Look Inside™

# From lab to enterprise - growing the Lustre* ecosystem

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# Drivers for change

## Lustre* has always supported high performance computing

- Extreme performance at extreme scale

## New challenges for Lustre as HPC expands into new IT domains and markets

- Performance requirements are changing
  - Not just about massive streaming IO performance and huge files
  - Small random IO to large files, massive collections of tiny files
  - Diverse and unstructured
- Reliability, Availability, and Serviceability (RAS)
  - Resilience, service level agreements (many 9’s uptime)
  - Disaster recovery across sites
- Security of data in flight and at rest

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# Performance – Market Drivers

Increasingly diverse data workloads requiring large scale storage systems

- [Very] Large files
- Millions of small files per directory
- Millions of files in complex directory hierarchies, mixture of sizes
- Sequential, streaming IO
- Random IO

Contained in a single addressable name space

Requires a versatile, scalable file system platform

# Requirements of key market segments

## Life sciences

- Small file workloads – very large file populations, millions of files
- Security and privacy – personal data, protected health information

## Weather and climate

- Reliability – mission-critical workloads for forecasts and emergency modelling
- Small files – mixed workloads, but small file workloads are prevalent

## Media, Manufacturing and EDA

- Small files, Reliability

## Financial services

- Small files, Reliability, Security

# Increasing versatility

Flexible layouts to accommodate diverse requirements in a single name space

- Decisions can be made per file, per directory, per filesystem
- Data on MDT for small file optimisation
- Replication for fault tolerance
- Progressive file layout
- As always, striping for throughput

HSM for long-term archival of permanent production data

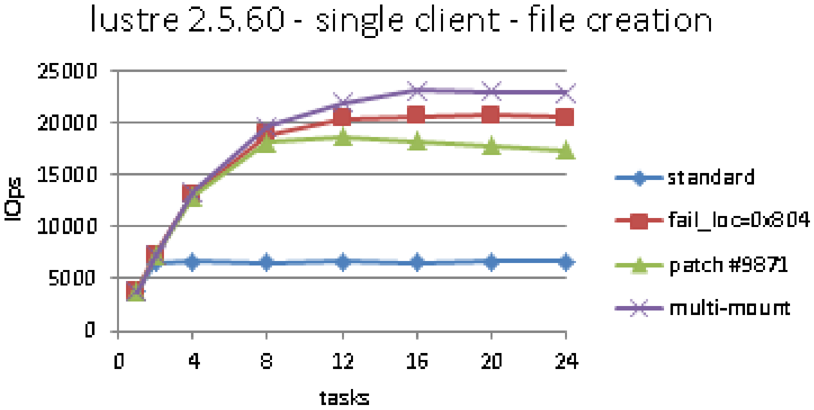
High performance parallel data movers for replication, disaster recovery

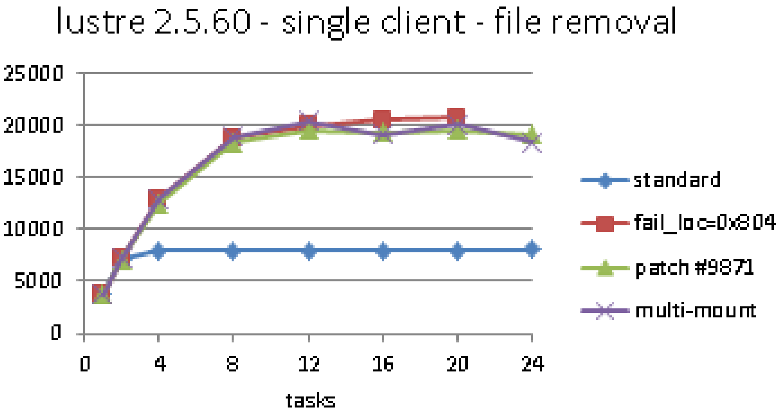
Securing data: access control and encryption

# Scaling metadata performance

## Increasing single client metadata performance

- Lustre* currently limits each client to 1 in-flight metadata modifying RPC
  - Single last_rcvd slot on MDT for each client to reconstruct RPC reply
- Change to dynamic log removes in-flight limit
  - Improved client multi-threading





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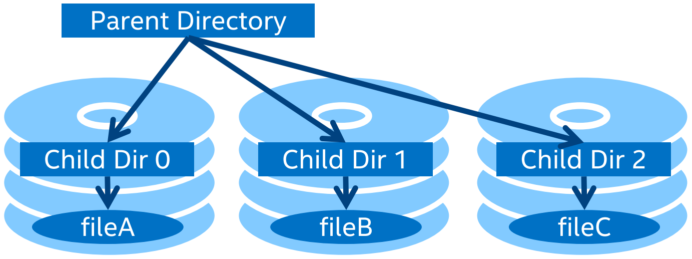
# Scaling Metadata Performance

## Horizontally scaling metadata performance

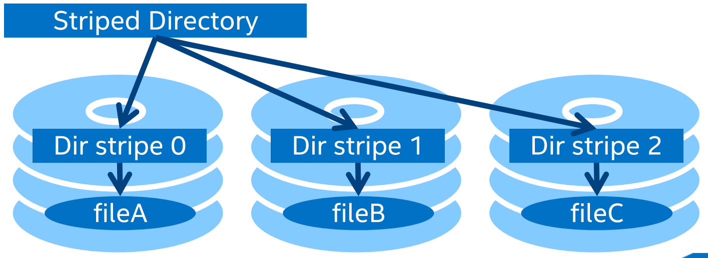
- Phase 1: Remote directories distribute a directory tree onto a separate MDT
- Phase 2: Striped directories distribute a single directory across multiple MDTs

## Efficient general purpose distributed transaction protocol

- Remove disk sync latency from critical RPC path
- Assured recovery on client and/or server failure



DNE Phase 1



DNE Phase 2

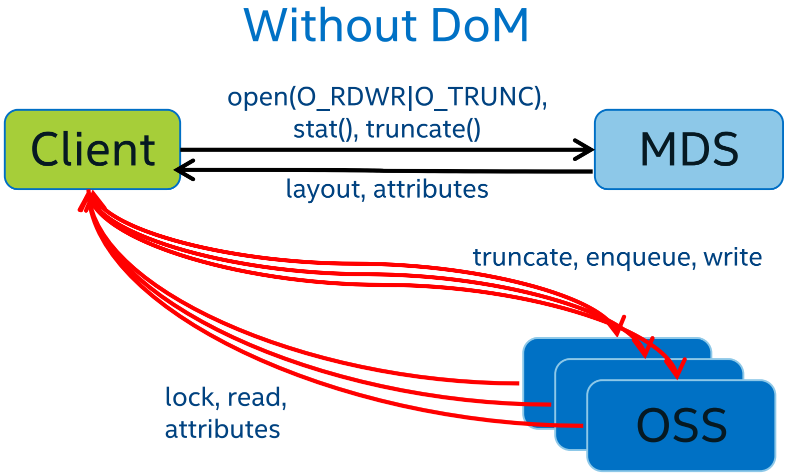
# Scaling Small File Performance

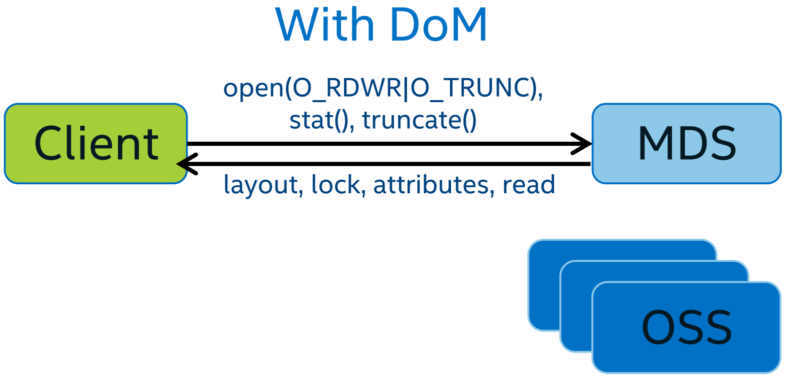
## Data on MDT

- Co-locate data and metadata for small files
- Large streaming IO on OSTs not disturbed
- Further optimize IO rates with flash storage
- Scale out performance with striped directories

## Differentiated Storage Services (DSS)

- All stack levels classify I/O
  - OSD: ext4 extent metadata
  - OST/MDT: object index
  - Application: Frequently accessed directory/file
- Classifications drive caching policies
  - SSD tier integrated into OSD and/or block storage
  - Intelligently prioritize cache utilization





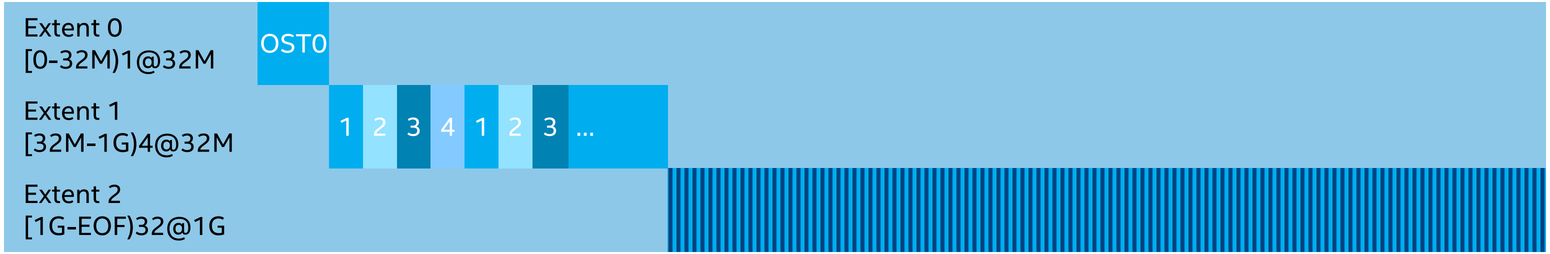
# Layout Enhancement

## Allow file layouts beyond simple striping

- Different layouts for different ranges of each file
- Layouts can overlap (mirror) and be on different types of storage

## Progressive File Layout

- Increase stripe count as file size increases
- Automatic layout for optimal performance of small and large files
- Layout extents can be disjoint or overlapping
  - RAID-1 mirroring → overlapping [0, EOF), [0, EOF)
  - Dynamic stripes → disjoint [0, 32M), [32M, 1G), [1G, EOF)



# Fault Tolerance

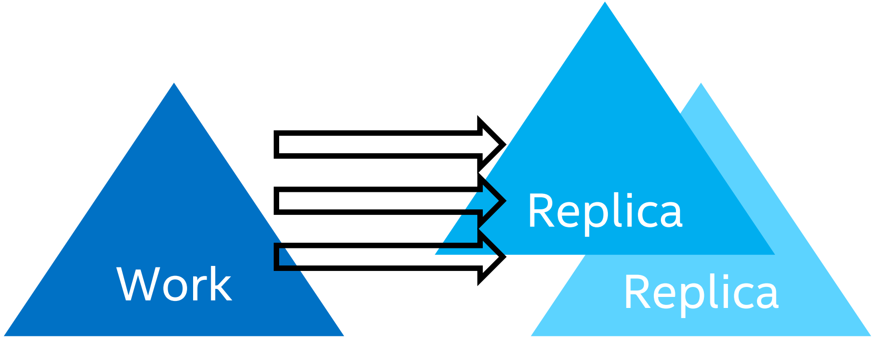
## Replication within the filesystem

| 4 stripes<br>3 mirrors | 0 | 1 | 2 | 3 | 0 | 1 | 2 | … |
|---|---|---|---|---|---|---|---|---|
| | 0’ | 1’ | 2’ | 3’ | 0’ | 1’ | 2’ | … |
| | 0’’ | 1’’ | 2’’ | 3’’ | 0’’ | 1’’ | 2’’ | … |

- Improve reliability of commodity storage hardware
- Increased data availability
  - No need to wait for failover
- Delayed or immediate mirroring of writes to replicas (overhead vs. availability)
- Improved read performance from multiple replicas

## Replication to external storage

- Off-site disaster recovery
- Multi-version backups
- Requires…
  - Incremental update
  - Safe, reliable, efficient data migration



# Scaling Capacity and Performance with HSM

## Hierarchical Storage Management

- Tiered storage provides an online library of permanent production data
- Massive performance in the Lustre* tier(s)
- Massive capacity in the archive tier
- Framework in place since Lustre 2.5
- Allows multiple storage tiers within the filesystem itself

## Ongoing investment to provide complete platform

- Parallel data mover – high performance interface to multiple archives
- Policy engine – data management automation for billions of files

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# Parallel Data Mover

Highly scalable parallel copy tool

- General-purpose “engine”
- Extensions to support diverse range of HSM archives
- Extensions to support multi-site replication
  - Disaster recovery
  - Online backup

When data has to be transferred, it should be transferred as fast as possible

# Policy Engine

Policy engine provides data management automation for digital assets

Defines rules for managing capacity, archival, replication, migration, etc.

- Archive and purge inactive files
- Migrate files between storage tiers within filesystem
- Manage file replicas in case of OST failures
- Copy critical data to DR site every 2 hours

A policy engine for Lustre* must support very large scale

- Billions of inodes
- Multiple metadata servers
- High transaction rates

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# Snapshot

Data protection mechanism for checkpointing a file system

Several purposes

- Quick undo / undelete / roll-back in case of user/administrator error
- Prepare a consistent, read-only view of data for backup
- Prepare for software upgrade

ZFS Snapshot

- Leverage the native snapshot in ZFS
- Create a coordinated snapshot across all storage targets

# Security – Market Drivers

Demand for control of restricted information

- Life sciences, including health care (HIPAA regulation)
- Government, e.g. defense (ICD 503 directive)
- Aerospace, shipbuilding

Increased regulation of personally identifiable information

Movement of workloads to cloud – access must be constrained, data secured

Financial impact of data theft is significant

- Healthcare average cost per breach $3.5M in 2013, some cases significantly larger
- Loss of credibility, loss of revenue as people move to other providers

# Features of a Secure System

Authentication - proper identification of systems and users

- Node or user based authentication

Authorization - permission based access control

- Allow only specific authorized users access to resources

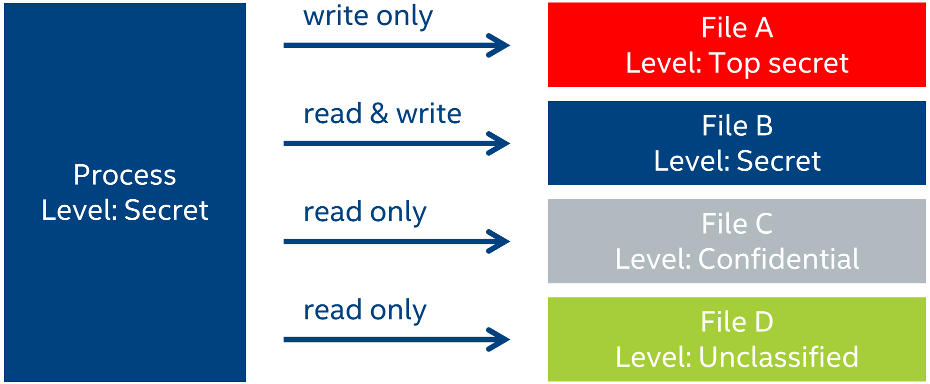
Encryption - protect data in flight and at rest

- RPC traffic encryption
- Disk or filesystem data encryption

# Access Control

## SELinux provides fine-grained, mandatory and role-based access control

- MAC – administrative control of policy definitions
  - Mandatory means enforcement by the OS – users cannot bypass
- RBAC – access controls are assigned to roles, not users
  - Users are then assigned to one or more roles
- MLS – multi-level security:



# Encryption

## Encryption of data in flight

- Native implementation in Lustre*
  - IU Shared-Key Crypto
  - Kerberos

## Encryption of data at rest

- Block device encryption with DM-Crypt / LUKS – no change to Lustre required
- Potential for client-side encryption / decryption integrated into Lustre client

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# Summary

Intel and the Lustre* community continue to drive innovation

Increase Lustre's versatility for an ever-widening spectrum of applications

- Deliver performance across a wide range of workloads

Enterprise data management

- Fault tolerance for critical production data
- HSM
- Replication for disaster recovery
- Snapshot

Security and encryption for sensitive data

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