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Enterprise

Global Distributed Client-side Cache

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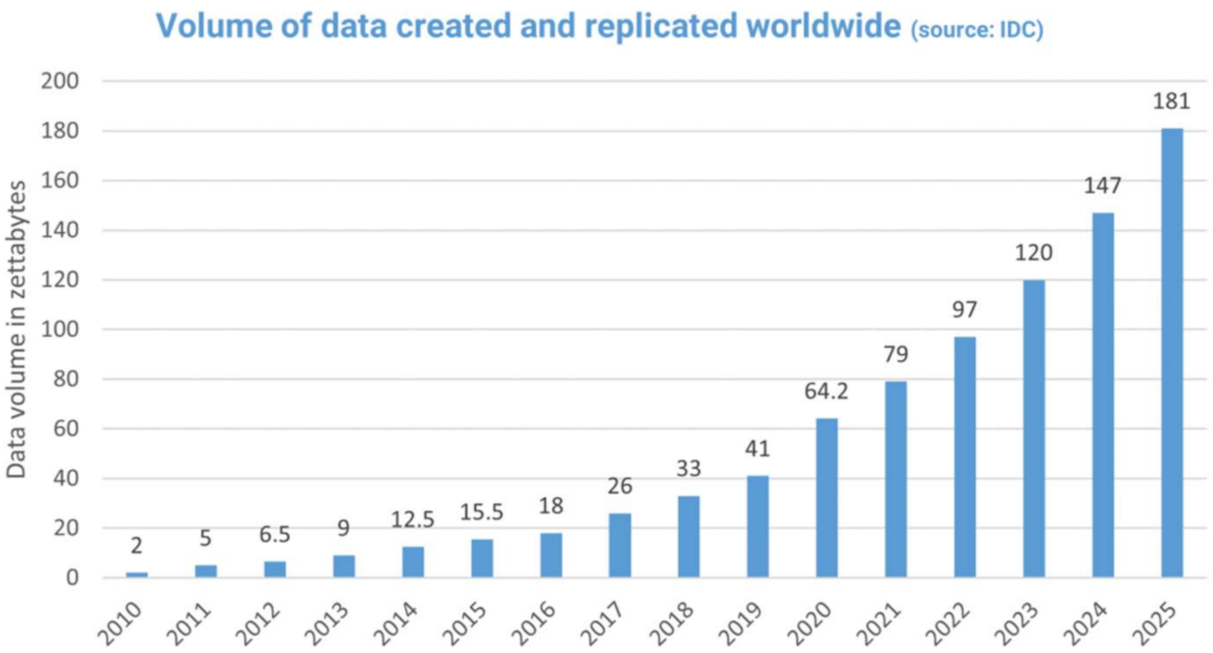
Motivation

Challenges:

- HPC and AI workloads demand efficient handling of petabyte-scale data.
- Centralized storage impacts performance.
- Server-side caches constrained by DRAM and network bandwidth; scalability is limited as server resources cannot grow dynamically with workload demands.
- Most node-local client-side caches lack data sharing across nodes.

Need: An effective caching solution compatible with modern memory/storage technologies.



Outline

- Motivation
- Global client-side cache architecture
- Components of the Global Client-side cache
- Evaluation of the benefits of the cache with PageRank
- Current status and future work
- Summary

Vision and Goal

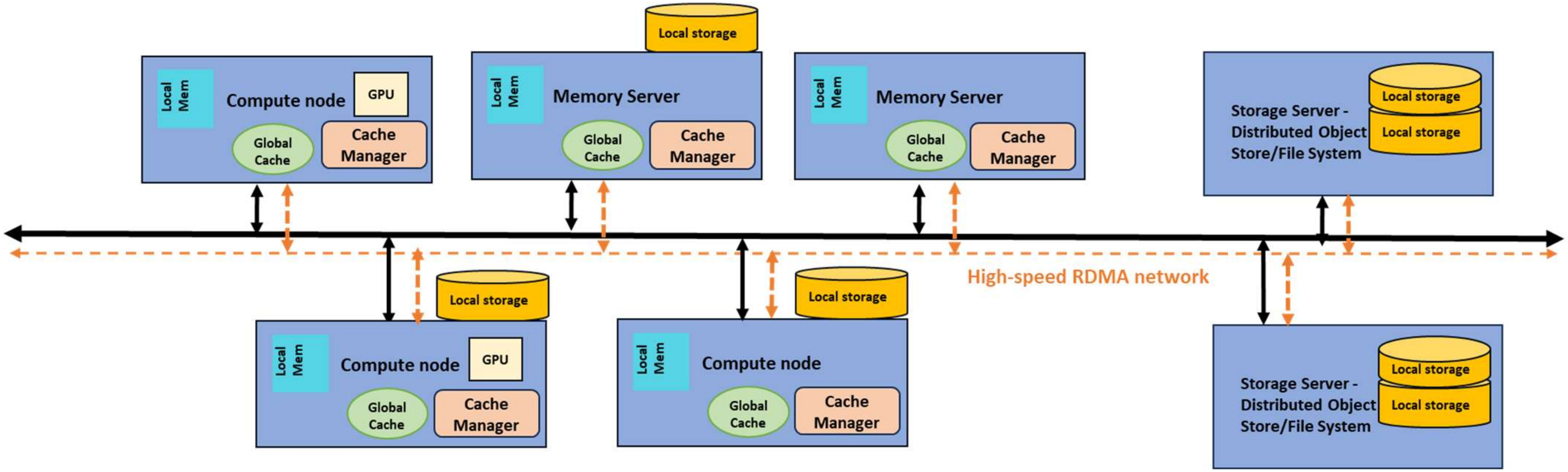
Opportunity with Global Client-Side Caching:

- Leverages higher aggregate client-side resources, such as DRAM and network bandwidth.
- Scales independently of the number of server nodes, offering a more flexible and efficient caching solution.

Our Goal:

- Integrate global client-side caching with Distributed Asynchronous Object Storage (DAOS), a high-performance exascale storage stack recently acquired by HPE and then with other HPC filesystems such as Lustre.

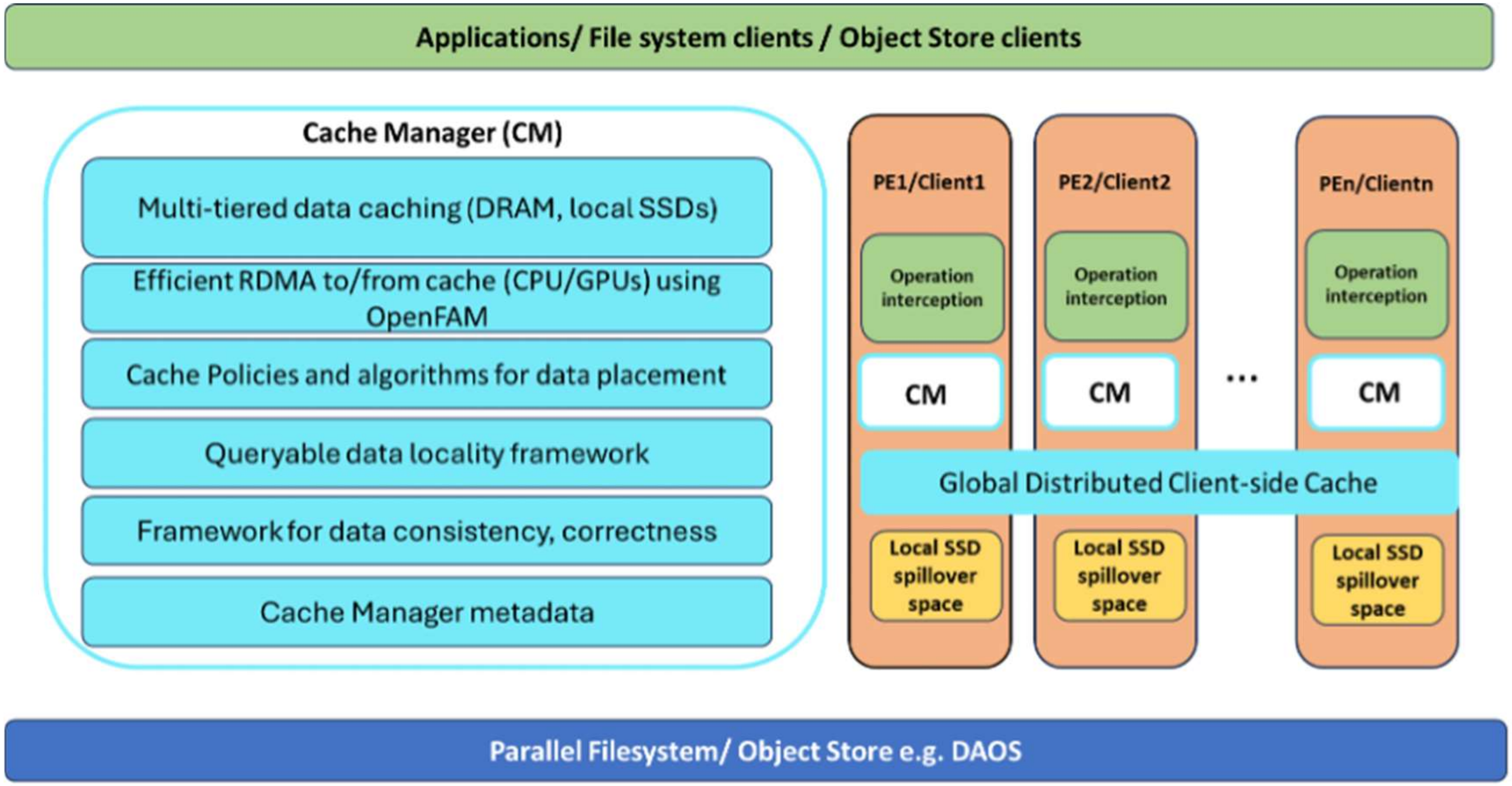
Global client-side cache architecture



- **Shared Cache:**
  - Tiered Caching: DRAM, local NVMe SSDs, and GPU memory.
  - A distributed cache manager consolidates per-node resources and access latencies for each tier.
  - Cache is shared across applications running in a cluster.

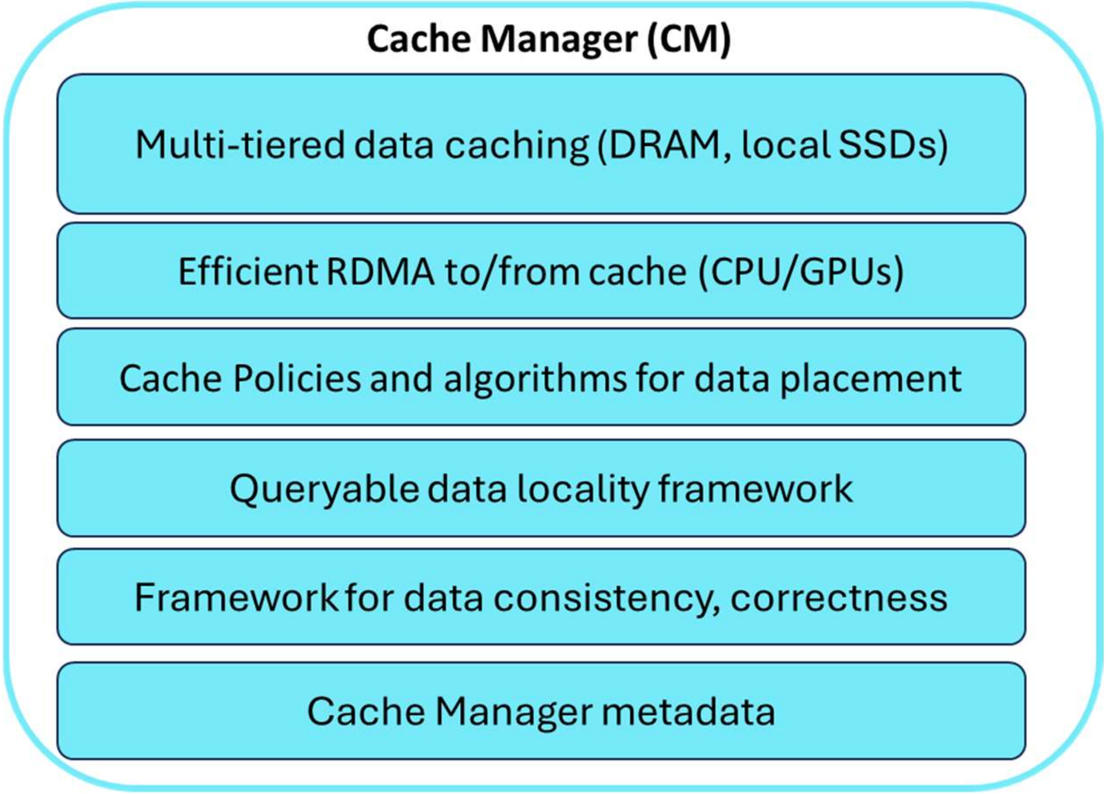
- **Efficient Data Access:**
  - Local SSDs as spillover storage, balancing cost and performance.
  - Data cached locally to nodes with higher probability of access, enables scheduling tasks closer to data.
  - Data moved dynamically located across tiers (DRAM, SSDs, HDDs).
  - RDMA-based high-speed data movement.

Components of the Global Client-side Cache


Applications/ File system clients / Object Store clients
Cache Manager (CM)
Multi-tiered data caching (DRAM, local SSDs)
Efficient RDMA to/from cache (CPU/GPUs) using OpenFAM
Cache Policies and algorithms for data placement
Queryable data locality framework
Framework for data consistency, correctness
Cache Manager metadata
PE1/Client1
PE2/Client2
PEn/Clientn
Operation interception
Operation interception
Operation interception
CM
CM
...
CM
Global Distributed Client-side Cache
Local SSD spillover space
Local SSD spillover space
Local SSD spillover space
Parallel Filesystem/ Object Store e.g. DAOS

1. **Cache Manager**:
   - Coordinates cache capacity and usage across nodes.
   - Ensures data consistency and correctness.
2. **RDMA-Based Framework**:
   - Enables high-speed, low-latency data movement.
   - Uses OpenFAM for efficient memory management.
3. **API and Configuration**:
   - Comprehensive APIs for object management, data access, and metadata handling.
   - Configurable eviction policies and invalidation mechanisms.

Cache Manager


Cache Manager (CM)
Multi-tiered data caching (DRAM, local SSDs)
Efficient RDMA to/from cache (CPU/GPUs)
Cache Policies and algorithms for data placement
Queryable data locality framework
Framework for data consistency, correctness
Cache Manager metadata

Functionality:

- Tracks dirty bits and maintains global metadata.
- Supports configurable invalidation and eviction policies
- Monitors cache usage and moves data across nodes and memory/storage tiers.

Mechanisms for Data Access:

- **CPU and GPU Memory**:
  - Uses RDMA for remote memory access.
  - Leverages OpenFAM for efficient inter-node data transfers.
- **SSDs/Flash Storage**:
  - Accesses data through operating system or file system interfaces.
- **Distributed File Systems/Object Stores**:
  - Integrates with APIs to access data stored in distributed systems.

API and Configuration Overview

Cache Manager APIs

- A robust set of APIs to manage distributed caching systems, enabling efficient data access, caching, and management across multiple nodes and memory/storage tiers.
- APIs are accessible to frameworks like runtime systems or storage clients (e.g., DAOS clients).
- User-visible APIs allow configuration of caching policies and parameters.

Key API Categories and Examples

- **Object Management**

  cm_open_object, cm_close_object, cm_delete_object
- **Data Access**

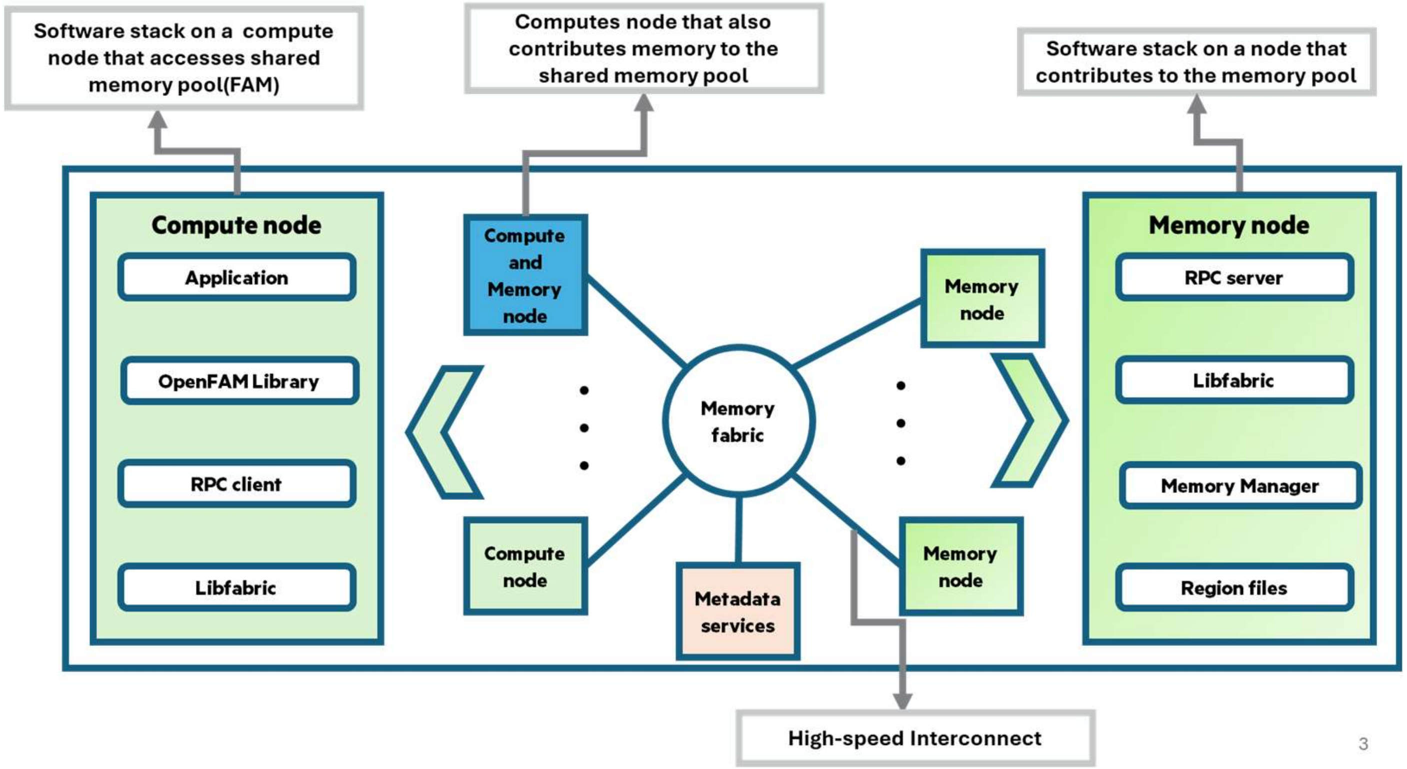
  cm_read, cm_write, cm_preserve
- **Metadata and Locality**

  cm_get_cache_config, cm_get_locality, cm_set_cache_config
- **Directory Management**

  cm_mkdir, cm_rmdir

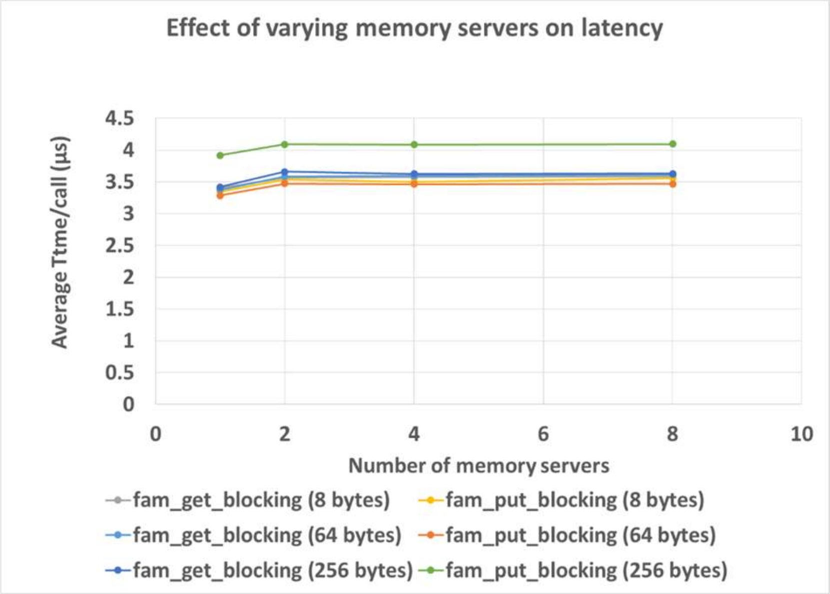
RDMA-Based Framework and Protocol for Global Cache

- **OpenFAM Integration**:
    - OpenFAM is an API and reference implementation for accessing a shared pool of memory over fabric.
    - Leverage OpenFAM for RDMA between nodes in the Global cache
- **OpenFAM Memory Servers**:
    - Manage memory contributions to the global cache on individual nodes.
    - Operate on each node to handle memory mapping, allocation, and release of cache segments.
    - Enables efficient data sharing across heterogeneous environments with CPUs and GPUs.



OpenFAM: A library for programming Fabric-Attached Memory

OpenFAM performance numbers

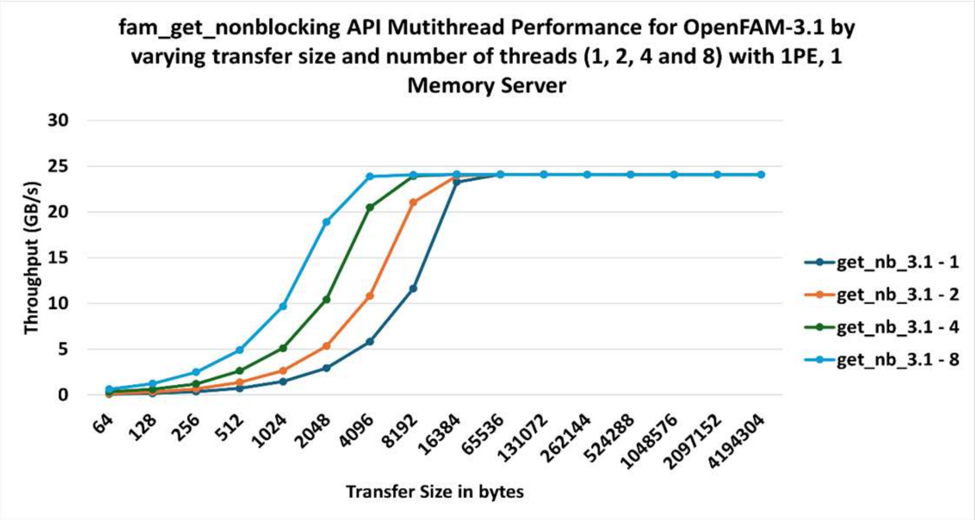


Effect of varying memory servers on latency

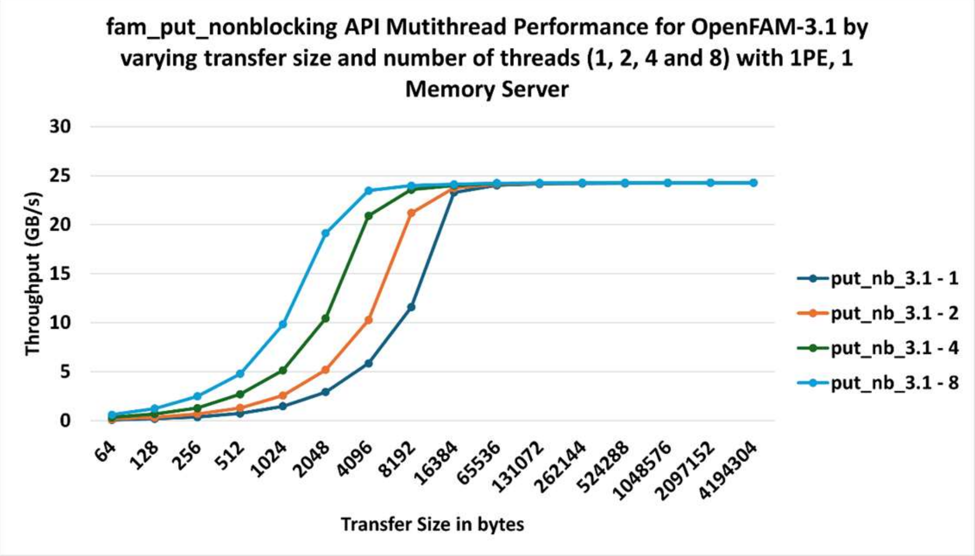
Cluster configuration

- 52-node Slingshot-based HPC cluster.
- Compute nodes: 2-socket AMD EPYC 7763, 1 TiB DRAM.
- Memory nodes: 4 TiB DRAM.

- **Results**:
  - Blocking and non-blocking RDMA operations achieve near link bandwidth.
  - Latency < 5 microseconds for short messages.



fam_get_nonblocking API Mutithread Performance for OpenFAM-3.1 by varying transfer size and number of threads (1, 2, 4 and 8) with 1PE, 1 Memory Server



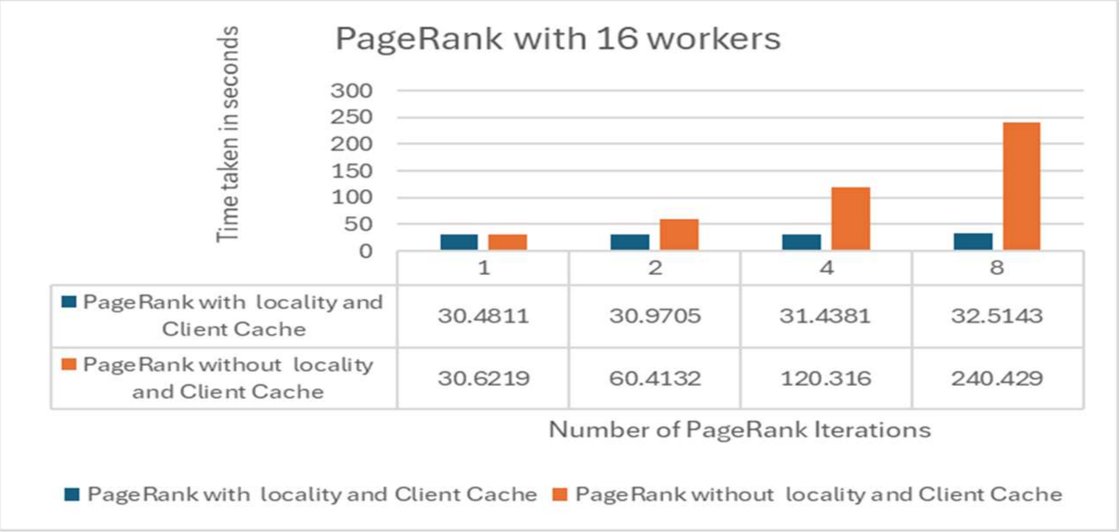
fam_put_nonblocking API Mutithread Performance for OpenFAM-3.1 by varying transfer size and number of threads (1, 2, 4 and 8) with 1PE, 1 Memory Server

Demonstration of the benefits of locality-aware scheduling and client-side caching

Experiment Setup:

- Baseline: No client cache; data fetched from remote memory every iteration.
- Optimized: Locality-aware scheduling with client-side caching.
- Matrix size: 16M x 16M.
- Hardware: 16 workers, 4 memory servers, Slingshot interconnect.
- Two-socket AMD EPYC 7763 64-Core Processor

Note: This comparison focuses solely on local vs. remote DRAM access and does not include any evaluation of DAOS operations.



	1	2	4	8
🟦 PageRank with locality and Client Cache	30.4811	30.9705	31.4381	32.5143
🟧 PageRank without locality and Client Cache	30.6219	60.4132	120.316	240.429

- **Results**:
  - Preliminary experiments show optimized version ~7x faster than baseline after 8 iterations.
- **Insights**:
  - Locality-aware scheduling significantly improves performance.

Current Status of Global Client-Side Cache Development

Cache Manager:

- Initial Functional model of the cache manager is complete.
- Detailed design specifications and implementation of complete Cache Manager functionality in progress.

Runtime System:

- Building a runtime system that
  - Leverages data locality information from the cache manager.
  - Enables optimal workload scheduling across the cluster.

Collaboration:

- With HPE DAOS team to integrate client-side global cache.
- Evaluating performance using standard DAOS benchmarks.

Use Cases

- Integration of the Global Client-side Cache with IDS (Intelligent Data Store) and other frameworks
- **https://doi.org/10.1002/cpe.7982**

Future Work

- **Planned Features**:
  - Multiple configurable caching polices.
  - Configurable invalidation mechanisms.
  - Enhanced GPU integration.
  - Resilient Runtime that takes advantage of the cache.

- **Long-Term Vision**:
  - Dynamic capacity adjustments for varying workloads.
  - Expand support to other file systems like Lustre.
  - Exploration of extension to server-side cache.

Summary

Proposed Solution:

Global, multi-tiered client-side cache for DAOS.

Supports heterogeneous compute environments with CPUs, GPUs, and accelerators.

Key Benefits:

Reduces latency and improves efficiency.

Scales independently of storage servers.

Adapts to diverse workloads and environments.

Future Potential:

Extend compatibility to additional file systems.

Optimize for emerging HPC and AI workloads.

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Thank you

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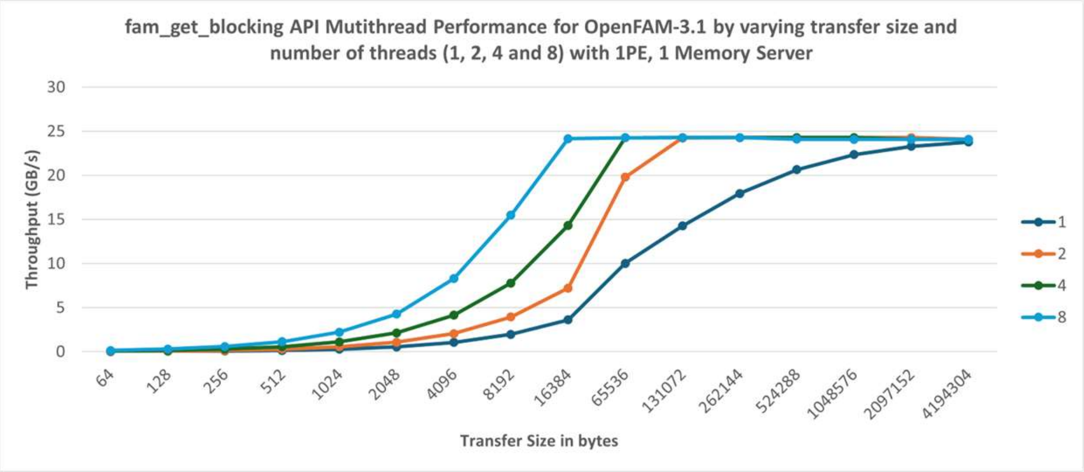
Backup

FAM blocking operations



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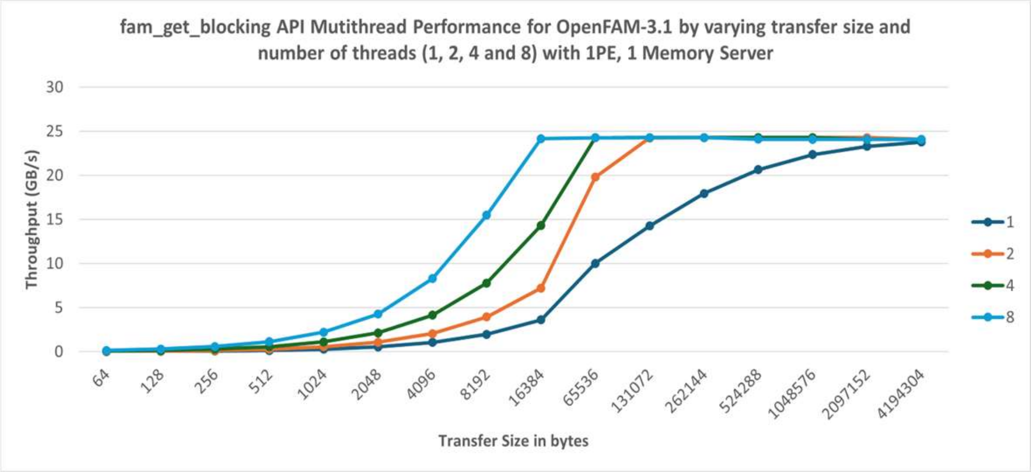

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