Lustre 2.14 and Beyond

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Planned Feature Release Highlights

- **2.14** at feature freeze, with several important additions
  - **DNE directory auto-split** – improve usability and performance with multiple MDTs
  - **OST Quota Pools** – manage space on tiered storage targets with OST pools
  - **Client-side *data* encryption** – persistent encryption of data from client to disk
- **2.15** feature development already well underway
  - **Client-side *directory* encryption** – encrypt filenames on disk on MDT
  - **File Level Redundancy - Erasure Coding (EC)** – efficiently store striped file redundancy
  - **LNet IPv6 addressing** - allow over 32-bit addresses, more flexible server configuration
- **2.16** plans continued functional and performance improvements
  - **Metadata Writeback Cache (WBC)** – low latency file operations in client RAM
  - **File Level Redundancy - Immediate Write** – write to mirrors directly from client
  - **Dynamic inode allocation for ldiskfs** - improve flexibility for DoM and large OSTs

DNE Usability Improvements (WC) (2.13+)

- **Space balance new directories** on "best" MDT based on available inodes/space
  - Transparently select "best" MDT for normal `mkdir()` based on parent policy (LU-10784)
  - Set default policy on parent via "`lfs setdirstripe -D –i -1 dir`" (LU-11213)
  - Most useful for root and top-level user directories

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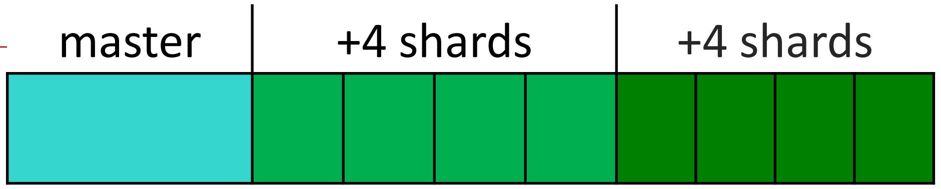
2.14

- **New `crush` directory hash type** (LU-11025)
  - Minimize number of directory entries migrated by restripe



- **Automatic directory restriping** as directory size grows (LU-11025)
  - Create one-stripe directory for low overhead, increase shards/capacity/performance with size
  - Add `mdt.*.dir_split_delta=4` shards if shard over `mdt.*.dir_split_count=50000` entries
  - Move fraction of existing **directory entries** to new directory shards (names only, not inodes)
  - New directory entries and inodes created directly on new MDTs

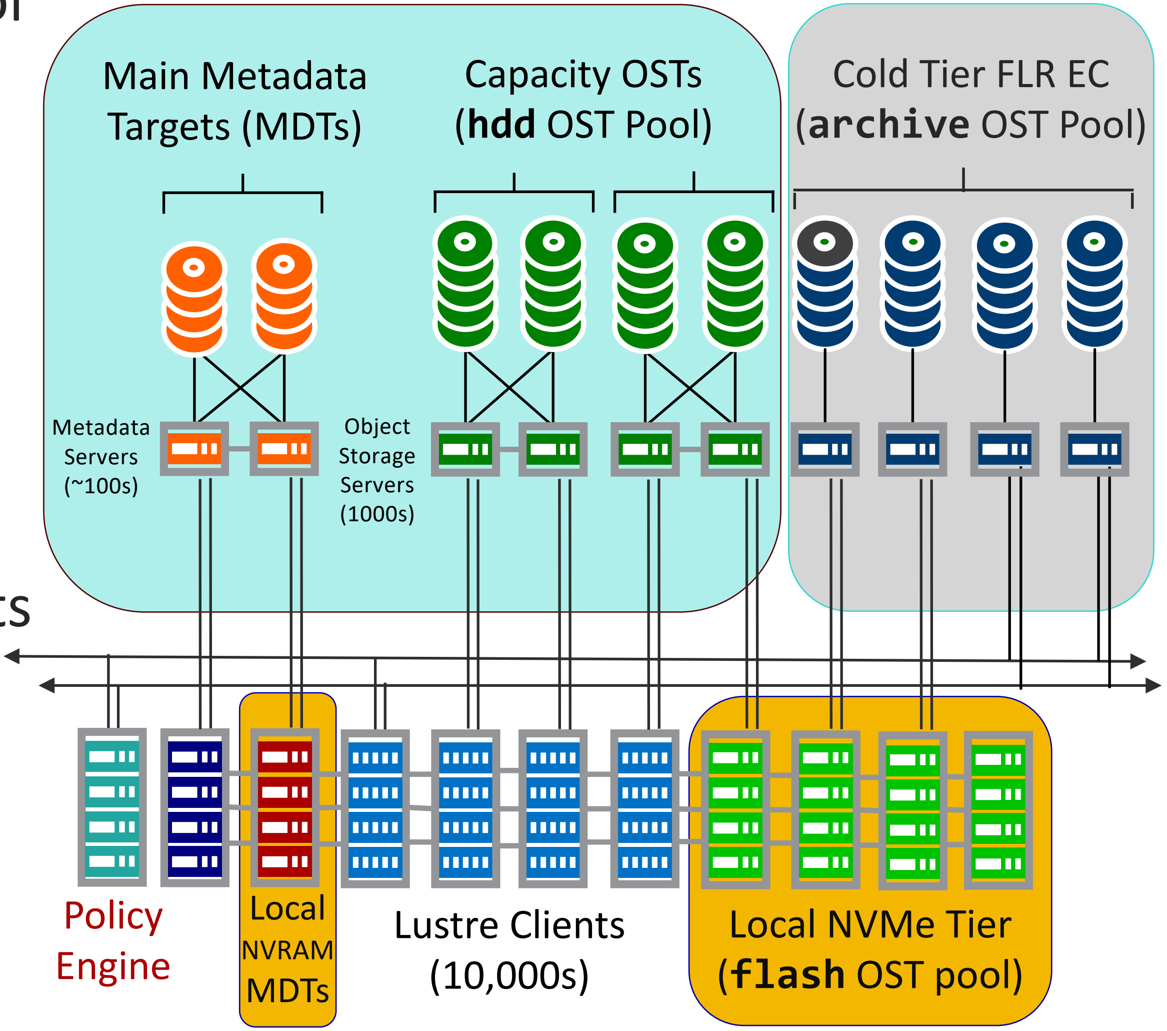
2.15

- Improve MDT usage/space balancing for new filesystems (LU-13417)
- Select closest network-local MDT(s) for mkdir for tiered/distributed configs (LU-12909)

OST Quota Pools (LU-11023, Cray/HPE) (2.14+)

- Account/limit space for OSTs in a specific pool
  - Control usage of small flash OSTs in tiered config
- Use existing Lustre quota infrastructure
  - OST already tracks space per UID/GID/ProjID
  - Pool usage based on sum of current OSTs in pool
- Add quota pool limits per UID/GID/ProjID
  - No extra accounting on the OSTs
  - 2.14 Only new aggregation/reporting by MDS

TBD
- Check quota limit when allocating OST objects
  - Avoid OSTs with little/no quota available
- **MDT pools** to allow MDT tiering
  - Manage/balance DoM MDT space usage
  - Handle MDT storage classes (e.g. NVRAM vs. NAND)



Main Metadata Targets (MDTs)
Capacity OSTs (hdd OST Pool)
Cold Tier FLR EC (archive OST Pool)
Metadata Servers (~100s)
Object Storage Servers (1000s)
Policy Engine
Local NVRAM MDTs
Lustre Clients (10,000s)
Local NVMe Tier (flash OST pool)

Client *Data* Encryption to Disk (LU-12755, WC) (2.14+)

- Protect from storage theft or loss, and network or malicious client snooping
- **Encryption on Lustre client** down to storage
  - **Securely store user crypto keys** in client kernel keyring
  - **Data encrypted before sending** to servers
  - **Data decrypted after receiving** from servers
  - Servers/storage only see encrypted data
  - **Transparent to backend** filesystem/storage (ldiskfs/ZFS)
  - Use larger client CPU capacity to encrypt/decrypt data
- **Use existing ext4/f2fs `fscrypt`** library/tools
  - Inventing your own encryption is a fool's errand
  - **Per-directory tree** tunable encryption setting/user master key
  - **Per-file encryption key**, itself encrypted by user master key
    - **Fast and secure deletion** of file once per-file key is erased
    - Decrypted data dropped from client cache when user master key removed

2.14

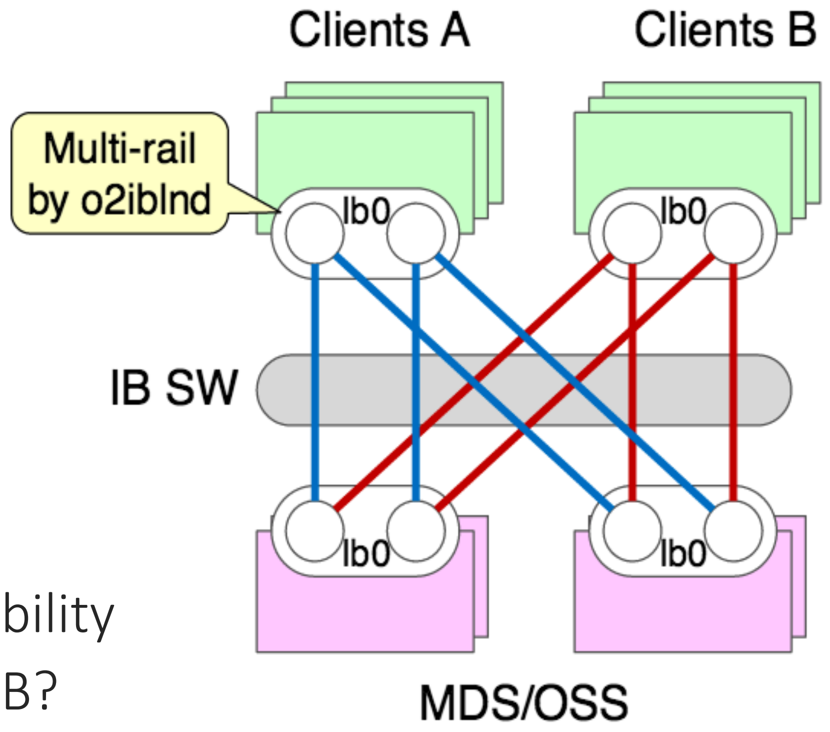
2.15 - ***Filenames* encrypted on client** for MDT directory entries

LNet Improvements (2.14+)

2.14 ▶ MR Router Health improvements (LU-12941, LU-13510, LU-13025, …, HPE, WC)

2.14 ▶ User Defined Selection Policy (LU-9121, WC)

- Fine grained control of interface selection
  - TCP vs. IB networks, primary vs. backup, local vs. remote
- Optimize internal RAM/CPU/PCI data transfers
- Useful for large NUMA machines with multi-rail



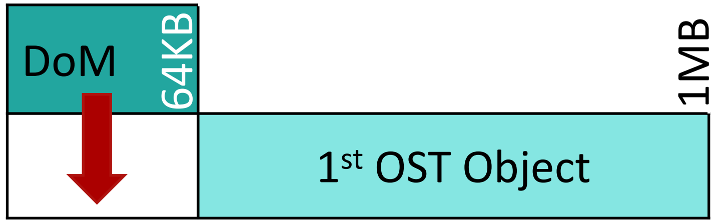
2.15 ▶ IPv6 Node Addressing (LU-10391, WC, SuSE)

- Allow NIDs larger than 32+32bits in TCP and IB
  - New sockv6lnd, o6iblnd nettypes for protocol compatibility
  - Allow direct IB GUID addressing, to avoid need for IPoIB?
- Use Imperative Recovery log for MDT/OST addressing on clients (LU-10360, WC)
  - Allow OSTs and MDTs to mount on any server, no *requirement* for failover addresses
- NIDs no longer needed in Lustre config (LU-13306, WC)

Data-on-MDT (DoM) Improvements (WC) (2.14+)

- Shrink DoM component size if MDT free space running out too quickly (LU-12785)
- 2.14 Early lock cancel for DoM, +28% IOPS on IO500 `mdtest-easy-delete` (LU-12321)

- 2.15 Optimized DoM->OST component removal (LU-13612)
  - Avoid whole-file copy when freeing space from MDT
- Merge data write with `MDS_CLOSE` RPC (LU-11428)
  - Reduce RPC count by half for **`mdtest-hard-write`**
- Cross-file data prefetch via statahead (LU-10280)



- 2.16 Store very small files (< 600 bytes) directly in ldiskfs inode (**`inline_data`**, LU-5603)
- Dynamic inode allocation for ldiskfs (LU-12099)
  - Simplify initial MDT setup, less need for up-front decision about bytes-per-inode ratio
  - Also improves flexibility for OSTs as they become larger

Miscellaneous Improvements (2.14+)

- **Upstream kernel client cleanups** still in active development/merge (ORNL, SuSE, HPE)
  - Lustre master <-> kernel client staying nearly in sync, hundreds! of patches landed
  - Need IPv6 support in LNet before submitting upstream, per upstream request
- **Update to use ZFS 0.8.4 by default**
  - Enables project quotas, on-disk encryption, Metadata Allocation Class, many other features/fixes
- **Disable server page cache for large IOs** to avoid kernel overhead (LU-12071, WC)
- **Stateless client-on-server mount** for data migration tasks (LU-12722, WC)
- **`statx()`** for lightweight attribute fetching, file creation time (LU-10934, WC)

2.14
- **`fallocate()`** for file preallocation (ldiskfs only) (LU-3606, WC, End User)

2.15
- **External HSM Coordinator** to simplify HSM optimization/improvement (LU-10968 , HPE)
- **`fallocate()`** for ZFS, PUNCH_HOLE, ZERO_RANGE (LU-11234, WC)
- **Pool Selection Policy** by filename extension, NID, UID/GID (LU-11234, WC)
- **Dynamic openlock** on client for repeated opens (LU-10948, WC)
- **`O_TMPFILE`** for creating temporary files outside namespace (LU-9512)

Improved Client Efficiency for AI/ML (2.14+)

- **Improve parallel client readahead** (LU-12043, LU-13386, LU-13412, WC)
  - Parallel readahead for single user thread (e.g. "dd") from 1.9GB/s -> 4.0GB/s
- **Improved strided readahead** (IO-500 `ior-hard-read`) (LU-12518, LU-12644, WC)
  - Detect and handle page-unaligned strided reads
  - Allow readahead to continue for slightly "imprecise" strides
- **Asynchronous Direct IO (AIO/DIO**, LU-4198, WC, Uber)
  - Improved 4KB random IO via **`libaio`** (write 100k->**266k IOPS**; read 80k->**610k IOPS**)
- **Bind service threads** to specific CPT cores (LU-13258, WC, ORNL)
  - Readahead, pinger, export cleanup limited to run on specified cores
  - 2.14 Avoid jitter in scheduling of other threads on node

- 2.15 **Optimized GPU data path** with RDMA
- **Local client mount on OST/MDT** for data mover/resync (LU-10191, WC)
  - Beginning of optimization for server-local IO path to avoid RPC + data copy

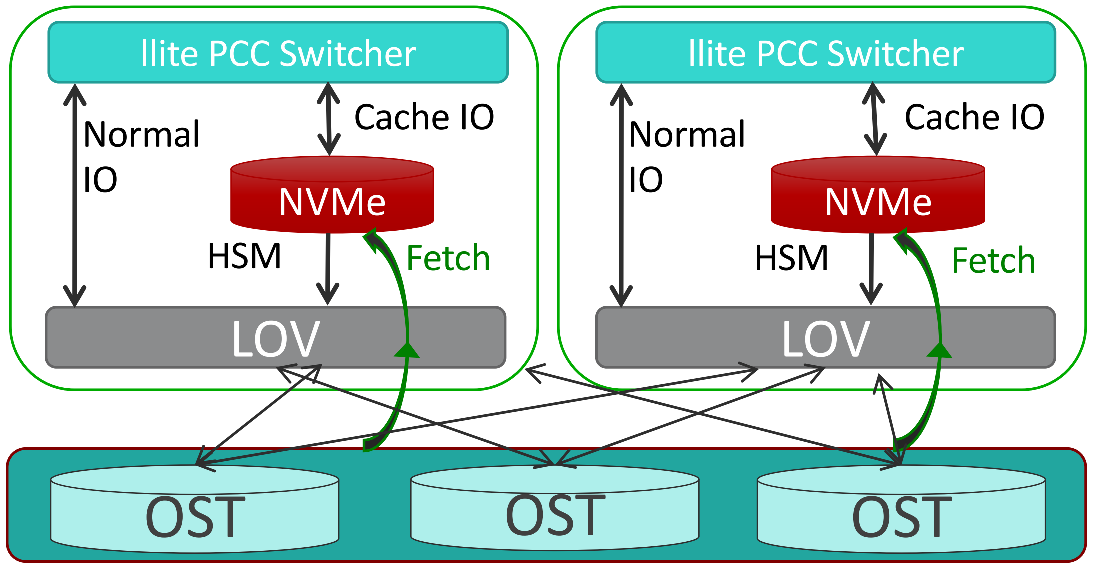
Persistent Client Cache (PCC) (LU-10092, WC) (2.13+)

- ▶ **Reduce latency**, improve small/unaligned IOPS, reduce network traffic
- ▶ PCC integrates Lustre with a persistent per-client **local cache storage**
  - A local filesystem (e.g. `ext4` or `ldiskfs`) is created on client device (SSD/NVMe/NVRAM)
  - New files created in PCC are *also* created on Lustre MDS

2.13

2.15

- ▶ Integrate PCC, HSM, FLR to manage layouts (LU-13637)
  - Simplify code, improve functionality
- ▶ Add **shared read** vs. **exclusive write** cache
- ▶ Integrate with DAX for NVRAM cache device
  - Use dedicated NVRAM filesystem (e.g. NOVA) for speed



Ongoing `ldiskfs` Improvements (2.14+)

2.14 ▶ **Fix huge OSTs mounting**, toward 1PiB `ldiskfs` OST (LU-12988, LU-13241, WC, HPE)

2.15 ▶ Existing features available that could be used by Lustre on `ldiskfs`

- **Efficient large block allocation** for large OSTs (**`bigalloc`**, LU-12967)
- **Files/dirs <600 bytes inside MDT inode**, 3.7KB in 4KB inode (**`inline_data`**, LU-5603)
- **Metadata integrity checksums** persistently stored on disk (**`metadata_csum`**, LU-13650)

▶ **Directory shrink** as files are deleted from old directories (LU-12051)

- Allow dynamic OST object directory allocation to improve performance (LU-12988)

▶ **Merge `ldiskfs dirdata`** feature to upstream `ext4/e2fsprogs`

2.16 ▶ **Integrated `ldiskfs` filesystem snapshots** for MDTs and OSTs (LU-13660, WC)

▶ **Dynamic ext4 inode allocation** for MDTs and OSTs (LU-12099)

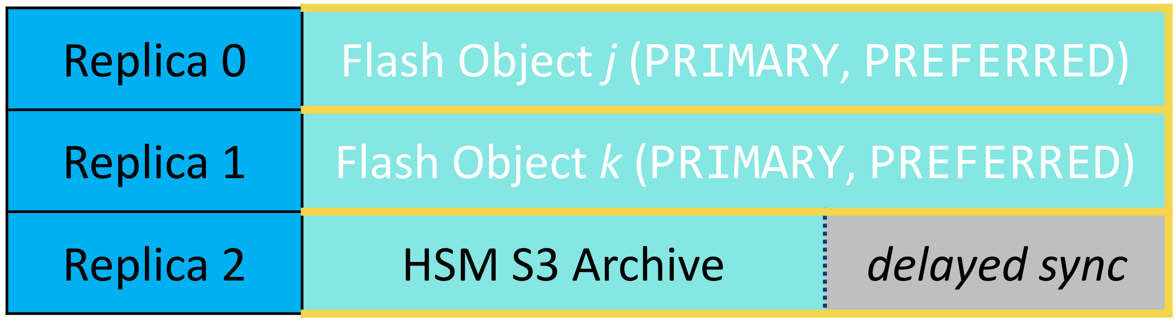
- Design discussions underway with upstream ext4 maintainers
- OSTs could allocate new inode tables when not enough free inodes for small files
- MDTs could release unused inode tables for DoM when many free inodes

File Level Redundancy (FLR) Enhancements (WC) (2.15+)

- **Erasure coding** adds redundancy without 2x/3x mirror overhead (LU-10911)
  - Delayed erasure coding to new/existing striped files *after* normal write
  - For striped files - add N parity per M data *stripes* (e.g. 16d+3p)
  - Leverage CPU-optimized EC code (Intel ISA-L) for best performance
  - 2.15 **Fixed RAID-4 parity** layout *per file,* **declustered Parity** across files to avoid OST bottlenecks

- 2.15 HSM in composite layout xattr like FLR mirror (LU-10606, WC)
  - Allow multiple archives per file (POSIX, S3, tape, ...)
  - Allow partial HSM file copy/restore to/from archive

- 2.16 **Immediate file write** mirroring (LU-13643)
  - Client writes both copies of mirror directly
    - Reduces available bandwidth on client
  - Mirrors kept in sync unless client write fails
  - Delayed resync if mirror goes stale, like before



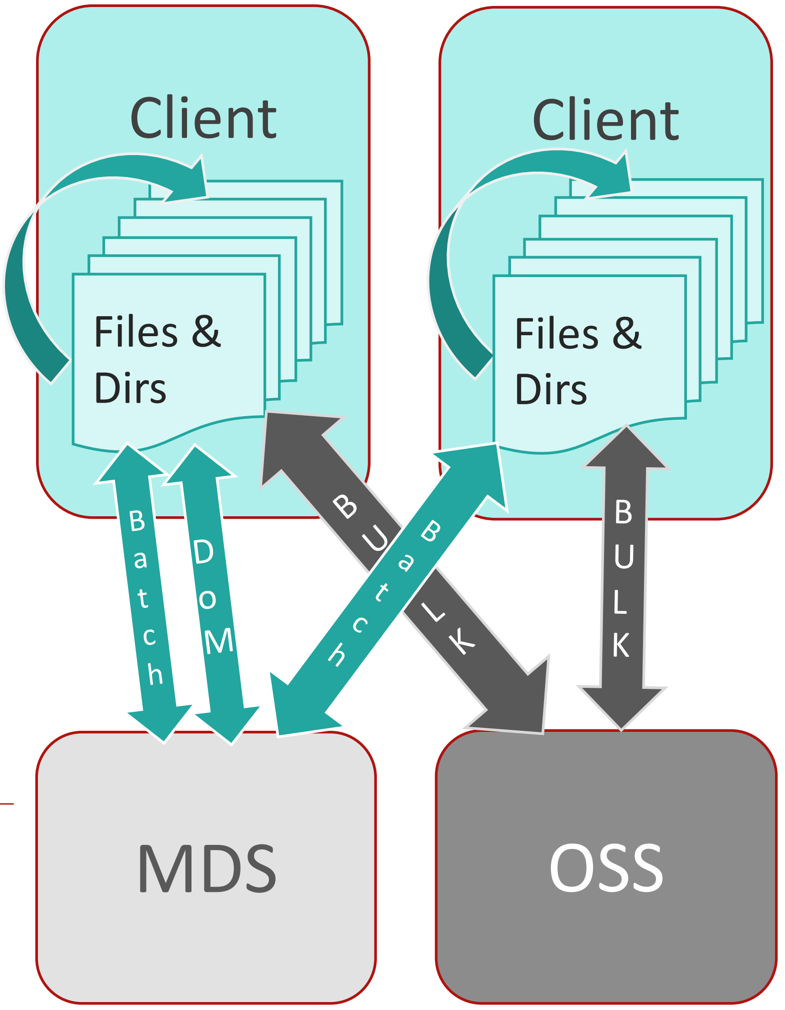
Replica 0
Flash Object *j* (PRIMARY, PREFERRED)
Replica 1
Flash Object *k* (PRIMARY, PREFERRED)
Replica 2
HSM S3 Archive
delayed sync

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

- 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
- **Files globally visible on MDS flush**, *normal use afterward*
  - 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
- WBC prototype developed to test concept
  - 10-20x *single-client* speedup in early testing (`untar`, `make`, …)
- Productization of WBC code well underway

2.16
  - Complexity handling partially-cached directories, space usage

2.17
- **Aggregate operations to server** to improve performance
  - Batch operations in one RCP to reduce network traffic/handling
  - Batch operations to disk filesystem to reduce disk IOPS?



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Thank You!
Questions?