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Integrated In-System Storage Architecture for High Performance Computing

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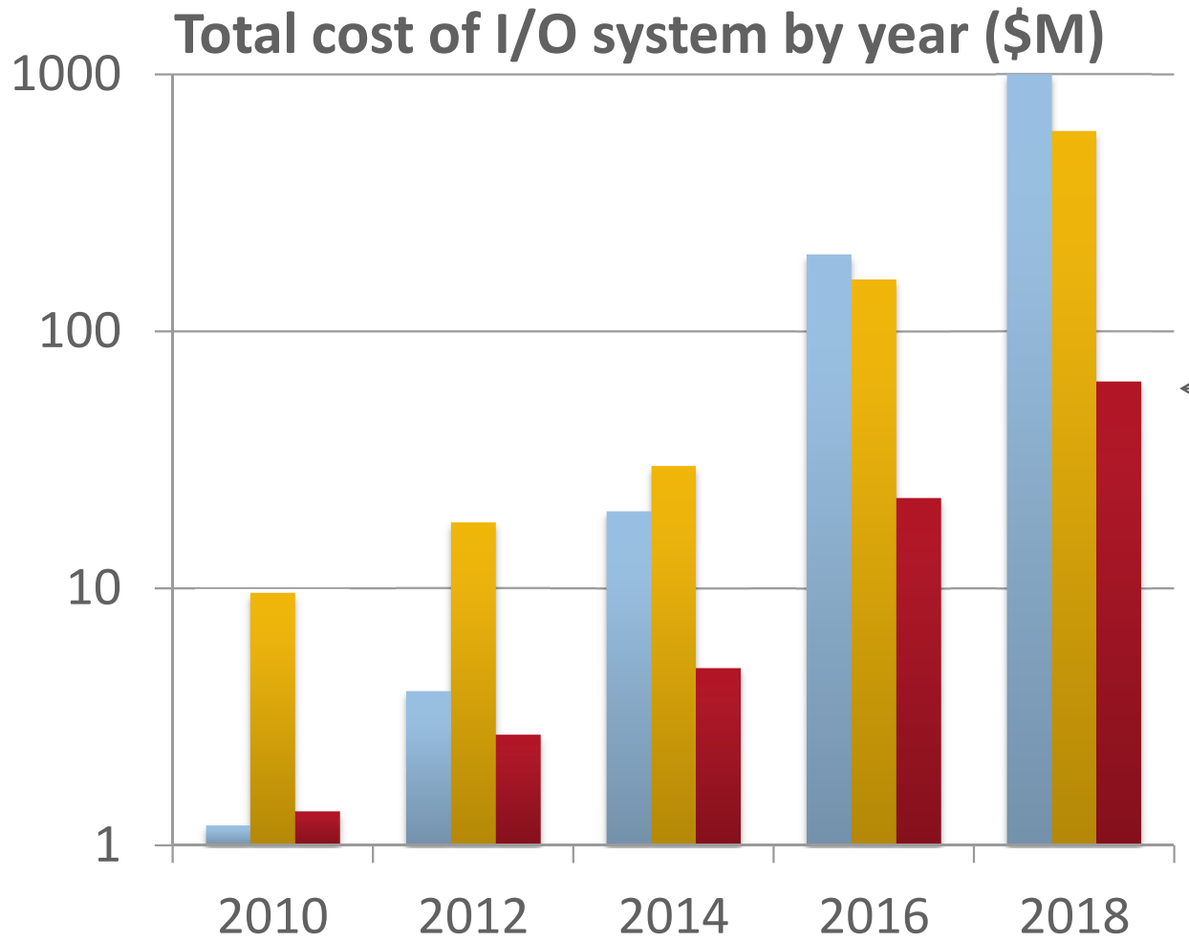
U.S. DEPARTMENT OF ENERGY

Motivation



Assumptions: Require 900 PB capacity @ 100 TB/sec peak in 2018. Associated HW 4x raw device costs. No revolutionary solid state developments. Enterprise storage.

Thanks to Gary Grider (LANL) for this data.

- Exascale storage will be a hybrid of disk and solid state, unless we dramatically reduce capacity requirements.

Motivation

- HPC systems are quickly moving into a realm where hybrid SSD/HDD systems are necessary to hit performance and capacity targets.
- Yet, we do not understand how SSDs can best serve our science needs.

Goal:

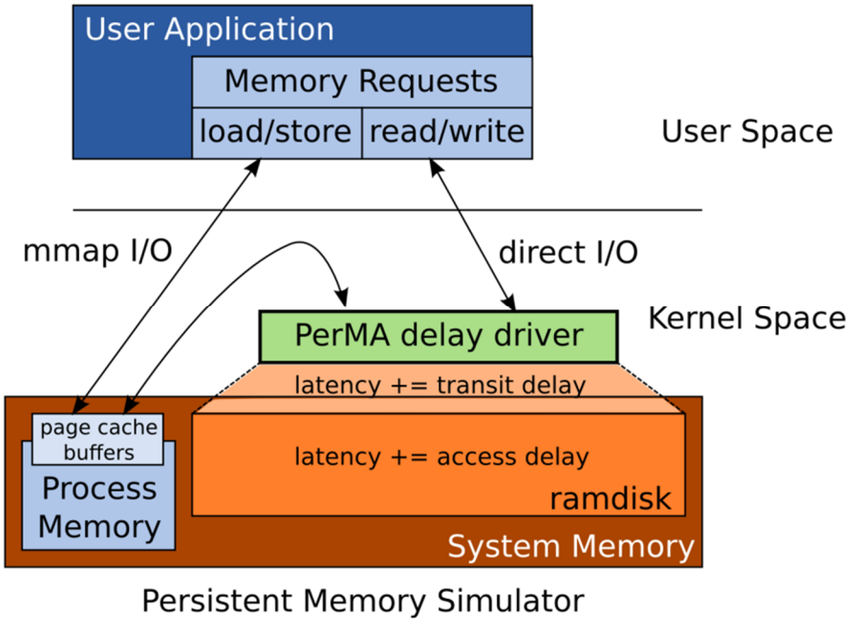
Conduct a detailed assessment of the potential roles and benefits of in-system storage in exascale computational science.

Thrusts:

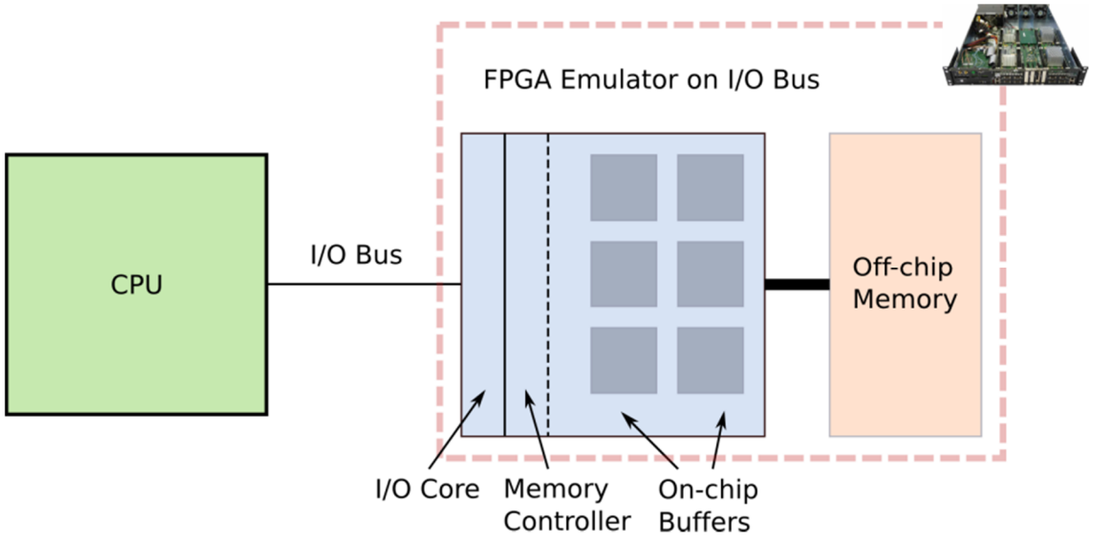
- Explore and evaluate existing/emerging hardware options
- Assess software mechanisms that best exploit them, implement examples, provide feedback
  - Checkpoint and restart
  - Data management

Hardware Exploration and Evaluation

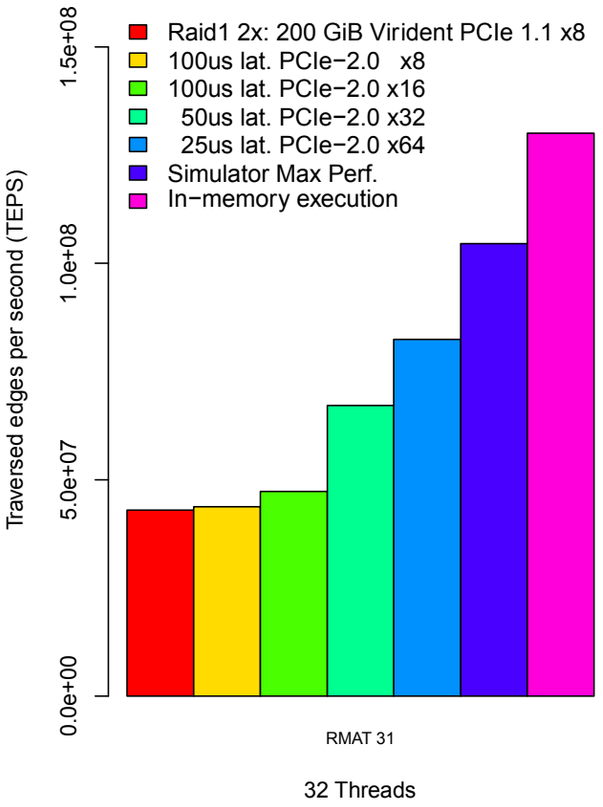
- **Simulation** and **emulation**
- Memory API to persistent memory
- Models latencies and bandwidth
  - Different memory technologies (NAND Flash, PCM, memristor, MRAM)
  - Different interconnects (SATA, PCIe, DIMM)

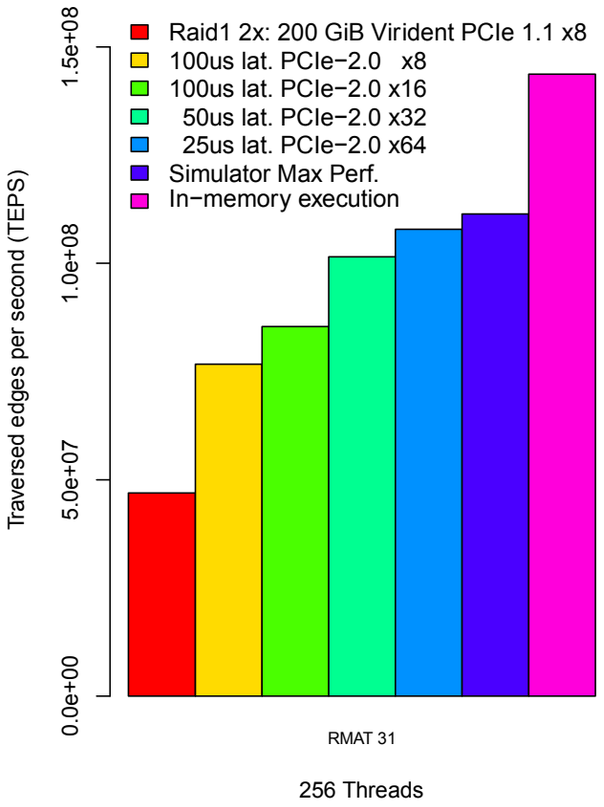


Persistent Memory Simulator



Hardware Exploration and Evaluation

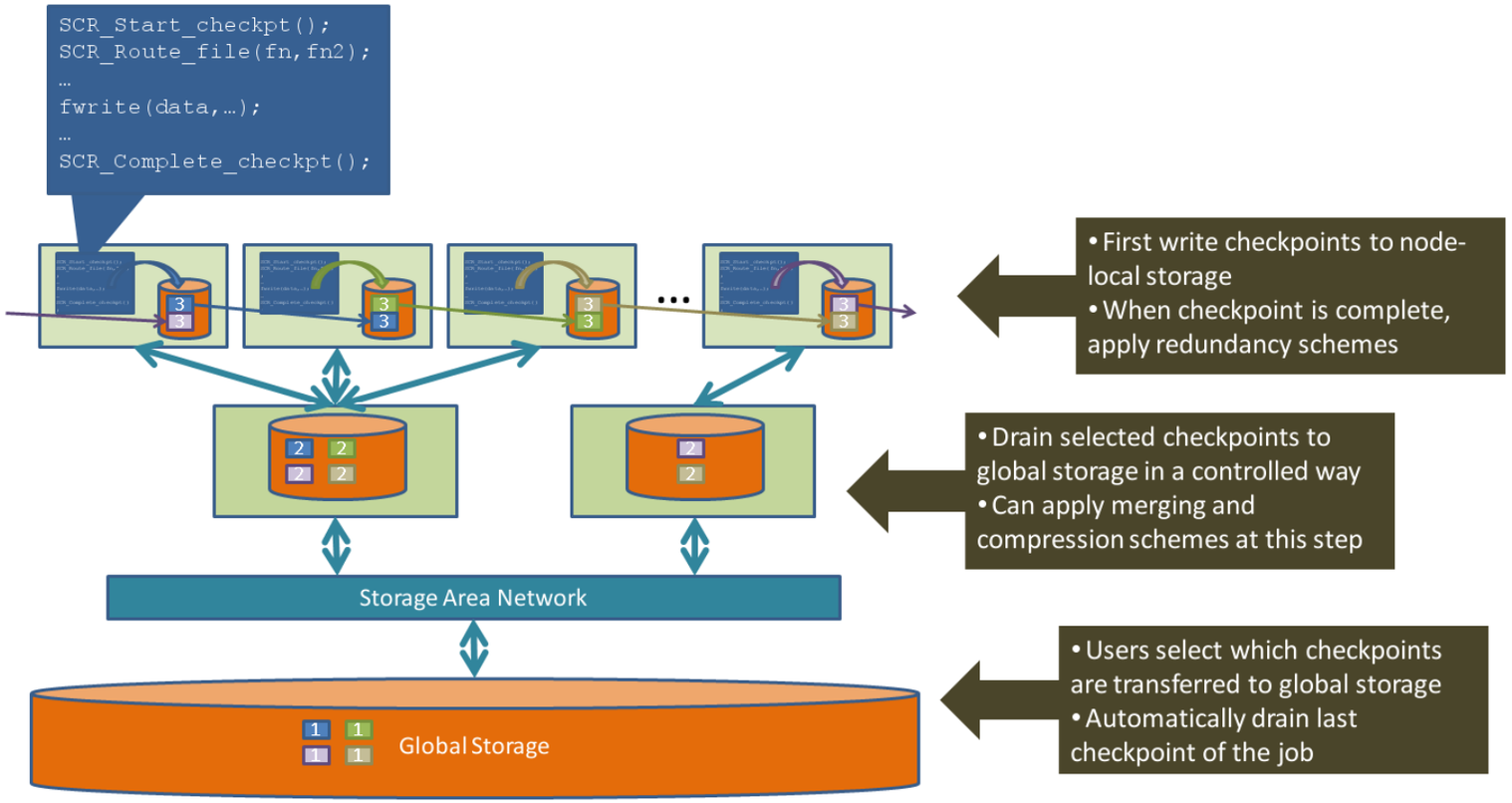




- Breadth first search graph traversal
- 170 GiB of data
- One and eight thread/core
- Comparison of
  - In-memory
  - PCIe-attached flash
  - Four generations of simulated NVRAM

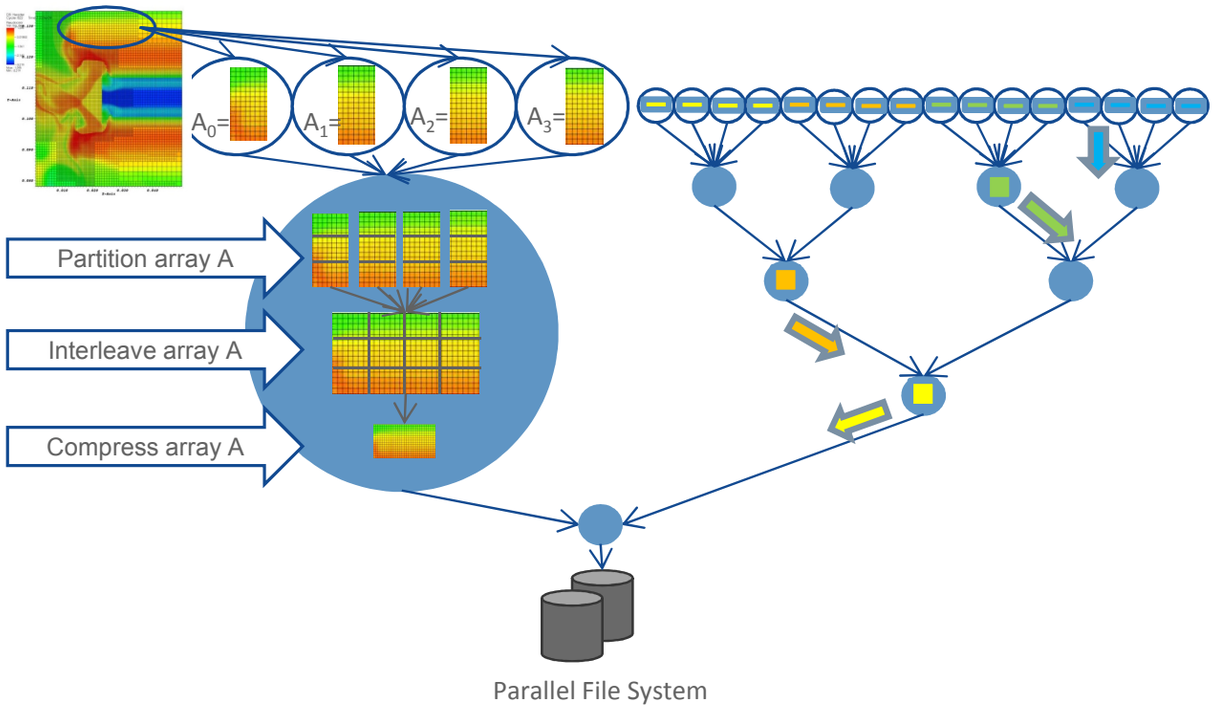
- Future NVRAM should achieve 75% performance of fully in-memory run

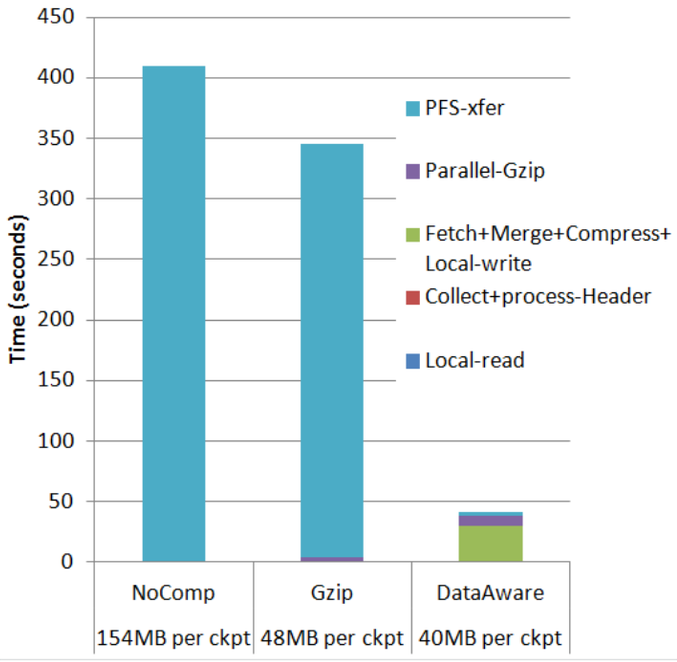
Checkpoint and Restart



- Based on **SCR**
- Utilize in-system storage and multiple checkpoint strategies for scalable, highly resilient checkpoint and restart

Data-Aware Compression

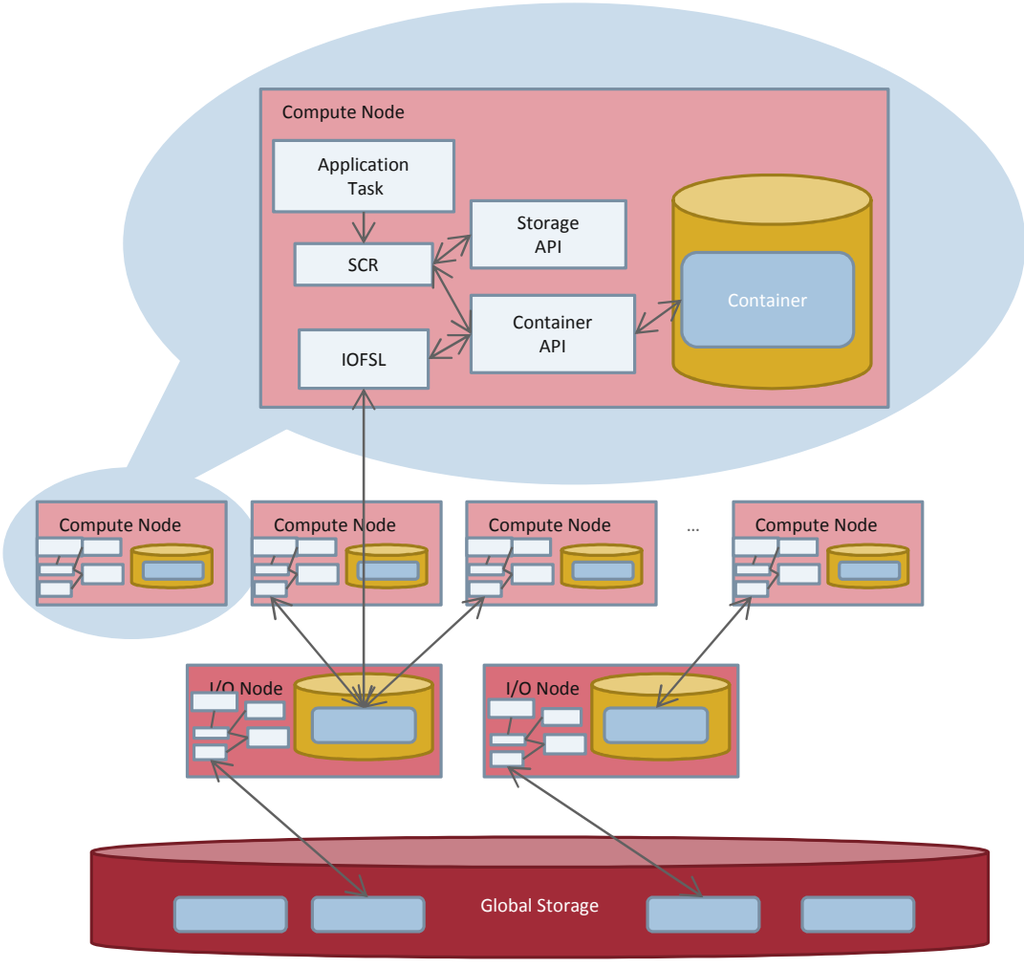




- Interleave like with like data from distinct processes before compression
- Move checkpoints asynchronously to minimize application overhead

Integration
(Overview)

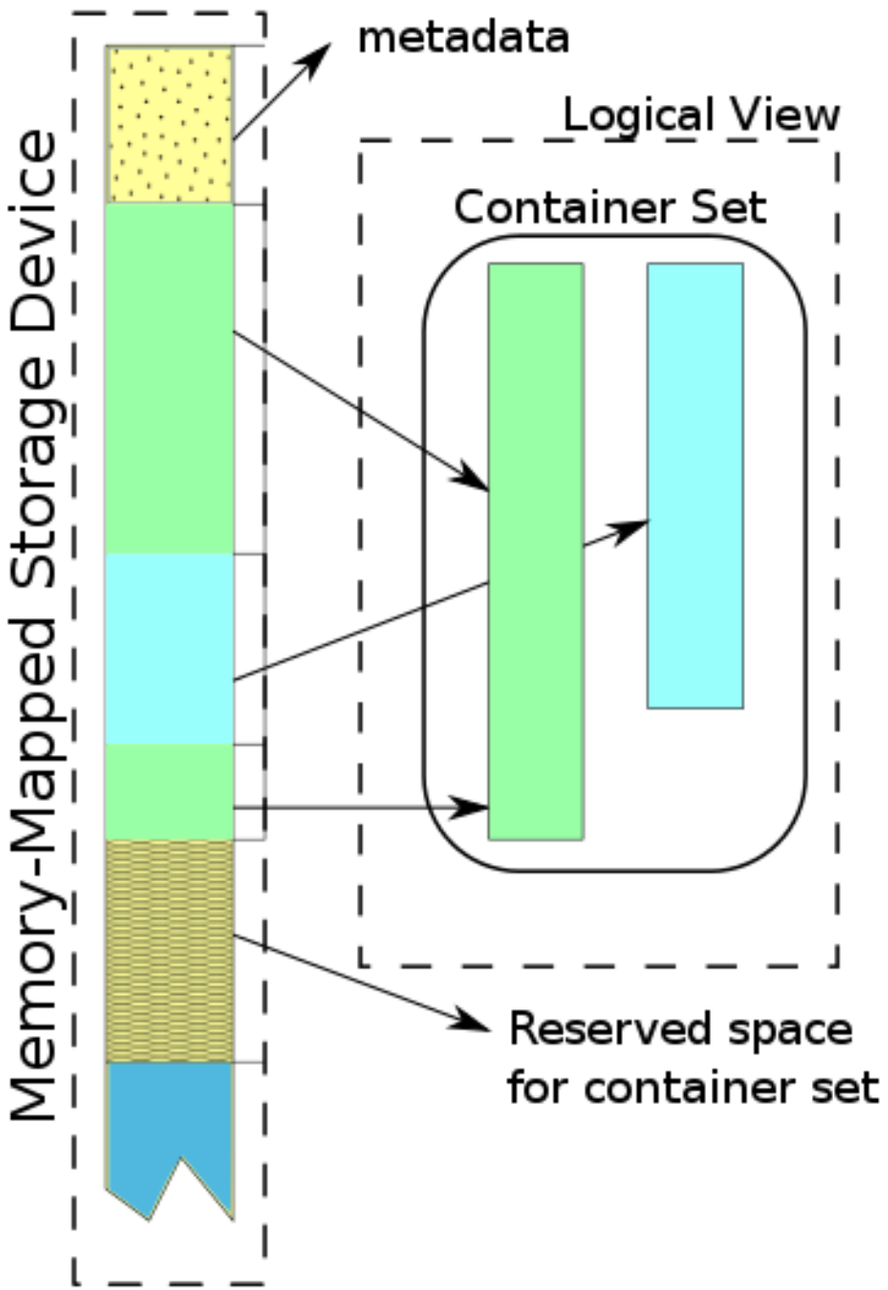
- Emulated NVRAM for now
- Storage abstraction API provides information on storage devices available in the system
- Container API provides lightweight management abstraction for in-system storage



Storage Hierarchy Abstraction

- Primarily static information on storage system configuration
- Designed for constant memory usage wrt the number of nodes
  - Query for resources as needed
  - Hierarchy of storage resources
    - Local, up, down
  - E.g., a Blue Gene I/O forwarding node can query for
    - local storage (nothing now; SSD in the future)
    - storage at the next level (parallel file system)
    - list of compute nodes that share the I/O node
- Each storage location has:
  - a URI for location, e.g., `storage://compute2/tmp`
  - a set of attribute-value properties, e.g., `capacity = 10E12`
- SCR can benefit from knowing
  - which processes share storage
  - persistency information
  - expected bandwidth

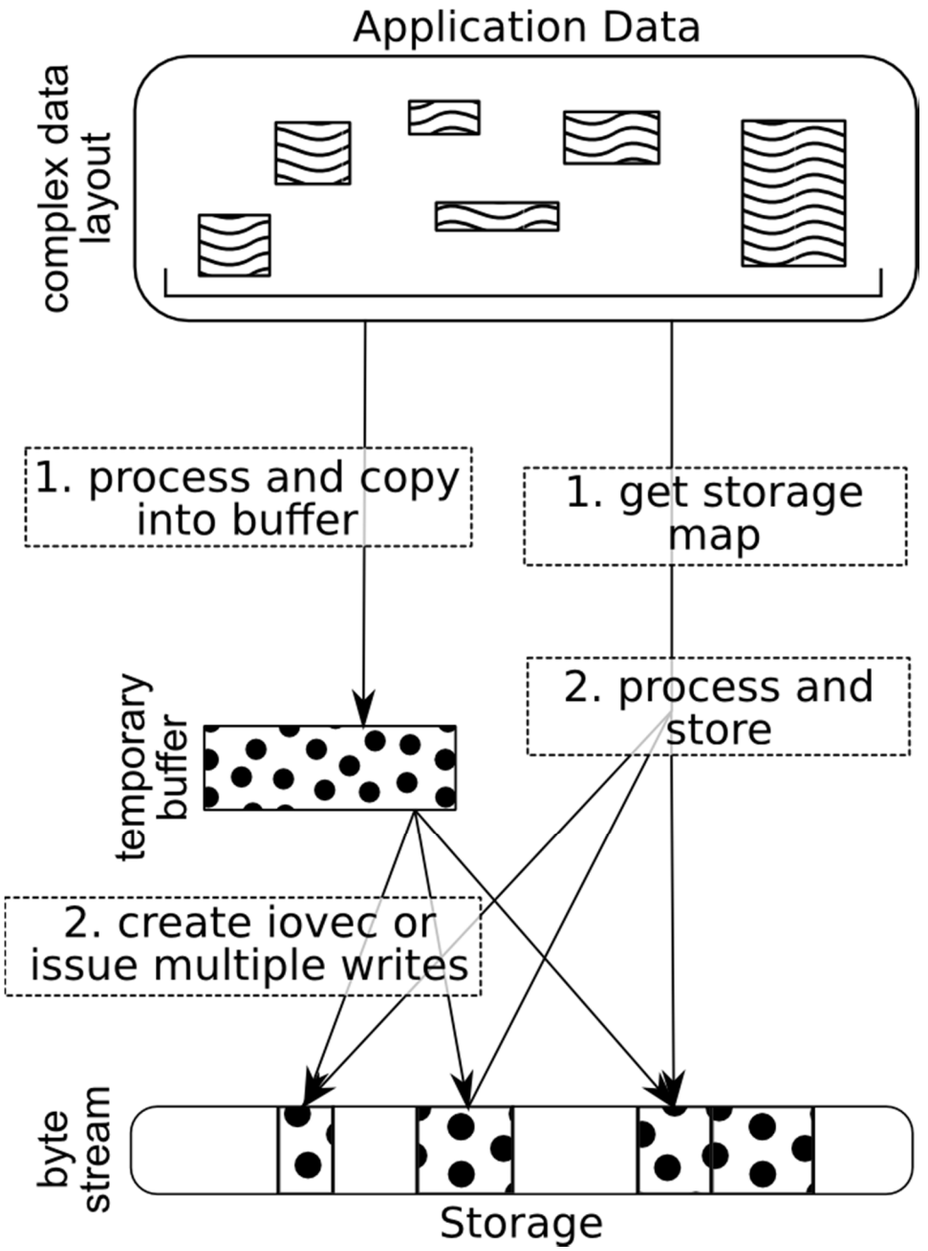
Container Abstraction



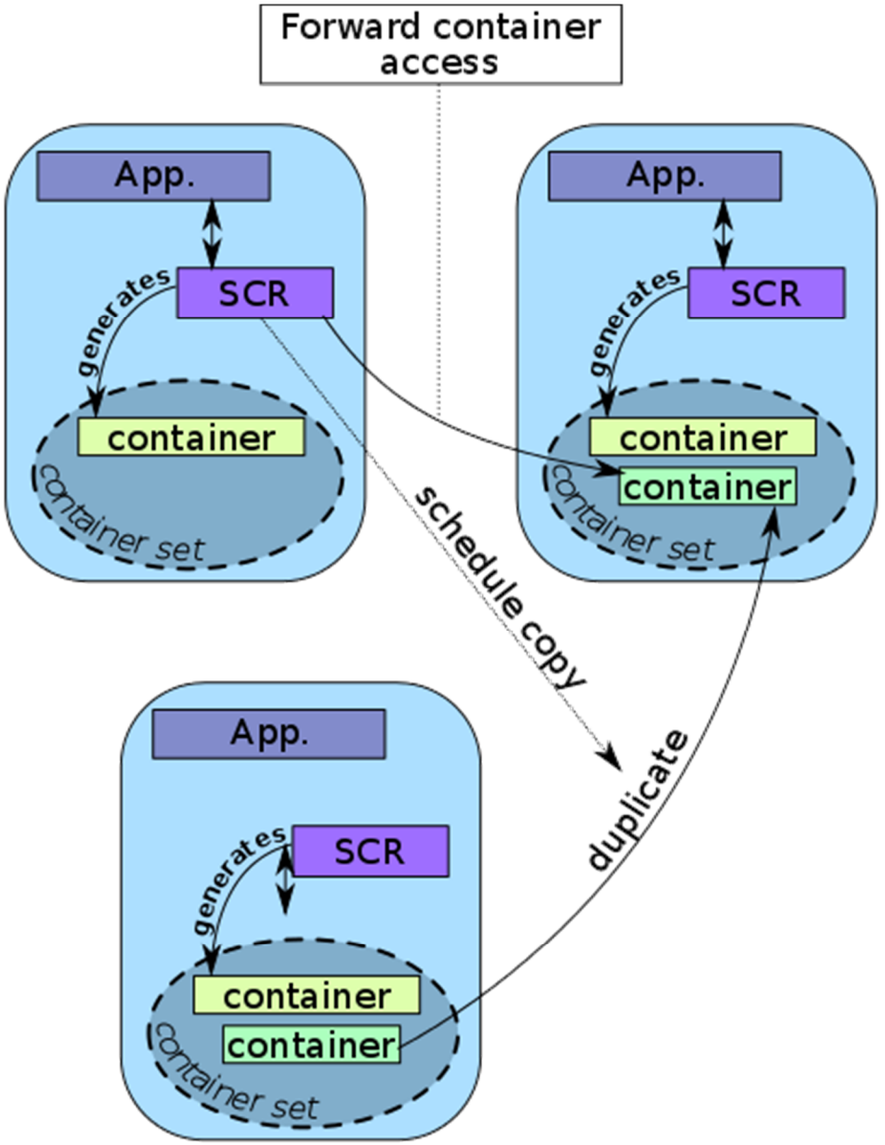
- Data model for in-system storage
  (designed for **memory mapped** storage)
- Why not a file on a local file system?
  - Functionality not needed for local temporary storage can come at a high cost.
  - Hard to add new capabilities
  - Require admin privileges
- User-space implementation simplifies **experimentation** and **deployment**
  (can run on flash emulator)
- Constructed for **direct storage access**
  (true zero-copy) – See next slide
- API overview:
  - `create`, `delete`, `rename`, get attributes, non-contiguous `read`, `write` and **explicit** `resize`.
  - Each container has a name
  - Containers grouped in sets for isolation, space reservation

Direct Storage Access

- Expose container storage layout
  - Storage format designed for direct access
  - **Application transfers** data
    - Avoid extra copy (processing data)
    - No complicated non-contiguous I/O description needed.
- Compare:
  - memory-mapped I/O (extra copy)
  - XIP (no write support, fs dependent)
  - direct-io (alignment restrictions, API bottleneck)
- Layout returned as set of pointers into storage.



Remote Container Access & Transport



- Containers are a purely **local concept**
  - **No global namespace**
- Some applications need **remote access**
  - **Use storage hierarchy abstraction to identify remote location.**
  - **Remote read/write**
- **Extension:** remote copy **operation**
  - **Request duplication of a container to another location**
  - **Remote source and dest (3rd party)**
  - **Global** scheduling **of data movement**
- Implementation using IOFSL (under construction)

Summary

- Provided an overview of a prototype, integrated in-system storage architecture
  - SCR, IOFSL, PerMA, abstraction layers
- Code under active development
  - Will be open sourced
  - Storage abstraction and container API developed as standalone libraries to encourage reuse

- This work is supported by US DOE ASCR within the NoLoSS project