AthenaMT: Upgrading the ATLAS Software Framework for the Many-Core World with Multi-Threading

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for the ATLAS Collaboration

CHEP 2016
Future Computing Challenges

CPU Core and Hardware Thread Count

- ATLAS reconstruction uses upwards of 3 GB of memory, more with high luminosity runs
- Cost to equip all grid compute nodes with full memory requirements is more than US$ 6 Million
- Increasing adoption of many-core systems, eg Cori, Aurora

Long Term Solution: Invest in multi-threading

Processor Scaling Trends

- CPUs are not getting faster
- CPUs are getting wider
- Memory prices have plateaued

Historical Memory Prices

- Moore's Law
- Original Gaudi design

Clock Speed (MHz)
Transistors (millions)
Power (W)
SpecFp2006

Processor Scaling Trends

- Reality

CPU Core and Hardware Thread Count
### Migration of ATLAS Software to AthenaMT

<table>
<thead>
<tr>
<th>Date</th>
<th>Framework</th>
<th>Algorithms</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>Event Store access via Data Handles; Event View design completed; Updated Configuration design; Re-integration of Hive features into Gaudi trunk</td>
<td>Few Algorithms as concurrent prototypes, concentrate on high inherent parallelism; general clean-up of code</td>
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<tr>
<td>2016 Q2</td>
<td>Event Views implemented; IO Layer redesigned; Core Gaudi service migration starts</td>
<td>Wider set, prototype CPU expensive Algs with internal parallelism</td>
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<tr>
<td>2016 Q4</td>
<td>Parallel Algorithm support; Detector/Condition Store re-implementation; Schedulable Incidents; Main Athena development branch moved to Gaudi trunk</td>
<td>First trigger chains running with Event Views; limited reconstruction</td>
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<tr>
<td>2017</td>
<td>All Athena and Gaudi Services made thread safe; Support for re-entrant Algorithms</td>
<td>Serious migration with select groups; Core of useful Algorithms to allow for framework optimization</td>
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<tr>
<td>2018</td>
<td>Framework optimization, and tuning for different hardware</td>
<td>Bulk of Algorithm migration</td>
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<tr>
<td>2019</td>
<td></td>
<td>Integration and Readiness for Run 3</td>
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- **Aggressive schedule**
  - many migrations steps are not parallelizable
- **On track for most milestones**
  - but not all!

- Will focus on what we've accomplished in 2016
Enabling Concurrency for Core Services

- Majority of hard work in migrating ATLAS code to AthenaMT is in making shared Services thread safe or able to handle multiple concurrent events.

- Some Services can be made concurrent / thread safe with simple mutexes or thread safe data structures

- Some need more modifications to handle state information of multiple concurrent events
  - **MagFieldSvc**: carry event specific cache along with each request
  - **THistSvc**: users can choose whether to share or clone histograms
    - thread safe access to shared histograms via smart locking handles

- Some need complete redesign
  - Conditions / **I0VSvc** (Intervals of Validity) / **GeoModelSvc** (Detector Alignment)
  - **IncidentSvc**
Concurrent Processing of Asynchronous Data

- **Conditions**
  - eg high voltages, calibrations, etc

- **Detector Geometry and Alignments**
  - eg position changes

- **Requirement**: Minimize changes to client code
  - there's lots and lots of it!
  - avoid forcing Users to implement fully thread-safe code by handling most thread-safety issues at the framework / Services level (without compromising concurrency)

- **Requirement**: All access to Event data is via smart **DataHandles**, which also declare data dependency relationship to the framework
  - we can use this by implementing **ConditionHandles**
    - do all the heavy lifting inside the Handle
Serial Processing with Conditions

- All framework elements process data from the same Interval Of Validity
- Algorithms are blind to the IOV, and retrieve data from the **ConditionStore**
- At the start of every Event, **IOVSvc** checks IOVs, and triggers any necessary updates
  - handled by the **Callback Functions**
  - Callback Functions are **shared** instances
- Only one copy of any Conditions object is maintained in the Store
Concurrent Processing with Conditions

Event 1

BeginEvent

IOVSvc

CF₁

Alg_A

Alg_B

Alg_C

Event 2

BeginEvent

ConditionStore

CF₂

c₁
c₂
c₃

Alg_A

Alg_B

Alg_C

ISSUES

► The current callback functions are NOT thread-safe

► Even if they were made thread-safe, could NOT run with multiple concurrent Events from different IOVs due to the single ConditionStore

► IOV infrastructure needs to be significantly modified for MT
Concurrent: Single Multi-Cache Condition Store

- **One** ConditionStore, shared by all Events.
- no wasted memory
- no duplicate calls
- Store elements are **ConditionContainers**, with one entry per IOV

- Data access via **ConditionHandles** that point to appropriate entry

- Callback Functions become **Algorithms**, scheduled by framework
- Detector Element position cached in **Full Physical Volume**
  - built from a **Physical Volume** description, a **Transform**, and a time dependent **Alignable Transform** that reads a **Delta** from a database

- Not functional with concurrent events that have different Deltas and associated caches
Encapsulate alignment deltas and cached positions in AlignmentObjects that reside in the ConditionStore
- accessed via ConditionHandles
- updated on demand via a scheduled GeoAlignAlg

Clients of DetectorElements are completely unaware of migration
IncidentSvc in AthenaMT

- **IncidentSvc**: manages asynchronous callbacks for clients using an Observer pattern

- **Study**: design is far more flexible than actual usage
  - mostly fired outside of the Algorithm processing loop

- **Solution**: limit scope: Incidents can be re-classified as discrete state changes
  - Incidents become **schedulable**, managed by framework
  - Incident handlers / observers become discrete Algorithms, that interact with EventContext aware Services
Event Views and DataHandles

- For performance reasons, the High Level Trigger operates on geometrical Regions of Interest (ROI).
- Since all Algorithms access Event data via smart DataHandles, they can be run unmodified in a ROI simply by having the framework modify the DataHandle itself.
- Implemented an **EventView** class that can be used interchangeably with the whole event store. Each View is populated with data corresponding to a single ROI:
  - Each EventView has the same interface as the whole event store.
  - Contain Data Objects that describe the corresponding ROI.
  - Allow for potential alternative use-cases.

See presentation by Ben Wynne on Tuesday at 2PM for further details.
Re-Entrant Algorithms

- Cloning of Algorithms in GaudiHive allows us to avoid most thread safety issues
  - clones can run concurrently with different Event Contexts without interference
  - have to avoid "thread hostile" behaviour
    - global statics
    - back channel communications
  - some Algorithms can't be cloned – scheduling bottleneck

- Downside of many clones is increased memory use
  - can limit number of clones, at the expense of limiting possible concurrency

- Added support for re-entrant Algorithms
  - only one instance
  - can be executed simultaneously in multiple threads in different Events
  - MUST be thread safe
    - enforced with new base class and `Algorithm::execute_r() const` signature
  - envision limited usage for special purpose tasks, written by experts
Summary

► ATLAS has begun the migration of core framework elements that require the most significant design changes beyond mere thread safety
  • sometimes by completely re-evaluating functionality and limiting design to actual use cases

► We have made design choices that minimized alterations to client code
  • leverage existing features of framework, eg DataHandles and the Scheduler

► Changes to Algorithmic client code that use these elements are also underway
  • relatively straight forward recipe for the most part (but a lot of grunt work)

► Anticipate on-schedule finalization of design, and implementation of essential core Services by end of 2016, with full support of MT concurrency by end of 2017
  • we already have production level Atlas G4 simulation running in MT on KNL. see Steve Farrell’s talk Thursday, track 2, 2PM

► Broad migration of Algorithm code to use these features will begin in 2017
Extras
AthenaMT / Gaudi Hive

- AthenaMT: based on Gaudi Hive: multi-threaded, concurrent extension to Gaudi

- Data Flow driven
  - Algorithms declare their data dependencies
  - Scheduler automatically executes Algorithms as data becomes available.
    - optimal traversal of graph possible if avg. Algorithm runtimes known

- Multi-threaded
  - Algorithms process events in their own thread, from a shared Thread Pool.

- Pipelining: multiple algorithms and events can be executed concurrently
  - some Algorithms are long, and produce data that many others need (eg track fitting). instead of waiting for it to finish, and idling processor, start a new event.

- Algorithm Cloning
  - multiple instances of the same Algorithm may exist, and be executed concurrently, each with different Event Context.
    - legacy: one instance, non-concurrent
    - cloneable: one or more instances, in its own thread
    - re-entrant: once instance, executed concurrently by multiple threads

- Thread Safety
  - Only shared Services and re-entrant Algorithms need to be thread safe
  - Algorithms must avoid thread-hostile behaviour
    - global statics, etc
Concurrent: Scheduling Barrier

Scheduler can only **concurrently** process events which have all Conditions in the **same** IOV.

NO changes required in User code and minimal changes in IOV code.
Scheduler can only **concurrently** process events which have all Conditions in the same IOV.

**ISSUES**

- loss of Concurrency when Scheduler is drained at a barrier
  - barrier is at intersection of all IOVs
  - significant impact on Event throughput if IOVs change often
- Events must be processed in order, or reshuffled by the Scheduler to avoid bouncing back and forth
ConditionHandles

Alg_A
In: a, b
Out: x

CondDbSvc
W
regHandle(x)

CondAlg_X
In: x
Out: y, z

Alg_B
In: a
Out: b

Alg_C
In: b, x
Out: