Using Flash for Intermediate Data Management in HPC Applications

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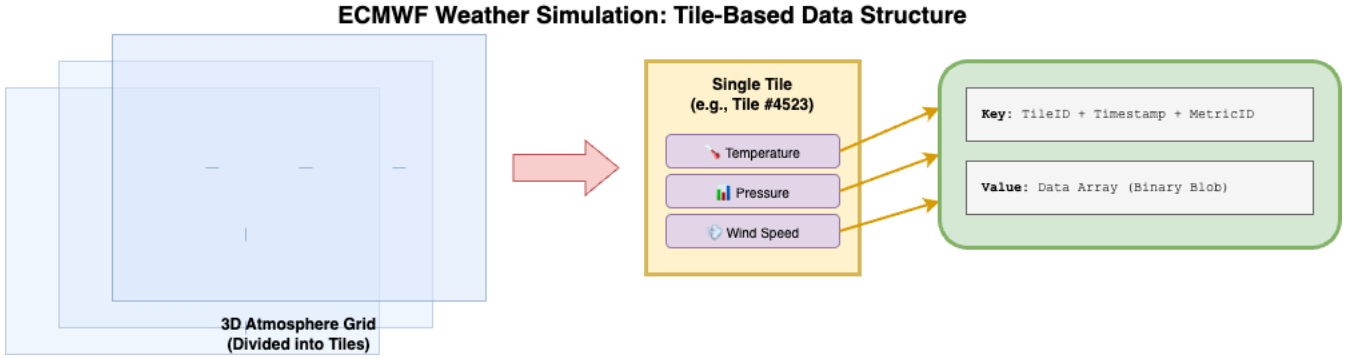
The Intermediate Data Challenge in HPC

- Modern simulations (weather, physics) produce a large volume of transient data
  - Produced concurrently from thousands of compute nodes
- Need for immediate indexing for near-real-time analysis
  - Consumed by post-processing tasks before being archived or discarded
- Traditional Parallel Filesystems (e.g. Lustre) not designed for these workloads
  - No efficient inherent indexing mechanism (metadata overhead)
- The opportunity: Flash memory provides the IOPS and latency needed
  - Need the right software stack to expose it without disrupting the applications

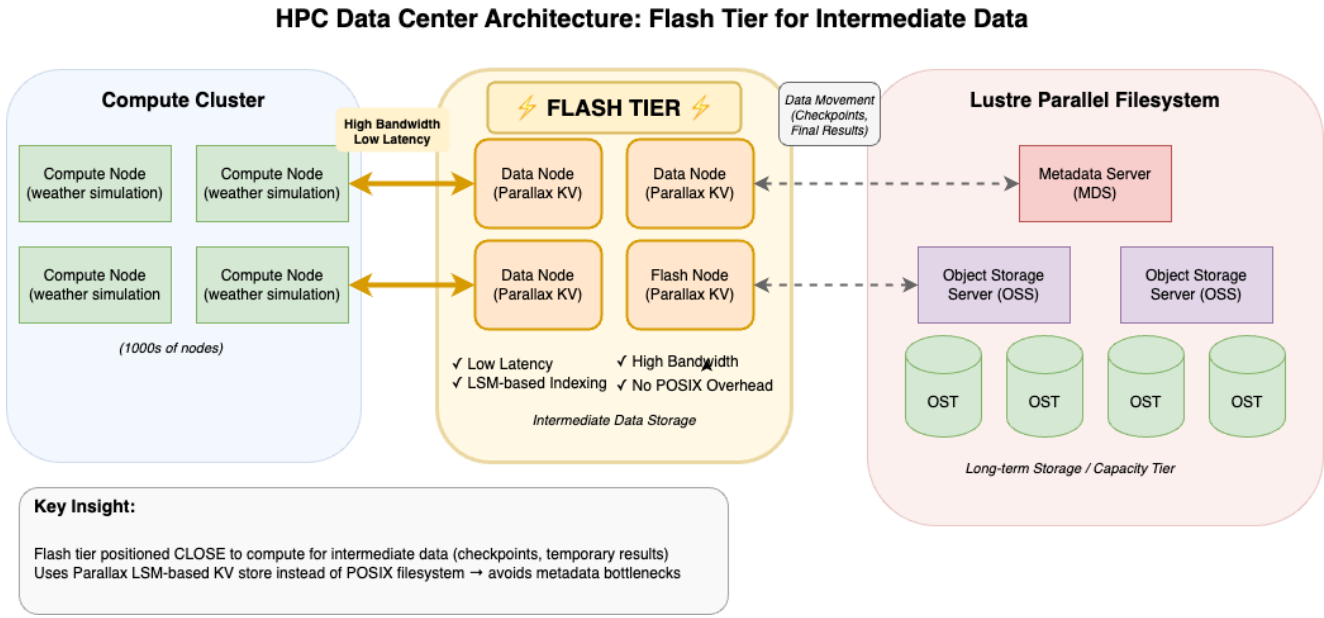
Weather Simulation Application (ECMWF)

- Runs across 100s-1000s of compute nodes
  - 4 times a day / tight time constraints for prognosis
- Atmosphere split into tiles
  - Keeps multiple metrics per tile
- Intermediate data are stored in Fields Database (FDB)
  - Implemented atop of POSIX filesystem (Lustre) (https://github.com/ecmwf/fdb)
- Both tile count and metrics per tile increase over time
  - Address challenge by using an flash tier for intermediate data
- How to use the flash tier in the weather prognosis without major disruption?



Flash Allocation and Exposure

- Data nodes equipped with flash devices
  - (NVMe SSDs)
- Allocate flash resources per job
  - Integration with Slurm
- Lifecycle management
  - Provision → Use→ Release



Ingestion Challenge: Fast Writes and on the Fly Indexing

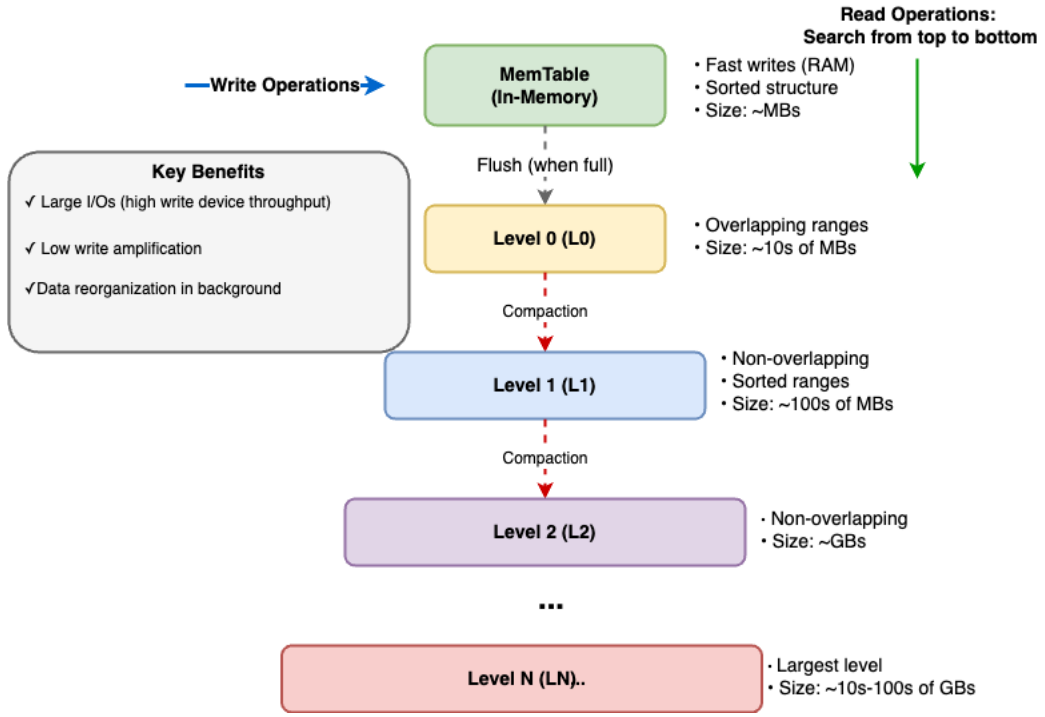
- Need to ingest data at high speeds (order of tenths of GB/s)
  - Thousands of compute nodes write simultaneously
- Must create searchable index during ingestion
  - Index must work efficiently regardless of I/O and data size
  - Write amplification must be controlled
  - Reads must remain fast even when executing in parallel with the ingestion phase

The Indexing Dilemma: POSIX and B-Trees Don't Scale

- Posix filesystems (LUSTRE)
  - Not designed for small files– metadata operations becomes bottleneck
  - Custom indexing withing the application adds complexity
- B-Tree writes generate high I/O amplification
  - Poor for flash - kills flash endurance
- LSM trees with lessons learned from the cloud come to the rescue

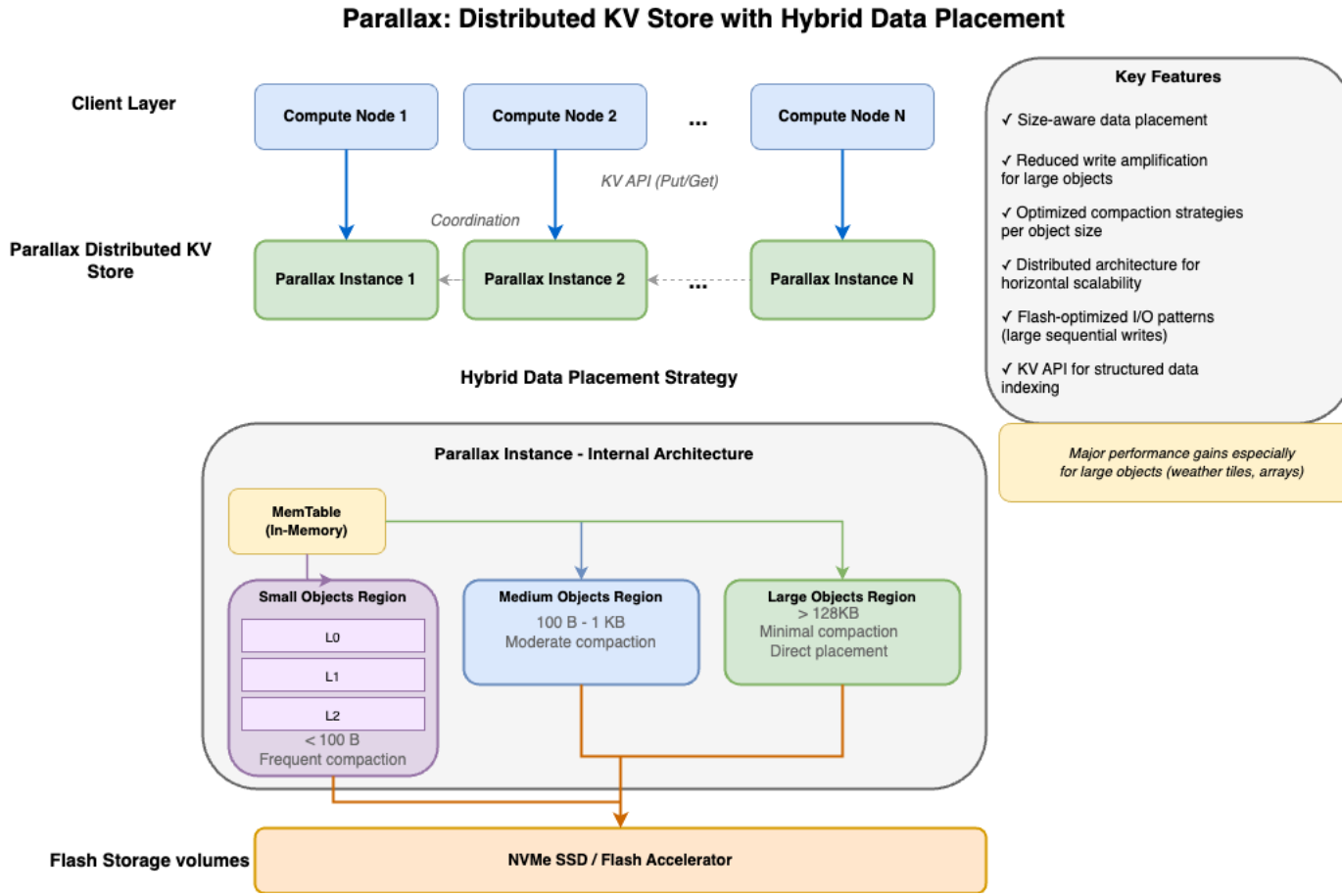
LSM-Trees: The Cloud's Answer to Write-Heavy Workloads

- Powers cloud infrastructure
  - Cassandra, RocksDB, LevelDB
- Guaranteed large I/Os (order of MB) regardless the I/O pattern
  - Batching of writes
  - Reorganization of the data
- Efficient reads comparable to a B-tree

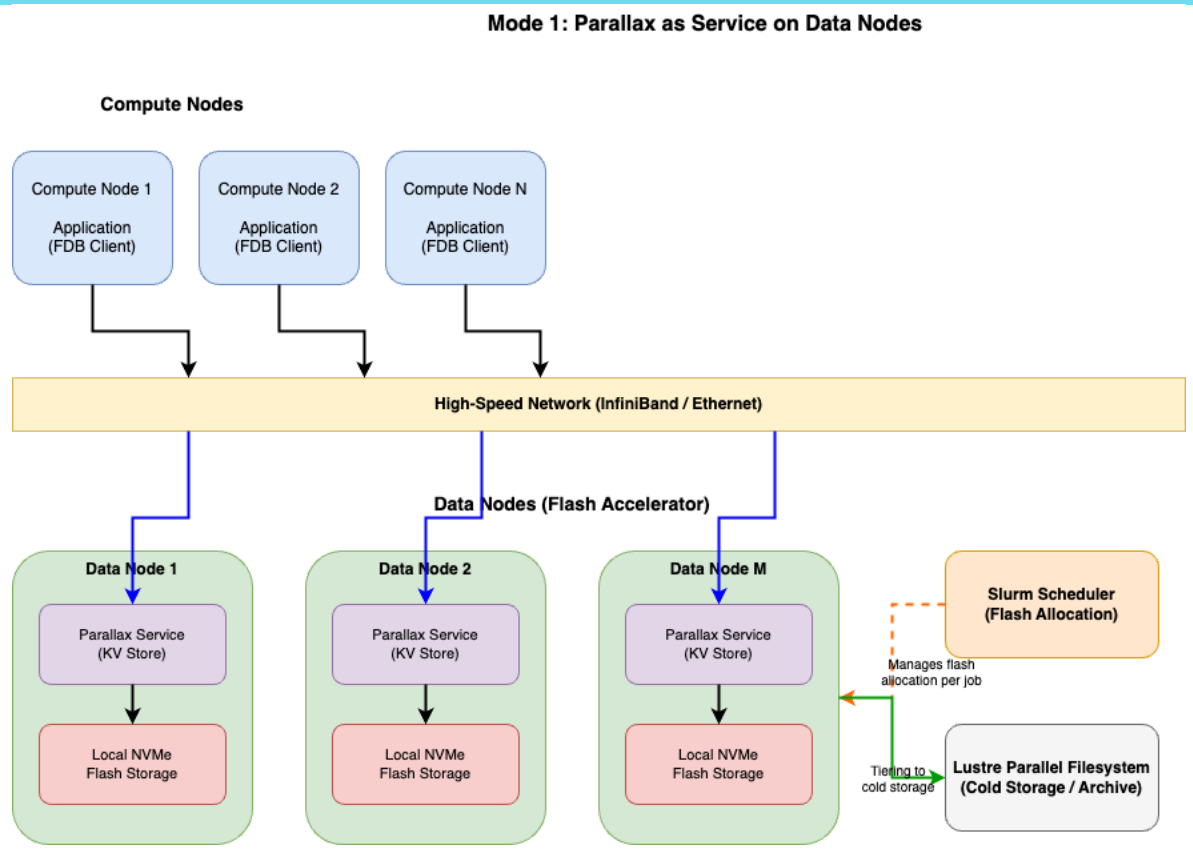


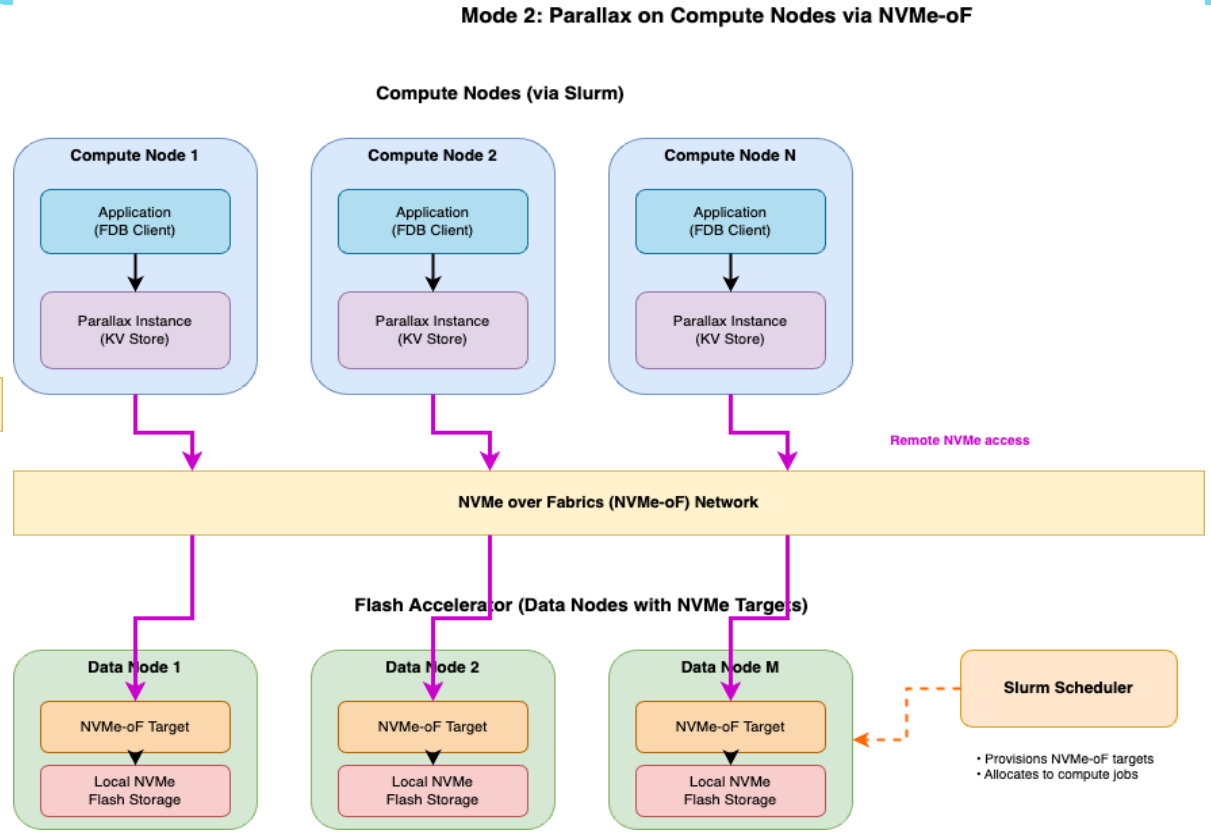
Parallax: LSM based KV Store for HPC

- Hybrid data placement to reduce amplification
- Different reorganization strategies according to object size
- Major gains especially for large objects
- Support for high speed networks
  - (Infiniband/BXI)



Deployment Modes

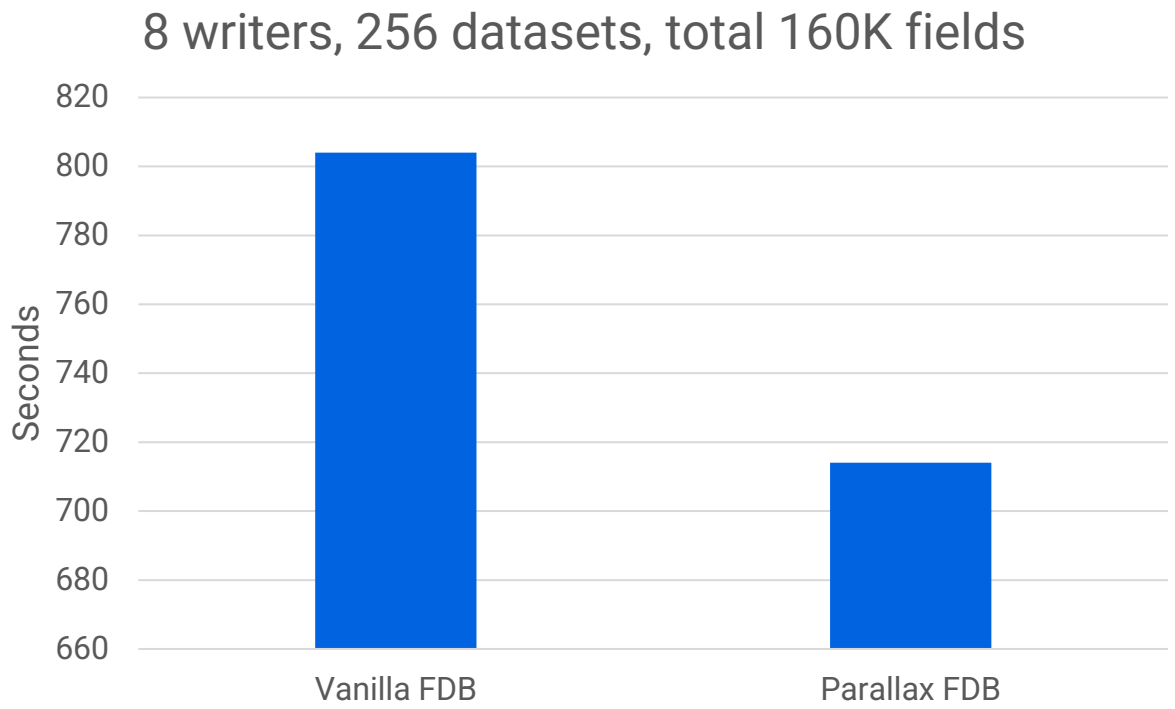




Preliminary Evaluation

- Single node setup
- 8 writers where they are a total of 256 tiles
- Stress the metadata part

Throughput for small KV pairs



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Thank you! Questions?

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Backup Slides

Challenges: Provisioning and Indexing

- #1: Allocation & Exposure
  - Provision flash memory and assign it per job
  - Integrate with existing HPC schedulers (Slurm): provision → use → release
- #2: Data Indexing & Access
  - Efficient indexing for structured, tile-based data
  - Must handle heterogeneous I/O: small metadata, medium records, large arrays
  - Efficient ingestion of simulation concurrently with reads for post-processing tasks

Provisioned Flash with Key-Value(KV) Storage

- Flash tier for transient data
- Provisioning through Slurm
  - Storage lifecycle management per job
- Data flow:
  - Compute → Flash (hot) → Lustre (cold/archive)
- KV storage atop of flash