



# Lustre 2.12 and Beyond

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# Upcoming Release Feature Highlights

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- 2.12 is feature complete
  - LNet Multi-Rail Network Health – improved fault tolerance
  - Lazy Size on MDT (LSOM) – efficient MDT-only scanning
  - File Level Redundancy (FLR) enhancements – usability and robustness
  - T10 Data Integrity Field (DIF) – improved data integrity
  - DNE directory restriping – better space balancing and DNE2 adoption
- 2.13 development and design underway
  - Persistent Client Cache (PCC) – store data in client-local NVMe
  - File Level Redundancy – Phase 2 Erasure Coding
  - DNE auto remote directory/striping – improve load/space balance across MDTs
- 2.14 plans continued functional and performance improvements
  - DNE directory auto-split – improve usability and performance of DNE2
  - Client metadata Write Back Cache (WBC) – improve interactive performance, reduce latency

# LNet Network Health, UDSP (2.12/2.14)

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- Builds on LNet Multi-Rail in 2.10/2.11 (LU-9120 Intel/WC, HPE/SGI)
  - Detect network interface and router failures automatically
  - Handle LNet fault w/o lengthy Lustre recovery, optimize resend path
  - Handle multi-interface router failures — DONE

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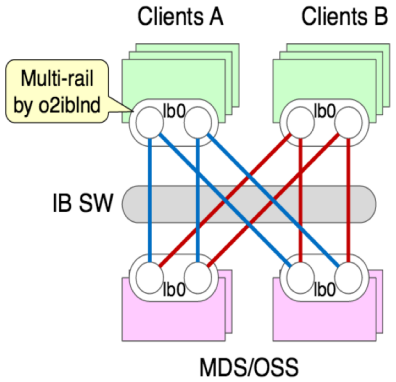
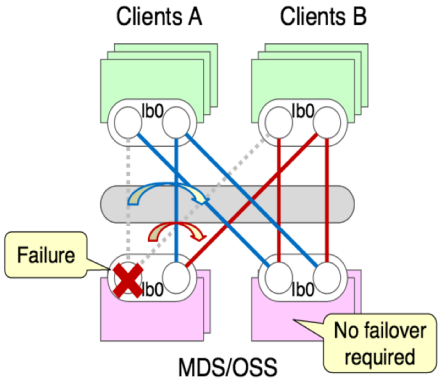
- User Defined Selection Policy (LU-9121 WC, HPE) — TODO
  - Fine grained control of interface selection
  - Optimize RAM/CPU/PCI data transfers
  - Useful for large NUMA machines



# Data-on-MDT Improvements (LU-10176 WC 2.12+)

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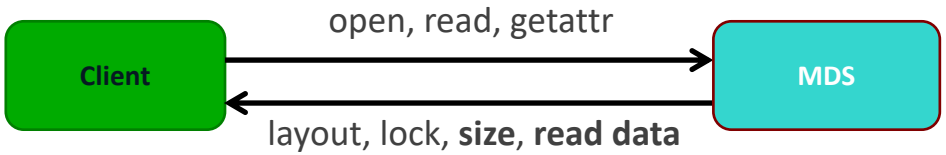
- Complementary with DNE 2 striped directories
  - Scale small file IOPS with multiple MDTs
- Read-on-Open fetches data (LU-10181)
  - Reduced RPCs for common workloads
  - Allow cross-file readahead for small files
- Improved locking for DoM files (LU-10175)
  - Drop layout lock bit without full IBITS lock cancellation
  - Avoid cache flush and extra RPCs
  - Convert write locks to read locks
- Migrate file/component from MDT to OST (LU-10177) — DONE
- Migrate file/component from OST to MDT via FLR (LU-11421) — TODO
- Cross-file data prefetch via statahead (LU-10280)




**Small file read directly from MDS**

# DNE Improvements (WC 2.12/2.13)

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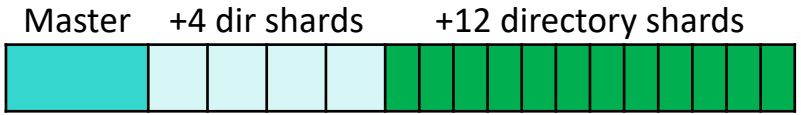
- Directory restriping from single-MDT to striped/sharded directories (LU-4684)
  - Rebalance MDT space usage, improve large directory performance
- Automatically create new remote directory on "best" MDT with `mkdir()`
  - Simplifies use of multiple MDTs without striping all directories, similar to OST usage
  - In 2.11 in userspace for `lfs mkdir -i -1` (LU-10277) DONE
  - In 2.13 in kernel for `mkdir()` with parent `stripe_idx = -1` (LU-10784, LU-11213) TODO
- Automatic directory restriping to avoid explicit striping at create (LU-11025)
  - Create one-stripe directory for low overhead, scale shards/capacity/performance with size
  - Add extra shards when master directory grows large enough (e.g. 10k entries)
  - Move existing direntries to new directory shards, keep existing inodes in place
  - New direntries and inodes created in new shards



# ZFS Enhancements Related to Lustre (2.12+)

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- Lustre 2.12 `osd-zfs` updated to use ZFS 0.7.9
  - Bugs in ZFS 0.7.7/0.7.10, not used by Lustre branch
  - Working on building against upstream ZoL RPMs
- Features in ZFS 0.8.x release (target 2018Q4)
  - Depends on final ZFS release date, to avoid disk format changes
  - Sequential scrub/resilver (Nexenta)
  - On-disk data encryption + QAT hardware acceleration (Datto)
  - Project quota accounting (Intel)
  - Device removal via VDEV remapping (Delphix)
  - Metadata Allocation Class (Intel, Delphix) — LANDED
  - Declustered Parity RAID (dRAID) (Intel) — IN PROGRESS

OpenZFS

# Miscellaneous Improvements (2.12)

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- Token Bucket Filter (NRS-TBF) UID/GID policy (LU-9658 DDN)
- Improved JobStats allows admin-formatted JobID (LU-10698 Intel)

```
lctl set_param jobid_env=SLURM_JOB_ID jobid_name=cluster2.%j.%e.%p
```

- HSM infrastructure improvement & optimizations (Intel/WC, Cray)
  - Improve Coordinator (LU-10699), POSIX Copytool (LU-11379), > 32 archives (LU-10114), …
- Lazy Size-on-MDT for local scan (purge, HSM, policy engine) (LU-9358 DDN)
  - LSOM is not guaranteed to be accurate, but good enough for many tools
  - LSOM made available on client for apps *aware of limitations* (e.g. `lfs find`, `statx()`, …)
- Lustre-integrated T10-PI end-to-end data checksums (LU-10472 DDN)
  - Pass data checksums between client and OSS, avoid overhead, integrate with hardware — DONE

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- Dump/restore of conf_params/set_param -P parameters (LU-4939 Cray) — TODO

```
lctl --device MGS llog_print testfs-client > testfs.cfg; lctl set_param -F testfs.cfg
```

# Improved Client Efficiency

(2.12+)

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- Disconnect idle clients from OSS (LU-7236 Intel)
  - Reduce memory usage on client and server for large systems
  - Reduce network pings and recovery times
- Aggregate `statfs()` RPCs on the MDS (LU-10018 WC)
  - Reduce OSS overhead, avoid idle OST reconnection on client `df`

DONE

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- Improved client read performance (LU-8709 DDN)
  - Improved readahead code, asynchronous IO submission

TODO

- Reduce wakeups and background tasks on idle clients (LU-9660 Intel)
  - Synchronize wakeups between threads/clients (per jobid?) to minimize jitter
  - Still need to avoid DOS of server if all clients ping/reconnect at same time

# Kernel Code Cleanup (ORNL, SuSE, Intel, WC, Cray)

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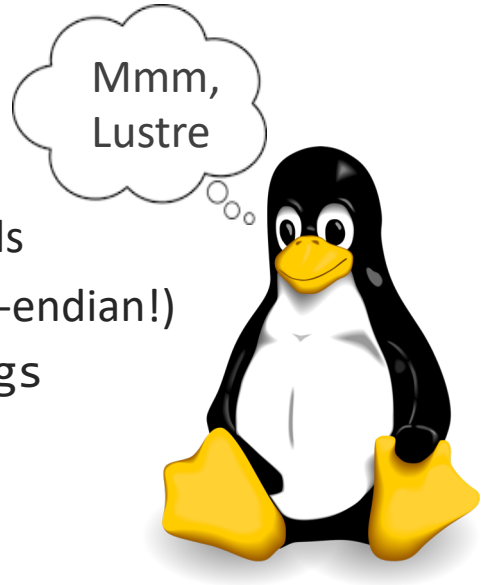
- Lustre client removed from kernel 4.17 ☹
  - Work continuing on client cleanups *for* upstream at https://github.com/neilbrown/linux
- Lustre 2.12 updates for kernel 4.14/4.15 (LU-10560/ LU-10805)
- Improve kernel time handling (Y2038, jiffies) (LU-9019)
- Ongoing `/proc` -> `/sys` migration and cleanup (LU-8066)
  - Handled transparently by `lctl` / `llapi_*` - please use them
- Cleanup of `wait_event`, `cfs_hash_*`, and many more internals
- Some builds/testing with ARM64/Power8 clients (LU-10157 little-endian!)
- Major `ldiskfs` features merged into upstream `ext4/e2fsprogs`
  - Large xattr (`ea_inode`), directories > 10M entries (`large_dir`)
  - `dirdata` feature not yet merged (needs test interface)



# Performance Improvements for Flash (WC 2.12+)

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- Reduce server CPU overhead to improve small flash IOPS
  - Performance is primarily CPU-limited for small read/write
  - Any reduction in CPU usage directly translates to improved IOPS
- Reduce needless `lu_env` operations in DLM (LU-11164)
- Avoid page cache on flash OSS (LU-11347)
  - Avoids CPU overhead/lock contention for page eviction
  - Streaming flash performance is often network limited
  - ZFS drops pages from cache after use (LU-11282) — DONE

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- Improved efficiency of ZFS IO pipeline — TODO
  - Integrate with ABD in ZFS 0.8 to avoid `memcpy()` of data
  - Further improvements with continued investigation/development

# FLR Enhancements (WC 2.12+)

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- Continuation of FLR feature landed in Lustre 2.11 (LU-9771)
- FLR-aware OST object allocator to avoid replicas on same OST/OSS (LU-9007)
- Improve "`lfs mirror resync`" performance (LU-10916)
  - Optimize multi-mirror resync (read data once, write multiple mirrors)
- "`lfs mirror read`" to dump specific mirror/version of file (LU-11245)
- "`lfs mirror write`" for script-based resync (LU-10258)
- Mirror NOSYNC flag + timestamp to allow file version/snapshot (LU-11400) — DONE

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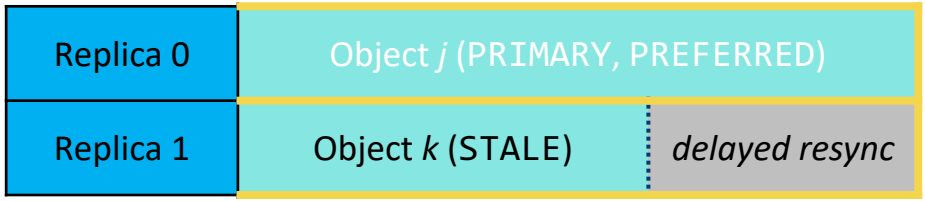
- Improved replica selection at runtime (LU-10158) — TODO
  - Select best write replica (PREFERRED, SSD vs. HDD , near to client), read (many mirror vs. few)
  - Allow specifying fault domains for OSTs (e.g. rack, PSU, network switch, etc.)
- Mount client directly on OSS for improved resync performance (LU-10191)
- Support DoM components (LU-10112)
- Pool or OST/MDT quotas (LU-11023)
  - Track/restrict space usage on flash OSTs/MDTs



# Tiered Storage with FLR Layouts (2.12/2.13)

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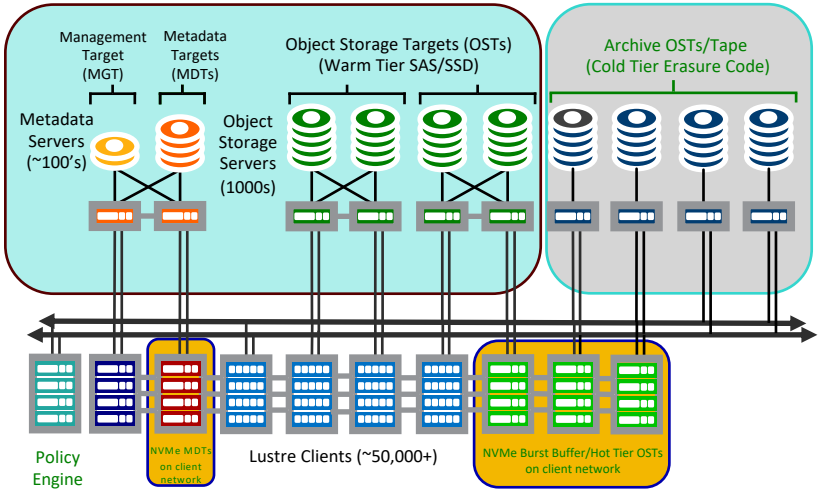
- Integration with job scheduler and workflow for file prestage/drain/archive
- Policy engine to manage migration between tiers, rebuild replicas, ChangeLogs
  - Policies for pathname, user, extension, age, OST pool, mirror copies, ...
  - FLR provides mechanism for safe migration of (potentially in-use) data
  - RBH or LiPE are good starting points for this
- Needs userspace integration and Lustre hooks
  - Integrated burst buffers a natural starting point
  - Mirror to flash, mark PREFERRED for read/write
  - Resync modified files off flash, release space
- Need OST/MDT/pool quotas to manage tiers



# FLR Erasure Coded Files (LU-10911 WC 2.13+)

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- Erasure coding adds redundancy without 2x/3x overhead
- Add erasure coding to new/old striped files *after* write done
  - Use delayed/immediate mirroring for files being actively modified
- For striped files - add N parity per M data stripes (e.g. 16d+3p)
  - Parity declustering avoids IO bottlenecks, CPU overhead of too many parities
    - e.g. split 128-stripe file into 8x (16 data + 3 parity) with 24 parity stripes

| dat0 | dat1 | ... | dat15 | par0 | par1 | par2 | dat16 | dat17 | ... | dat31 | par3 | par4 | par5 | ... |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0MB | 1MB | ... | 15M | p0.0 | q0.0 | r0.0 | 16M | 17M | ... | 31M | p1.0 | q1.0 | r1.0 | ... |
| 128 | 129 | ... | 143 | p0.1 | q0.1 | r0.1 | 144 | 145 | ... | 159 | p1.1 | q1.1 | r1.1 | ... |
| 256 | 257 | ... | 271 | p0.2 | q0.2 | r0.2 | 272 | 273 | ... | 287 | p1.2 | q1.2 | r1.2 | ... |

# Persistent Client Cache (PCC) (LU-10092 DDN, WC 2.13+)

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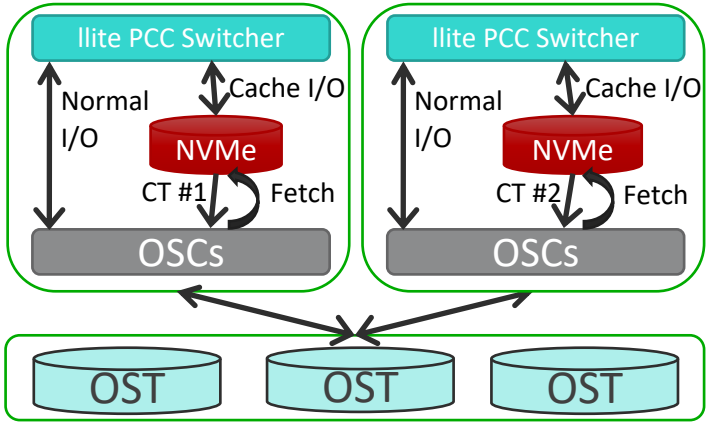
- Reduce latency, improve small/unaligned IOPS, reduce network traffic
- PCC integrates Lustre with persistent per-client local cache devices
  - Each client has own cache (SSD/NVMe/NVRAM) as a local filesystem (e.g. ext4/ldiskfs)
  - No global/visible namespace is provided by PCC, data is local to client only
  - Existing files pulled into PCC by HSM copytool per user directive, job script, or policy
  - New files created in PCC is *also* created on Lustre MDS
- Kernel uses local file if in cache or normal Lustre IO
  - Further file read/write access "directly" to local data
  - No data/IOPS/attributes leave client while file in PCC
  - File migrated out of PCC via HSM upon remote access
- Separate functionality read vs. write file cache
- Could later integrate with DAX for NVRAM storage



# Client Metadata Writeback Cache (WBC) (LU-10983 2.14+)

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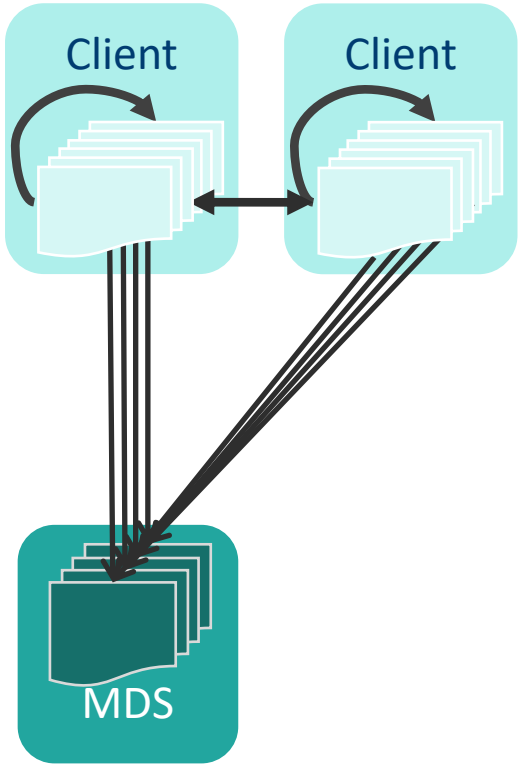
- Metadata WBC creates new files in RAM in *new directory*
  - Avoid RPC round-trips for each open/create/close
  - Lock directory exclusively, avoid other DLM locking
  - Cache file data only in pagecache until flush
  - Flush tree incrementally to MDT/OST in background batches
- Could prefetch directory contents for existing directory
- Can integrate with PCC to avoid initial MDS create
- Early WBC prototype in progress
  - Discussions underway for how to productize it
  - Early results show 10-20x improvement for some workloads



# Client Container Image (CCI)

(2.14+)

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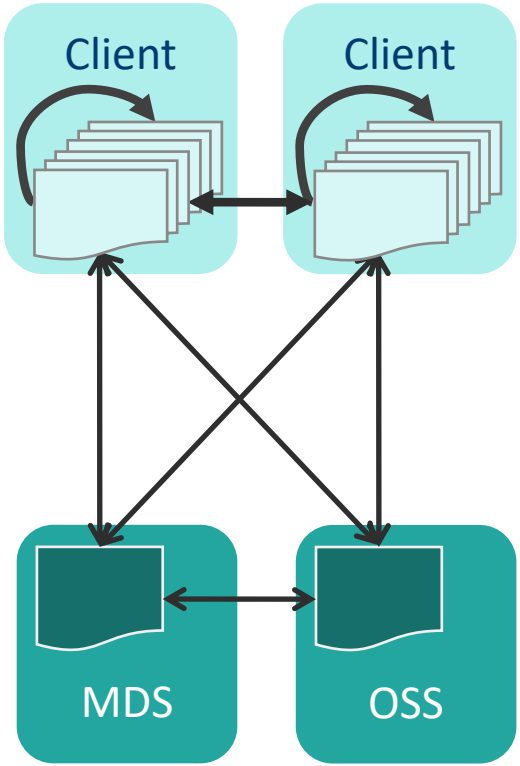
- Filesystem images have had *ad hoc* with Lustre in the past
  - Read-only cache of many small files manually mounted on clients
  - Root filesystem images for diskless clients
- *Container Image* is local ldiskfs image mounted on client
  - Holds a whole directory tree stored as a single Lustre file
- CCI integrates container handling with Lustre
  - Mountpoint is registered with Lustre for automatic mount
  - Automatic local loopback mount of image at client upon access
  - Image file read on demand from OST(s) and/or cached in PCC
  - Low I/O overhead, few file extent lock(s), high IOPS per client
  - Access, migrate, replicate image with large read/write to OST(s)
- MDS can mount and re-export image files for shared use
- CCI can hold archive of whole directory tree for HSM
- Unregister/delete image and all files therein with a few ops



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# DNE Metadata Redundancy (2.14+)

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- New directory layout hash for mirrored directories, mirrored MDT inodes
  - Each dirent copy holds multiple MDT FIDs for inodes
  - Store dirent copy on each mirror directory shard
  - Name lookup on any MDT can access via any FID
  - Copies of mirrored inodes stored on different MDTs
- DNE2 distributed transaction for update recovery
  - Ensure that copies stay in sync on multiple MDTs
- Mirror policy per-filesystem/subtree, is flexible
- Flexible MDT space/load balancing with striped dirs
- Early design work started, discussions ongoing