Lustre: some protocol basics & debugging

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Topics

- Building Lustre
- Some protocol basics
  - Request lifecycle
  - llog
  - I/O in the OST
  - ldlm
  - quota
- Debugging

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Pre-built rpms

- We provide pre-built rpms
  - For 1.6, RHEL4/5, SLES9/10
  - For 1.8 & 2.0, RHEL5/SLES10 and RHEL6/SLES11 (when available)
- Include OFED & TCP support
- Rebuilding rpms is needed if:
  - Need support for another interconnect (Myrinet, ...)
  - Need to apply kernel or lustre patches

Building lustre (server side)

- Kernel patches needed
  - Re-add journal callback support in jbd
  - Jbd fixes & statistics
  - scsi disk statistics
    - could be removed if blktrace enabled
  - Export some symbols used by lustre
  - API for setting block device read-only
  - ...
- First step is to apply those patches & build the patched kernel
  - Use quilt to manage patches
  - Patch series available in lustre/kernel_patches/series
  - Quilt setup /path/to/series, quilt push -a
  - kernel config files in lustre/kernel_patches/kernel_configs

Building lustre (server side)

- Once the kernel is built, we are ready to build the lustre rpms:
  - Get the lustre source
  - ./configure --with-linux=/path/to/kernel ..
  - make rpms
- This produces serveral rpms:
  - lustre-modules: the lustre kernel module
  - lustre-ldiskfs: ext3+patches
  - lustre-$version: utils (mkfs.lustre, mount.lustre, ...)
- Install the patched kernel + lustre/ldiskfs rpms on the servers (OSSs/MDSs)

Building lustre (client side)

- No kernel patches needed
  - except for RHEL4/SLES9
  - You can run the patched kernel on the clients if you wish
- Get the lustre source

  -
    ```
    ./configure --with-linux=/path/to/kernel --disable-server ..
    ```

  -
    ```
    make rpms
    ```
- Build the lustre rpms as previously:

  -
    ```
    ./configure --with-linux=/path/to/kernel
                        --disable-server ..
    ```
  - Generate rpms with client only support
- Install the lustre rpms on the client nodes

Building lustre with DMU support

- No change
- ldiskfs rpm replaces by kDMU rpm
- kDMU integrated in lustre source
  - built as part of lustre, like ldiskfs today
  - only needed on OSS/MDS (again as ldiskfs)

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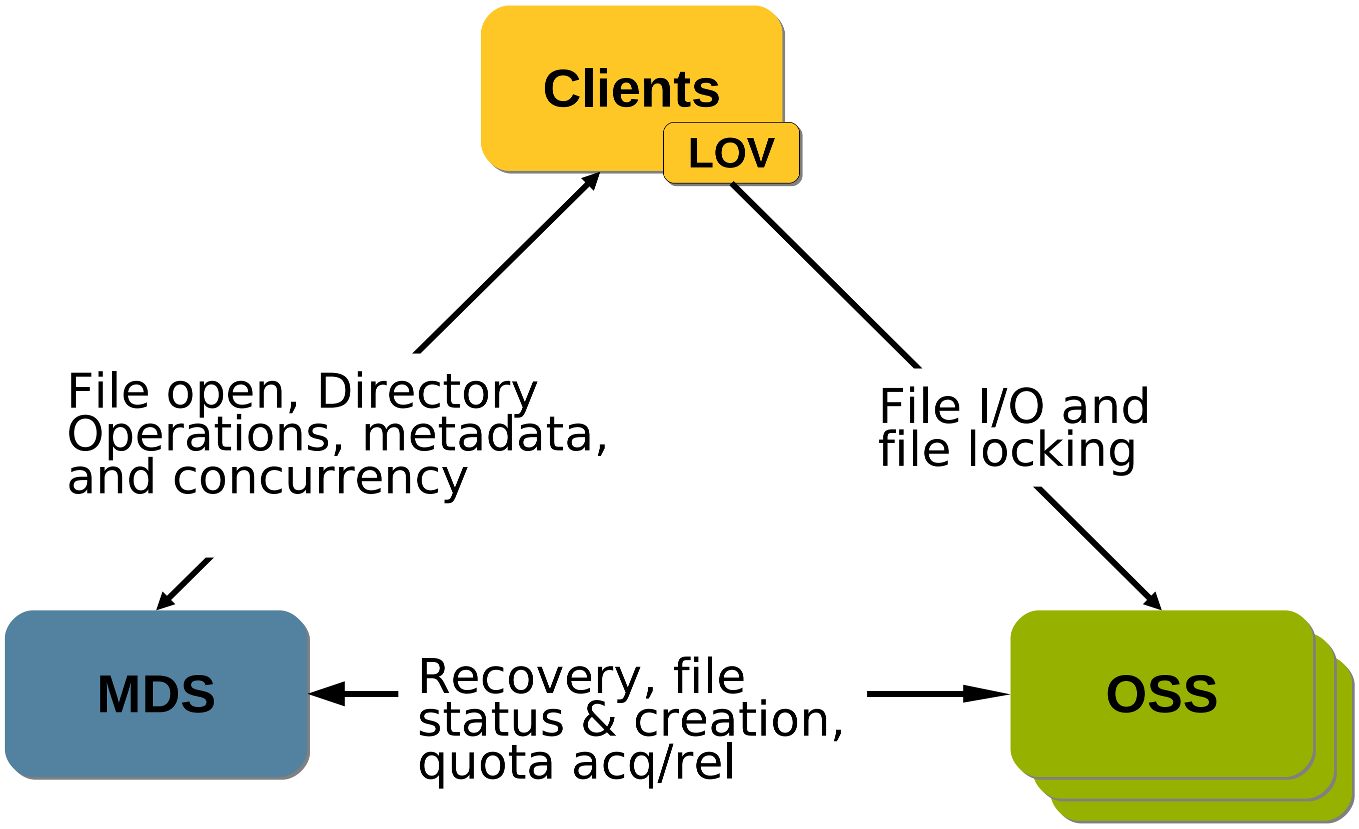
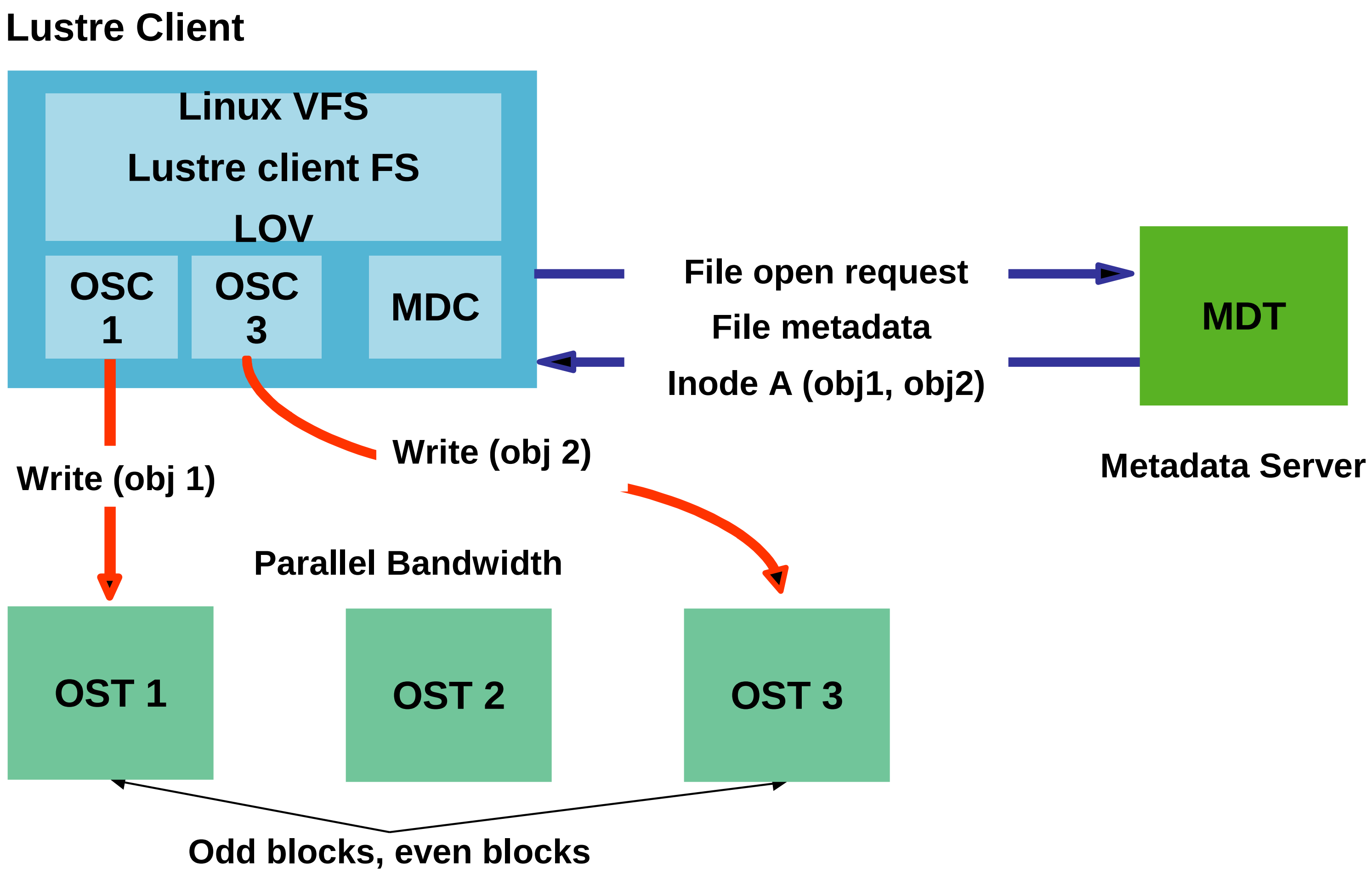
Lustre Components


Clients
LOV
File open, Directory Operations, metadata, and concurrency
File I/O and file locking
MDS
Recovery, file status & creation, quota acq/rel
OSS

File open & write



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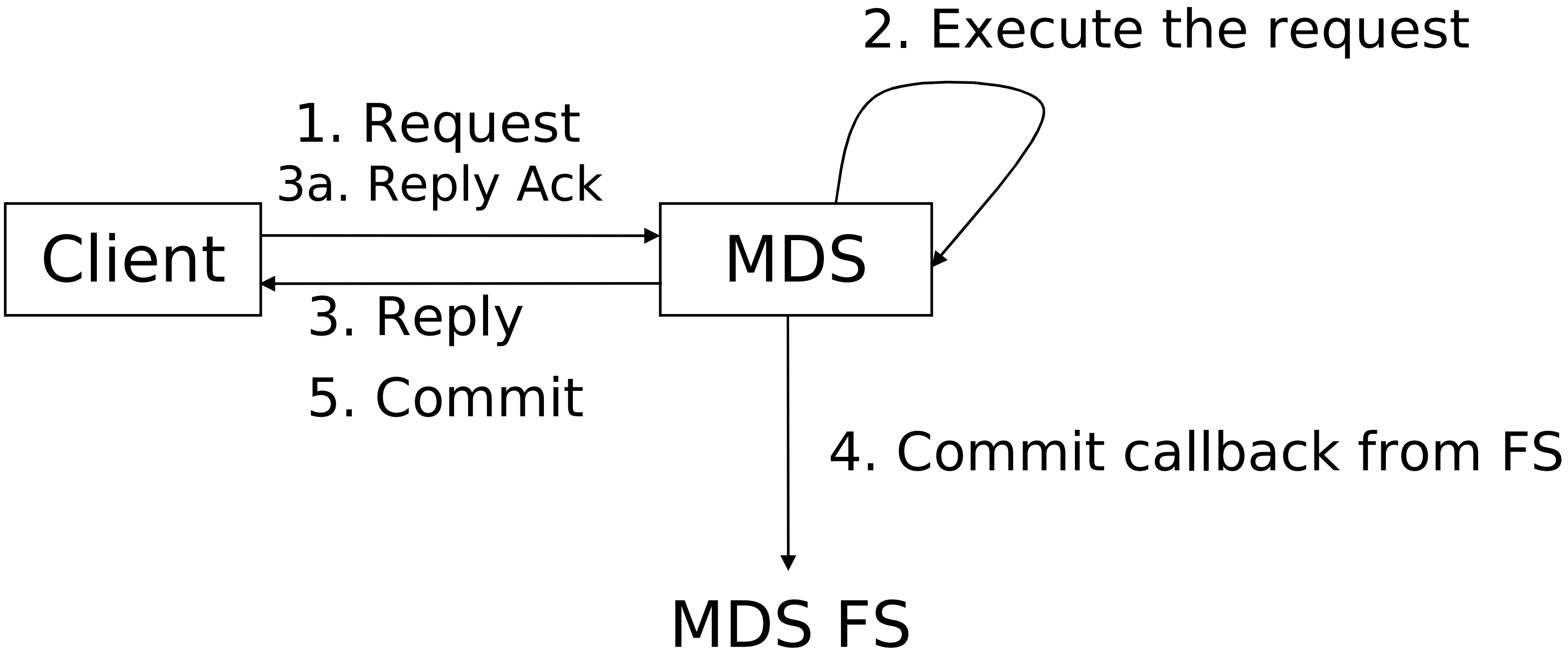
MDS execution

- MDS 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
- Key recovery issue
  - Lustre MDS can lose some transactions
  - Clients need to replay in precisely same order

Request lifecycle



Client MDS interaction

- Send request
- Request is allocated a 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
  - That's where we need commit callback
  - Purpose: client can compensate for lost trans
- MDS has disk data per client
  - Last executed request, last reply information

Commit callbacks

- Run a callback, when disk data commits
- Ability to register & run callbacks has been removed from JBD in 2.6.10
  - Added back by the jbd-jcberr* patches
- Similar mechanism needed for DMU support

Bulk write replay

- Before 1.6.7
  - > No replay for bulk write
  - > Once the write rpc is acknowledged, data are safely written to disk
- No longer true in versions >= 1.6.8
  - > Including 1.8.0
  - > Oleg's async journal patch
  - > Same scheme as for MDS requests now

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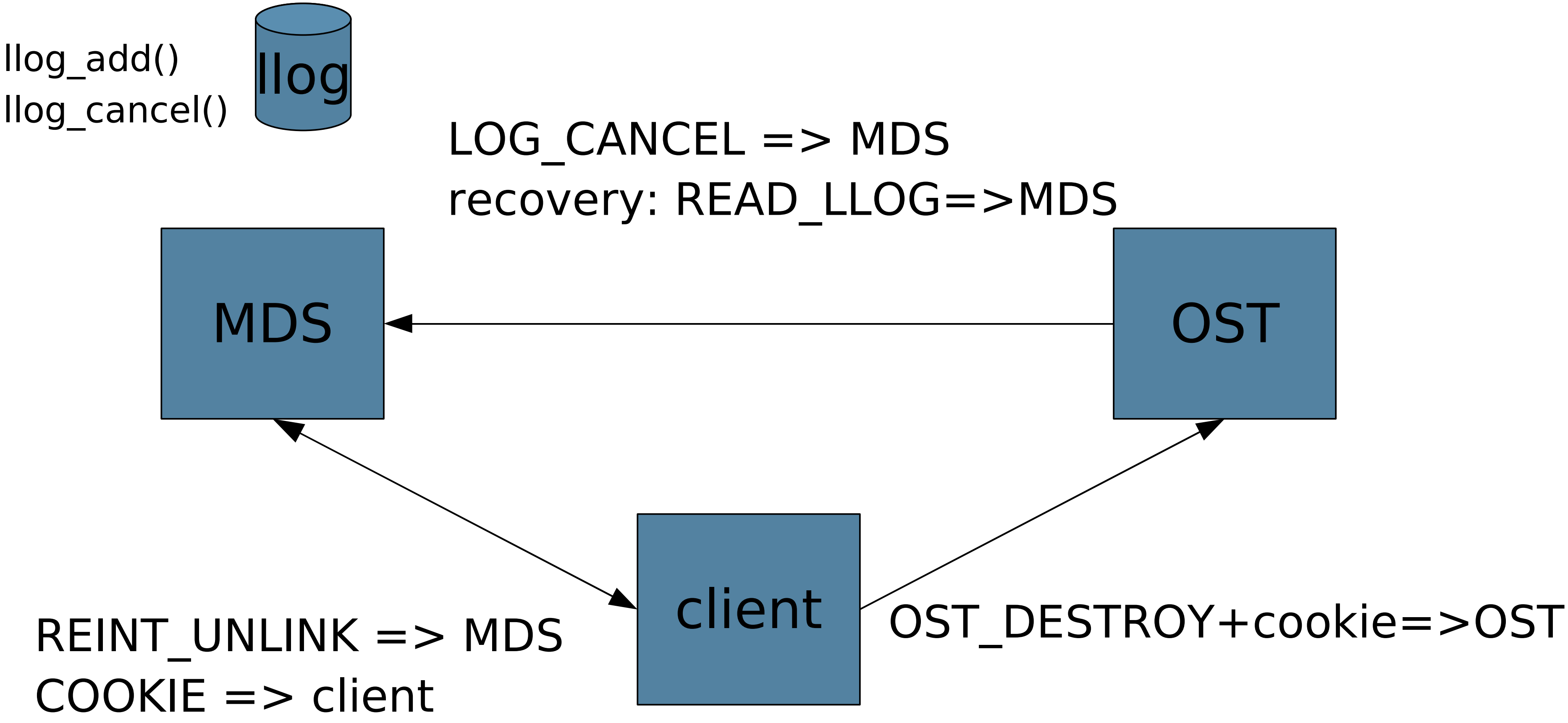
Problem Statement

- Lustre is distributed filesystem
- some POSIX calls change on-disk state on few nodes
- Examples:
  - unlink removes MDS and OST inodes
  - setuid changes owner on MDS and OST
- need to maintain consistent state after failure

Maintaining Consistency: llog

- For distributed transaction commits
- 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
    - Commit callback needed here
- Recovery
  - Process the log entries on the initiator

Use case: unlink



Use case: unlink (cont'd)

- OST commits objects destroy
  - Then it’s time to cancel the MDS llog records
  - Add the cookies to the llog cancel page
  - … truncate the object
  - Start a transaction (fsfilt_start_{log})
  - Remove the object (filter_destroy_internal)
  - Add the commit callback (fsfilt_add_journal_cb)
    - CB is filter_cancel_cookies_cb
  - Finish the transaction (fsfilt_finish_transno)

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I/O in the OST

- The page cache made things too slow in Linux 2.4
- Reserved memory registered for DMA can help
- In 1.6, OSS does non-cached direct IO
  - Nothing ends up in the OSS page cache
- OSS page cache has been resurrected in 1.8
  - For now, only for read
  - Huge performance increase when reading small files back

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Lustre Distributed Lock Manager

- A lock protects a resource
  - Typically, a lock protects something a client caches
- A client enqueues a lock to get it
- An enqueued lock has a client and server copy
- Servers send blocking callbacks to revoke locks
- Servers send completion callbacks to grant locks
- Processes reference granted client locks for use
- Processes de-reference client locks after use
- Clients cancel locks upon callbacks or LRU overflow

- Callbacks were called AST’s in VAX-VMS lingo
- Cancel was de-queue in VAX-VMS lingo

LDLM history

- Basic ideas are similar to VAX DLM
  - You get locks on resources in a namespace
  - All lock calls are asynchronous and get completions
  - There are 6 lock modes with compatibility
  - There are server to client callbacks for notification
  - There are master locks on the “server” and client locks
- Differences
  - We don’t migrate server lock data, except during failover
    - LDLM is more like a collection of lock servers
  - There are extensions to:
    - Handle intents – interpret what the caller wants
    - Handle extents – protect ranges of files
    - Handle lock bits – lock parts of metadata attributes

Client Lock Usage

- DLM locks are acquired over the network
  - The locks are owned by clients of the DLM
    - MGC, OSC & MDC are examples
- Use of locks
  - Locks are given to a particular lock client
  - Processes reference the locks
  - Locks can be canceled only when idle
- Differences
  - Locks are not owned by processes (VAX)
- Servers can take locks also

Lustre Lock Namespaces

- OST: namespace to protect object extents.
  - Resources are object ids
  - Extents in the object are “policy data”
- MDS: namespace to protect inodes and names
  - FIDs are the resources
  - Lock bits are policy data
  - Intents bundle a VFS operation with its lock requests
- MGS: namespace for configuration locks
  - Presently only one resource
  - Protects the entire configuration data

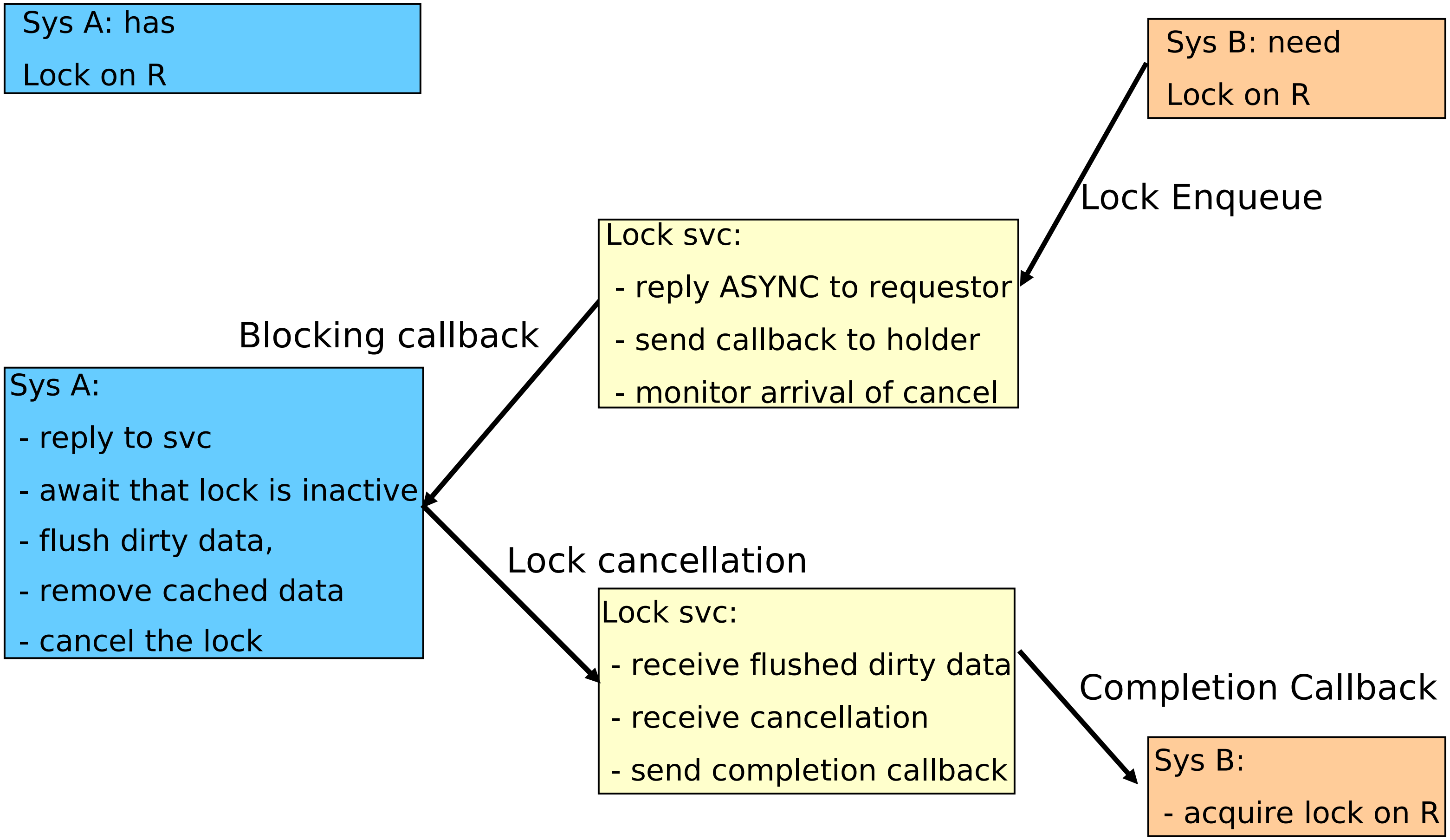
File I/O locks and lock callbacks

- Clients must acquire a read-lock to cache data for read
    - Locks cover an optimistically large file extent
    - Locks are cached on clients
- Before writing, a client obtains a write lock
- Upon concurrent access by another client
    - Client locks see a callback when others want a conflicting lock
    - After the revocation callback arrives, dirty data is flushed
    - Cached data is removed
    - Then the lock is dropped

Client Lock Callback Handling

- Callback function is bound to lock
  - upon client side lock enqueue
  - RPC’s made to the client ldlm service by servers
  - Handed by client lock callback thread : ldlm_cbd
- Completion callback
  - When lock is granted
- Blocking callback
  - Called when servers try to cancel locks in clients
  - Causes cache flush

Typical Simple Lock Sequence



Sys A: has
Lock on R

Sys B: need
Lock on R

Lock Enqueue

Lock svc:
- reply ASYNC to requestor
- send callback to holder
- monitor arrival of cancel

Blocking callback

Sys A:
- reply to svc
- await that lock is inactive
- flush dirty data,
- remove cached data
- cancel the lock

Lock cancellation

Lock svc:
- receive flushed dirty data
- receive cancellation
- send completion callback

Completion Callback

Sys B:
- acquire lock on R

I/O & Locking

- Stripe locking
  - Change from
    - Lock all stripe extents, do all IO in parallel, unlock all
  - To
    - For all stripes in parallel: lock, do IO, unlock
  - Holding locks from multiple servers
    - Can lead to cascading aborts
    - Is necessary for truncate and O_APPEND writes
- Disallow client locks under contention
  - When an extent in a file sees concurrent access
    - Ask the client to write through to the server
  - This eliminates callback traffic and cache flushes

File size and glimpses

- Normal case
  - Only one client does IO to a file, this client knows the size
- Size of file without active IO from any client
  - Currently file size derived from object sizes
  - Will be on the MDS in the future (SOM) - optimal for quiescent files
- Size of a file under active IO
  - Now any client with “far write lock” maybe growing the file
  - A full file write lock would protect the size, but flushes all caches!
    - Lustre does NOT DO THIS, unless the file is not busy
  - In Lustre the OSS’s ask the clients with furthest locks for the size
    - This is a glimpse callback - gives one view of file size
    - A glimpse callback causes clients to cancel locks if they are not using them
  - Glimpsing is the optimal method to get file size during active IO

Configuration Lock

- The central configuration server is the MGS
- When a client fetches a log it also gets a lock
  - > The lock gets callbacks when the configuration changes
- Callback triggering events
  - > Online addition of OST devices
  - > Setting timeouts is global now
  - > Many others usage (OST pools creation, quota setup, ...)
  - > More robustness fixes

Timeouts and Eviction

- Client requests time out unless a reply is received
- Client-originated RPC timeouts will cause the client to:
  - Disconnect from the affected server
  - Ping, reconnect to server or failover and retry/complete operations
- Server callback RPC timeouts *evict* the affected client
  - Reconnects to server like an evicted NFS client (not a perfect solution, but OK)
  - The client will learn of eviction during its next request
  - Upon eviction the client must purge its cache
    - if data is dirty, this means a small amount of data loss!
  - In-flight network ops will return -EIO to application
  - Eviction prevents one bad client halting the whole cluster

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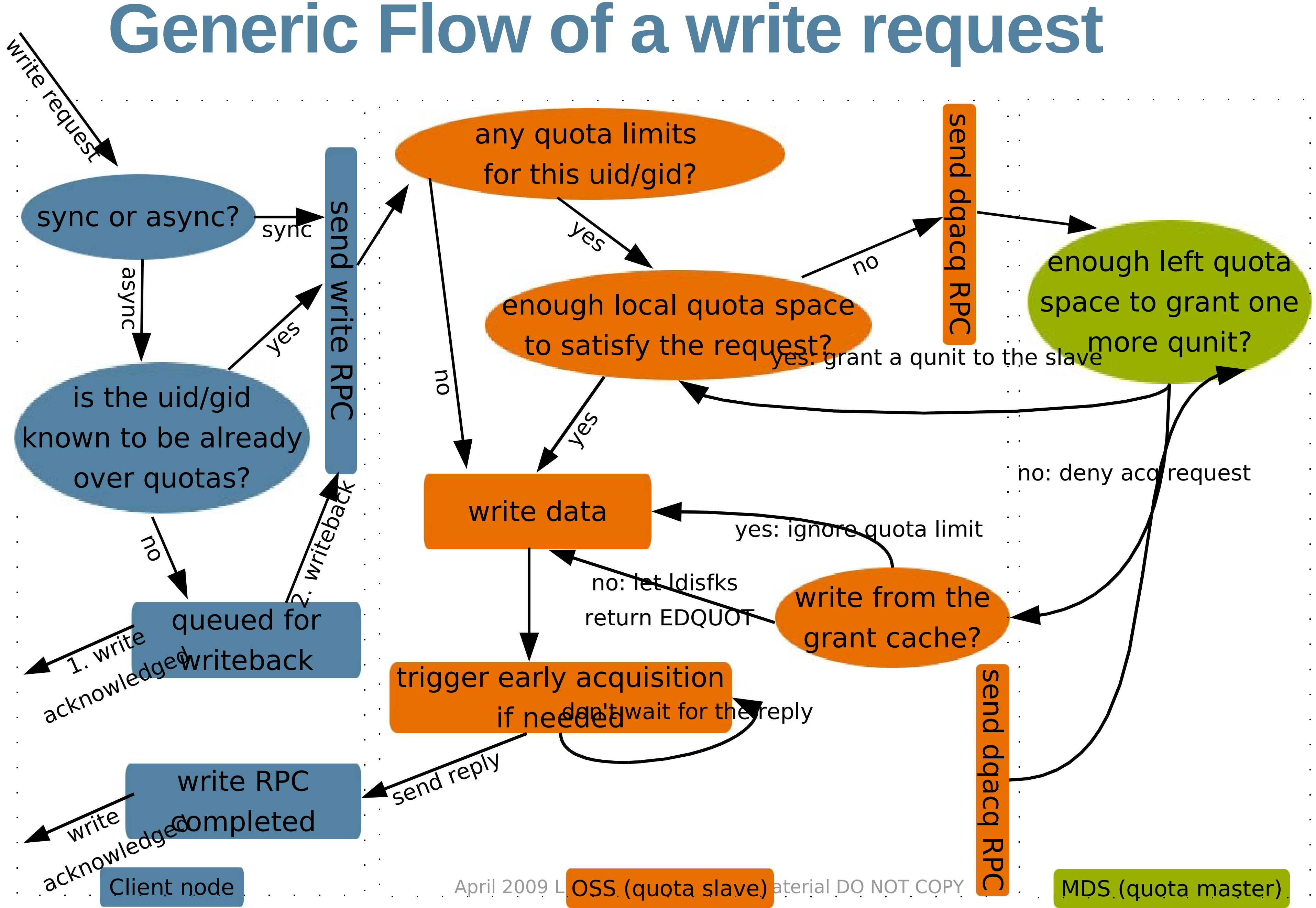
Quota Architecture Primer

- A centralized server hold the cluster wide limits: the quota master(s)
  - > guarantees that per-uid/gid global quota limits are not exceeded
  - > track quota usage on slaves
  - > 1.6/1.8/2.0: single quota master
  - > 3.0: multiple quota master required for CMD
- Quota slaves
  - > all the OSTs and MDT(s)
  - > manage local quota usage/hardlimit
  - > acquire/release quota space from the master
- Acquire/release RPC to grant space to slave
  - > initiated by slaves & processed by master(s)
  - > Early space acquisition to prevent blocking write/create rpcs

Quota Master(s)

- 1.6/1.8/2.0: 1 single master running on the MDS
- 3.0: multiple master required for CMD
- In charge of:
  - storing the quota limits for each uid/gid
  - accounting how much quota space has been granted to slaves
- quota information are stored in administrative quota files
  - files proper to Lustre (admin_quotafile.usr/grp)
  - format identical to the one used in the VFS

Generic Flow of a write request



Quotas support with kDMU

- ZFS currently doesn't support per-uid/gid quotas
  - uses quotas on fileset instead
  - Per-uid/gid quotas is under development
- Future plan
  - Currently lustre quota relies on the linux quota module
  - Implement quota inside lustre instead
  - Relies on ldiskfs/dmu only for block/inode usage accounting
  - Using standard dlm mechanisms to manage both quotas & grant space

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Manifestations of trouble

- Problems manifest themselves in multiple ways:
  - An LBUG / Oops / Panic
    - Messages on consoles
    - Modules will not unload
  - A timeout of a client RPC or bulk data transfer
    - Systems are stuck, clients can report timeouts
    - Server threads being stuck (no progress)
  - A timeout of a lock callback (formerly AST)
    - Servers report timeouts
  - Incorrect results
  - Performance is awful

General actions

- Diagnose
  - Check local console and server consoles
    - Oopses, LBUGS and timeouts are found here
  - Server problems can have different manifestation
    - Hung threads, high load, no cpu usage – server thread is stuck
  - /var/log/messages
    - Less common errors may end up here
- Check your network
  - **`lctl ping`**
  - **`LNET Self Test (LST)`**
- If there is trouble
  - Collect information – Lustre Diagnostics
  - Reboot some nodes to get cluster moving again

LBUG / Oops / Panic

- An LBUG *always* requires a reboot
  - We intentionally hang the thread that LBUGs -- it will never return
  - We do this to make it easy to gather stack traces
    - or if you have a crash dump utility, to examine kernel structures on that task
  - That thread may have locks held
  - In any case, it found something bad
- Oops - a failed kernel assertion
  - an oops will usually kill the thread
  - it may or may not have been fatal to the node
  - you should reboot at your earliest convenience
- Report oops/LBUG output and the events leading to it

LBUG Example

```
LustreError: 6596:0:(rw.c:159:ll_truncate())
   ASSERTION(atomic_read(&lli->lli_size_sem.count) <= 0) failed
LustreError: 6596:0:(module.c:46:kportal_assertion_failed()) LBUG
LustreError: dumping log to
    /tmp/lustre-log-b2.boston.clusterfs.com.1108864884.6596
```

- Post-process the log:

```
lctl df /tmp/lustre-log-b2.boston.clusterfs.com.1108864884.6596
   /tmp/foo
```

- Collect other information
  - > See next section
  - > File in a bug at Sun

Reboot some nodes

- Reboot OSS or MDS – minor if any consequences
  - Before you do this collect the bug information – see later
- Reboot a stuck client – quite safe
  - **`umount`** – unmount client
    - may hang & disconnects only once
  - **`umount -f`** – client will not attempt to disconnect

Check the Console First

- It might have your answer
- Include messages with any bug report or support request
- In many cases, this is Lustre’s only way to communicate
  - dmesg
  - /var/log/messages

Check *Other* Consoles

- Lustre is an enormous distributed system
- Most problems involve multiple nodes
- Chances are, the log will tell you which nodes:

```
LustreError: Connection to service ost2_svc (on
   192.168.0.107) was lost (timeout waiting for reply);
   in progress operations using this service will wait
   for reconnection

LustreError: This client was evicted by ost2_svc (on
   192.168.0.107); in progress operations using this
   service will fail.
```

Lkcd / kdump / netdump

- These tools were an amazing benefit early on
- They pay for themselves with the first 1-in-a-million crash
- Historically, its stack traces are more trustworthy than SysRq-T
- You can also examine data structures in the kernel
- You can also examine live, running kernels
- We sometimes ask customer to upload crash dumps to our ftp site (if possible)
  - We are very familiar with crash/lcrash

SysRq

- Turn it on:
  - /etc/sysctl.conf, add “kernel.sysrq=1”
  - sysctl -w kernel.sysrq=1
  - Trigger it with /proc/sysrq-trigger
- SysRq-P (one stack trace) is usually uninteresting
- SysRq-T (all stack traces) is voluminous but very useful
  - Especially if a process is hung and won’t make progress
- SysRq-M (memory info) is sometimes enlightening
  - Is the system essentially out of memory?
  - Are any of the counters impossible values?
- ps is often useless – the kernel “D” state is not unique
  - It means “uninterruptible sleep”
  - It’s interesting to know, but could be *anything*.
  - Get the Sysrq-T traces!

Collecting Lustre Debug Logs

- Lustre keeps a ring-buffer of pages in the kernel
  - by default, 5 MB/CPU
  - /proc/sys/portals/debug_mb
- /proc/sys/lnet/debug is a bitmask
  - Let's turn on and off some kinds of messages
  - We may ask you to modify this before reproducing a problem
  - The default is not bad for production use, but you might try others
- These logs are extremely user-unfriendly

Getting a Debug Log

- Sometimes the system volunteers a debug log
  - after a LBUG
- Other times we’ll ask you to generate one
- If we do, please clear the buffers before you reproduce:
  - lctl clear
- 5 MB sounds like a lot, but it’s usually not.
  - These logs are incredibly verbose.
  - Try to have as little running alongside your test as possible.

Post-processing

- If you get a log the normal way:

  lctl dk [filename]

  ...then lctl post-processes it for you.
- If the kernel dumps it on its own (e.g., an LBUG):

  lctl df INFILE [OUTFILE]
- Please do this before you send it to us.

Lock Dump

- You can get a complete lock dump in the logs
- Only visible if DLMTRACE is enabled in portals/debug

```
echo > /proc/fs/lustre/ldlm/dump_namespaces
```

- Sometimes need a lock snapshot from several nodes

```
--- Resource: c277aa80 (717958/0/0/0) (rc: 1)
Granted locks:
   -- Lock dump: c8175280/0xa6f5f87dbc6b3693 (rc: 1) (pos: 1) Node: NID
   0:192.168.0.3 on socknal (rhandle: 0x7899f232a33d8fb8)
   Resource: c277aa80 (717958/0)
   Req mode: PR, grant mode: PR, rc: 1, read: 0, write: 0
   Extent: 0 -> 18446744073709551615 (req 253112320-253128703)
```

Questions?

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