Fermilab U.S. DEPARTMENT OF ENERGY Office of Science

Porting CMS Heterogeneous Pixel Reconstruction to Kokkos

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vCHEP 2021 18 May 2021

HEP-CCE CMS

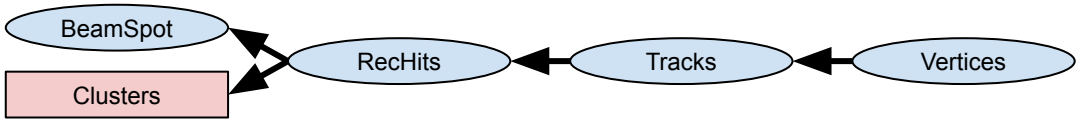
Introduction

- CMS will use GPUs as part of the High-Level Trigger farm in LHC Run 3
- GPU vendors provide their own APIs that also differ from programming the CPU
  - Want to minimize development and maintenance effort → looking for a technology enabling portable code between CPU and different GPUs (at least)

- Used Patatrack heterogeneous pixel reconstruction from the CMS experiment as a use case for a set of realistic algorithms utilizing GPU effectively
  - Algorithms are fully integrated in CMSSW and will be used in HLT in 2022
- In this talk we report preliminary experience of porting the heterogeneous pixel reconstruction code from CUDA to Kokkos
- For more reports on the use of Kokkos by HEP-CCE see
  - FastCaloSim in Monday plenary
  - WireCell in Thursday plenary

CMS Heterogeneous Pixel reconstruction

- About 40 kernels organized in 5 “framework modules”
  - arXiv:2008.13461



- Raw pixel detector data (~250 kB/event) transferred to the GPU
- Only final results transferred back to the CPU: ~4 MB for tracks, ~90 kB for vertices
  - Not considered in throughput measurements in this talk
- Extracted into a standalone program to enable rapid prototyping
  - Flexible GNU Make -based build system
  - Simple framework mimicking CMSSW’s use of TBB tasks
  - Disk I/O contribution to time measurements is ignored
    - 1000 events from TTbar + pileup 50 simulation from CMS Open Data read at the beginning of the job and recycled

Introduction to Kokkos

- Kokkos is a C++ library for writing performance portable applications
  - Single-source implementation, descriptive programming model
- Supported backends (execution spaces) in Kokkos 3.3.1
  - CPU (host) serial
  - CPU (host) parallel: OpenMP, POSIX threads
  - Device parallel: CUDA, HPX, HIP, OpenMP Target, SYCL 2020
- We have tested serial, threads, CUDA, and HIP backends
- High-level API
  - `parallel_for`, `parallel_scan`, `parallel_reduce`; can be nested
  - Details of iteration and operations controlled with a policy
  - `Kokkos::View<T>` as an N-dimensional array of type `T`
    - Works similar to `std::shared_ptr`
    - Memory layout can be controlled, default layout depends on the backend

Porting experience

- Building
  - Kokkos requires a runtime library, only subset of backends can be enabled at a time
  - Spent a lot of time to figure out build rules when used in conjunction with shared libraries
    - For CUDA had to build Kokkos as a static library with `-fPIC`
    - For HIP could (had to) build Kokkos as a dynamic library
- Algorithms
  - Mostly straightforward to port from CUDA
    - Figuring out a good mapping for some low-level constructs took time
- Data structures, i.e. `Kokkos::View`
  - Useful for unified memory allocation interface and smart pointer
  - Not particularly useful building block for Structures-of-Arrays of runtime size
  - By default initializes the data on device memory, can be expensive if not needed
- Able to run on CPU and NVIDIA GPUs, same results within numerical precision
  - Run-time failures with AMD GPUs, being investigated further

Performance comparison (CPU)

- On Cori GPU nodes at NERSC
- Pinned on one socket of Xeon Gold 6148 (“Skylake”)
  - 20 cores, 40 threads
- Filled the socket with CPU intensive work

Test	Throughput (events/s)
CPU version, 1 thread	13.5 ± 0.2
Kokkos version, Serial backend	8.5 ± 0.2
CPU version, 40 threads	539 ± 9
Kokkos with Threads backend, peak at 18 threads	28 ± 1

- Repeated 8 times on random nodes, jobs run 5-10 minutes at a time
- Different parallelization strategies
  - “CPU version”: process events concurrently, one event per thread
  - “Kokkos Threads backend”: one event in flight, parallelize within that event

Performance comparison (NVIDIA GPU)

	Test	Throughput (events/s)
CUDA version	9 concurrent events and threads (peak)	1840 ± 20
	1 concurrent event	720 ± 20
	1 concurrent event, caching allocator disabled	**159 ± 1**
Kokkos version	**CUDA backend**	**115.7 ± 0.3**

- On Cori GPU nodes, with 1 NVIDIA V100 GPU, repeated 8 times
- No memory pool (not supported yet) or concurrent events (attempts so far lead to assert failures) in Kokkos version, so disable those in CUDA version for comparison

Conclusions

- Successfully ported CMS heterogeneous pixel reconstruction to Kokkos
- Kokkos provides an API that is at higher level than CUDA
  - Potentially easier to use by physicists
- Achieved almost full portability between CPU and CUDA (and HIP up to compiling)
  - Runs on CPU and on NVIDIA GPU, produces same results within numerical precision
- Current Kokkos port has still a large overhead compared to native implementations
- Kokkos could work well for a project that compiles code separately for each target architecture, does not use much shared libraries, uses CMake as build system, and does not rely on concurrent work outside Kokkos