HIPification and Profiling Tools

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Agenda

- Porting CUDA codes to HIP
- Profiling tools
Objectives

This training:

• Demonstrates how to convert CUDA codes into HIP
• Explains the meaning of the term ‘hipify’
• Provides an idea of the common ‘gotchas’ of porting apps
Getting started with HIP

CUDA VECTOR ADD

```c
__global__ void add(int n,
    double *x,
    double *y)
{
    int index = blockIdx.x * blockDim.x
                 + threadIdx.x;
    int stride = blockDim.x * gridDim.x;

    for (int i = index; i < n; i += stride)
    {
        y[i] = x[i] + y[i];
    }
}
```

HIP VECTOR ADD

```c
__global__ void add(int n,
    double *x,
    double *y)
{
    int index = blockIdx.x * blockDim.x
                 + threadIdx.x;
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    for (int i = index; i < n; i += stride)
    {
        y[i] = x[i] + y[i];
    }
}
```

KERNELS ARE SYNTACTICALLY THE SAME
## CUDA APIs vs HIP API

<table>
<thead>
<tr>
<th>CUDA</th>
<th>HIP</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>cudaMalloc(&amp;d_x, N*sizeof(double));</code></td>
<td><code>hipMalloc(&amp;d_x, N*sizeof(double));</code></td>
</tr>
<tr>
<td><code>cudaMemcpy(d_x, x, N*sizeof(double), cudaMemcpyHostToDevice);</code></td>
<td><code>hipMemcpy(d_x, x, N*sizeof(double), hipMemcpyHostToDevice);</code></td>
</tr>
<tr>
<td><code>cudaDeviceSynchronize();</code></td>
<td><code>hipDeviceSynchronize();</code></td>
</tr>
</tbody>
</table>
## Launching a kernel

### CUDA KERNEL LAUNCH SYNTAX

```c
some_kernel<<<gridsize, blocksize, shared_mem_size, stream>>> (arg0, arg1, ...);

some_kernel<T_ARGS> <<<gridsize, blocksize, shared_mem_size, stream>>>(arg0, arg1, ...);
```

### HIP KERNEL LAUNCH SYNTAX

```c
hipLaunchKernelGGL(some_kernel, gridsize, blocksize, shared_mem_size, stream, arg0, arg1, ...);

hipLaunchKernelGGL(HIP_KERNEL_NAME(some_kernel<T_ARGS>), gridsize, blocksize, shared_mem_size, stream, arg0, arg1, ...);
```
HIPification Tools for faster code porting

- ROCm provides ‘HIPification’ tools to do the heavy-lifting on porting CUDA codes to ROCm
  - Hipify-perl
  - Hipify-clang


- In practice, large portions of many HPC codes have been automatically Hipified:
  - ~90% of CUDA code in CORAL-2 HACC
  - ~80% of CUDA code in CORAL-2 PENNANT
  - ~80% of CUDA code in CORAL-2 QMCPack
  - ~95% of CUDA code in CORAL-2 Laghos

  The remaining code requires programmer intervention
HIPify Tools

- **Hipify-perl:**
  - Easy to use – point at a directory and it will attempt to hipify CUDA code
  - Very simple string replacement technique: may make incorrect translations
    - `sed -e 's/cuda/hip/g'` (e.g., cudaMemcpy becomes hipMemcpy)
  - Recommended for quick scans of projects

- **Hipify-clang:**
  - Requires CLANG compiler
  - More robust translation of the code
  - Uses clang to parse files and perform semantic translation
  - Can generate warnings and assistance for code for additional user analysis
  - High quality translation, particularly for cases where the user is familiar with the make system
Hipify-perl

- Sits in $HIP/bin/ (export PATH=$PATH:[$MYHIP]/bin)

- Command line tool: `hipify-perl foo.cu > new_foo.cpp`

- Compile: `hipcc new_foo.cpp`

- How does this this work in practice?
  - Hipify source code
  - Check it in to your favorite version control
  - Try to build
  - Manually work on the rest
Hipify-clang

- Available at https://github.com/ROCm-Developer-Tools/HIPIFY
- Build from source
- ‘Hipification’ requires same headers that would be needed to compile it with clang:
  - ./hipify-clang foo.cu -I /usr/local/cuda-8.0/samples/common/inc
- Understands how to translate many CUDA libraries (cuBLAS, cuFFT, cuSPARSE, etc.)
- Will get useful warning messages about unknown conversions
Gotchas

- Hipify tools are not running your application, or checking correctness
- Code relying on specific hardware aspects (e.g., warp size == 32) may need attention after conversion
- Hipifying can’t handle inline PTX assembly
  - Can either use inline GCN ISA, or convert it to HIP
- Hipify-perl can’t handle library calls, hipify-clang can handle library calls
What to look for when porting:

- Inline PTX assembly
- CUDA Intrinsics
- Hardcoded dependencies on warp size, or shared memory size
  - Grep for "32" just in case
  - Do not hardcode the warpsize! Use something like #define WARPSIZE size
- Code geared toward limiting size of register file on NVIDIA hardware
- Functions implicitly inlined
- Unified memory
Example: HACC

- **Hardware Accelerated Cosmology Code**
- Simulates time-evolution of universe
  - $\text{Mpc} = \text{Megaparsec} = 3.09 \times 10^{22}$ meters

- **Our HIP success story:**
  - **Ported in an afternoon**

- **Profiling:**
  - 10% of time is spent in the tree walk
  - >80% in the short force kernels
    - *(GPU kernel)*
  - 5% in the 3d Transposes / FFTs

\[ f_{SR} = (s + \epsilon)^{-3/2} - f_{grid}(s) \]

where,
\[ s = \mathbf{r} \cdot \mathbf{r} \]

and,
\[ f_{grid}(s) = POLY_5(s) \]
HACC: What made it a success

• **What was easy?**
  • Simple GPU kernel
  • Few library dependencies (FFTW, not in kernel)
  • No advanced CUDA features

• **What was difficult?**
  • Inline PTX: required translation to AMD GCN
  • Hand-written wave-32 code (for a reduction)
Porting HACC

**CUDA**

```c
cudaMemcpyAsync(d_npos, h_npos, Nposbytes, cudaMemcpyHostToDevice, stream);

cudaMemcpyAsync(d_mask, h_mask, NmaskBytes, cudaMemcpyHostToDevice, stream);

calchHHCullenDehnen<<<blocksPerGrid, threadsPerBlock, 0, stream>>>(cnt, SIZE, d_npos, d_mask, rsm);

cudaMemcpyAsync(h_pos, d_npos+(SIZE-cnt), cntBytes, cudaMemcpyDeviceToHost, stream);

cudaMemcpyAsync(h_mask, d_mask, NmaskBytes, cudaMemcpyDeviceToHost, stream);
```

**HIP**

```c
hipMemcpyAsync(d_npos, h_npos, Nposbytes, hipMemcpyHostToDevice, stream);

hipMemcpyAsync(d_mask, h_mask, NmaskBytes, hipMemcpyHostToDevice, stream);

hipLaunchKernelGGL(calcHHCullenDehnen, blocksPerGrid, threadsPerBlock, 0, stream, cnt, SIZE, d_npos, d_mask, rsm);

hipMemcpyAsync(h_pos, d_npos+(SIZE-cnt), cntBytes, hipMemcpyDeviceToHost, stream);

hipMemcpyAsync(h_mask, d_mask, NmaskBytes, hipMemcpyDeviceToHost, stream);
```
Fortran + CUDA C/C++ -> Fortran + HIP C/C++

- The only difference here is that the CUDA C/C++ code is linked with some Fortran routines
- Assumption is these Fortran routines do not contain CUDA Fortran
- This behaves like you would expect:
  - hipify the CUDA
  - Compile your HIP C/C++ with hipcc
  - Compile your Fortran code
  - Link with hipcc
- Example scenario: your HIP C/C++ code makes calls to Fortran functions (e.g., LAPACK functions) on the host
CUDA Fortran -> Fortran + HIP C/C++

- There is no HIP equivalent to CUDA Fortran
- But HIP functions are callable from C, using `extern C`, so they can be called directly from Fortran
- The strategy here is:
  - Manually port CUDA Fortran code to HIP kernels in C++
  - Wrap the kernel launch in a C function
  - Call the C function from Fortran through Fortran’s ISO_C_binding
- This strategy should be usable by Fortran users since it is standard conforming Fortran
- ROCm has an interface layer, hipFort, which provides the wrapped bindings for use in Fortran
  - [https://github.com/ROCmSoftwarePlatform/hipfort](https://github.com/ROCmSoftwarePlatform/hipfort)
Portability layers using HIP

Several portability layers are already supporting, or implementing, HIP

- **RAJA**
  - HIP kernel execution policies syntactically identical to CUDA
  - Official PRs under review

- **Kokkos**
  - HIP kernel execution policies syntactically identical to CUDA
  - Support is in beta and under development by Kokkos and AMD developers

- **OCCA**
  - OKL kernels can compile for HIP devices
  - Available in OCCA’s master branch

- **OpenMP 5.0**
  - gcc and Cray's C++ compiler support target offload regions
AMD GPU Profiling

- ROC-profiler (or simply rocprof) is the command line front-end for AMD's GPU profiling libraries
  - Repo: [https://github.com/ROCm-Developer-Tools/rocprofiler](https://github.com/ROCm-Developer-Tools/rocprofiler)
- rocprof contains the central components allowing the collection of application tracing and counter collection
  - Under constant development
- Provided in the ROCm releases
- The output of rocprof can be visualized using the chrome browser with chrome tracing
rocprof: Getting started + useful flags

- To get help:
  - $ /opt/rocm/bin/rocprof -h

- Useful housekeeping flags:
  - --timestamp <on|off>: turn on/off gpu kernel timestamps
  - --basenames <on|off>: turn on/off truncating gpu kernel names (i.e., removing template parameters and argument types)
  - -o <output csv file>: Direct counter information to a particular file name
  - -d <data directory>: Send profiling data to a particular directory
  - -t <temporary directory>: Change the directory where data files typically created in /tmp are placed. This allows you to save these temporary files.

- Flags directing rocprofiler activity:
  - -i input.<txt|.xml> - specify an input file (note the output files will now be named input.*)
  - --hsa-trace - to trace GPU Kernels, host HSA events (more later) and HIP memory copies.
  - --hip-trace - to trace HIP API calls
  - --roctx-trace - to trace roctx markers

- Advanced usage
  - -m <metric file>: Allows the user to define and collect custom metrics. See rocprofiler/test/tool/*.xml on GitHub for examples.
rocprof: Collecting application traces (1)

- rocprof can collect a variety of trace event types and generate timelines in JSON format for use with chrome-tracing, currently:

<table>
<thead>
<tr>
<th>Trace Event</th>
<th>rocprof Trace Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIP API call</td>
<td>--hip-trace</td>
</tr>
<tr>
<td>GPU Kernels</td>
<td>--hip-trace</td>
</tr>
<tr>
<td>Host &lt;-&gt; Device Memory copies</td>
<td>--hip-trace</td>
</tr>
<tr>
<td>CPU HSA Calls</td>
<td>--hsa-trace</td>
</tr>
<tr>
<td>User code markers</td>
<td>--roctx-trace</td>
</tr>
</tbody>
</table>
rocprof: Collecting application traces (2)

- rocprofiler can collect traces
  - $ /opt/rocm/bin/rocprof --hip-trace <app with arguments>
  - This will output a .json file that can be visualized using the chrome browser
  - Go to chrome://tracing and then load in the .json file.
    - The trace will display HIP calls, mem copies, kernels.
rocprof: Collecting application traces (3)

- rocprofiler can collect traces
  - `$ /opt/rocm/bin/rocprof --hsa-trace <app with arguments>`
  - This will output a .json file that can be visualized using the chrome browser
  - Go to chrome://tracing and then load in the .json file
    - The trace will display copies, hsa signals, and kernel calls
    - Slowest trace mode – Use with caution
rocprof: Collecting application traces (4)

- rocprofiler can collect multiple trace modes simultaneously
  - `$ /opt/rocm/bin/rocprof --hsa-trace --hip-trace <app with arguments>`
  - This command will additionally add HIP API calls to the trace
rocprof: Collecting application traces (5)

- Rocprof can collect user code-markers using rocTX
  - See MatrixTranspose.cpp example on roctracer GitHub page for sample in-code usage
  - `$ /opt/rocm/bin/rocprof --hip-trace --roctx-trace <app with arguments>`
rocprof: Collecting hardware counters

rocprofiler can collect a number of hardware counters and derived counters

- $ /opt/rocm/bin/rocprof --list-basic
- $ /opt/rocm/bin/rocprof --list-derived

Specify counters in a counter file. For example:

- $ /opt/rocm/bin/rocprof -i rocprof_counters.txt <app with args>
- $ cat rocprof_counters.txt

```
pmc : Wavefronts VALUInsts VFetchInsts WWriteInsts VALUUtilization VALUBusy WriteSize
pmc : SALUInsts SFetchInsts LDSInsts FlatLDSInsts GDSInsts SALUBusy FetchSize
pmc : L2CacheHit MemUnitBusy MemUnitStalled WriteUnitStalled ALUStalledByLDS LDSBankConflict
...
```

A limited number of counters can be collected during a specific pass of code.

- Each line in the counter file will be collected in one pass
- You will receive an error suggesting alternative counter ordering if you have too many / conflicting counters on one line

A .csv file will be created by this command containing all of the requested counters.
rocprof: Commonly Used Counters

- VALUUtilization: The percentage of ALUs active in a wave. Low VALUUtilization is likely due to high divergence or a poorly sized grid
- VALUBusy: The percentage of GPUS time vector ALU instructions are processed. Can be thought of as something like compute utilization
- FetchSize: The total kilobytes fetched from global memory
- WriteSize: The total kilobytes written to global memory
- L2CacheHit: The percentage of fetch, write, atomic, and other instructions that hit the data in L2 cache
- MemUnitBusy: The percentage of GPUS time the memory unit is active. The result includes the stall time
- MemUnitStalled: The percentage of GPUS time the memory unit is stalled
- WriteUnitStalled: The percentage of GPUS time the write unit is stalled

Full list at: https://github.com/ROCm-Developer-Tools/rocprofiler/blob/amd-master/test/tool/metrics.xml
Performance counters tips and tricks

- GPU Hardware counters are global
  - Kernel dispatches are serialized to ensure that only one dispatch is ever in flight
  - It is recommended that no other applications are running that use the GPU when collecting performance counters

- Use "--basenames on" which will report only kernel names, leaving off kernel arguments.

- How do you time a kernel’s duration?
  - $ /opt/rocm/bin/rocprof --timestamps on -i rocprof_counters.txt <app with args>
  - This produces four times: DispatchNs, BeginNs, EndNs, and CompleteNs
  - Closest thing to a kernel duration: EndNs - BeginNs
  - If you run with "--stats" the resultant results file will automatically include a column that calculates kernel duration
    - Note: the duration is aggregated over repeated calls to the same kernel
rocprof: Multiple MPI Ranks

- rocprof can collect counters and traces for multiple MPI ranks.

- Say you want to profile an application usually called like this:
  - `mpiexec -np <n> ./Jacobi_hip -g <x> <y>`
  - Then invoke the profiler by executing:
    ```
    rocprof --hip-trace mpiexec -np <n> ./Jacobi_hip -g <x> <y>
    ```

- This will produce a single unified CSV file for all ranks

- Multi-node profiling currently isn’t supported
rocprof: Profiling Overhead

Simple estimation of profiling overhead, obtained via wall-clock timing of entire application run via Linux ‘time’ utility:
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