ICARUS Signal Processing With HEPnOS

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In partnership with:

Background: File-based workflows for grid-computing

- Current workflow uses a **file-based workflow** suited for **grid-computing:**
  - Input is a set of files, each containing ~30 events, ~10-20 Gb (for ICARUS).
  - Run each task (set of analysis modules) in the analysis pipeline as a **process.**
  - Size of a task is limited by available time, memory, disk space for output files.
  - Use **files to pass the results** between tasks.

- ICARUS uses the *art* framework to analyze events. Each *art* instance can concurrently process multiple events (each harnessing multiple-threads).

- Typically, one *art* process runs on a node and analyzes all the events in a file, producing one output file containing the **data products produced by the analysis and ones produced by preceding analysis**.

- Thus, we **typically have fewer *art* processes than files!**

Harness HPC resources using a distributed data store

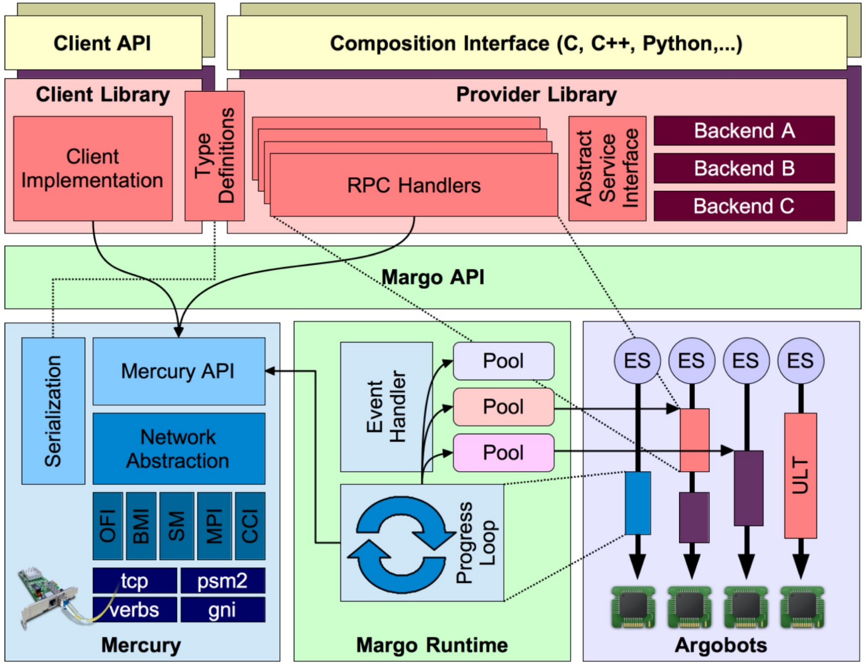
- Parallelism in analysis pipeline **limited by number of files.**
- **Remove this bottleneck** by **harnessing HPC resources** which have **low latency, high bandwidth interconnects** between nodes.

- We aim to achieve this by using a distributed data store which:
  - **Holds all data products for the duration of the analysis** on a set of (server) nodes
  - Allows *art* process to **store/retrieve data-products via the interconnect**

- By using it, we have now:
  - **Removed the constraint on parallelism** imposed by number of files.
  - **Reduced memory usage by each process** by fetching only the data-products required by a module and storing the results at the end of the module.
  - **Harnessed the interconnect** instead of the file-system to store/fetch data-products.

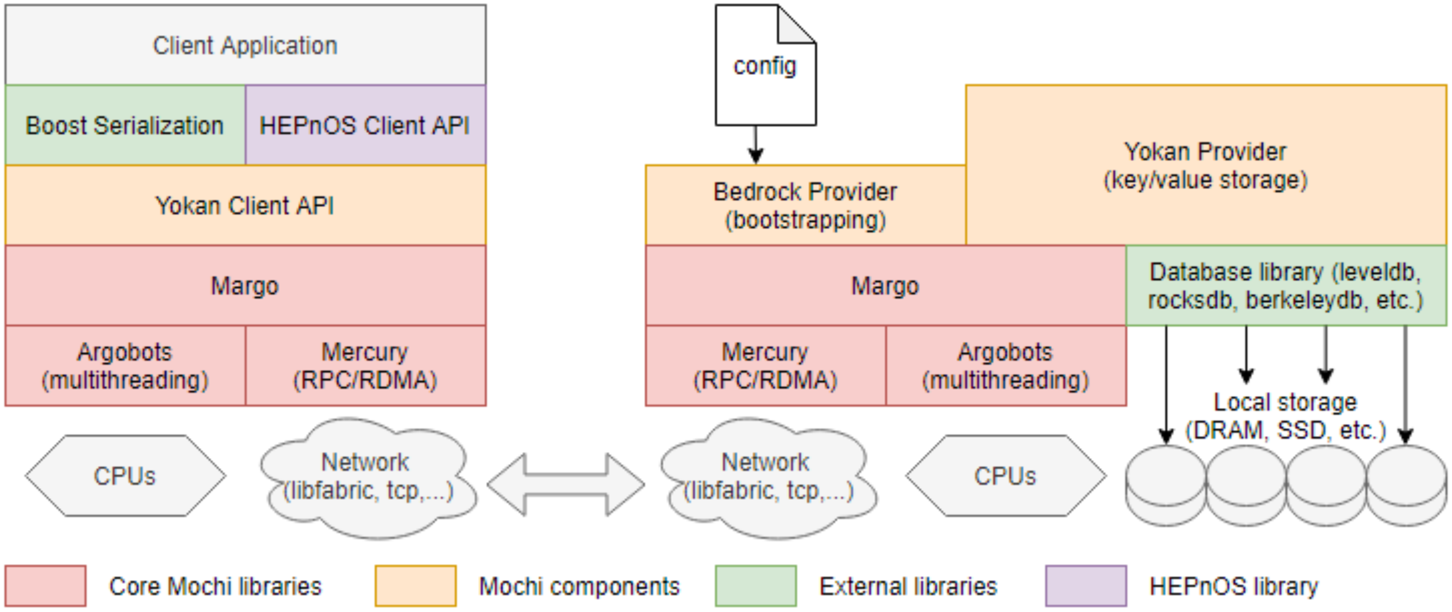
Background: Custom data services with Mochi

- Mochi microservices: a suite of re-usable components for building data services including:
- Mercury: RPC framework that can use a variety of transports, which supports bulk data transfers.
- Argobots: Lightweight user level threads to run tasks in execution streams.
- Margo: Utilities for argobots aware mercury requests.



Anatomy of a data service backed by mochi microservices. Illustration by Matthieu Dorier.

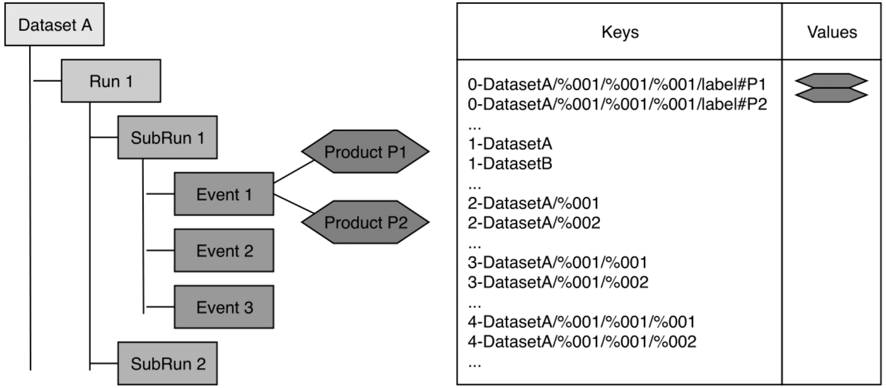
High-Energy Physics's new Object Store: Architecture



Architecture of HEPnOS: (Left) Client stack, (Right) Server stack. Illustration by Matthieu Dorier.

High-Energy Physics's new Object Store: Features

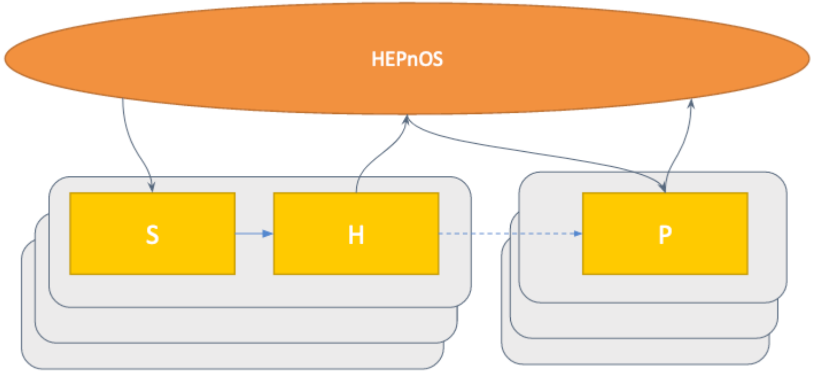
- Write-once, read-many access.
- Bulk ingest and iterative access.
- Eliminates software artifacts related to the filesystem and grid computing.
- Parallelism expressed at the event level instead of file level, allowing for better load balancing.



(Left) Hierarchical dataset organization. (Right) Representation in HEPnOS. Illustration by Matthieu Dorier.

Integrating HEPnOS into *art*

- HEPnOS allow for interaction via “queues”.
  - “Producer” mode allows one to put data products into the “queue”.
  - “Consumer” mode allows one to pop data products form the “queue”.
- Prototype I/O modules for *art* implemented corresponding to the two modes.
- This design allows for load-balancing at the event-level as **we can now have as many concurrent processes as events.**
- Compute resources can be partitioned based on the needs of tasks with this design, leading to efficient “pipelining”.



Data-flows for the first few steps of the ICARUS analysis pipeline. S: Signal Processing, H: Hit finding (JINST 17 (2022) 01, P01026), P: Pandora (Eur. Phys. J. C78, 1, 82 (2018)).

Preliminary evaluation

- Can we demonstrate event-level parallelism with HEPnOS by running as many processes as there are events in a file?

- We chose a typical ICARUS file with 30 events and ran the S and H steps using:
  - File based workflow: one *art* process with 4 threads analyzing all the events sequentially.
  - HEPnOS based workflow: varying number of *art* processes (each with 4 threads) fetching data products from HEPnOS, analyzing them and storing the resulting products back into HEPnOS.

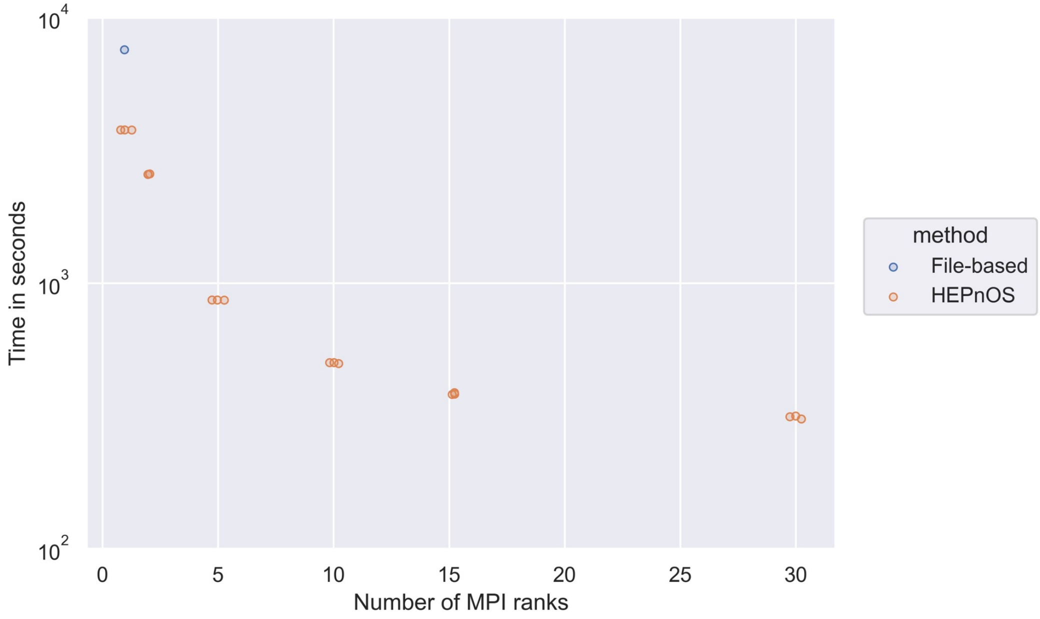
- We want to determine the scaling efficiency of the HEPnOS based workflow.

Preliminary evaluation

- Used 1 KNL node on Theta, with 64 (x86_64) cores for the analysis and 1 KNL node as the server for the *HEPnOS* workflow.

- Used MPI to launch multiple *art* processes.

- We observe a scaling efficiency of 75% at 10 MPI ranks and 66% at 15 MPI ranks.



Summary

- Demonstrated the use of a system-wide distributed event store suited to harness HPC interconnects.
- Demonstrated the ability to **harness workflow parallelism at the event-level** with *HEPnOS*.
- Work is currently underway on:
  - Demonstrating speedups using a larger dataset of 10k events (~4.5Tb).
  - Measurements of improvements from better pipelining.
  - Analyzing HEPnOS server configurations remove bottlenecks.

SciDAC team

- HEP and ASCR Collaboration
  - LHC and neutrino physics: N. Buchanan (CSU, NOvA/DUNE), P. Calafiura (LBNL, LHC-ATLAS), Z. Marshall (LBNL, LHC-ATLAS), S. Mrenna (FNAL, LHC-CMS), A. Norman (FNAL, NOvA/DUNE), A. Sousa (UC, NOvA/DUNE)
  - FASTMath Optimization: S. Leyffer (ANL), J. Mueller (LBNL)
  - RAPIDS Workflow, Data Modeling: T. Peterka (ANL), R. Ross (ANL)
  - Data science: M. Paterno (FNAL), H. Schulz (UC), S. Sehrish (FNAL)
  - J. Kowalkowski – PI (FNAL)
- Research Associates and Graduate students
  - Steven Calvez (CSU/PD), Pengfei Ding (FNAL), Matthieu Dorier (ANL/PD), Derek Doyle (CSU/GS), Xiangyang Ju (LBNL/PD), Mohan Krishnamoorthy (ANL/PD), Jacob Todd (UC/PD), Marianette Wospakrik (FNAL/PD), Orçun Yıldız (ANL/PD)
- http://computing.fnal.gov/hep-on-hpc/

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