HPS

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Emerging Trends in Parallel File System

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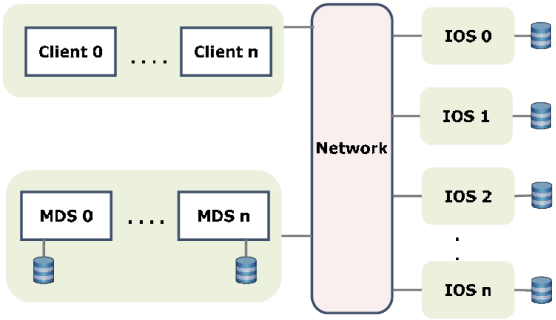
Definition

A kind of distributed file system that allows data to be stored across multiple networked servers and coordinate input/output operations between clients and storage nodes.

- Often uses a metadata server to store information about the data, such as the file name, location and owner.



Architecture of Parallel File System.
Image source: Shameem and Shaji, “A Methodological Survey on Load Balancing Techniques in Cloud Computing”

Function

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  - The coordinated use of multiple I/O paths can provide significant performance benefit.
- Uses a global namespace to facilitate data access.
- Is ideal for HPC workloads that require coordinated I/O and support for large volumes of shared data.

Some of the Major PFS in HPC

- General Parallel File System (GPFS).
- Lustre.
- Parallel Virtual File System.
- Expand 1.0
- BeeGFS

Boito, Pallez, and Teylo, “The role of storage target allocation in applications’ I/O performance with BeeGFS”

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Motivation

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- Performance bottlenecks in terms of I/O operations.
- Metadata management efficiency crucial in improving system performance.

Need for emerging trends

File systems need to adopt to these challenges:

- to enhance performance, scalability, efficiency and availability.

Garcia-Carballeira et al., “A new Ad-Hoc parallel file system for HPC environments based on the Expand parallel file system”.

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Selected Emerging Trends

Two emerging metadata management will be presented in this talk.

- AdaM: Adaptive Metadata Management scheme based on Deep Reinforcement Learning.
- Duplex: A scalable metadata service based on full-path indexing.

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- Traditional file systems use centralised strategy with one Metadata Server (MDS).
- Simple design but suffers heavy concurrent access and single point of failure.
  - Efficiency, availability and reliability problems.
- Allocation of metadata nodes across multiple MDSs can help to solve address single MDS problem.

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  - POSIX standard can present conflict.

AdaM

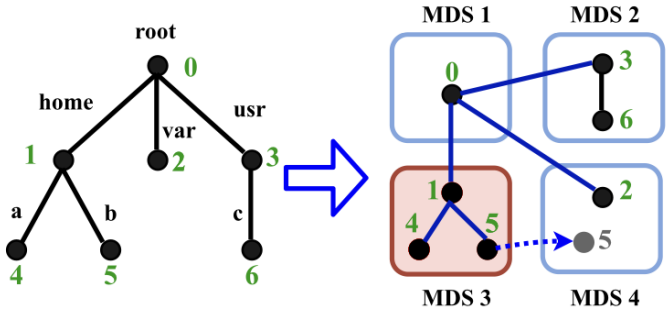

Figure: Partition the entire namespace tree, distribute among four MDS's. Then, the subtree "/home" in MDS3 becomes a hot spot.

Image sources: Huang et al., "An Adaptive Metadata Management Scheme Based on Deep Reinforcement Learning for Large-Scale Distributed File Systems"

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  - access pattern,
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  - current distribution of nodes on MDSs.

AdaM

- Automatically does migration among servers.
- Ensures load balance.
- Preserves metadata locality.

AdaM Design Architecture

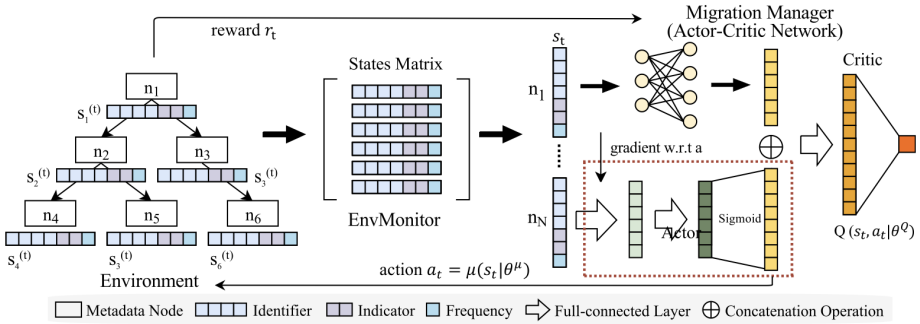

Figure: "A graphical illustration of AdaM.

Image source: Huang et al., "An Adaptive Metadata Management Scheme Based on Deep Reinforcement Learning for Large-Scale Distributed File Systems"

Development of Metadata Management Techniques over the years

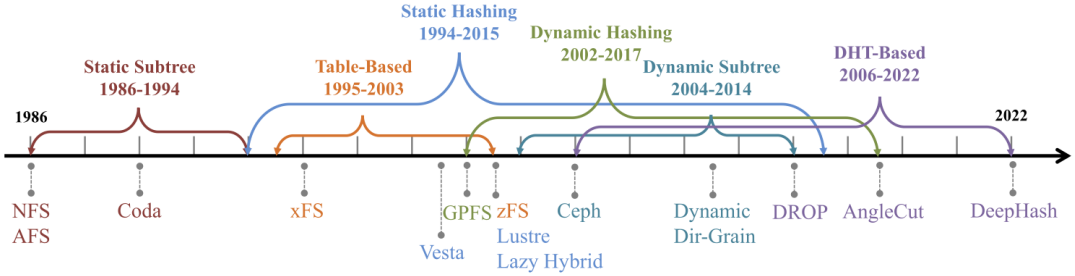

Figure: Timeline of milestones in the development of metadata management techniques.

Image source: Huang et al., “An Adaptive Metadata Management Scheme Based on Deep Reinforcement Learning for Large-Scale Distributed File Systems”

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  - single point of failure (reliability)
  - scalability challenges.

Duplex

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Simple Scalability improvement approach

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  - especially as workloads change dynamically.
- Access hotspots at the root directory.
- Other approach involves flattened metadata management.

Duplex

Design and Architecture

Duplex adheres to three fundamental architecture to optimise the indexing mechanism metadata management:

- Dual access path that support POSIX-style permission verification:
  - fast access path featuring a centralized permission server (PMS) for low latency access.
  - Slow path with high throughput.
- Tree-based permission merging algorithm to reduce the PMS's space footprint.
- flattened metadata management based on double consistent hashing.
  - This enables low-latency access to deep files and super directories.

Duplex

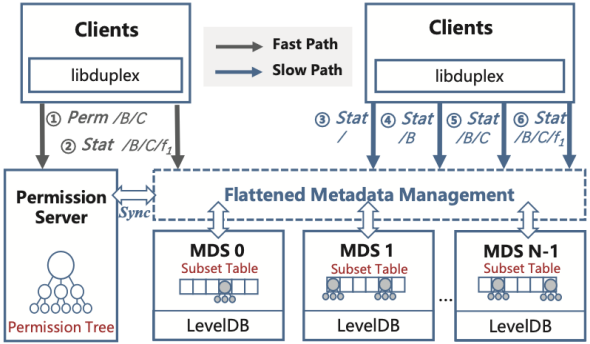

Figure: Duplex Architecture.

Image source: Dong et al., “Low-Latency and Scalable Full-path Indexing Metadata Service for Distributed File Systems”

Duplex

How the permission server works on the namespace?

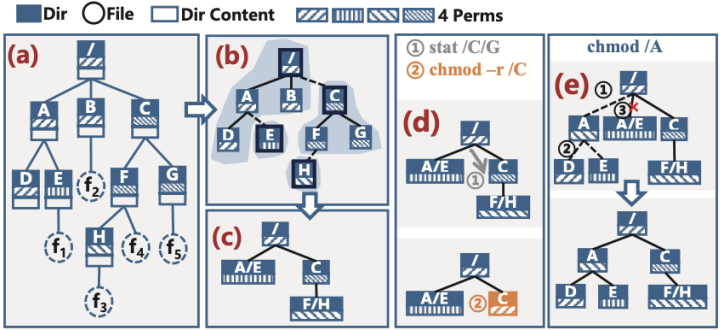

Figure: (a) The original directory tree; (b) The initial permission tree generated from (a); (c) The merged permission tree from (b); (d) A lookup and a recursive update to (c); (e) A non-recursive update to (c).

Image source: Dong et al., “Low-Latency and Scalable Full-path Indexing Metadata Service for Distributed File Systems”

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  - The average lookup latency by up to 84%
- Enhancement in lookup IOPS:
  - Up to 7.6 times against CephFS
  - Up to 2.3 times when compared to BeeGFS.

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In this talk, two emerging trends for metadata management have been presented:

First, an Adaptive Metadata Management Scheme (AdaM) for migrating hot metadata nodes to different MDSs.

- AdaM has two main components:
  - Environment Monitor
  - Migration Manager.
- Environment Monitor collects node information on the namespace tree.
  - Access pattern
  - Structure of namespace tree
  - Current distribution of nodes on MDSs
- Migration manager uses this information to migrate hot metadata nodes across MDSs to ensure load balance while preserving node locality.

Second, Duplex for fast permission verification to reduce high and unstable latency to super directories.
Duplex has three key designs:

- fast access path with centralized permission server for quick permission verification.
- permission merging algorithm to avoid overburdening the permission server.
- flattened metadata management based on DCH for low latency access to super directories.

With that I look forward to your questions.

Boito, Francieli, Guillaume Pallez, and Luan Teylo. “The role of storage target allocation in applications’ I/O performance with BeeGFS”. In: *2022 IEEE International Conference on Cluster Computing (CLUSTER)*. IEEE. 2022, pp. 267–277.

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