Future of Scheduling in Athena

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on behalf of the ATLAS Computing Activity

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ATLAS EXPERIMENT

The HPC Challenge

Traditional Grid (HTC)

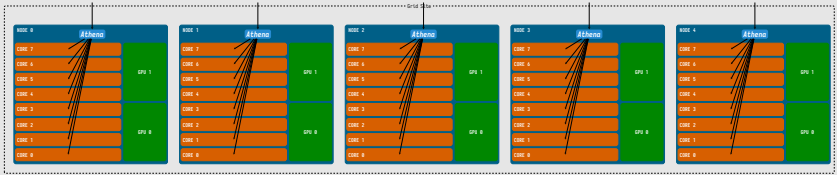
- Each job runs on single node
- Every node has direct outside network access
- Accelerators generally not available

HPC

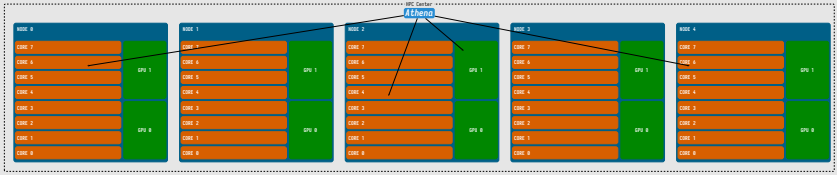
- HPC jobs generally need to run on many nodes
- On many HPCs, nodes can't access outside network
- HPCs often rely on accelerators for majority of FLOPS
  - Can't waste CPU time blocking on accelerator

General Concept

Traditional Grid Sites

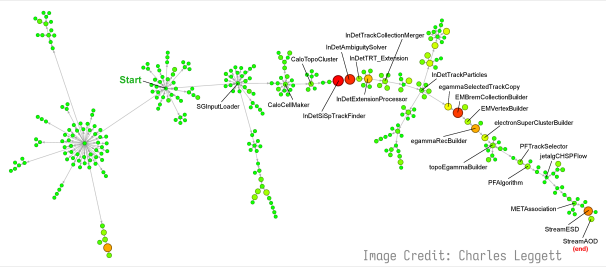


HPC Concept



Athena Scheduling Primer

- Processing represented by Directed Acyclic Graph of *Algorithms* repeated for each event
  - Derived from `Gaudi::Algorithm` (Gaudi)
  - `execute` member function
- AthenaMT exhibits both inter- and intra-event parallelism
  - Two threads may run algorithms from the same, or different events



Implementation

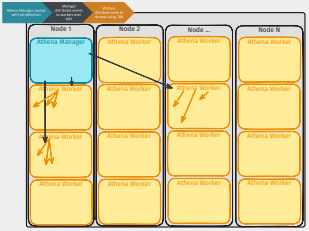
- Can split challenge into two components
  - Distribute work across multiple nodes
    - Avoid starving nodes
  - GPU-aware scheduling
    - Avoid blocking CPU

AthenaMPI

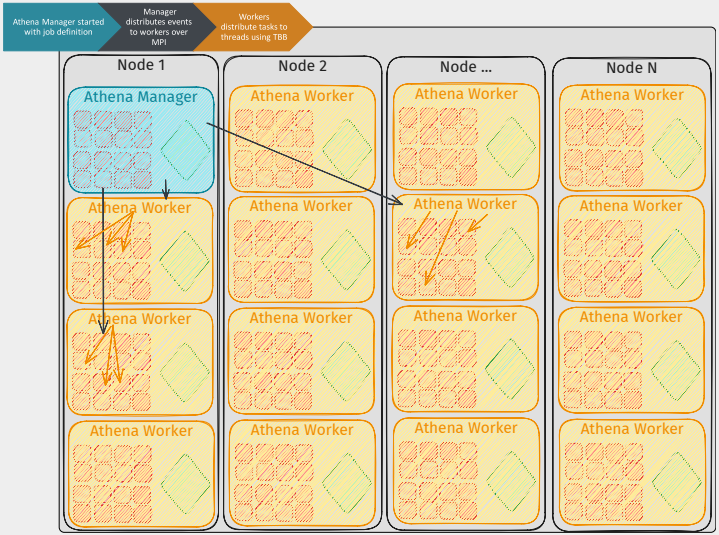
ACAT 2024 Poster

AthenaMPI

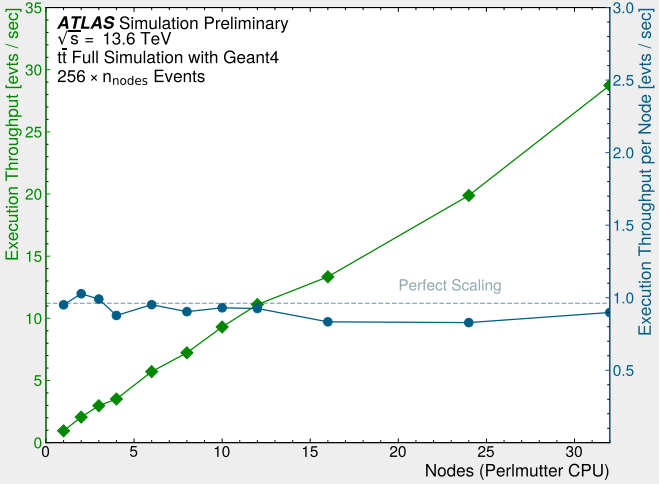
- Solves the problem of distributing work across multiple nodes
- Manager – Worker paradigm with MPI (Message Passing Interface) for communications
- Each worker requests event assignment from manager as needed
  - Pull architecture automatically balances load across workers
  - Avoids trying to schedule onto a busy node
    - Lesson from HPX experience: Not just inefficient, but *slow*



Architecture



Performance



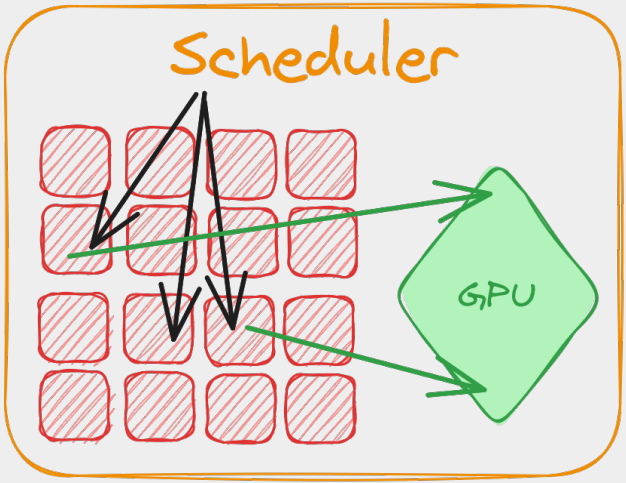
Ideal Scaling Behaviour

Next step: Grid trials

AsynchronousAlgorithm

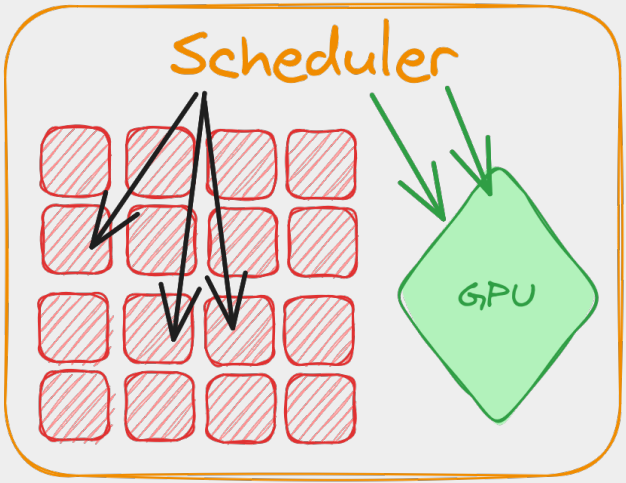
ACAT 2024 Talk

Classic Architecture



Algorithms offload to GPU and block CPU

GPU-Aware Architecture



Algorithms offloading to GPU don’t block

Implementation

- Strictly following GPU-Aware Architecture restricts GPU hardware that can be supported
- Instead implemented a general framework for `AsynchronousAlgorithms`
  - i.e. `Algorithms` with an asynchronous `execute` member function
- Also implemented CUDA support using this framework

Asynchronicity through Fibers

- Chose to use 

  - Fibers are lightweight (user mode) threads
  - Stackful coroutines + scheduler + convenience features

Why not C++20 Coroutines?

- Started before C++20 supported in Athena
- Reduced burden on users
  - No need to “coroutinify” user code
- Reduced development burden
  - Boost Fiber provides a scheduler, and fiber-local storage classes
  - Boost Fiber provides usable CUDA (and HIP) support
- Avoids pitfalls
  - e.g. Running CPU parts on scheduler thread

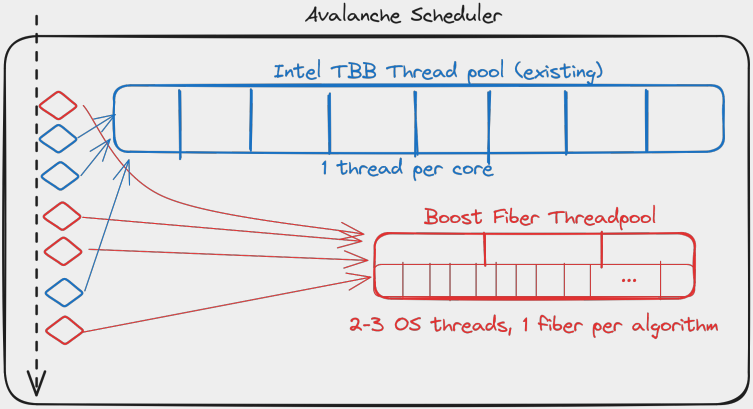
Usage

- Derive from `Gaudi::AsynchronousAlgorithm` instead of `Gaudi::Algorithm`
  - NB for ATLAS folk: Actually `AthAsynchronousAlgorithm` instead of `AthReentrantAlgorithm`
- `yield` after submitting work
- Using provided CUDA support:
  - Use provided support to create a CUDA stream
  - Use CUDA `Async` functions with this stream
  - Call `cuda_stream_await` on stream to yield

Under the Hood

- `AsynchronousAlgorithm`s scheduled on separate small thread pool
- OS thread freed for next fiber whenever you yield
- If CUDA support used, Boost Fiber can handle checking if CUDA is done
  - Fiber not woken to carry out this check
- Use Fiber-specific storage to restore necessary data when fiber resumed
  - `EventContext` and whiteboard information telling us where event data is stored

Scheduling



queue of CPU and GPU tasks

Synchronous → TBB Asynchronous → Fiber

Current Status

- Gaudi prototype demonstrated at ACAT 2024
- Now complete and merged into Gaudi
- Athena interface added and ready
  - Awaiting move to Gaudi v39
- Plan to add support for other hardware (AMD, Intel)
  - Boost Fiber includes HIP (AMD) support analogous to CUDA support
  - SYCL (Intel) support would need to be added using callback support
- Work ongoing to use NVidia's Triton in Athena. `AsynchronousAlgorithms` could be used here too.

Summary

- Athena *must* support HPCs as a first-class citizen
- Unique challenges due to multi-node jobs and accelerator use requirements
- AthenaMPI handles multi-node scheduling
  - About to start grid trials
- `AsynchronousAlgorithm`s handle accelerators
  - Awaiting final merge
  - Further feature development planned

Backup

Perlmutter CPU Node

```
OS: SUSE Linux 15 SP3 x86_64
Host: HPE_CRAY_EX425 1.6.3
Kernel: 5.3.18-150300.59.87_11.0.78-cray_shasta_c
Uptime: 8 days, 23 hours, 30 mins
Packages: 1238 (rpm)
Shell: zsh 5.6
Terminal: /dev/pts/8
CPU: AMD EPYC 7763 (256) @ 2.450GHz
Memory: 24482MiB / 515316MiB
```

History

Athena is ATLAS's offline data processing framework

- Classic Athena is single-process and single-threaded
  - Events are processed in order, one-at-a-time, by the event loop
- AthenaMP developed to control memory use
  - Exploits the `fork` syscall and Linux's copy-on-write behaviour.
    Allows sharing of memory used for conditions *at start*
  - Data doesn't stay de-duplicated
- AthenaMT brought true multithreaded scheduling
  - Single process, single event loop, multiple events in parallel on multiple threads
  - Data shared between events stays de-duplicated
  - Accelerators also on the scene
    - Handled by ad-hoc offloading outside central scheduler
  - Central technology is Intel's TBB (Threaded Building Blocks)

Previous Talks and Posters

Previous Work on This Project

- ACAT 2022 talk
- CHEP 2023 talk
- ACAT 2024 talk and poster

Previous Related Work

- Raythena proceedings from CHEP 2019
- GPU Usage in ATLAS proceedings from CHEP 2019

Other Talks at this Conference

- Machine Learning Inference in Athena with ONNXRuntime (Poster Session)
- AthenaTriton (Earlier Today)