Whamcloud

Lustre 2.16 and Beyond

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Planned Feature Release Highlights

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- **2.16** opening to land new feature patches
  - **LNet IPv6 addressing** – allow 160-bit NIDs, more flexible server configuration (SuSE)
  - **Optimized Directory Traversal** (WBC1) – cross-directory statahead (WC)
- **2.17** has several major features already lined up
  - **Client-side data compression** – use client CPU to reduce network and storage usage (WC)
  - **Metadata Writeback Cache** (WBC2) – low latency file operations in client RAM (WC)
  - **File Level Redundancy - Erasure Coding (EC)** – efficiently store file redundancy
- **2.18** feature proposals in early discussion stages
  - **Lustre Metadata Redundancy (LMR1)** – MDT0000 service redundancy

LNet Improvements (2.15/2.16)

2.15

- Multiple TCP sockets for 100GigE+ performance (LU-12815, WC)
  - Add `conns_per_peer=N` for `socklnd` (4.1GB/s->9.5GB/s on 100GbE)
  - Auto-configure based on interface speed (e.g. 10Gbps=>2, 100Gbps=>4, …)
- LNet Network Selection Policy (UDSP) (LU-9121, WC)
  - Allow policies for local/remote interface prioritization by NID
    - e.g. primary IB with TCP backup, select "best" router NID for client/server

2.16

- IPv6 NID support (LU-10391, SuSE)
  - Variable-sized NIDs (8-bit type, 8-bit size, 16-bit network, 128-bit+ address)
  - Interoperable with existing current LNDs whenever possible
- Simplified/dynamic server node addressing (LU-14668, WC)
  - Detect added/changed server interfaces automatically (LU-10360)
  - Reduce (and eventually eliminate) static NIDs in Lustre config logs

Client Improvements (ORNL, SuSE, WC)

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- **GPU Direct RDMA** - directly into GPU, bypass CPU (LU-14798, WC, NVIDIA, HPE)
  - A100 2x200Gb IB 36GB/s write, 39GB/s read, 174GB/s with 8x200Gb IB
- **Parallel large DIO** optimization (LU-13798, LU-13799, HPE, WC)
  - Improve single-thread `read()`/`write()` (1.5GB/s->15.8GB/s!)
  - Particular benefits for AIO/DIO and `io_uring` in client kernels 5.1 and later

2.15
- Improved "`lfs find -printf`" option for scanning files (LU-10378, ORNL)

2.16
- `o2iblnd` cleanups for in-kernel OFED (LU-8874, ORNL)
- Buffered/DIO/mmap performance/efficiency improvements (LU-13805, WC)
- Ongoing code style/structure cleanup for upstream submission (ORNL)
- Ongoing updates for newer kernels (ORNL, SuSE)

Backend OSD Improvements (2.16+)

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- Parallel e2fsck for pass2/3 (directory entries, name linkage) (LU-14679, WC)
  - Now slowest part of e2fsck (was 7% of total time, now 70% after pass1/pass5 speedups)
- ZFS 2.1 dRAID VDEVs - declustered parity and hot space (LLNL, HPE, Intel)
- `fallocate()` and `FALLOCATE_FL_PUNCH_HOLE` for ZFS (LU-14157, AEON)
- Improved ldiskfs mballoc efficiency for large/full filesystems (LU-14438, Google, WC)
  - O(1) lookup of power-of-two free space, O(logN) lookup of other sizes
- Improved ldiskfs "`-o discard`" efficiency (LU-14712, Kuaishou, WC)
  - Allow real-time TRIM of flash storage to maintain peak performance
- OST object directory scalability for large OSTs (LU-11912, WC)
  - Large OSTs (500-1000TB) have billions of objects, only 32 dirs per MDT!
  - Wider dir fanout not better, object create/remove access all dirs randomly
  - New OST FID Sequences more often (e.g. 32M vs. 4B objs), retire old SEQ
  - Groups objects by age to limit directory size and improve efficiency

Batched Cross-Directory Statahead (WC 2.16)

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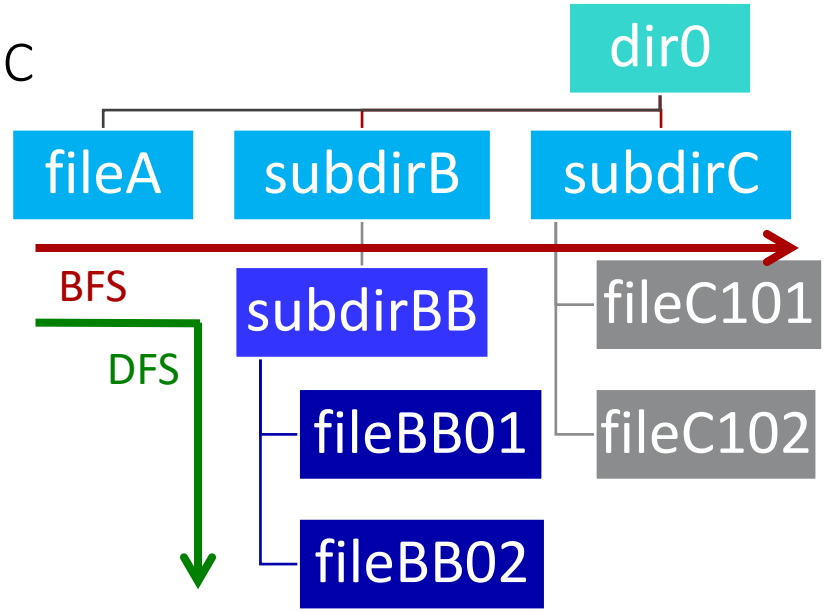
- **Batched RPCs** for multi-update operations (LU-13045)
  - Allow multiple getattrs/updates packed into a single MDS RPC
  - More efficient network and server-side request handling
- **Batched statahead** for `ls -l`, `find`, etc. (LU-14139)
  - Aggregate getattr RPCs for existing statahead mechanism
- **Cross-Directory statahead** pattern matching (LU-14380)
  - Existing statahead only detects `readdir()`-ordered `stat()`
  - Detect pattern for alphanumeric ordered traversal + `stat()`
  - Detect breadth-first (BFS) depth-first (DFS) directory traversal
  - Direct statahead to next file/subdirectory based on pattern



Metadata Writeback Cache (WBC) (LU-10983) (WC 2.16+)

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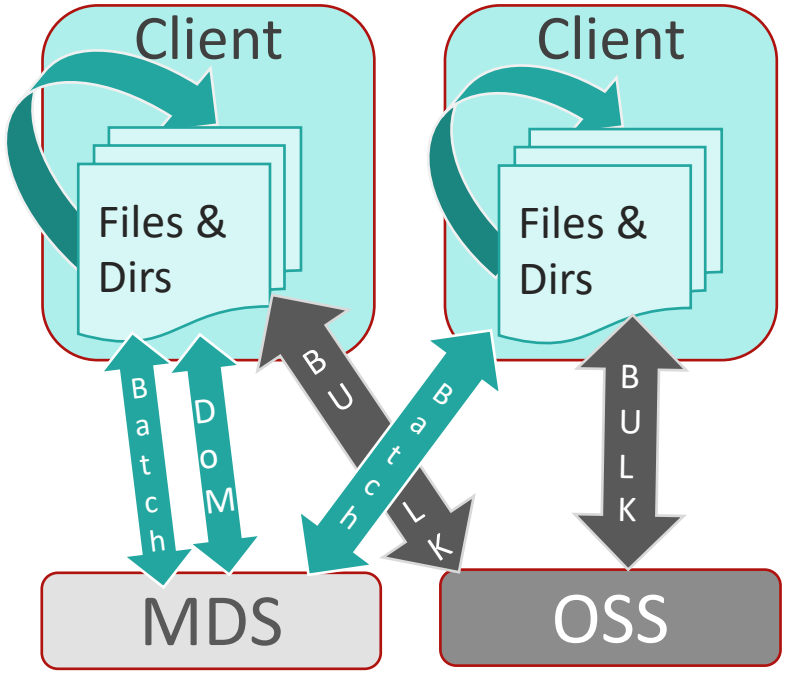
- Create new dirs/files **in client RAM without RPCs**
  - Lock new directory exclusively at `mkdir` time
  - Cache new files/dirs/data in RAM until cache flush or remote access
- **No RPC round-trips** for file modifications in new directory
- Batch RPC for efficient directory fetch and cache flush
- **Files globally visible on remote client access**
  - Flush top-level entries, exclusively lock new subdirs, unlock parent
  - Repeat as needed for subdirectories being accessed remotely
  - Flush rest of tree in background to MDS/OSS by age or size limits
- Productization of WBC code well underway
  - Some complexity handling partially-cached directories
  - Need to integrate space usage with quota/grant

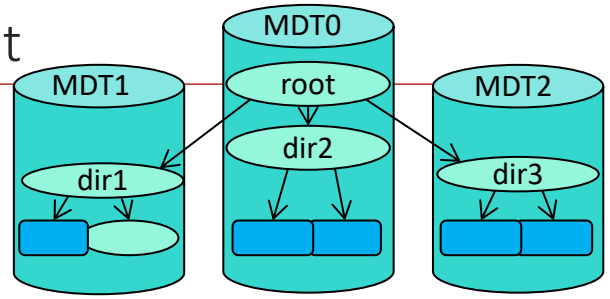


MDT DNE Improvements (WC 2.15+)

- **DNE MDT Space Balance** - load balancing with normal `mkdir` (LU-13439, LU-13440)
  - Round-robin/balanced subdirs, prefer to stay on parent, limited layout inheritance depth
  - Keep MDTs within free inodes/space (`mdt.*.mdt_qos_threshold_rr=5%`)
- Single-dir migration - `"lfs migrate -m -d <dir>"` (LU-14975)
  - Move only one directory level, instead recusing down full subdirectory tree
- Balanced migration - `"lfs migrate -m -1 <dir>"` (LU-13076)

2.15
  - Auto-select less-full MDTs for each directory, keep inodes local to parent

2.16
- OST object directory scalability for large OSTs (LU-11912)
  - Request new OST FID Sequences more frequently
- DNE locking, migration, remote RPC optimization (LU-15528)
  - Improve distributed transaction performance, reduce lock contention



Lustre Metadata Redundancy (LU-12310) (2.17+)
LMR1a: Replicate MDT0000 Services to Other MDS Nodes

- Add replication for FLDB across MDTs
  - Updated very rarely (new MDT/OST addition, every 1B sequences)
  - Maybe OK in LMR1a to only update FLDB when MDT0000 is available?
  - Mechanism to mark MDT FLDB as primary copy (version increment?, for LMR1b?)
  - Other MDTs fetch primary FLDB and store to local FLDB copy on initial connection
- Add replication for Quota Master to other MDTs
  - Updated more frequently than FLDB, less replication possible
  - Only need to replicate quota *limits*, not usage/accounting (on each target locally)
  - Could rebuild quota usage tables on backup MDT from OSTs/MDTs after takeover?
- Distribute or failover `flock()` locking to other MDTs
  - Improved performance for independent flock-intensive workloads
  - Complex deadlock detection, failover to backup MDT may be easier

LMR1b: DNE Distributed Transaction Performance

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- DNE2 Distributed Transactions have excessive ordering/sync operations
  - Single OSP RPC in flight between each MDT pair (code issue, patch in Gerrit)
- Compromised from original design due to implementation issues
  - Difficult to journal bit-level updates in recovery llog file
  - Must order updates within a single byte to ensure other bits are not clobbered
- Use alternative to llog for storing DNE recovery logs
  - Index with named records does not have serialized transaction ordering issues
  - Remove sync write from transaction commit?
  - Batched OSP/OUT updates in a single RPC?
- Optimizations improve **all** DNE ops, independent of LMR

LMR1c: Replicate Top-level Directories (2.18+)

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- ROOT/ directory is replicated across multiple MDTs
  - Up to 7 replicas (?), prefer separate MDTs (different NIDs if possible, also racks?)
  - ROOT/ is rarely modified, performance overhead should not affect normal usage
  - ROOT/ is critical for filesystem usage, must always be available to access filesystem
  - ROOT/ directory lookup by name on secondary MDTs
- Read-only under downgrade mode (only directory replication, not files?)
- New incompatible flag LMAI_REPLICA in LMA EA
- User tools to add/remove replicas to directories on non-LMR system
- Enhance LFSCK to verify/repair consistency between replica objects

- Additional LMR2/3 phases to reach full MDT redundancy

Thank You!
Questions?