Lustre* 2.9 and Beyond

Andreas Dilger, High Performance Data Division

Overview of Features

Features completed for 2.8

- LFSCK Phase 4 - Performance Improvements (Intel, OpenSFS)
- DNE Phase 2 Striped Directories - Asynchronous Commits (Intel, OpenSFS)
- Client IO Simplification (Intel, OpenSFS)
- Multiple metadata-modifying RPCs (multi-slot `last_rcvd`) (Bull=Atos)
- Kerberos/GSS revival (Bull=Atos, Seagate)

Features starting development for 2.9 and later

- UID/GID mapping (IU)
- ZFS* Enhancements (Intel, LLNL)
- Project quotas (DDN)
- Shared-key/GSS crypto (IU)
- Progressive File Layout Prototype (Intel & ORNL)
- Data on MDT Prototype (Intel)

ZFS Enhancements (Intel/LLNL, 2.9+)

Changes for ZFS OSD (2.9)

- 1MB+ ZFS blocksize (IO performance, LLNL)
- Read IO optimization (IO performance, Intel)
- ZIL support for fast sync (IO & metadata performance, Intel)

Changes to core ZFS code (2.9+)

- Inode quota accounting (base functionality, Intel)
- Large dnodes (metadata performance, LLNL)
- Parity declustering (reliability & availability, Intel)
- Distributed hot spares (reliability & availability, Intel)

Miscellaneous features

Code cleanups (Cray*/Intel®/ORNL)

- Update to match upstream kernel coding style
- Port patches to/from upstream kernel
- Clean up and/or eliminate server kernel/ldiskfs patches

Project Quotas (DDN*)

- Allow quota tracking on directory subtrees independent of UID/GID
- Not strictly hierarchical, can be multiple trees with the same project

Network Authentication and Encryption (Bull*/IU*/Seagate*)

- Kerberos user/node authentication, RPC encryption
- Shared Secret Key node authentication, RPC encryption

Data on MDT (Intel, 2.10+)

Efficiently store small files on the MDT(s)

- Avoid OST BRW RPC + disk seek + OST lock for each file access
- Use small-file optimized MDT storage (RAID-10/SSD/NVRAM)
- Avoid RAID-5/6 read-modify-write for small writes

Space usage on MDT(s) managed by quota

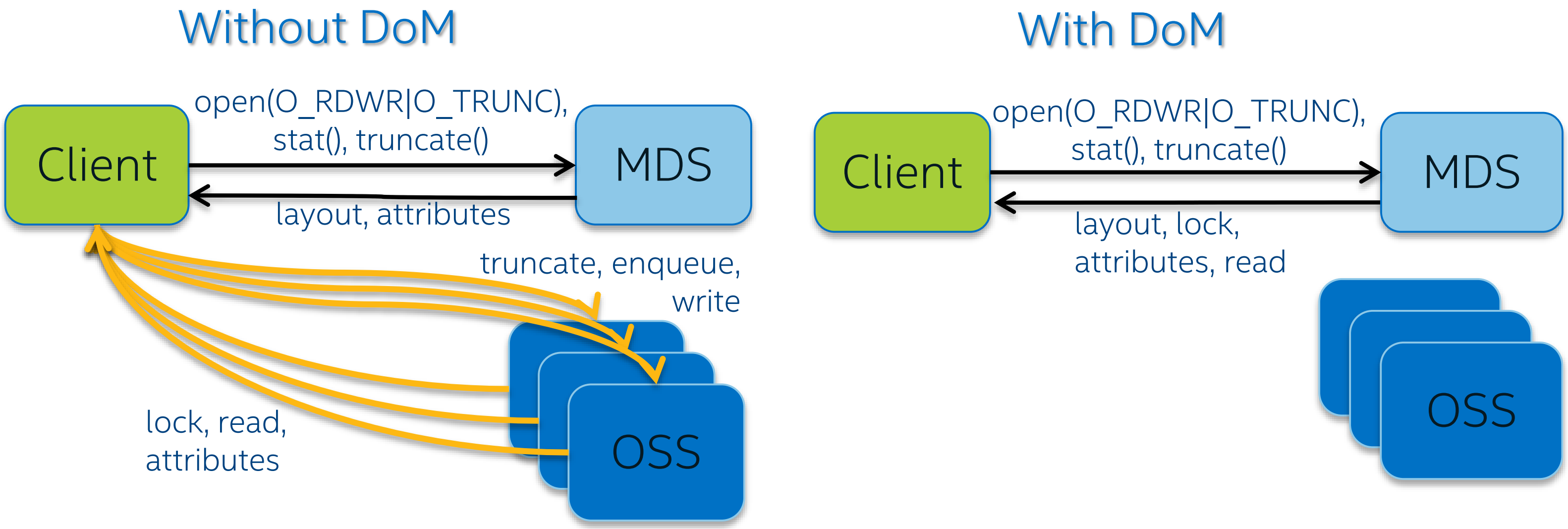
Small files are determined by the file layout

- Maximum MDT file size can be specified by **min(**user, admin**)**
- Typically expected to be <= 1MB, dependent on MDT space

Complementary with DNE 2 striped directories

- Scale small file IOPS horizontally with multiple MDTs

Data on MDT Implementation (Intel, 2.10+)


Without DoM
Client
open(O_RDWR|O_TRUNC), stat(), truncate()
MDS
layout, attributes
truncate, enqueue, write
lock, read, attributes
OSS
With DoM
Client
open(O_RDWR|O_TRUNC), stat(), truncate()
MDS
layout, lock, attributes, read
OSS

DoM layout chosen at file creation time like files on OSTs

- Can't do it after write because objects are allocated at **open()**
- Default DoM striping on subdirectories inherited by newly created files

http://cdn.opensfs.org/wp-content/uploads/2014/04/D1_S10_LustreFeatureDetails_Pershin.pdf

http://wiki.opensfs.org/images/b/be/DataonMDSDesign_HighLevelDesign.pdf

Composite Layouts (Intel, 2.10)

Add *Composite Layouts* for regular files

- Allow describing more complex file structures and interactions
- A composite layout contains multiple *components* (`LOV_MAGIC_V[13]`)
- Composite layouts do not restrict components themselves
- Specific features may impose their own restrictions

```
struct lov_comp_md_v1 {
        __u32 lcm_magic;         /* LCM_MAGIC_V1 */
        __u32 lcm_size;          /* overall size including this struct */
        __u32 lcm_layout_gen;    /* incremented each time layout changes */
        __u16 lcm_flags;         /* LCM_FL_RS_READ_ONLY, LCM_FL_RS_SYNC_PENDING, ... */
        __u16 lcm_entry_count;   /* number of components in lcm_entries[] */
        __u64 lcm_padding[2];
        struct lov_comp_md_entry_v1 lcm_entries[];
};
```

Composite Layout Components

- A *Component* describes one extent of a composite file
- Each component is a separate *plain* layout within a file
  - Currently `LOV_MAGIC_V[13]` (RAID-0) layouts are handled
  - Other layout patterns can be added in the future (`LOV_MAGIC_DOM`, …)
- Components cannot be nested
- Objects are not shared between components

```
struct lov_comp_md_entry_v1 {
    __u32 lcme_id;                  /* unique identifier of component within composite */
    __u32 lcme_flags;               /* LCME_FL_STALE, LCME_FL_PRIMARY, LCME_FL_PREFERRED */
    struct lu_extent lcme_extent;   /* file logical extent for component */
    __u32 lcme_offset;              /* offset of component layout from start of composite */
    __u32 lcme_size;                /* size of component layout data in bytes */
    __u64 lcme_padding;
};
```

What can be done with Composite Layouts?

Progressive File Layouts

- Non-overlapping component layouts for different parts of the file
- Increasing stripe count as file grows larger is expected, but not required

File Level Replication

- Overlapping component layouts provide redundancy
- Replica components can be marked stale or offline if OST failure is detected
- Resync stale components when OST online or add new replicas for failed OSTs

File versioning

- Replica components that are not updated by later writes or resync'd
- Old versions could be accessed via `lfs` or via `ioctl()` on open file descriptor

HSMv2 partial file restore

- One component for each archive copy, along with a timestamp/version for age
- Regular file component(s) for online data, may not cover whole file

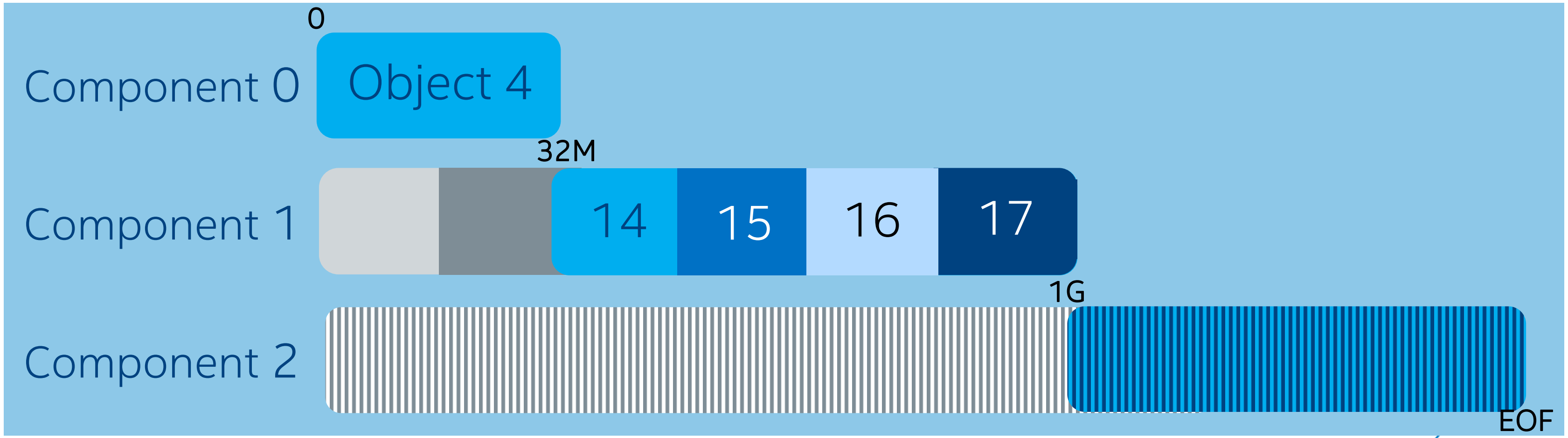
Progressive File Layouts (Intel/ORNL, 2.10)

Allow stripe count to increase for larger files

- Improve aggregate IO bandwidth for large files
- Do not add overhead for small files
- Start with one stripe, add stripes incrementally as file size increases
- Balance lower overhead vs. performance and space balance

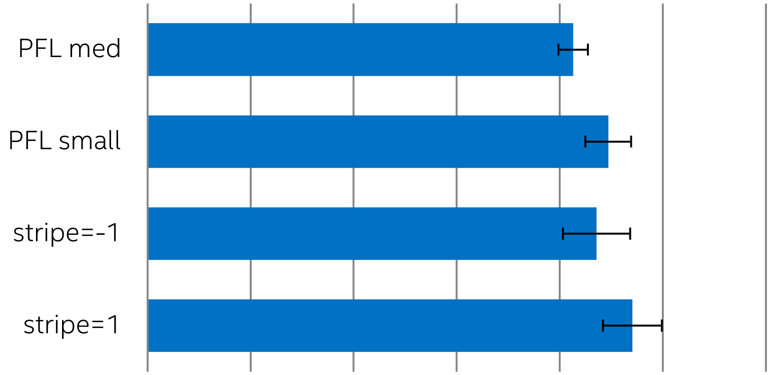
Covered (grey) region of component is inaccessible/sparse

- Allows merging/replication/separation of components from plain files

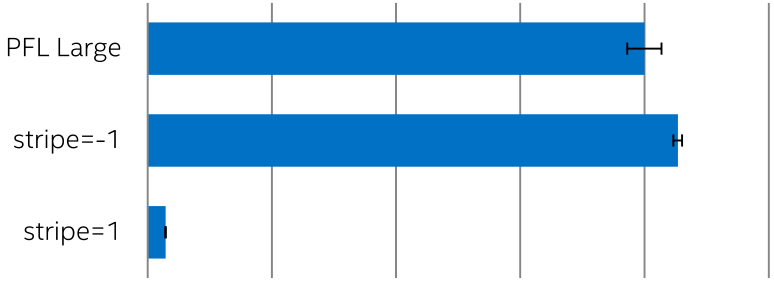


PFL Prototype Performance Comparison

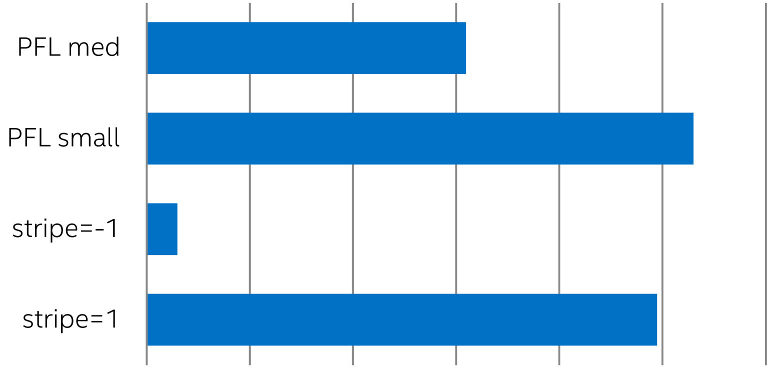
16 threads - Single Client
IOR File per Process Write



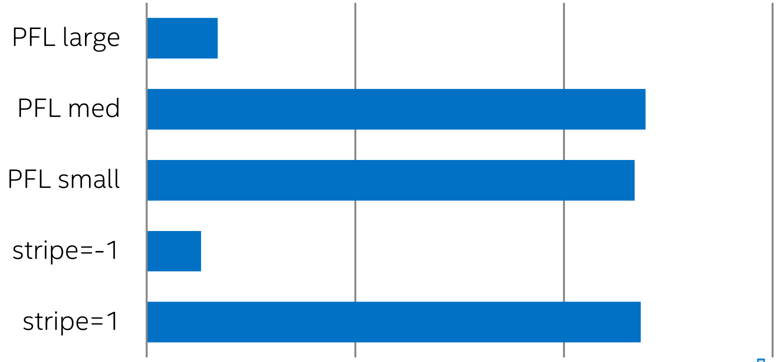
512 Threads - 32 Client
IOR Shared File Write



16 threads - Single Client
mdtest file stat/sec



512 Threads - 32 Client
mdtest file stat/sec



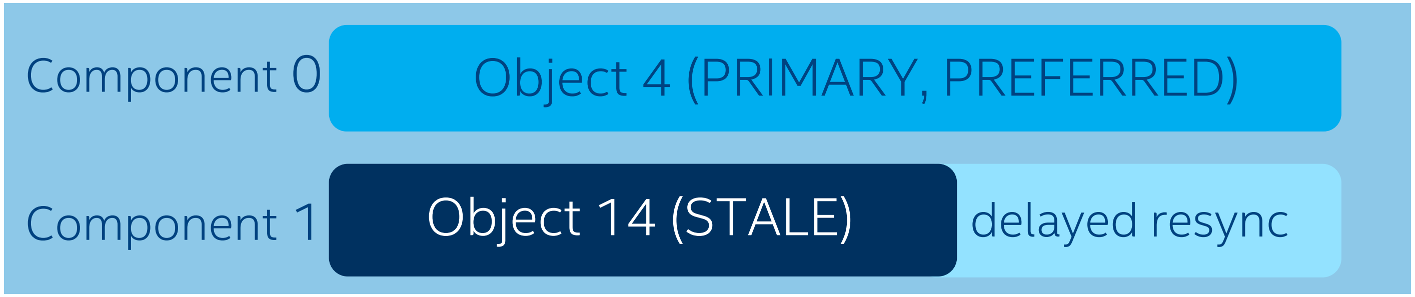
File Level Replication

Allow redundancy at the file level

- Avoid the need for multi-path storage or failover (local server storage OK)
- Redundancy can be selected/added/removed on a per-file basis
- Reads balanced between replicas, recover read errors from replica
- Can tune IO overhead/performance vs. file availability

Phase 1: Delayed replication by external resync tool

- For read-mostly workloads, minimizes write overhead at client
- Only primary replica modified, non-primary replica(s) marked stale on first write
- ChangeLog/copytool drives resync tool after write finished, or if OST is offline in Phase 2



Component 0 Object 4 (PRIMARY, PREFERRED)

Component 1 Object 14 (STALE) delayed resync

Phase 2: Replica updated immediately by client

- Client sends writes to each OST, marks component stale if write fails

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Software

Backup Slides

LFSCK Phase 4 (Intel/OpenSFS 2.8)

LFSCK performance improvements (Phase 4)

- Improve object iteration, don't load objects unnecessarily
- Avoid a full scrub if only a few objects are found inconsistent
  - Tunable, launch full scrub if more than 60 errors within 60s
- Limit DLM locking to only affected name instead of whole directory
- Predict locking based on recent history
  - LFSCK doesn't lock by default, only lock & reverify on inconsistency
  - If errors recently seen LFSCK locks objects before doing checks
- Improved logging of LFSCK-detected inconsistencies

LFSCK Phase 4 is the final phase of this project

http://wiki.opensfs.org/images/3/3c/LFSCK_Performance_SolutionArchitecture.pdf

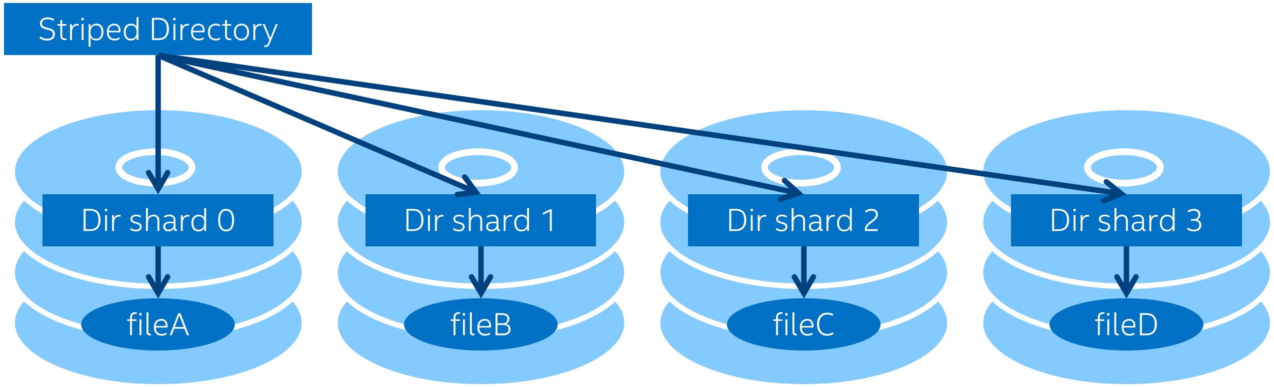
http://cdn.opensfs.org/wp-content/uploads/2013/04/Zhuravlev_LFSCK.pdf

DNE Phase 2 Striped Directories (Intel/OpenSFS 2.8)

Spread a single directory across multiple MDTs

- Reduce contention, improve performance for large directories
- Directory layout + name hash locates slave MDT directory entry
- Directory shard on each MDT independent (lock, lookup, modify)
- Inode created on the same MDT as name entry
- Tool to migrate directories/files from one MDT to another

DNE Phase 2 Async Commits is the final phase of this project



DNE 2 Asynchronous Commit (Intel/OpenSFS 2.8)

Change ***within*** MDT (mkdir, rmdir, rename) **never** synchronous

DNE remote/striped directory create synchronous in 2.4-2.7

- Cross-MDT **rename()** or **link()** weren't working (returned **-EXDEV**)

Async commit implements distributed DNE recovery

- Each target (master/slave) writes a full redo log of all updates
- If *any* target commits a change it can be replayed on *all* involved targets
- Ensures all-or-nothing semantic for namespace-visible changes
- Reduced latency for remote/striped directory creates
- Allow **rename()** and **link()** to work correctly across MDTs
- Foundation for future features (e.g. cross-MDT mirrored objects)

http://wiki.opensfs.org/images/f/ff/DNE_StripedDirectories_HighLevelDesign.pdf

Client IO Cleanup/Speedup (Intel/OpenSFS 2.8+)

Clean up CLIO code and interfaces

- Simplify complex internal locking code
- Replace old ioctl interfaces with proper methods
- Remove non-functional interop code for WinNT and MacOS
  - Remove extra abstraction layer complexity and overhead
  - Remove non-functional liblustre code and abstractions
- Remove access to LOV layout internals throughout code
  - Preparation for handling of more complex file layouts (e.g. PFL)

Client Performance Improvements

- Larger RPC sizes for improved allocation and disk IO
- Single-threaded IO performance improvements

http://wiki.opensfs.org/images/b/b7/CLIOSimplificationDesign_HighLevelDesign.pdf

Client Metadata RPC Scaling (Bull/Intel 2.8)

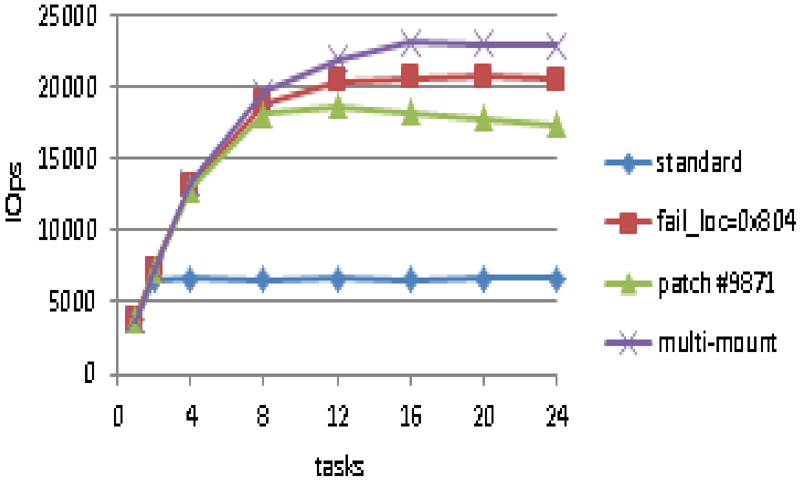
(aka multi-slot **last_rcvd**)

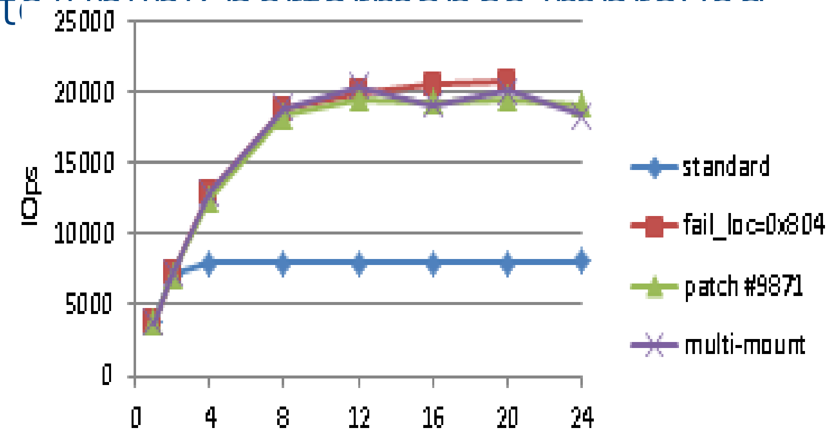
Currently limited to one modifying RPC (+close) per client

- **last_rcvd** slot on MDT for each client to reconstruct reply
- Many concurrent clients limited by MDS performance

Dynamic log on MDT for multiple saved RPC replies per client

- Each metadata-modifying RPC has a separate tag/index
- Single client multi-threaded create/unlink performance improved





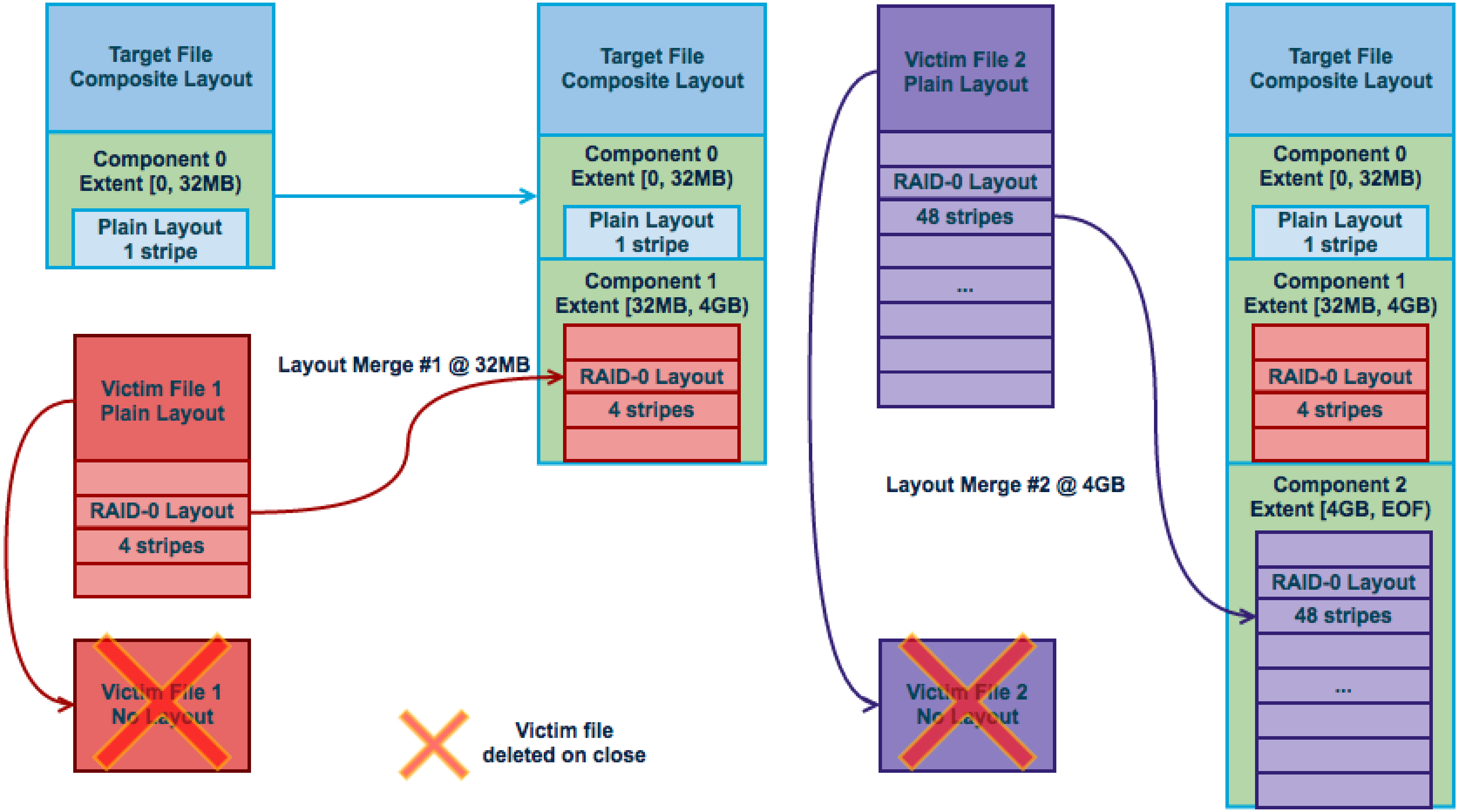
https://jira.hpdd.intel.com/browse/LU-5319

Intel® Omni-Path Architecture Gen 1 (Intel 2.8)

LNet support for Intel® Omni-Path host fabric interface (HFI)

- Next generation interconnect from Intel
- Compatible with OFED verbs interface
- Lustre automatically sets LNet o2iblnd tuning for improved performance

Creating Progressive File Layouts


Target File
Composite Layout
Component 0
Extent [0, 32MB)
Plain Layout
1 stripe
Victim File 1
Plain Layout
RAID-0 Layout
4 stripes
Victim File 1
No Layout
Layout Merge #1 @ 32MB
Target File
Composite Layout
Component 0
Extent [0, 32MB)
Plain Layout
1 stripe
Component 1
Extent [32MB, 4GB)
RAID-0 Layout
4 stripes
Victim file
deleted on close
Victim File 2
Plain Layout
RAID-0 Layout
48 stripes
...
Layout Merge #2 @ 4GB
Victim File 2
No Layout
Target File
Composite Layout
Component 0
Extent [0, 32MB)
Plain Layout
1 stripe
Component 1
Extent [32MB, 4GB)
RAID-0 Layout
4 stripes
Component 2
Extent [4GB, EOF)
RAID-0 Layout
48 stripes
...