Coupling Chapel-Powered HPC Workflows for Python, part 2

John Byrne, Harumi Kuno, Chinmay Ghosh, Porno Shome, Amitha C, Sharad Singhal, Clarete Riana Crasta, David Emberson, Abhishek Dwaraki

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How quickly can we simultaneously ingest and interactively process data ... using Chapel and Fabric-Attached Memory?
Challenge: maximize concurrency for interactive workloads

Sizing:

- Allocate too few nodes: could run out of resources (e.g., out of memory)
- Allocate too many nodes: could underutilize resources (e.g., low concurrency)
- Share nodes between servers: could run out of resources.
Increase Concurrency via Batch-oriented dataset manager + Work-Stealing

Analysts use Python to interactively operate upon the ingested Data Sets. The Data Set Manager returns early results and registers the bulk of the work for asynchronous processing.

Python program / Jupyter Notebook (Arkouda Client)

Asynchronous workers steal work from shared pool and use Arkouda to distribute the working dataset into DRAM of compute nodes and stores results in the storage tier.

Ingest programs process raw data and publish batches of data, integrated into Data Sets, into storage tier.

10 Ingest Nodes (running Chapel Ingest program)

Arkouda Server

Python program Async Worker (Arkouda Client)

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32 compute nodes (running Arkouda Servers)

High speed network

High Bandwidth / Low Latency Storage Tier (10 Nodes running OpenFAM Servers)
The OpenFAM library for programming Fabric-Attached Memory lets programmers create and share in-memory data using fabric-attached memory (FAM) hosted on conventional nodes.

OpenFAM uses RDMA for operations like put, get, scatter, gather, copy, backup, and restore, as well as standard atomic operations like fetch-and-add, compare-and-swap.

Arkouda extension lets programmers move data between Arkouda pdarrays and OpenFAM.

FAM bandwidth and latency are currently superior to Flash but inferior to local DRAM.
Performance Tuning

1. Dual NIC, dual socket servers: bound a locale to each socket + NIC.
2. Lock-free concurrency control while processing batches using work-stealing.
3. Memory registration – registered Chapel memory with OpenFAM’s Libfabric endpoints so all memory within every Chapel locale was pre-registered for RDMA.
4. Update OpenFAM to use Mochi Thallium instead of GRPC for communication between OpenFAM servers and clients.
5. Extended FAM Dataset Storage Manager to support option for registering operations as ongoing, meaning results with available data will be returned immediately and as the source data evolves, the result dataset will be updated automatically by workers.
Ingest 8 TB (20 locales, 10 ingest nodes)

Update OpenFAM to use Mochi Thallium instead of GRPC for communication between OpenFAM servers and clients.
Isolated Ingest Performance for 8 and 16 TB, varying batch size

Measured uni-directional bandwidth is about 24 GB/s per NIC: total 480 GB/s.
Isolated Workflow Performance 16 TB, varying number of workers

Measured uni-directional bandwidth is about 24 GB/s per NIC: total 480 GB/s.
Simultaneous Workflow and Ingest, 16 TB, 64 workers

Measured bi-directional bandwidth is about 17 GB/s per NIC: total 340 GB/s each way.
Trace-Driven Animation: ingest & process 16 TB

- **Experiment Setup**
  - 64 asynchronous worker Arkouda servers/clients running on 32 nodes
  - 20 ingest locales running on 10 nodes
  - 20 memory servers running on 10 nodes
  - Workflow creates 21 derived data items (derived datasets and derived columns)
Experiment: Ten times a second, record number of batches for ingested data & derived data items.

• At the start:
  • A single batch of data has been ingested; all ingest and Arkouda workers are waiting on a barrier.
  • The Interactive User has processed one batch and registered the workflow for asynchronous processing.

• Tracing starts when everyone reaches the barrier.

• The ingest processes all begin to publish batches of data to FAM.

• The Arkouda Workers all start looking for and processing data.

• Stop when 1600 processed batches have been published for all 21 derived data items.
BACKUP
### Summary of Dataset Management Approach

1. Partition incoming data into ordered discrete batches.
2. Single batch of data can be efficiently processed by an Arkouda Server running on the compute nodes.
3. Provide a Dataset Storage Manager that organizes the discrete batches of data into logical datasets (like an Arkouda/pandas dataframe).
4. The Dataset Storage Manager supports the creation of derived dataset (indexes) and derived columns.
5. The Dataset Storage Manager supports the incremental maintenance of derived datasets and derived columns. Multiple instances of the FAM Dataset Storage Manager can attach to a store and leverage each other’s results.
6. To increase concurrency, we extended the FAM Dataset Storage Manager, leveraging its support for incremental maintenance to implement work-stealing functionality.

When a data analyst explores a large dataset in an interactive session by deriving new datasets and columns, they can request that the Dataset Storage Manager present them with early results and delegate completion of the new datasets to a multitude of Arkouda Servers that will complete the work.
FAM Dataset Storage Manager for Arkouda

- **FAM Dataset Storage Manager**
  - famDatasetStore class

- **Arkouda Client Python Module**
  - famarray and famstore classes

- **Arkouda Server (Chapel application)**
  - FamMsg Module

- **Chapel programming language**
  - FAMArrayStore Module
  - OpenFAM Module
  - OpenFAM C Linkage Library

- **OpenFAM**
  - OpenFAM Client
  - OpenFAM Server

Operations (e.g., filter, scatter, gather, sortruns, topXperrun, toPdarray, toDataFrame) on FAM Datasets.

Over-the-wire messages that let Arkouda clients request that the Arkouda server perform operations on arrays of data residing in FAM.

Movement of data between Arkouda pdarrays and named arrays of data stored in FAM.

Store FAM objects in Arkouda Symbol Table.

Multi-locale put, get, gather, scatter of data stored in FAM.

OpenFAM API for single-locale operations on data stored in FAM.
FAM Dataset Storage Manager

A transient FAM Dataset Storage Manager instance runs within the Jupyter Notebook process. Working metadata resides in memory here.

Data and metadata “persist” in memory on FAM nodes as FAM Arrays.

Within the Arkouda server processes, the FAM Dataset Storage Manager “pages” batches of data between famarrays and Arkouda parallel distributed arrays (pdarrays). Working data resides in the local memory of compute nodes.
Isolated workflow throughput, 16 TB

16 TB Analytic workflow (vary number of workers)

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<th>40 GB</th>
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Isolated workflow latency, 16 TB

16 TB Analytic workflow (vary number of workers)

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