORTING FOR COMPARABILITY

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### Listing 1: CUDA Example
```c
const size_t block_size = 256;

#define DATA_SETUP_CUDA
Double a; \[ \]
  cudaMalloc(&a, 1); \[ \]
  cudaMemcpy(a, m_a, 1); \[ \]
#undef DATA_SETUP_CUDA

#define DATA_TEAR_DOWN_CUDA
  cudaMemcpy(m_a, a, 1); \[ \]
  cudaFree(a); \[ \]
#undef DATA_TEAR_DOWN_CUDA

__global__ void example(double a) {
    size_t i = blockIdx.x * blockDim.x + threadIdx.x;
    if (i < m_a) {
        EXAMPLE_BODY
    }
}

void EXAMPLE::runCudaVariant(VariableID vid) {
    const size_t tind = getRunSize();
    DATA_SETUP_CUDA;
    startTimer();
    for (size_t irep = 0; irep < num_reps; ++irep) {
        const size_t grid_size = DIVIDE_CEILING(tind, block_size);
        n.submit<@>(sycl::handler& h) {
            auto a =
                d_a.get_access<sycl::access::mode::read_write>(h);
            h.parallel_for<class EXAMPLE>(sycl::nd_range<1> {
                (grid_size, block_size),
            }, [a](sycl::nd_item<1> item) {
                size_t i = item.get_group(0) *
                    item.get_local_range().get(0) +
                    item.get_local_id(0);
                if (i < tind) {
                    EXAMPLE_BODY
                }
            });
        }
    }
    stopTimer();
    DATA_TEAR_DOWN_CUDA;
}
```

### Listing 2: SYCL Example
```c
const size_t block_size = 256;

#define DATA_SETUP_SYCL
  sycl::buffer<double> d_a{m_a, 1}; \[ \]
#undef DATA_SETUP_SYCL

void EXAMPLE::runSyclVariant(VariableID vid) {
    // Buffer Scope
    const size_t tind = getRunSize();
    DATA_SETUP_SYCL;
    startTimer();
    for (size_t irep = 0; irep < num_reps; ++irep) {
        const size_t grid_size = block_size *
            DIVIDE_CEILING(tind, block_size);
        n.submit<@>(sycl::handler& h) {
            auto a =
                d_a.get_access<sycl::access::mode::read_write>(h);
            h.parallel_for<class EXAMPLE>(sycl::nd_range<1> {
                (grid_size, block_size),
            }, [a](sycl::nd_item<1> item) {
                size_t i = item.get_group(0) *
                    item.get_local_range().get(0) +
                    item.get_local_id(0);
                if (i < tind) {
                    EXAMPLE_BODY
                }
            });
        }
    }
    stopTimer();
}
```
DATA MOVEMENT

- No explicit data movement in SYCL.

```cpp
void force_memcpy_real(cl::sycl::buffer<Real_type, 1> buf, cl::sycl::queue q) {
    q.submit([&] (cl::sycl::handler &h) {
        sycl::accessor<Real_type, 1, cl::sycl::access::mode::read_write> acc(
            buf, h, buf.get_size());
        h.single_task<class forceMemcpy_Real_t>([](()) {acc[0];});
    });
    q.wait();
}
```

- DPC++ USM proposal would allow for a direct performance comparison including data movement.
PERFORMANCE ANALYSIS METHODOLOGY

- Hardware – NVIDIA V100 GPU
- hipSYCL – git revision 1779e9a
- CUDA – version 10.0.130

Utilized nvprof to collect kernel timing without the time spent on memory transfer.

<table>
<thead>
<tr>
<th>Type</th>
<th>Time(%)</th>
<th>Time</th>
<th>Calls</th>
<th>Avg</th>
<th>Min</th>
<th>Max</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPU activities:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10.60%</td>
<td>692.74ms</td>
<td>4460</td>
<td>155.32us</td>
<td>1.2470us</td>
<td>101.74ms</td>
<td>[CUDA memcpy HtoD]</td>
</tr>
<tr>
<td>2.64%</td>
<td>172.26ms</td>
<td>16000</td>
<td>10.766us</td>
<td>9.7910us</td>
<td>13.120us</td>
<td>rajaperf::lcals::first_diff(double*, double*, long)</td>
<td></td>
</tr>
</tbody>
</table>
PERFORMANCE SUITE

Results

• Problem size is scaled by a factor of five to fill the GPU.

• Five kernels were not measured due to missing features.

• Most kernels show similar performance.
PERFORMANCE SUITE

Results

- Problem size is scaled by a factor of five to fill the GPU
- Five kernels were not measured due to missing features
- Most kernels show similar performance

- Memory bandwidth utilization.
- CUDA is using non-coherent memory loads.
N-BODY SIMULATION MINI-APP

- Simulation of point masses.

- Position of the particles are computed using finite difference methods.

- Each particle stores the position, velocity and acceleration.

- At each timestep the force of all particles acting on one another is calculated.
  \[ O(n^2) \]
N-BODY

Results

Similar performance metrics
• Memory throughput
• Occupancy

<table>
<thead>
<tr>
<th>Metric</th>
<th>SYCL</th>
<th>CUDA</th>
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<tr>
<td>FP Instructions (single)</td>
<td>128000000</td>
<td>128000000</td>
</tr>
<tr>
<td>Control-Flow Instructions</td>
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<td>25004048</td>
</tr>
<tr>
<td>Load/Store Instructions</td>
<td>16018000</td>
<td>16018000</td>
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<tr>
<td>Misc Instructions</td>
<td>4010096</td>
<td>26192</td>
</tr>
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28000048
25004048
16018000
16018000
4010096
26192

Similar performance metrics
• Memory throughput
• Occupancy

Average Kernel Time (ms)

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</tr>
</tbody>
</table>

764.78
887.66

Nbody

Average Kernel Time (ms)
- Mini-app representing key kernel in Monte Carlo neutron transport for nuclear reactor simulation
- Driven by large tables of cross section data that specifies probabilities of interactions between neutron and different types of atoms
- Features a highly randomized memory access pattern that is typically challenging to get running efficiently on most HPC architectures
- Open source, available on github
  - github.com/ANL-CESAR/XSBench

Example of cross section data for 1 atom type
**XSBENCH Results**

**CUDA**
- Load #1
- Load #2
- FLOPS...
- Load #3
- Load #4
- Load #5
- Load #6
- Load #7
- Load #8
- Load #9
- Load #10
- Load #11
- Load #12

**hipSYCL**
- Load #1
- Load #2
- FLOPS...
- Load #3
- Load #4
- Load #5
- Load #6
- Load #7
- Load #8
- Load #9
- Load #10
- Load #11
- FLOPS...
- Load #12

FOM

**Unionized**
- CUDA: 48
- CUDA (Optimized): 26
- hipSYCL: 15

**Hash**
- CUDA: 65
- CUDA (Optimized): 28
- hipSYCL: 16

**Nuclide**
- CUDA: 62
- CUDA (Optimized): 27
- hipSYCL: 17

*Uses __ldg()__ to force contiguous load instructions*
CONCLUSIONS

- SYCL using hipSYCL is showing competitive performance on NVIDIA devices.

- Common performance analysis tool very useful. Many subtle details when using difference performance measurement tools on different devices with different programming models.

- Cross programming model studies can provide insight into optimization opportunities.
FUTURE WORK

- Utilize larger HPC codes running multi-node problem sizes.
- Investigate the performance of additional toolchains for SYCL and CUDA.
- Investigate performance of the same code across various GPUs.
- Explore the performance of Intel’s DPC++ extensions.
ACKNOWLEDGEMENTS

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THANK YOU
REFERENCES