Hewlett Packard Enterprise

ENABLING FAM ACCESS IN CHAPEL

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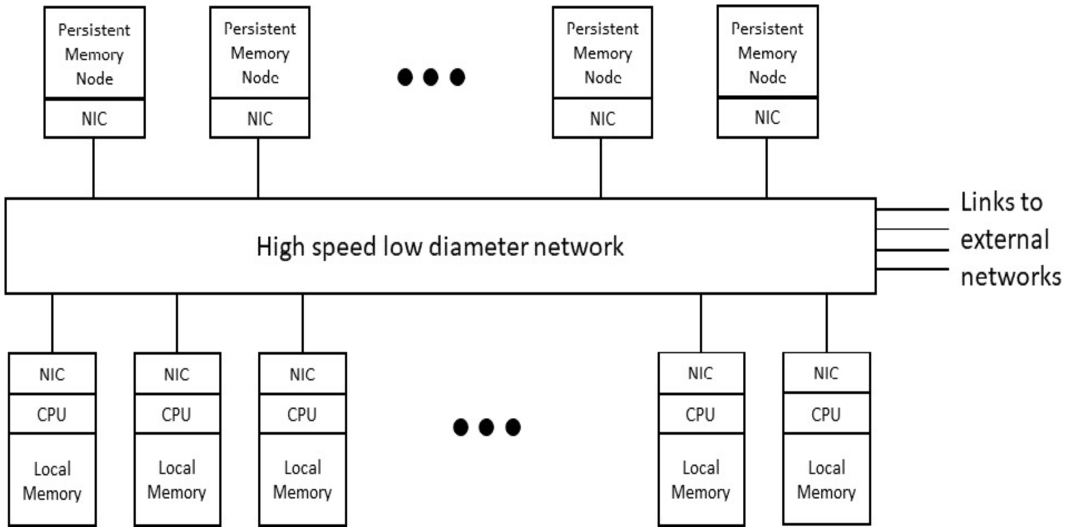
AGENDA

- Fabric-Attached Memory(FAM) – Context
- Why Chapel?
- FAM access from Chapel
  - FAM Distributed Arrays – Design
- Status and Next Steps
- Competitive approaches

FABRIC-ATTACHED (PERSISTENT) MEMORY

- Converging memory and storage
  - Resource disaggregation leads to high capacity shared memory pool
  - Local volatile memory provides lower latency, high performance tier
- Distributed heterogeneous compute resources
  - High-speed interconnect
  - Operating system instance per compute node
- Fabric Attached Memory is
  - Large – enabling workloads with large data sets
  - Shared – enabling communication across compute nodes through FAM
  - Persistent – enabling faster checkpointing and access to persistent data



CHAPEL

Our Goal:

Enable FAM access through multiple programming languages to make FAM available for a variety of workloads.

FAM enablement in Chapel, because Chapel is :

- **written for HPC**
- **scalable**: Designed to be as scalable as MPI & OpenMP parallel computing
- **fast:** performance competes with or beats C/C++
- **portable:** runs on laptops, clusters, the cloud, and HPC systems
- **Programmable**: Designed with programmer productivity in mind
- **open source:** hosted on GitHub, permissively licensed

Guiding Philosophy

- Access FAM-resident data with minimal language changes
- Abstraction of FAM access from the application

CHAPEL

Chapel simplifies parallel programming through elegant support for:

- **data parallelism** to efficiently use the cores of a laptop, cluster, or supercomputer
- **task parallelism** to create concurrency within a node or across the system
- **a global namespace** supporting direct access to local or remote variables
- **Distributed Arrays**
  - An important aspect of large-scale programming on HPC clusters
  - Chapel distributes the elements of the array across nodes, and so the tasks associated with the elements
  - Array distributions provide a “global view” as if it was a local array

Ref: https://chapel-lang.org/

FAM ACCESS FROM CHAPEL

Proposed Solution

- New distribution module - Array resides on FAM
- Modified the Chapel external module to define new distribution policy for FAM
- Provides support for named array allocation in the application
- Supports implicit parallelism through domain partitioning

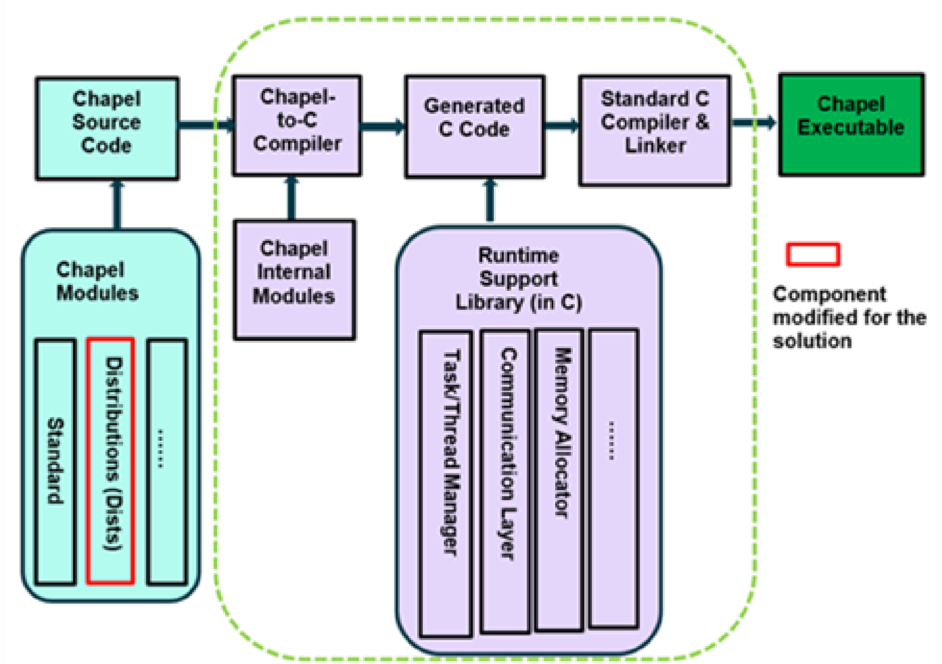
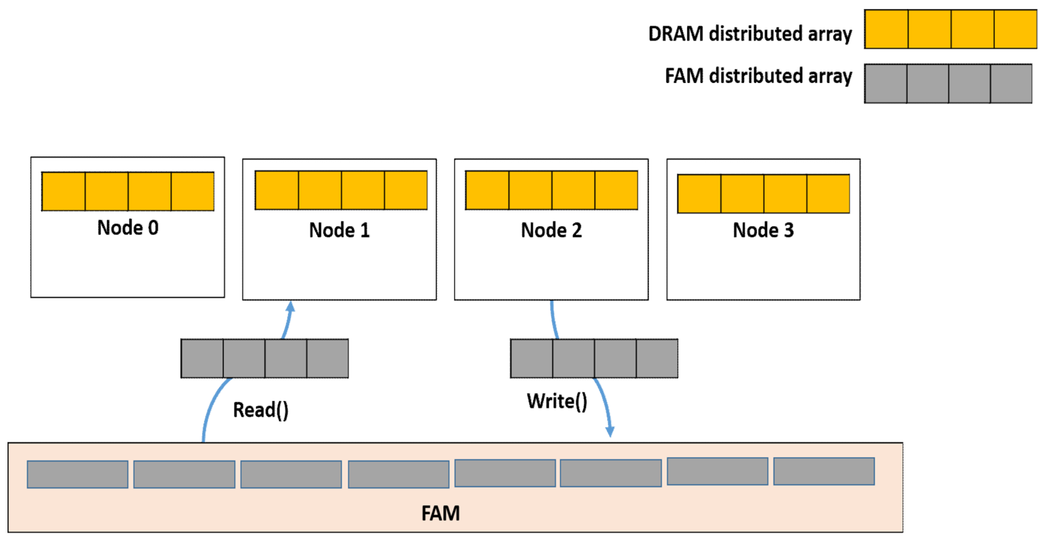


Figure 1: Chapel components

FAM DISTRIBUTED ARRAYS - DESIGN

High Level Design:

- FAM distribution module converts high level array operations into FAM-specific accesses underneath
- Complete array is allocated on FAM by the locale creating the array
- Each locale is then assigned a partition upon which to operate
- Array operations executed in parallel by target nodes
  - Example: forall, reduce or scan are divided into multiple tasks based on the partitioning, and executed in parallel by the target nodes.



FAM DISTRIBUTED ARRAYS - STATUS

Enable longer-term vision

Current Status:

Initial Implementation of

- Array allocation, Array lookup, Array Destroy
- Random indexed access
- Iteration (serial and parallel loops with zippering)
- Bulk transfers
- Reduce and scan
- Array slicing and re-indexing

Design ensures that:

- Applications can allocate and reuse arrays located on FAM
- Our solution honors Chapel's programming philosophy, e.g., programmer productivity
- Management of FAM data allocation and accesses are abstracted away from the application
- Semantics of a FAM array is as close to that of existing Chapel distributions as possible

```
const Dfam = {1..1000000} dmapped  Fam() ; // FAM distributed domain
// Allocate new FAM distributed array
var FamArr: [Dfam] int;
FamArr.allocate(name="MyArray1", auto_destroy=false);
```

```
const Dfam = {1..1000000} dmapped  Fam() ; // FAM distributed domain
var FamArr: [Dfam] int;
FamArr.find(name="MyArray2");
```

```
// Serial Loop on FAM array
for fa in FamArr do
  fa = 1;         // assign the value "1" to array elements serially

// Parallel Loop on FAM array
forall fa in FamArr do
  fa = fa * 2;  // Update the array data in parallel

forall (fa,ba) in zip(FamArr,BlockArr) do
  fa = ba;    // Copy elements from Block array to FAM array
```

Examples of FAM access from Chapel

BULK TRANSFER RESULTS

Preliminary results with bulk transfer

- 25 GiB array copied from FAM to a DRAM distributed array using the bulk transfer operation
- Array directly copied from the application using OpenFAM APIs

- With bulk transfer
  - Throughput increases as the number of locales increase due to task parallelism with FAM distributed array
- Without bulk transfer
  - Throughput drops as the number of locales is increased as a result of the communication overhead between locales with application copy

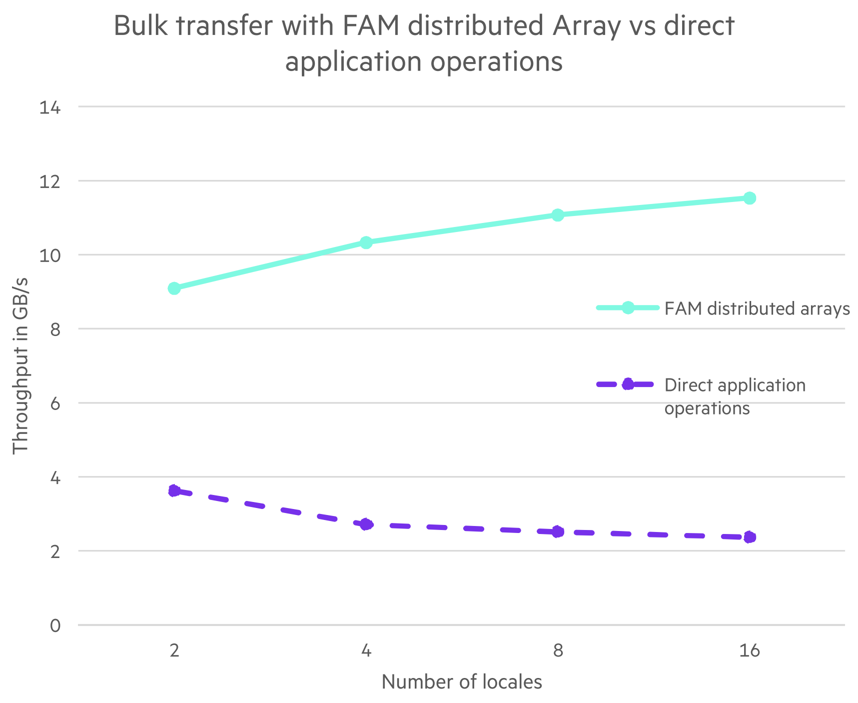
Configuration:

– Chapel 1.24

– 40 Xeon Gold 6248 cores (80 hyper threaded cores) with 128 GB memory running RHEL 8.3

– Infiniband cluster interconnected using 12.5 GB/s link fat-tree

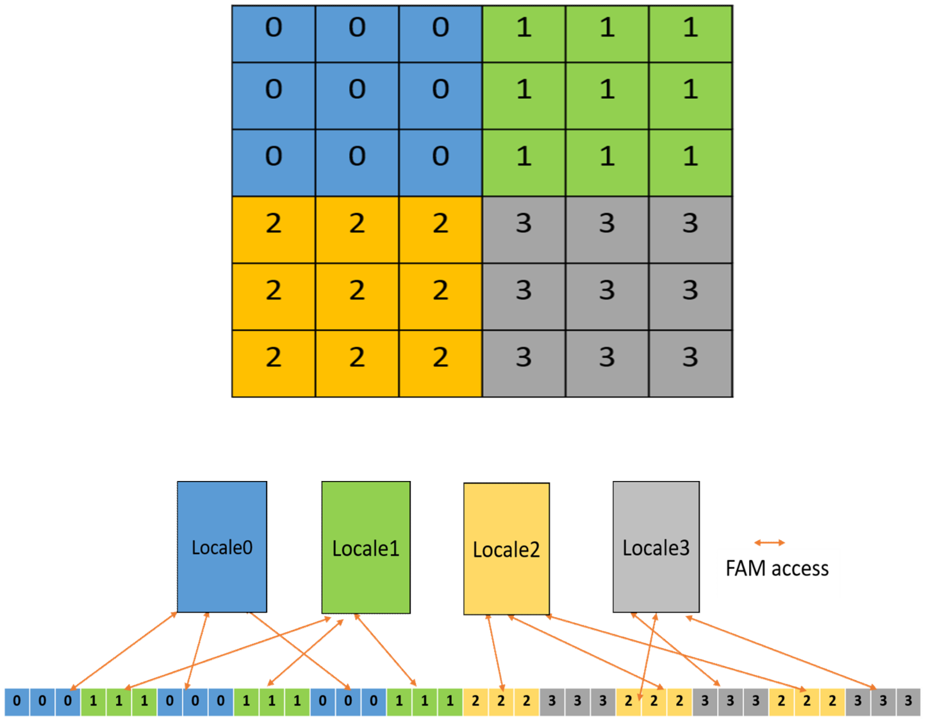
– One of the nodes used as memory server



MULTI-DIMENSIONAL ARRAYS

Block Partitioning

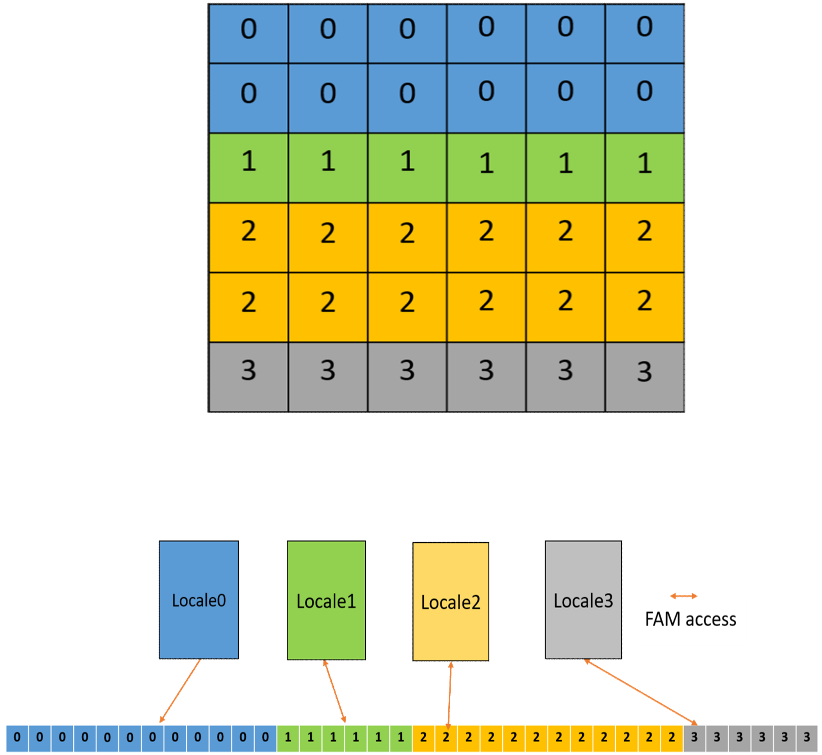
- Arrays are divided into blocks similar to Chapel's Block distribution
  - Block partition may result in non-contiguous elements per locale.
- Data may be stored on FAM contiguously
  - To access a given block, multiple data access requests are involved.



MULTI-DIMENSIONAL ARRAYS

Row Partitioning

- Array is divided based on the number of rows and locales
  - Each node gets a partition where all of its indices are contiguous
- Data is stored on FAM by row-major
  - Only a single OpenFAM data access call to access its data elements
  - Can result in unused locales if number of locales are more than the number of rows



ALTERNATE APPROACHES TO PRESENTING FAM IN CHAPEL

- ***FAM as a locale:*** FAM as new top-level locality in Chapel
  - Chapel Locales[] array, provides an abstraction of all the localities
  - FAM as a remote locality visible to the other compute localities
  - Differs semantically from other localities, since it is a memory-only locality

- ***FAM as a sub-locale:*** Introduce FAM as a virtual sub-locale
  - Inspired by the KNL locality model for supporting high-bandwidth on-package memory (HBM)
  - Requires significant compiler changes to support external memory over the network
- ***FAM as an object:*** New class that represent FAM objects
  - Abstract the FAM access semantics within this FAM class
  - Helper methods within the FAM class handle FAM access details through the communication layer

FAM ACCESS FROM CHAPEL – LOOKING AHEAD

- Next Steps:
  - Characterize performance of FAM distributed arrays
  - Evaluate FAM distributed arrays usage in workloads like Arkouda
  - Fix known temporary solutions – Extra parenthesis for Random indexed read
  - Enable multi-dimensional array
  - Integrate with Chapel mainline code
  - Evaluate other proposals for enabling FAM access in Chapel
    - Enabling FAM as a Chapel object class
    - Present FAM as a sub-locale
- Other ways to access FAM:
  - Represent data in FAM using file-system or key-value store abstractions
  - FAM access to Chapel applications cluster-wide through external libraries such as OpenFAM, or DAOS
  - Involve programming overhead, contrasts with Chapel's philosophy of programmer productivity

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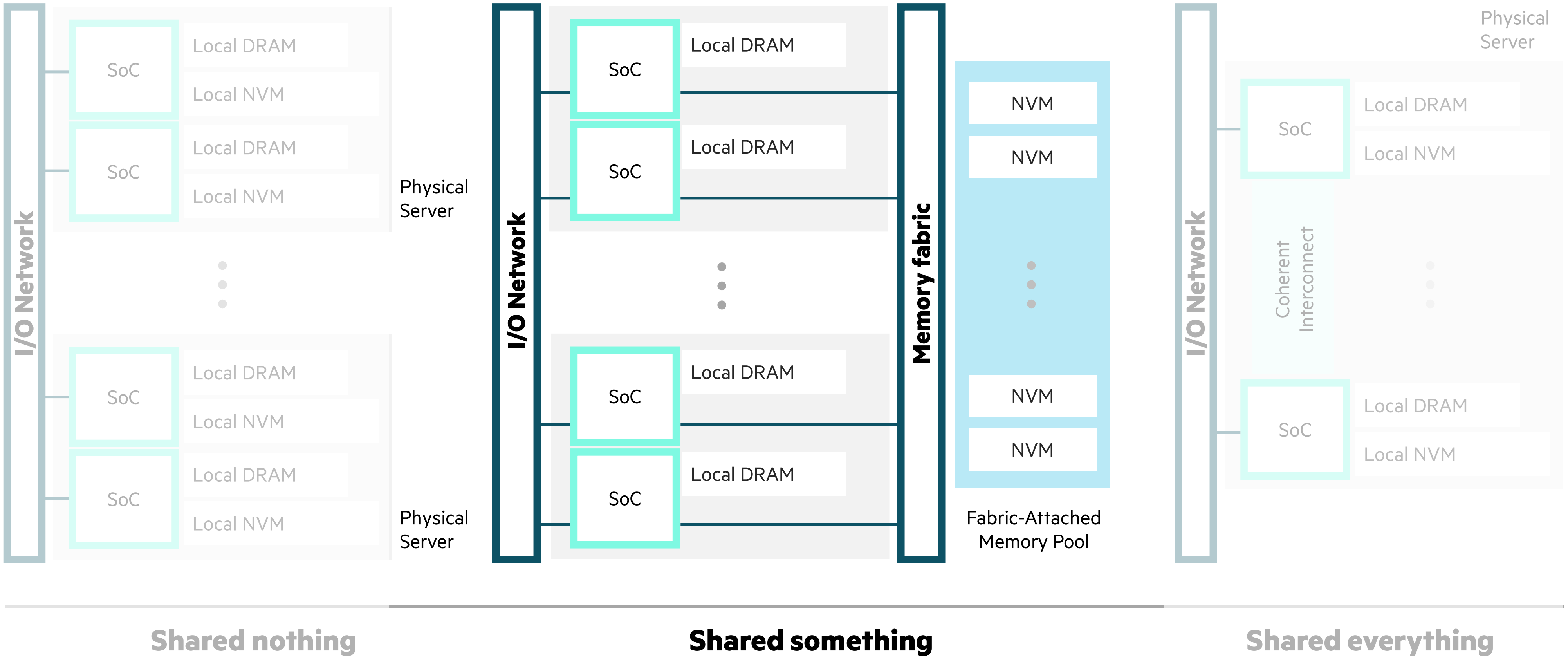
THANK YOU

FABRIC-ATTACHED (DISAGGREGATED) MEMORY IN CONTEXT



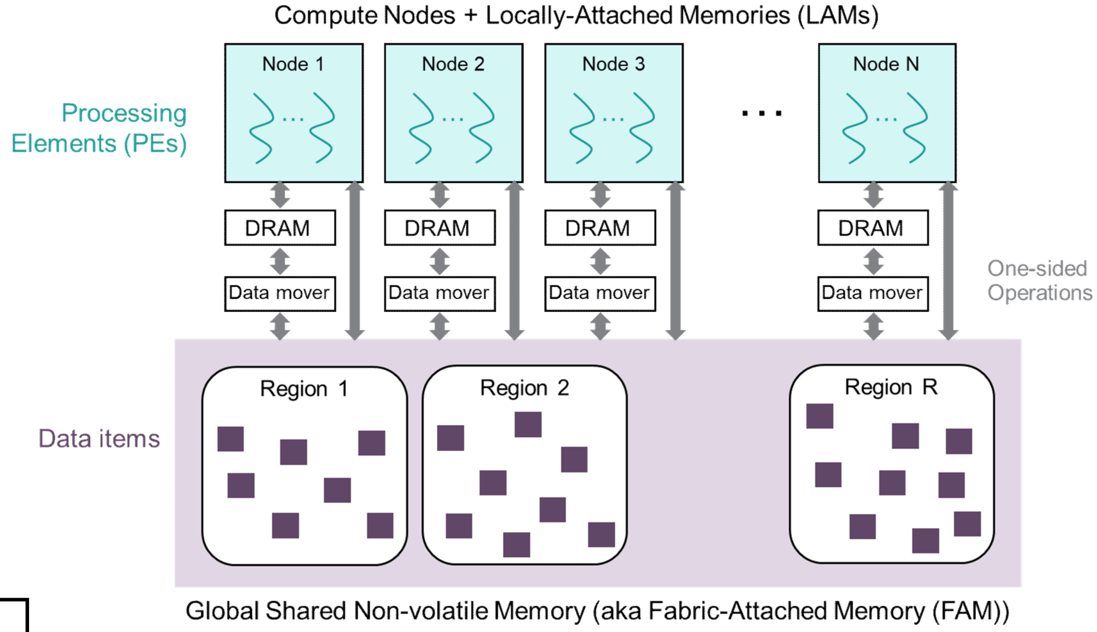
OPENFAM

- **Purpose**:
  - Develop an API and reference implementation to enable programmers to easily program FAM.
- **Challenges**
  - API should be “natural” to HPC programmers.
  - Usable across scale-up machines, existing scale-out clusters, and emerging FAM architectures.

More detail available from

Keeton K., Singhal S., Raymond M. (2019) *The OpenFAM API: A Programming Model for Disaggregated Persistent Memory*. In: Pophale S., Imam N., Aderholdt F., Gorentla Venkata M. (eds) OpenSHMEM and Related Technologies. OpenSHMEM in the Era of Extreme Heterogeneity. OpenSHMEM 2018. Lecture Notes in Computer Science, vol 11283. Springer, Cham

Open source reference implementation: https://github.com/OpenFAM



Status:

- Reference implementation is available
  - Omnipath and Infiniband clusters
- Currently we are
  - Optimizing the implementation
  - Adapting it for slingshot