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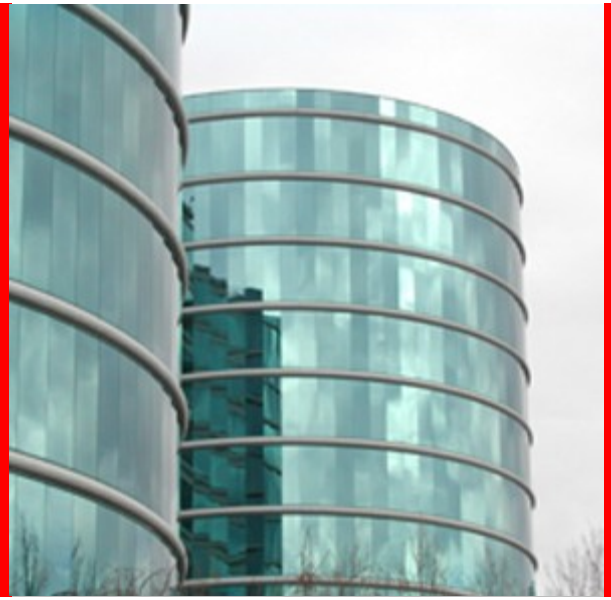

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Deep Dive into Lustre Recovery Mechanisms

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Lustre engineering

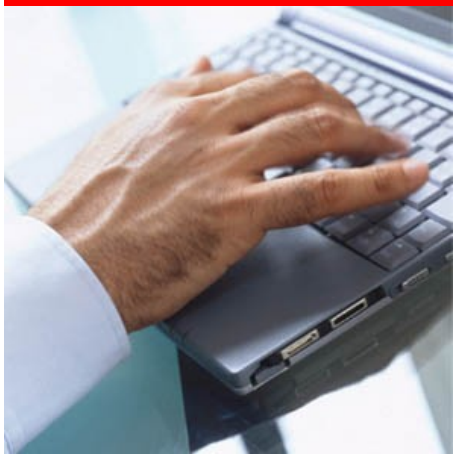
Possible failures

- Network failures
  - Packet loss
  - Can be either a lustre request or reply
- A lustre client or server is down
  - HW problems, SW crash, reboot, power outage, ...
- Distributed state inconsistencies
  - State of multiple nodes out of sync

Aspects of Recovery

- Connection recovery
  - Pings, evictions, lost requests or replies
- Persistent state recovery
  - Server failure, journal replay & lustre replay
- Replicated state recovery
  - State of multiple nodes out of sync

Agenda



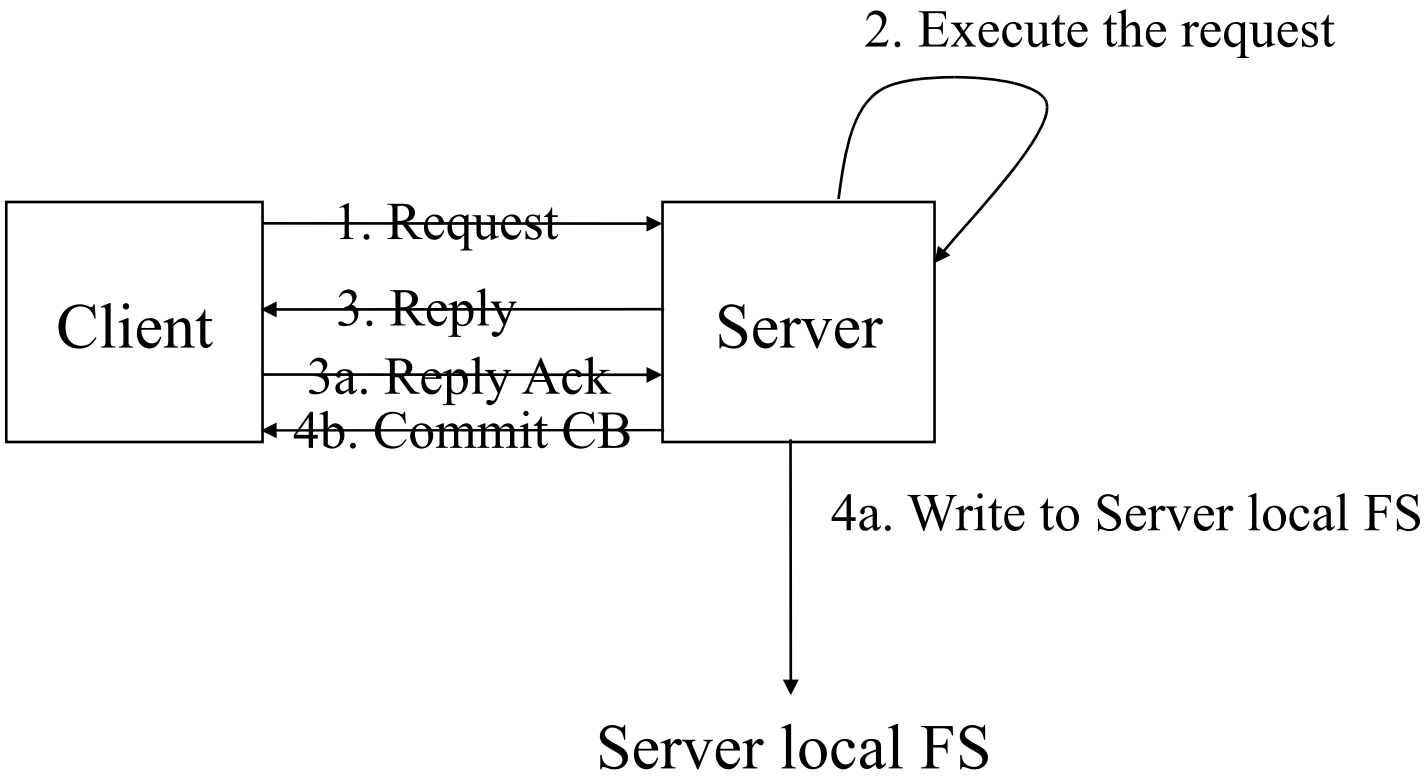
- Request Execution Flow
- Request Resending
- Request Replaying
- Version Based Recovery
- File I/O Recovery
- Distributed state recovery

Request Execution Flow

Server Execution

- Server executes transactions
  - In parallel by multiple threads
- Two stage commit:
  - Commit in memory – after this, results are visible
  - Commit on disk – in same order but later
  - This batches the transactions

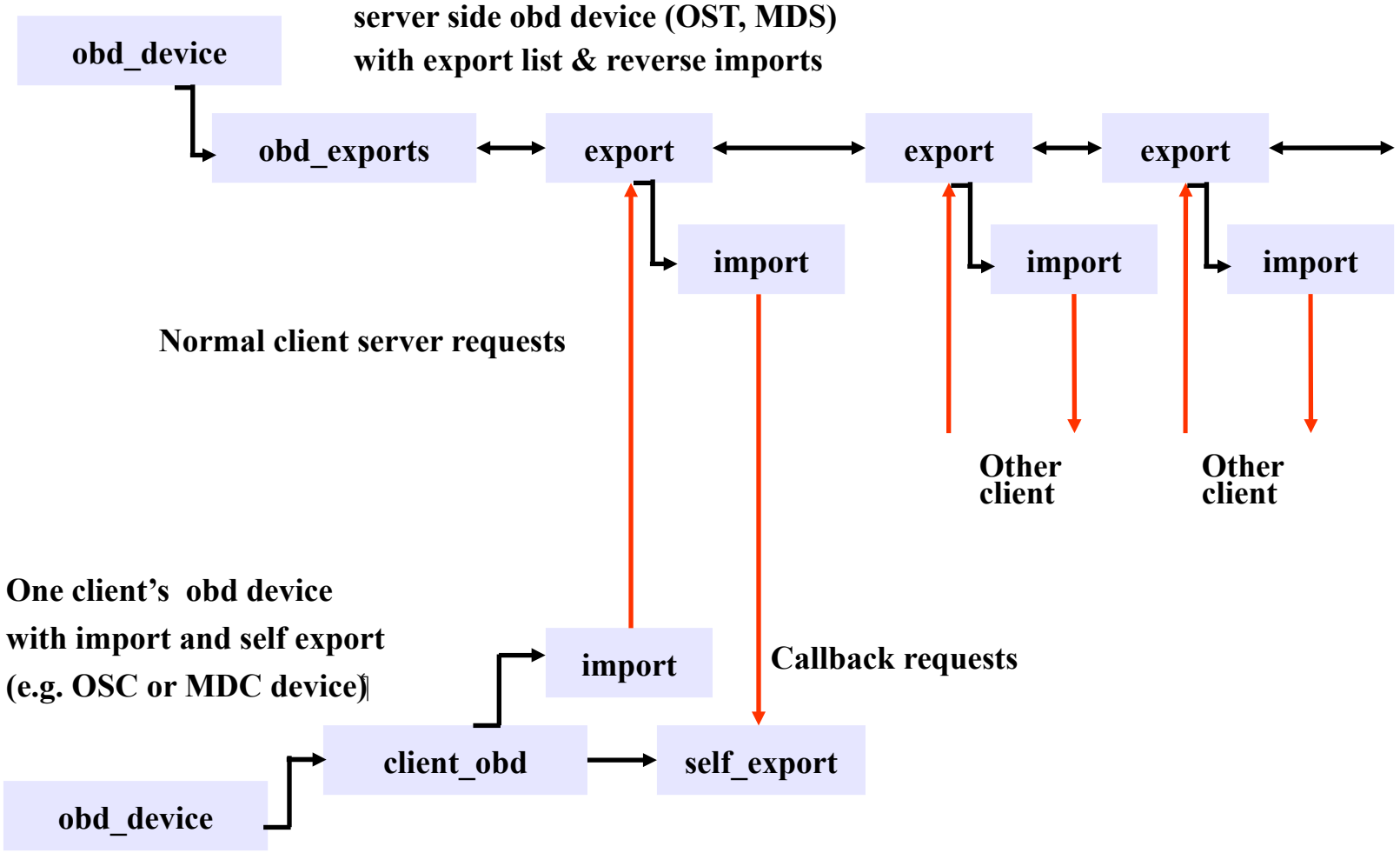
Request Lifecycle



Client/server interaction

- Send request
- Request is allocated a transaction number (transno)
- Send reply which includes transno
- Clients acknowledge reply
  - Purpose: MDS knows clients has transno
- Clients keep request & reply
  - Until MDS confirms a disk commit
- Each server has disk data per client
  - Last executed request, last reply information

Import/Export for RPC's

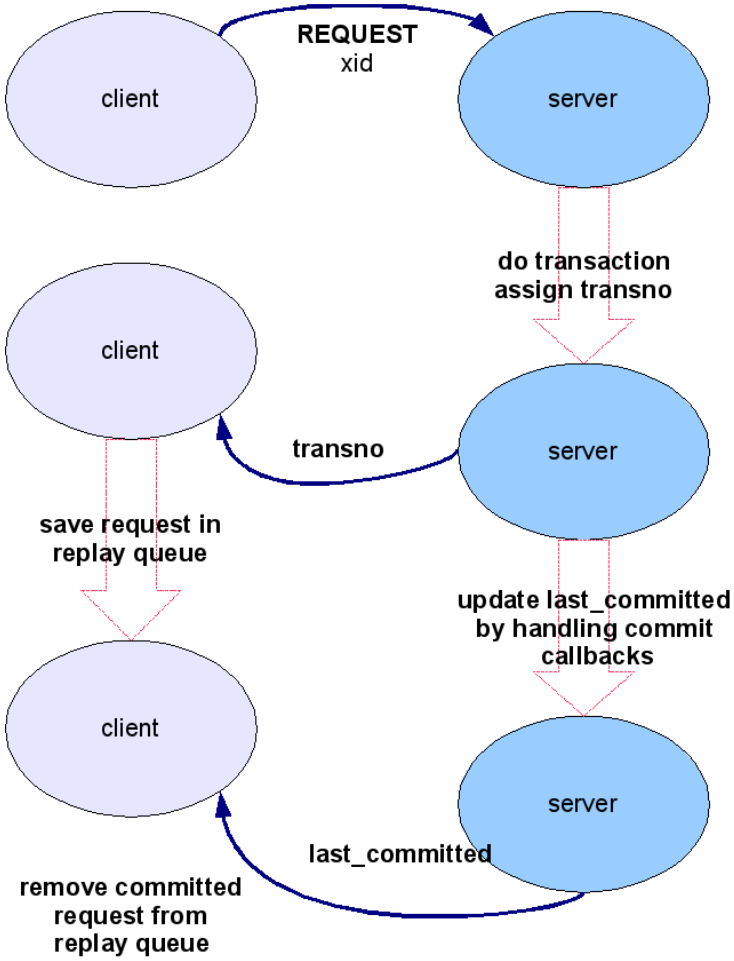


Xid & transno

- Xid
  - Each ptlrpc request is tagged with a specified xid
  - Xid is unique for an import/export pair
- Transaction number (transno)
  - Server side transaction number
  - unique per target
  - Servers record on disk last committed transno for each client

Normal Operation

- Client sends request
  - Unique xid
- Server replies
  - Transno allocated
  - last_commited transno
- Client gets reply
  - Put request in replay list
  - Remove from replay list all reqs with transno <= last committed



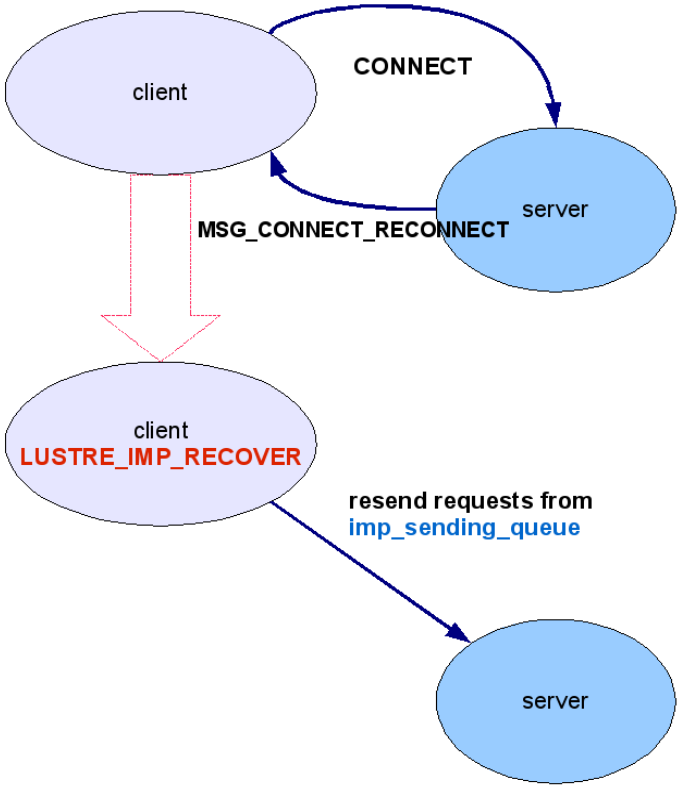
Request Resending

Resending

- Client has not received any reply
- What happened?
  - request OR reply was lost
- Request may have executed or not
- Server determines whether it has already processed this request
  - Original request was lost and never reached the server
    - Server executes the request
  - Request was processed already but reply was lost
    - Server reconstructs the reply
    - Only done on MDT
      - Request processing idempotent on OST

Resending (cont'd)

- Client sends connect and gets reply
- LUSTRE_IMP_RECOVER
- Resend requests from sending list



How does MDT know if a request has been executed already?

- MDT stores last executed xid
  - Works because each client has <= one RPC in flight
  - MDT processes request in xid order
  - Stored on disk in the last_rcvd file
- if req xid == last processed xid
  - Request has already been processed
  - Reconstruct the reply

Reply reconstruction

- Only done on MDT
  - No reply reconstruction on OST
  - Request processing is idempotent on OST
- Use reply data stored in last_rcvd file
  - store Information about each client
  - lsd_client_data structure
    - 1 separate slot for MDS_CLOSE request
    - 1 slot for all the other request types
    - Store results of RPC processing

Request Replaying

Persistent State Recovery

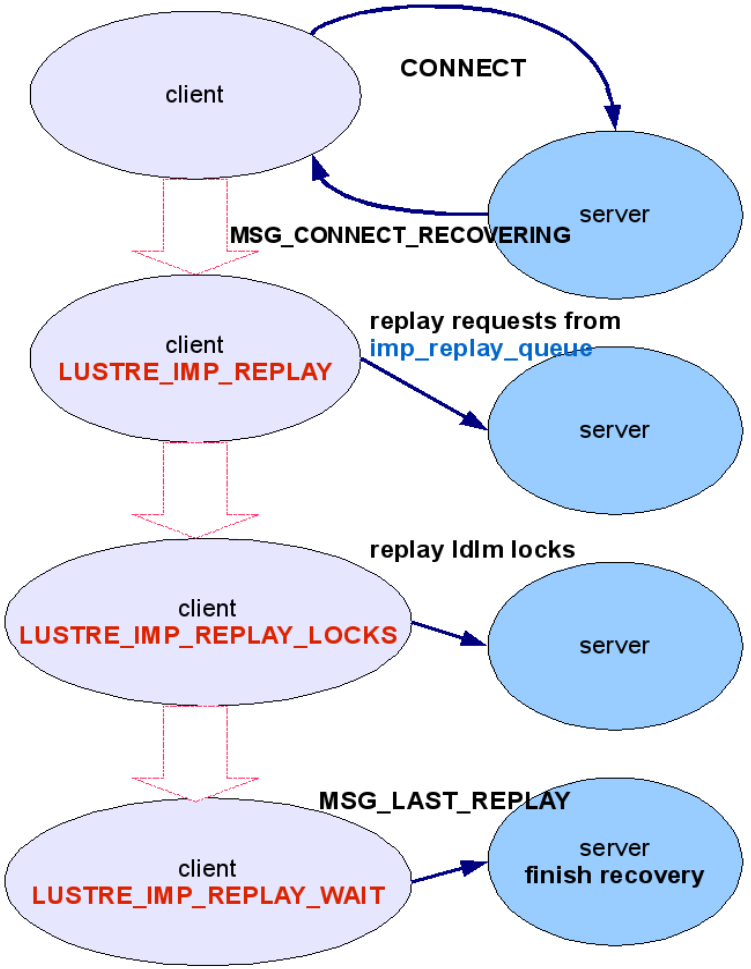
- Server restarts after uncleaned shutdown
  - SW crash, HW failure, power outage ....
- Disk filesystems need recovery
  - ldiskfs journalling
- Servers roll back when they crash
  - server can thus lose some transactions
  - Rely on client to rebuild server state before crash
- Clients keep request & reply
  - Until server confirms a disk commit
  - Purpose: client can compensate for lost transactions

What happens during client recovery?

- Clients reconnect to the server
- Server reports the last transno it committed
- Request Replay – resending requests that have replies
  - Clients resend requests including transno's
  - Server merges & sorts requests to get correct sequence
  - Server re-executes requests in transno order
- Lock Replay
- After replay, only a few requests remain
  - Requests for which client has not seen a reply
  - Resend phase

Replay

- Client sends connect and gets reply
- MSG_CONNECT_RECOVERING is set
  - Get last committed from reply which is starting point for replay
  - LUSTRE_IMP_REPLAY
    - Clients replay requests
  - LUSTRE_IMP_REPLAY_LOCKS
    - Clients replay locks
  - LUSTRE_IMP_REPLAY_WAIT
    - Clients send MSG_LAST_REPLAY
  - Continue with resend



Server side

- List of clients from last_rcvd file
  - Calculate last_committed transno
  - Set next_replay_transno to last_commit + 1
- Server orders replays by transno
  - Check if replay transno == next_replay_transno and execute it, otherwise put replay request to waiting queue

Gap in transaction sequence

- Clients offer transaction sequence to servers during replay
- There can be gaps in the sequence
  - Some clients are missing and failed to offer transaction
- Correct replay requires all clients to join
  - During restart, server waits for clients to join
  - No new clients are allowed to connect during recovery window

Recovery Window

- Clients have to reconnect within dedicated recovery window
  - No new clients allowed to connect
- Server starts recovery window when first client reconnects
  - Adjusted as the clients reconnect
    - Clients report request service time
- After recovery times out
  - if not all clients have reconnected
    - clients are evicted (1.6)
    - clients with version mismatch are evicted (1.8)

Example: Open-unlinked files

- On a local filesystem: both application & fs crash
  - Inode put in the orphan list and is destroyed during filesystem recovery
- On a cluster filesystem, if server crashes
  - Applications on client nodes are still alive
  - Client nodes want to reopen open-unlinked files
  - Open unlinked files must be retained in a separate directory (PENDING dir on MDT)

Version Based Recovery

Motivation

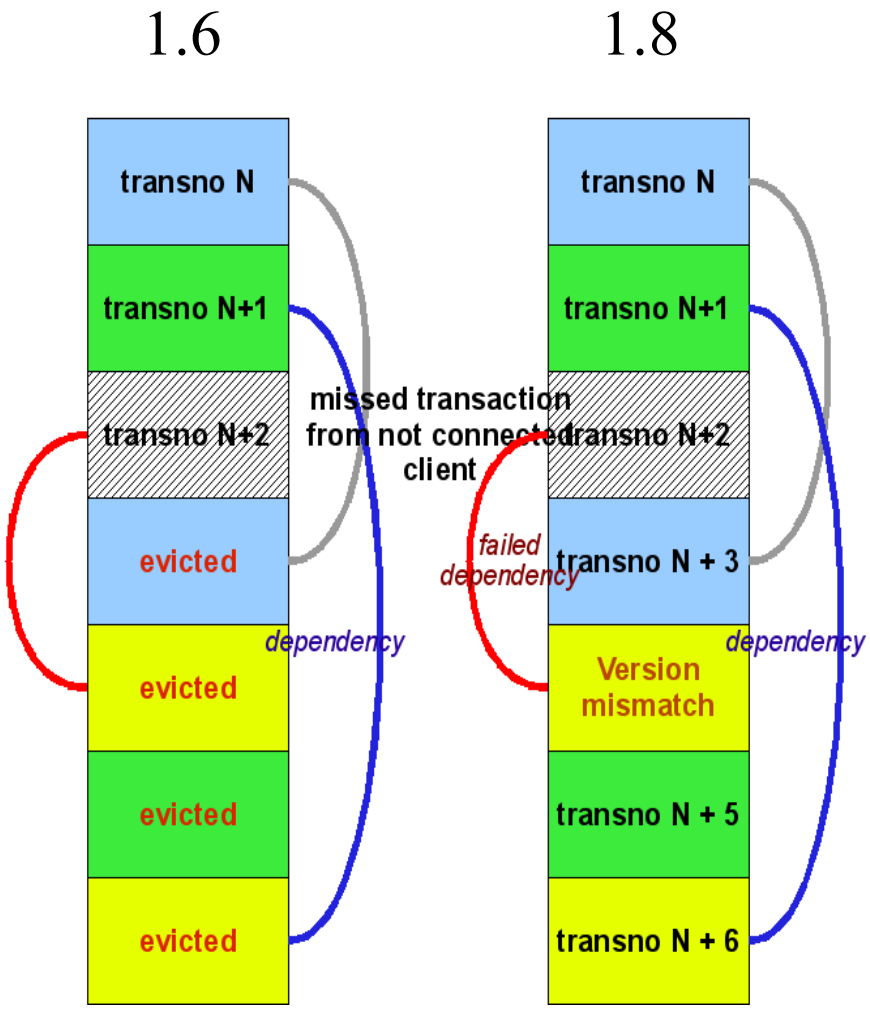
- Recovery requirements are too strict
  - All clients have to reconnect within specified window
  - No gaps in transaction sequence are allowed
    - Not aware of transaction dependencies
- Objectives
  - Relax requirements
    - Allowing gaps
    - Allowing clients who missed the recovery window to rejoin
      - support for disconnected operations in the future

Version Based Recovery Primer

- Use inode versioning
  - stored on disk
  - set to last transno which modified the inode
- Server replies include
  - operation transno (as before) which is the new inode version
  - BUT also the pre-op version of the inode
- Clients provide this pre-op version during replay
- Transaction is replayed only if the inode version matches provided pre-op version

Gap in transaction sequence

- Client can recover even if gap in transaction sequence
  - Only clients with version mismatch are evicted
- Client can recover later after recovery window is finished
  - Client reintegrates fully if versions match
  - Make disconnected operation possible

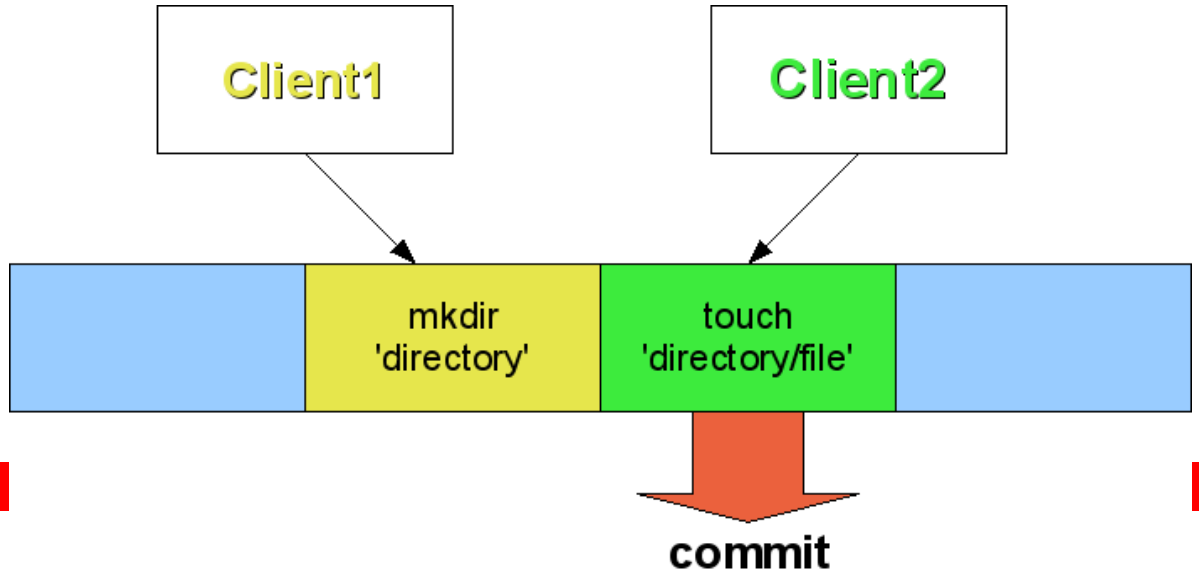


Delayed Recovery

- Clients who missed the recovery window allowed to replay
  - Provided that versions have not changed
- Delayed recovery is not working yet
  - Inode versioning key feature to support this
  - But still some problems to address
    - e.g. Orphan recovery

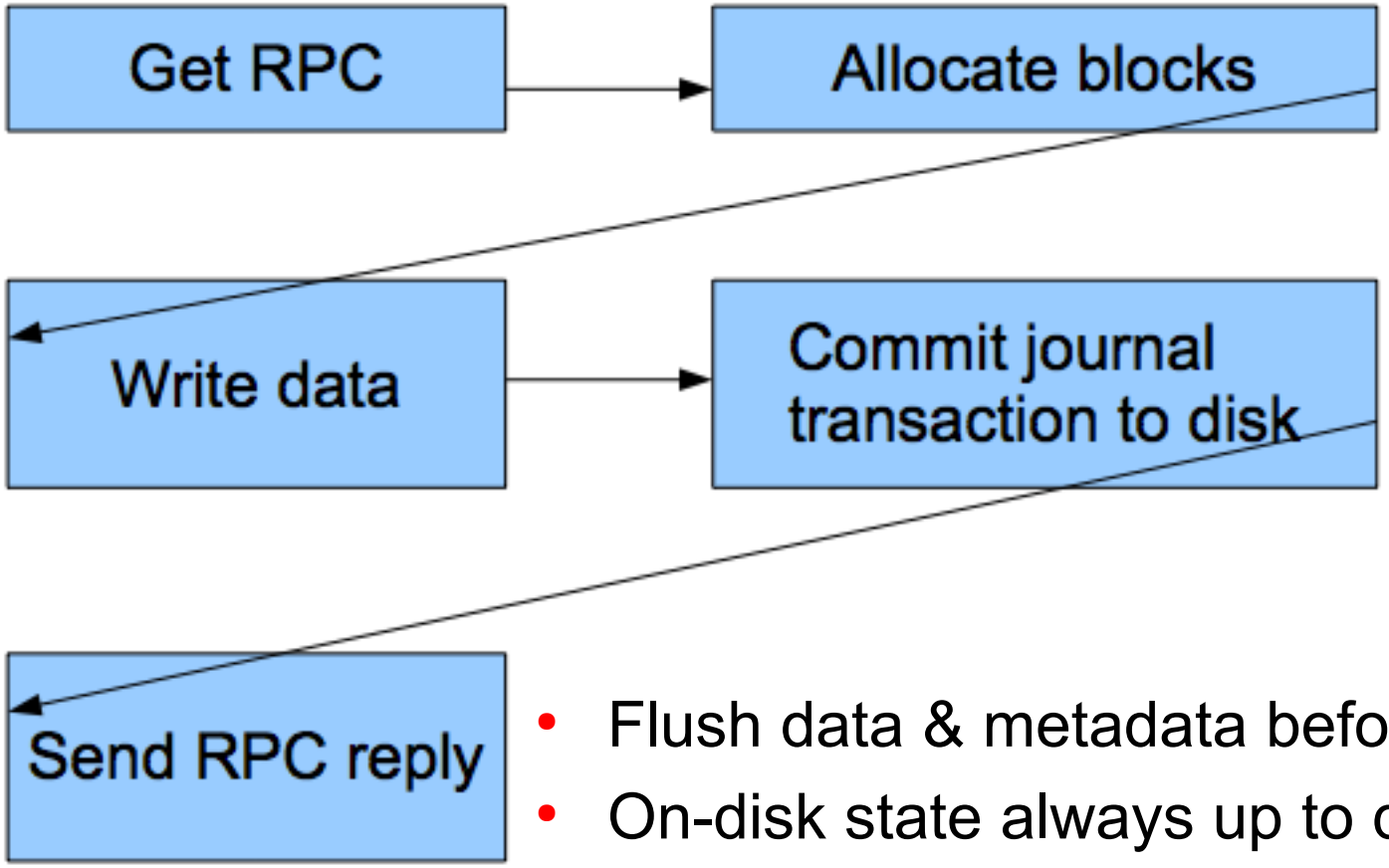
Commit On Share (COS)

- Version based recovery allows to recover as much as possible with reconnected clients
  - one of the original goals
- **but** can lead to incomplete recovery
- With Commit On Share we regain correctness
  - Eliminates dependencies between clients by committing immediately
  - Commit removes depended replays from clients
  - COS only available in 2.0, not in 1.8



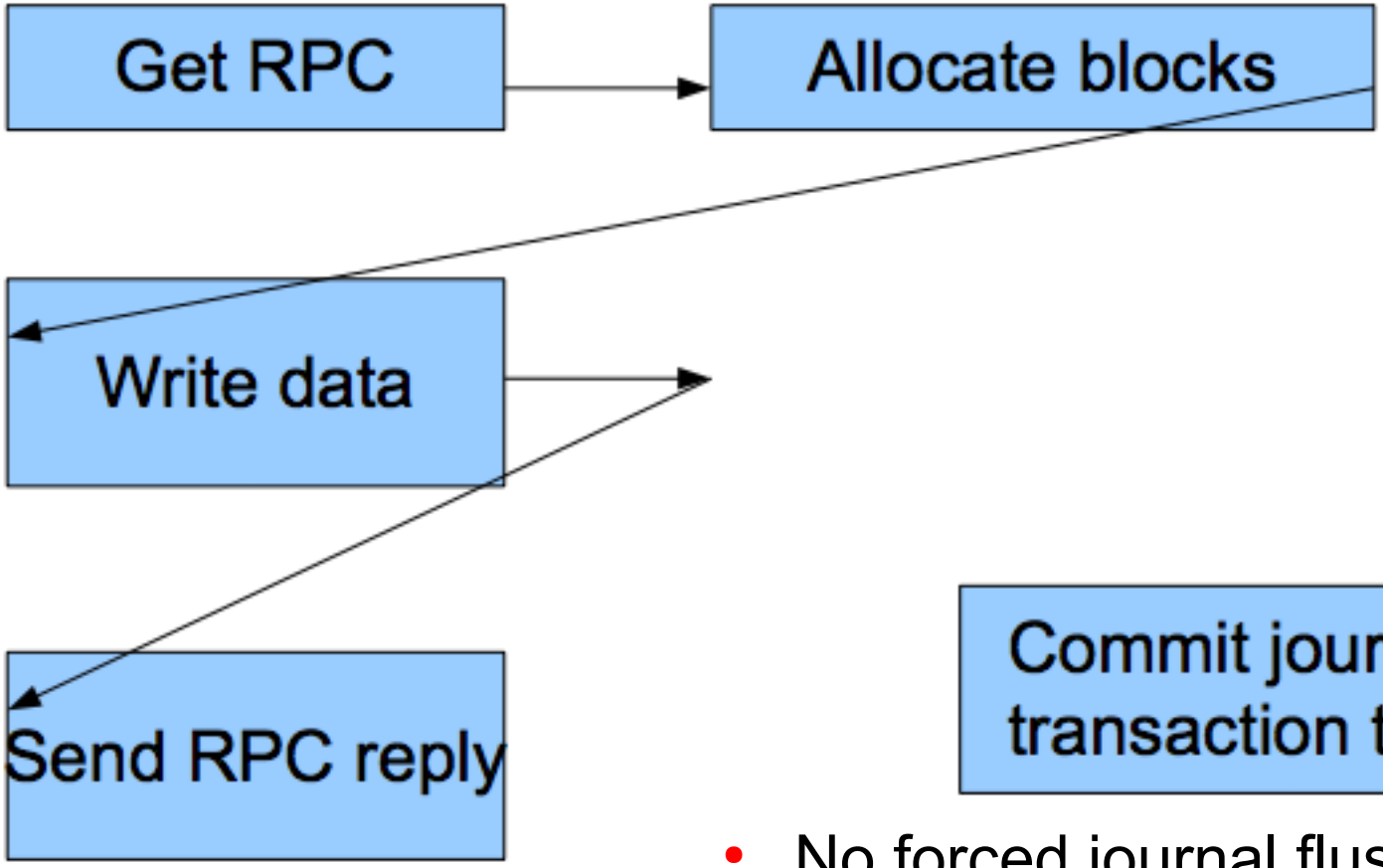
File I/O Recovery

OST Bulk Write Handling



- Flush data & metadata before replying
- On-disk state always up to date
- No need to replay write requests

OST Bulk Write Handling with async journal commit feature enabled



- No forced journal flush any more
- Less disk seeks

Recovery aspects

- Data still written synchronously but metadata updates are now asynchronous
- **Consequence**: bulk writes have to be replayed by clients now
- Clients have to keep copy of written data in page cache
  - Until OSS confirms metadata updates have hit the journal on disk
  - Only possible with cached I/O, not with direct I/O

Flush journal on lock cancel

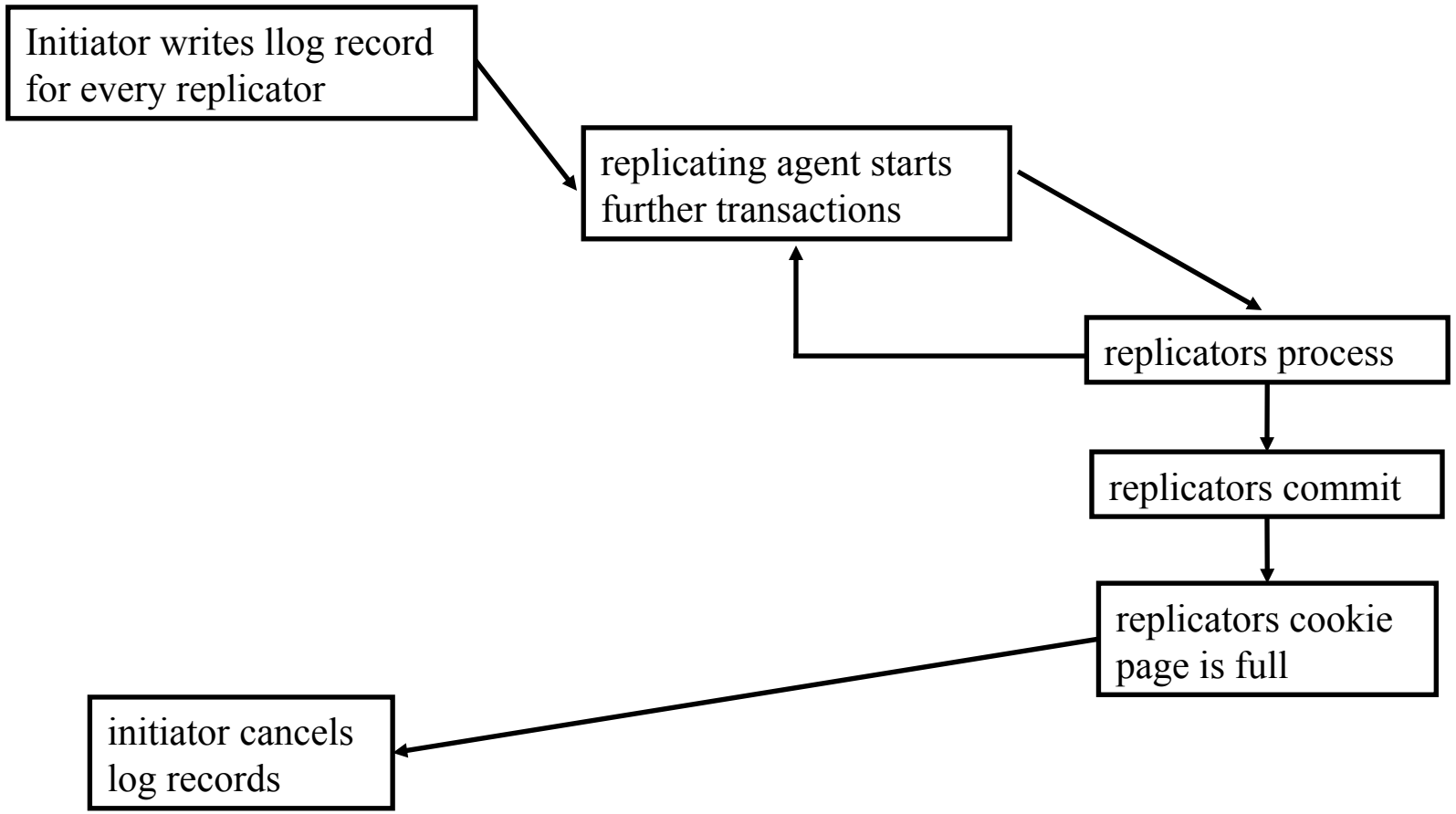
- Problem:
  - Client holds extent lock and receives blocking AST
  - Client flushes dirty data protected by extent lock
  - Client sends lock cancel to OSS
    - Client no more able to replay bulk writes
  - OSS crashes
    - Cannot recover state before crash
- Solution:
  - Flush journal on lock cancel
  - Problem with excessive stack consumption
    - fixed in 1.8.3
  - Procfs tunable sync_on_lock_cancel

Distributed state recovery

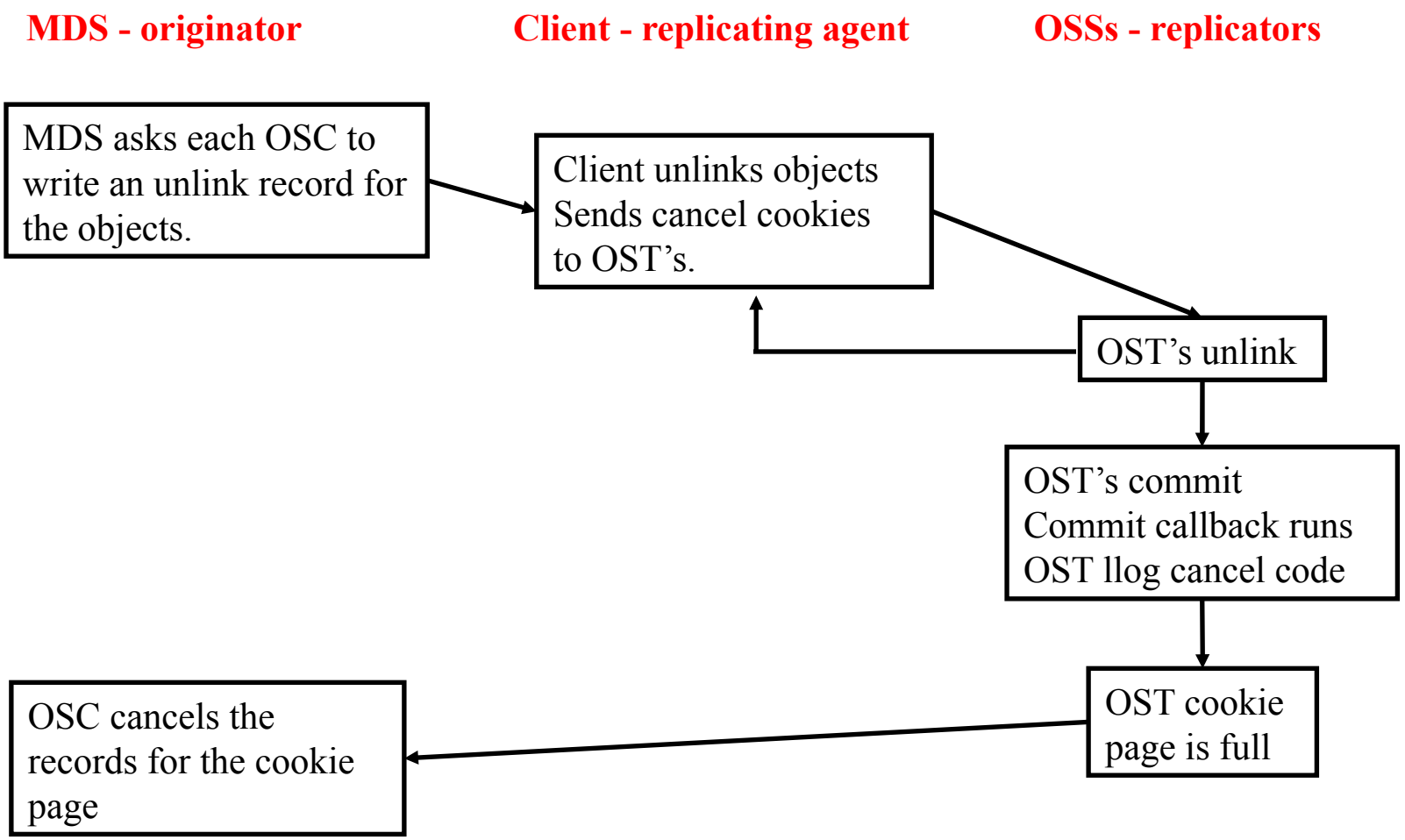
LLOG

- For distributed transaction commits
  - e.g. unlinking a file and destroying its objects
- Terminology
  - Initiator – where the transaction is started
  - Replicators – other nodes participating
- Normal operation
  - Write a replay record for each replicator on the initiator
  - Cancel that record after the replicators commit, in bulk
- Recovery
  - Process the log entries on the initiator

Replicated transaction execution



File & Object Removal - example



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