DataWarp Transparent Cache: Data Path Implementation
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Agenda

● Overview of DataWarp

● Implementation of the DataWarp scratch data path

● Expanding DataWarp for the transparent cache data path
**Transparent Cache Overview**

- SSDs on service nodes serve as a cache layer between compute nodes and PFS
- DataWarp automatically moves data between SSDs and PFS
DataWarp Components

- DataWarp has both user space and kernel space components
- Focus is on the kernel level components
- Cray Inc. developed filesystems
Stackable Filesystems

- Linux VFS layer allows filesystems to be stacked
- VFS operations are the API
  - Stackable filesystem must appear as a normal filesystem to kernel VFS
  - Stackable filesystem must appear as the kernel VFS to lower filesystem
- wrapfs is a GPL pass through stackable filesystem

![Diagram showing system calls and file system operations]
DataWarp Scratch Filesystem

- kdwfs – simple distributed filesystem
- Based on wrapfs
DataWarp Scratch Filesystem (cont.)

- Metadata and data are separated
- Single metadata server
- Data is striped across multiple SSDs
DataWarp Scratch Filesystem (DVS)

- DVS is an I/O forwarder
- POSIX filesystem interface
  - Some limitations
- DVS servers interact with underlying filesystem
- Data can be striped to multiple servers
- Scalable
● Each metadata inode has one or more data objects
● DVS handles I/O forwarding between computes and DW servers
  ● Metadata and data operations target correct server
  ● Data is striped based on set block size
● kdwfs handles communication between DW servers
DataWarp Cache Filesystem

- Extension of the scratch filesystem infrastructure
- Use DVS and kdwfs to stitch SSDs together into a distributed filesystem
- How does Lustre get tied in?
DataWarp Cache Filesystem (metadata)

- **kdwfs on metadata server is stacked on top of PFS (Lustre)**
  - PFS client is DW server
  - DW metadata directory tree is identical to PFS
- **PFS keeps coherency between clients**
  - Multiple DW metadata servers are possible
  - DW metadata servers have to handle remote changes
DataWarp Cache Filesystem (data)

- Data is still striped to multiple data objects
- Data objects read and write to SSD
- DW manages data movement
  - SSD holds cache file
  - PFS holds backing file
- kdcfs (kernel data caching filesystem)
  - Based on wrapfs
  - Node local
  - File handles
  - I/O targets cache file
kdcfs Internals (cache operations)

- **Cache operations modify cache file data**
  - Implemented as a pool of worker threads
- **Cache operations: copy-up, write-back, evict, invalidate**
  - Copy-up – Copy data from PFS to cache file
  - Write-back – Copy data from cache file to PFS
  - Evict – Deallocate a clean region from the cache file
  - Invalidate – Deallocate a dirty or clean region from the cache file
- **`fallocate()` is used to allocate and deallocate space in the cache file**
kdcfs Internals (extents)

- Cache file is logically divided into extents
  - Default size is 1MB
- Data in each extent is handled independently
- Extent states:
  - Not-present – Cache data is older than PFS data
  - Present – Cache data is the same as PFS data
  - Dirty – Cache data is newer than PFS data
- Per inode extent states are tracked in an in-memory tree
**kdcfs Internals (example)**

- **VFS operations can trigger cache work**
  - Example: `write()` results in copy-up

```
write()
  lock cache
  Extent present?
    yes
      copy-up
    no
      unlock cache
  unlock cache
  copy-up

copy-up
  lock cache
  Extent present?
    yes
      backing file read
    no
      cache file write
  unlock cache
  return
```

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kdcfs Internals (management)

- Management sub-component monitors cache events
- Management policies for write-back and evict
  - Policies are swappable
  - Separate for write-back and eviction
- File LRU policy for write-back
  - High water 50% low water 0%
- File LRU policy for eviction
  - High water 100% low water 95%
kdcfs Internals (control API)

- External components can influence data in the cache
- `ioctl()` interface
  - Individual files
  - Mount point
- DWS flushes data at job end
- Exported to compute nodes as cache control API (future release)
Transparent Cache Performance

- **Cache size is important**
  - PFS interaction is slow
  - Files larger than the cache are limited by PFS

- **Good workloads**
  - Bursty writes
  - Read after write
  - Multiple reads

![Relative Write Bandwidth to Empty Cache](image-url)

- Full SSD bandwidth
- Write-back contention
- PFS limited

Diagram showing bandwidth over time with different states of operations.
Summary

- **DataWarp transparent cache builds on existing scratch filesystem**
  - Scratch already has good performance
  - Increased stability
  - Fixes and features benefit both modes
- **Metadata operations go through Lustre**
  - All files within the mount are accessible
- **Filesystem implementation allows easy integration of different caching policies**
- **Cache control API will allow manual data movement similar to scratch**
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