Argonne NATIONAL LABORATORY

Persistent Data Layout and Infrastructure for Efficient Selective Retrieval of Event Data in ATLAS

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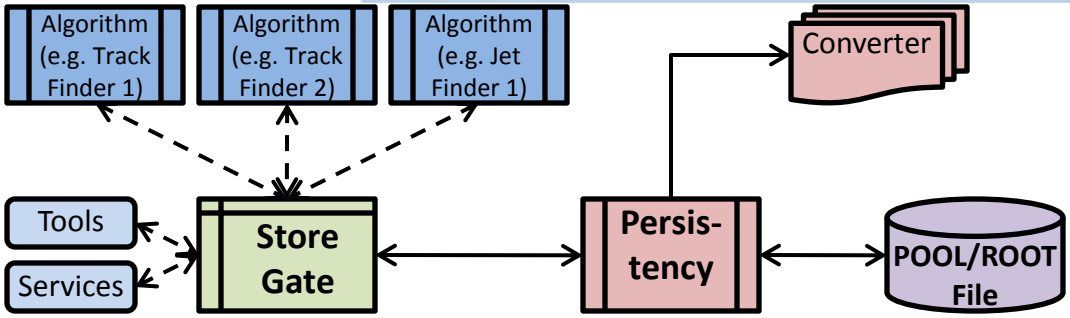
Outline:

- ATLAS Software & Event Data Model
- POOL / ROOT Persistency Framework
- ROOT Object Streaming & Splitting
- History of Storage Layout
- Mismatch of Transient vs. Persistent Event Data Layout
- Changes:
  - No single attribute retrieval
  - Almost event level retrieval
- Performance Measurements:
  - Reading all events sequentially
  - Selective reading 1% of events
- Summary

Abstract

- The ATLAS detector at CERN has completed its first full year of recording **collisions at 7 TeV**, resulting in **billions of events** and **petabytes of data**.
  - At these scales, physicists must have the capability to read only the data of interest to their analyses.
- ATLAS has developed a **sophisticated event-level metadata infrastructure** and **supporting I/O framework**.
  - The ultimate success of such a system, however, depends significantly upon the efficiency of selective event retrieval.
  - Supporting such retrieval can be challenging, as ATLAS stores its event data in **column-wise orientation** using **ROOT TTrees** for a number of reasons, including compression considerations, histogramming use cases, and more.
- For 2011 data, ATLAS will utilize **new capabilities in ROOT** to tune the persistent storage layout of event data, and to significantly speed up **selective event reading**.

ATLAS Software & Event Data Model

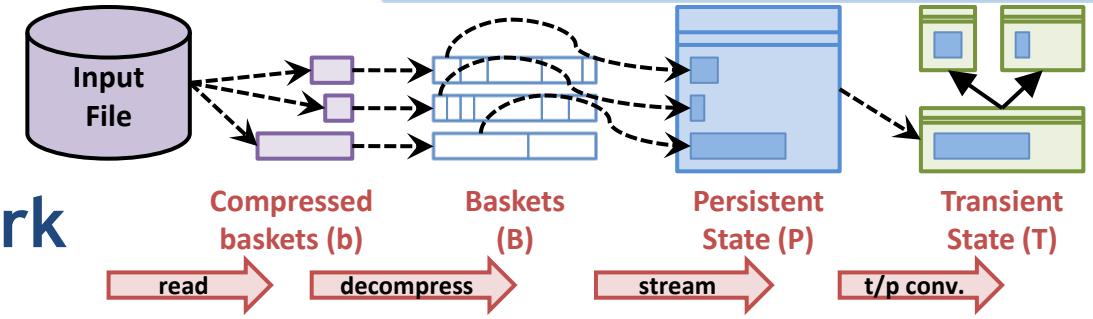


- **Simulation**, **reconstruction**, and **analysis** are run as part of the **athena framework**:
  - Using the most current (transient) version of the **event data model**
- Athena software architecture belongs to the **blackboard family**:
- **StoreGate** is the Athena implementation of the blackboard:
  - Allows a module to use **transparently** a data object created by an upstream module or read from disk.
  - A proxy defines and **hides the cache-fault mechanism**:
    - Upon request, a missing data object instance can be created and added to the transient data store, retrieving it from persistent storage on demand.
  - Support for **object identification** via data **type** and **key** string:
    - Base-class and derived-class retrieval, key aliases, versioning, and inter-object references.

Event Selection using TAGs

- TAGs are **event-level metadata** records.
- TAGs contain event attributes chosen to support efficient identification and selection of events of interest to a given analysis.
  - E.g.: Trigger, event properties (like missing ET), particle data (jets, electrons, muons, photons…).
- TAG data can be stored in **ROOT files** and uploaded into a **relational database**.
- TAGs allow jobs to process only events that satisfy a given predicate.
  - Less complex predicates can be applied as SQL-style queries on the TAG database using a web browser interface or on TAG files directly.
  - For more complex criteria, C++ modules can be written using the TAG attributes for event selection.
- No payload data is retrieved for unselected events.
  - Data files containing only unselected event are not accessed.

POOL / ROOT Persistency Framework



- ATLAS offline software uses **ROOT I/O** via the **POOL persistency** framework, which provides **high-performance** and **highly scalable** object serialization to **self-describing**, **schema-evolvable**, **random-access** files.
- POOL software is based on a **hybrid approach**: Combines **two technology types** into a **single consistent API** and storage system:
  1. **Object streaming** (e.g., **ROOT I/O**), addresses **persistency for complex C++ objects** such as high energy physics event data.
     - In practice, **ROOT I/O** is the only technology currently supported by POOL for object streaming into files.
  2. **Relational Database** (e.g., MySQL), provides **distributed**, **transactionally consistent**, **concurrent** access to data that may need to be updated.

ROOT Object Streaming & Splitting

- State of the objects is captured by special methods, **streamers**:
  - A streamer **decomposes** composite data objects into their member data and calls the streamers of all base classes and for all object data members.
    - Ultimately, **only simple data types** are written containing all data of an object.
- When ROOT writes objects to TTrees, **splitting of data members into separate TBranches** can be controlled by setting the split-level.

  Split-level 0: causes the whole object to be written entirely to a single TBranch.

  Split-level 1: will assign a branch to each object data member.

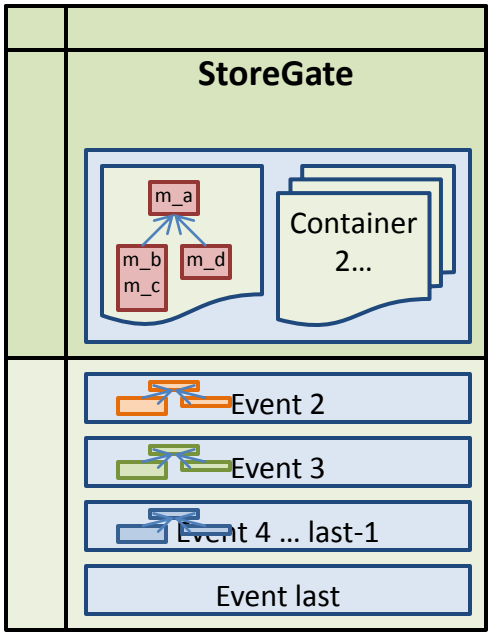
  Split-level 2+: composite data members are also split.
- When splitting TTrees, each TBranch will have its own buffer that can be **compressed individually**.
  - A split TTree has smaller **size on disk**, can be **faster** to read, but requires **more memory**.
  - Data members contained via pointer cannot be split.

History: Storage Layout

- When ATLAS started using POOL/ROOT, we wrote a **separate TTree** for each **StoreGate Collection** and did **not use splitting**.
  - At that time, POOL did work only for Container matching to TTree.
  - Before Transient-Persistent Separation, data was stored in DataVectors, which contain Pointer to Objects, which couldn't be split by ROOT.
- After **Transient-Persistent Separation**, ATLAS designed persistent objects that could be split and used the **default split-level of 99**.
- When POOL learned how to create Container as **TBranches** of a TTree, ATLAS decided to assemble most of our **event data in a single TTree**.
- **Basket sizes** were left up to POOL/ROOT to use a POOL **default of 16KB**, until **memory constrains** forced ATLAS to lower it to **2KB** for all baskets.
  - For 2011 data so far ATLAS is using a new ROOT feature to optimize Baskets in the main event **TTree to share 30MB**.

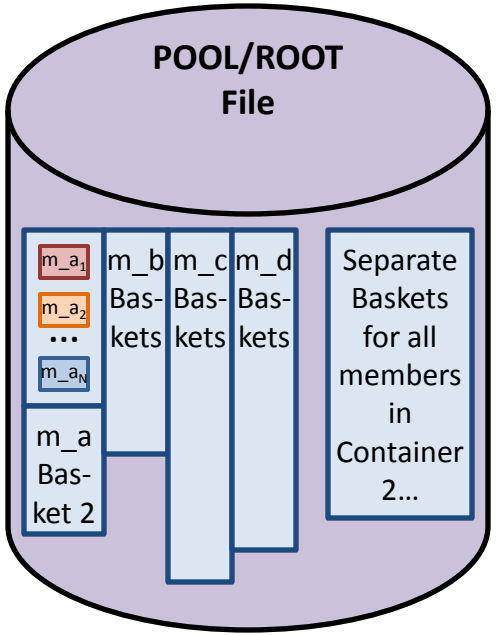
Mismatch:
Transient vs. Persistent Event Data Layout

- **Event-wise oriented**.
  - DataObject / Container retrieval on demand.
    - No partial object or data member retrieval.
- **Column-wise oriented**.
  - Size of column depends on split-level:
    - Split-level 99, split object down to individual member.



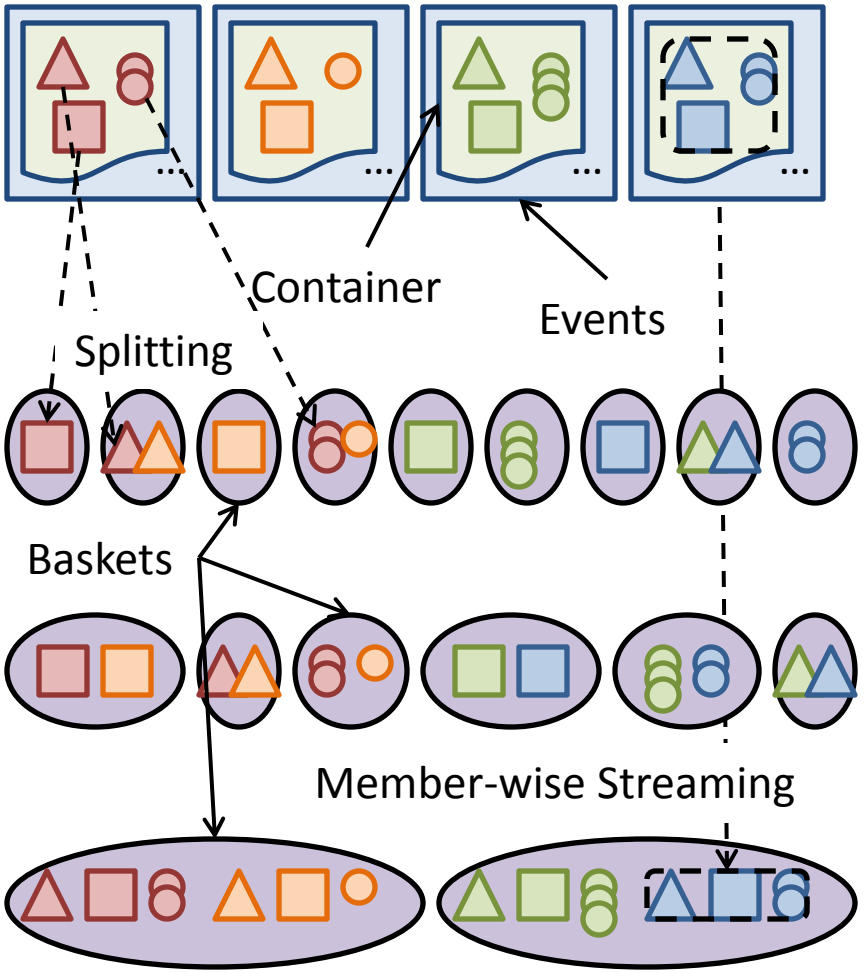
← **StoreGate EventStore holds one event only.**
  - Cleared after each event is processed.

→ **ROOT compresses data for many events into common baskets**.
  - Completely read and uncompressed when single event is retrieved.



1st Change: No single attribute retrieval

- Switched **splitting off** while retaining **member-wise streaming**.
  - Each collection (or POOL container) will be stored in a single Basket.
  - Except for largest container:
    - New feature in POOL allows custom split-level.
- This decreases the number of baskets from ~10,000 to ~800, and therefore increases their average size >x10.
  - Therefore lowers the number of total reads.



2nd Change: Almost event level retrieval

- **Current**: With 30 MB optimized TTrees, **~50 – 200 entries** (events) will share the same basket.
  - For selective reading of a single event, 30 MB of data have to be read from disk and uncompressed.
  - **Past**: For fixed sized 2 KB baskets, the number of entries varies to a large degree. To read a single event, >10K baskets -> ~5-10 MB had to be read from disk and uncompressed.
- Use **automatic basket optimization** to write **fewer events per basket**, by flushing every **5 events for ESD** and every **10 events for AOD**.
  - Increase size for baskets outside the main event tree to 32K (ROOT default):
  - Switch off basket optimization for all auxiliary container.

Details for Changes

- For ESD:
  - Trk::TrackCollection#Tracks
- And for AOD:
  - CaloClusterContainer#CaloCalTopoCluster
  - Rec::TrackParticleContainer#TrackParticleCandidate
- Container are very large and do not gain by streaming member-wise, therefore they remain being written in split mode.
  - Avoids file size increase.
- Part of main event tree, therefore flushed every 5/10 events.

1st Performance measurements: Reading all events sequentially (ESD and AOD)

- This use case is most often considered.

1. **Current**: Full splitting and 30 MB to optimize main event tree:
   - Total read **ESD**: **420 ms/event**
   - Total read **AOD** : **55** (+/- 3) **ms/event**
2. **New Storage Layout**: No splitting and flushing of main event tree every 10/5 events:
   - Total read **ESD**: **360 ms/event**
   - Total read **AOD**: **35** (+/- 2) **ms/event**

- Reading all events is **~15 - 30% faster**
- Fewer reads, 10-30 x less branches only ~10 x more baskets.
- Better sequencing of baskets in file.

2nd Performance measurements: Selective reading 1% of events via TAGs (AOD only)

- This use case is the main motivation for changing the storage layout.

1. **Current**: Full splitting and 30 MB to optimize main event tree:
   - Total read **AOD**: **270 ms/event**
     - Per event reading is ~5 times slower than reading all events. However, total read time is reduced by almost a factor of 20.
     - A 1% selection ends up reading and uncompressing most data.
2. **New Storage Layout**: No splitting and flushing of main event tree every 10/5 events:
   - Total read **AOD**: **60 ms/event**
     - Per event reading is 50-100% slower than reading all events (almost as fast as with the current layout). Total read time is reduced by more than a factor of 50.
     - A 1% selection ends up reading and uncompressing less than 10%.

- Reading (1%) selected events is **~4 - 5 times faster**.

Performance Details for DataObjects

- **Large** containers are not changed and do not gain (or lose) in I/O performance.
  - These container already performed well.
- **Very small** DataObjects did not see a performance gain either.
  - Small DataObjects tend to have only few data objects, so there is limited gain by streaming member-wise.
- Medium sized container show the **biggest improvements**:
  - Analysis::MuonContainer ~3 x faster
  - TrigMuonEFInfoContainer ~3 x faster
  - Trk::SegmentCollection ~3 x faster
  - egammaContainer >2 x faster

Performance Gains for Selective Reads

- When reading via TAGs, all DataObjects show great improvements.
- For this study, TAGs were only used as the mechanism to trigger selective reading.
- There are many use cases for selective reading of events or DataObjects / Containers:
  - The user may need some information only for a subset of events:
    - E.g.: A slepton search may need to use the lepton containers only if there is missing energy greater than a threshold.
    - In many of these cases using TAGs can be beneficial, as they were designed to enable efficient event selection.
      - E.g.: One can select events with a certain number of jets, without having to read the Jet container (for the rejected events).
  - When using the **multi-processor athenaMP** framework, multiple worker processes, each read only a non-sequential part of the input file.

Further Performance Results

- **File Size** is **very similar** to old and current format.
- **Virtual Memory** foot print **reduced by about 50-100 MB** for writing and reading new data:
  - Fewer baskets loaded not memory.
- **Write Speed** has **increased** by about **20%**.
  - The write speed was increased even further (almost 50%), as the compression level was relaxed.

Fall 2011 Reprocessing

- This month ATLAS started to reprocess all data taken in 2011, using release 17 software, which deploys the new storage layout:
  - No splitting and flushing of main event tree every 10/5 events
- Until end of August, ATLAS Tier 0 continues to process data using the current release 16 software:
  - Full splitting and 30 MB to optimize main event tree
- By end of the reprocessing campaign, all 2011 data will have been reprocessed using the new storage layout and I/O performance benefits will be available to reader of ESD and AOD.

Summary

- Changes to the event data storage layout:
  - No ROOT splitting, but member-wise streaming.
  - Optimize ROOT baskets to store small number of events.
- Improve I/O performance:
  - Reading is ~30% faster.
  - Selective Reading is 4-5 times faster (for 1%)
- To be deployed in fall reprocessing.

	Read all events	Read 1% of events
AOD 1 split, 30MB TTree	55 ms/ev.	270 ms/ev.
AOD 2 un-split, flush 10 evt.	35 ms/ev.	60 ms/ev.
Difference	**~30 % faster read**	**4-5 times faster read**

vs. **OLD** ROOT TTree