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Lustre SMP Scaling Improvements

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Agenda

- Where we started from
- Why we need this project
- The problems
- What we can improve
- Current status

Where we started from

- Initial goal of this project
  - Soft lockup of LNet on client side
    - RDMA Portal can have very long buffer list (hundreds even thousands of match-entries on the list, need to compare one by one)
- Survey on low-end 4-core machines
  - LNet has one single global spinlock to protect everything
  - Lockmeter shows extremely high contention on the global lock while running insanity network test (lnet_selftest)
    - 40+% UTIL (fraction of time that the lock was held during the report interval)
    - 60% CON (fraction of lock requests that found the lock was busy when it was requested)
  - RPC rate is not good enough - it’s CPU bound!

Why we need this project

- With more powerful CPU, is metadata performance improving?
  - Unfortunately… ☹
- Metadata performance is not disk bound
  - We have tested with ramdisk
  - Profiles show that performance is CPU-bound on scaling tests, especially on metadata stack
- Stability of Lustre
  - Not all soft lockup is a real BUG, it's probably just bad implementation
- I/O performance on NUMA systems

Why we need this project

Our objectives

- Make metadata performance faster
  - Unlock potential of higher IOPS from Flash/SSD
- Better I/O performance on NUMA systems
- Take advantage of rate of innovation in commodity microprocessor technology so our Lustre storage products can keep pace
- Less pressure on CMD ☺

The problems

LNet is the clue

- No heavy operation by LNet itself after we resolve the long ME-list (Match Entry) issue
  - List (search/change) operations, assignments, simple calculations
- Splitting the global lock by logic-path and making some cacheline optimizations…
  - 4 cores: better performance, Lockmeter: 4% UTIL, 15% CON
  - 8+ cores: barely better. It’s still a disaster while running insanity network test like lnet_selftest

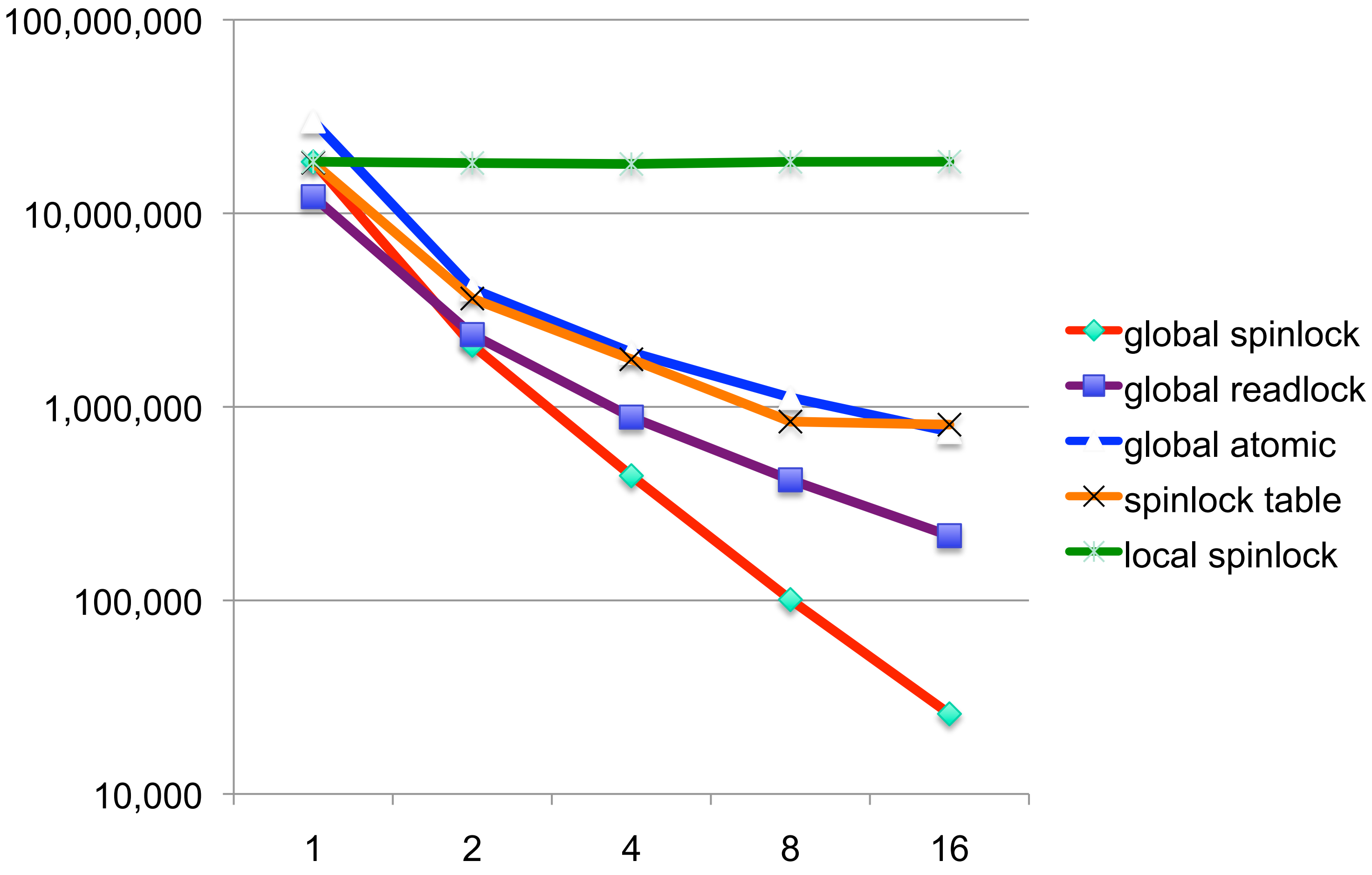
The problems

Overhead of synchronization (1 of 2)

- Memory speeds can’t catch up with CPU speeds
- Synchronization requires consistent view of data across CPUs, so synchronization is much much slower than normal instructions because of memory latency
- Huge amount of data traffic for synchronizations
- We tried to make critical section faster, but critical section efficiency is bad
  - Ta (lock acquisition), Tc (Critical section), Tr (lock release)
  - Efficiency = Tc / (Ta + Tc + Tr)

The problems

Overhead of synchronization (2 of 2)



The problems

All globals are hurting us

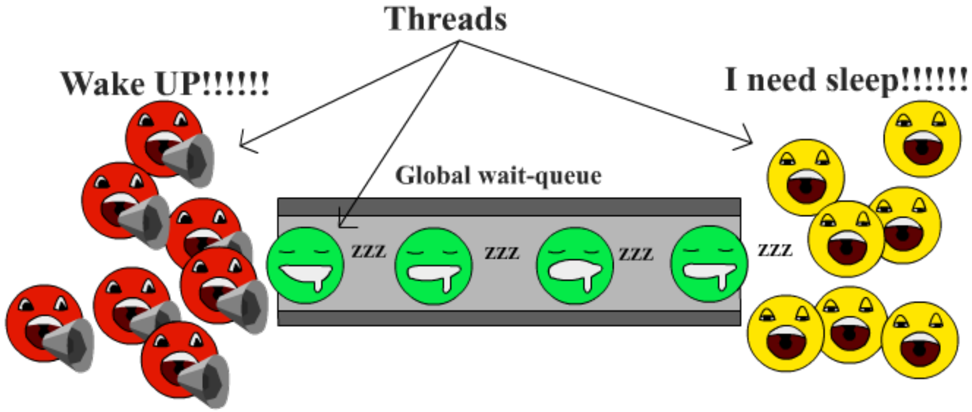
- Global locks are everywhere
  - Simple, but really bad
- Global stats, global refcount
  - Huge amount of data traffic between CPUs
- Few people care about cacheline conflicts
  - A simple code sample

```
struct foobar {
    spinlock_t        locka;
    Int               a;
    Spinlock_t        lockb;
    Int               b;
  }
```

The problems

Non-CPU affinity threads pool

- Most LND threads and ptlrpc service threads are not CPU affinity
  - Threads are scheduled by different CPUs, all data need to be taken to local cache of CPUs again and again
- Global waitq
  - Contention on waitq (sleep / wakeup)
  - Round robin wakeup, refresh cache again and again



The problems

Hash tables & Misc

- We are not careful enough about our hash tables
    - The two biggest hash tables are not well-hashed
        - Object hash
        - Ldlm hash
    - We have a hash table implementation for general purposes which is used everywhere, however…
        - Not good enough, a lot of unnecessary addref / decref, they are expensive atomic operations most of the time
        - Soft lockup
- Misc
    - Over-protected logic
    - LASSERT on very expensive conditions

What we can improve

libcfs infrastructure (1 of 2)

- CPU abstraction
  - CPU-node of libcfs can be (1-N) physical core, or NUMA node
- New interfaces for NUMA allocator
  - Local memory for each node, not only for MDT stack, also helpful for OST stack
- New interfaces for per-CPU data allocator
- New interfaces for cacheline aligned allocator
- LIFO wait-queue
  - Instead of FIFO wait-queue

What we can improve

libcfs infrastructure (2 of 2)

- Scalable local-global lock
  - Very fast local change
  - Slow global change
- A better implementation of cfs_hash
  - More flexible APIs
  - Different refcount modes and more efficient find-add
  - Much less addref/decref
  - Much SMP safer rehash & iteration

What we can improve

Restructured LNet & LND

- Each CPU has its local entry for LNet
- Each CPU has its own buffers (ME & MD list)
  - Requests are received on local buffer
  - Lazy portal is more important now
- EQ (Event Queue) improvements
  - EQ callback can happen concurrently on different CPUs
  - EQ has per-CPU refcount
- CPU affinity LND threads
  - Connections are hashed by NIDs
  - Each CPU has its own peer table
  - Completion vector of OFED

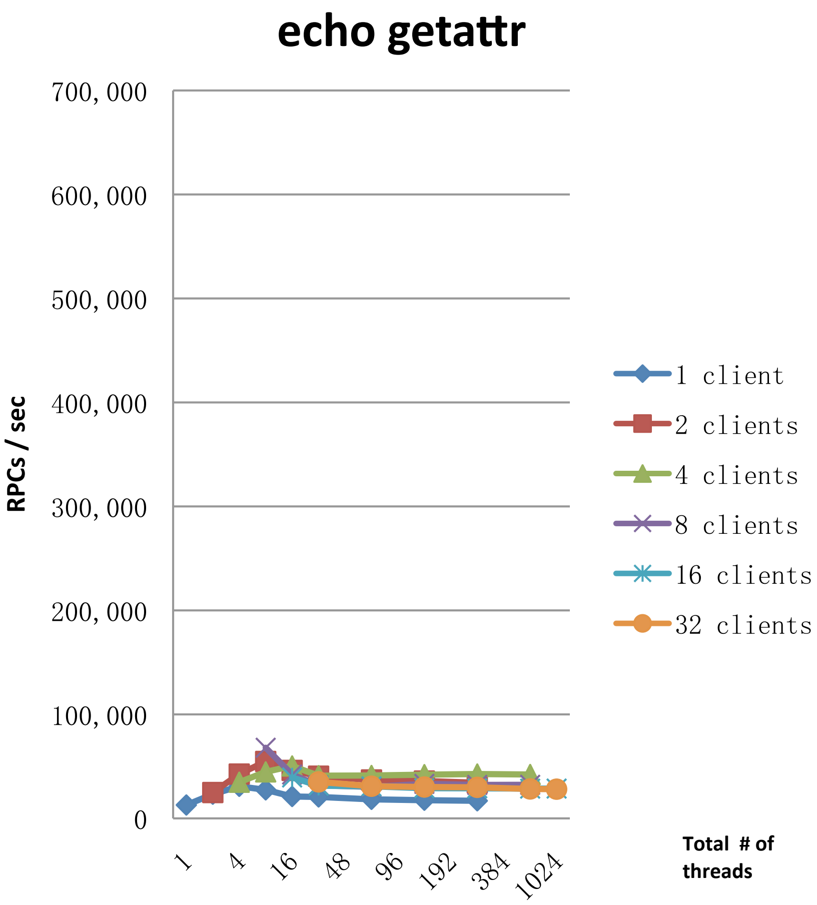
What we can improve

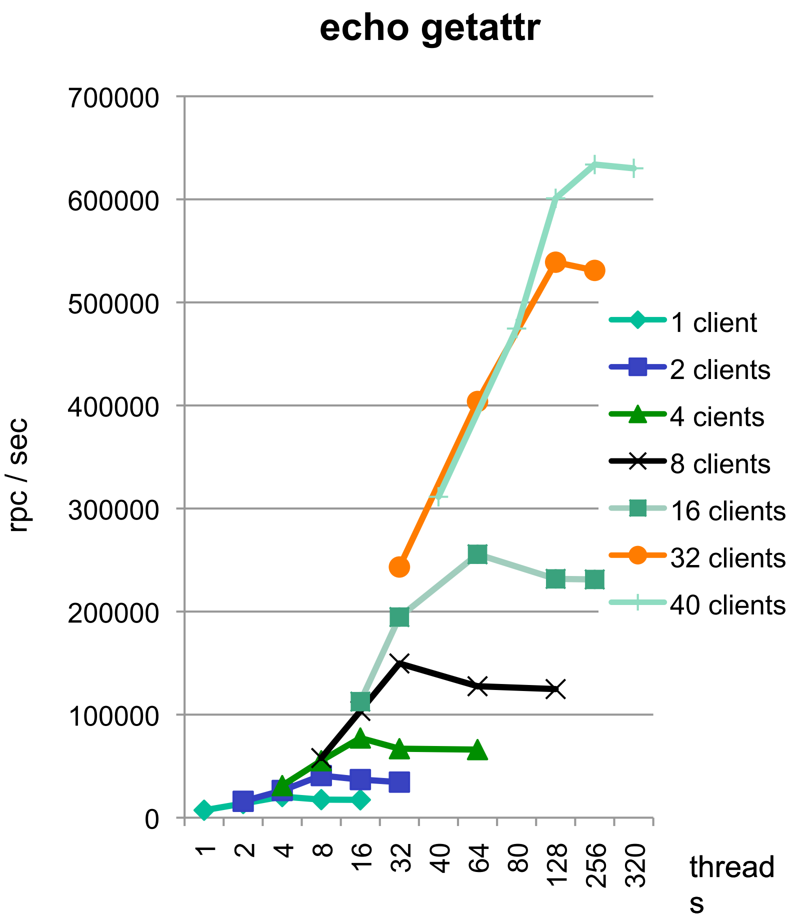
ptlrpc service

- Per-CPU service data
  - Locks, request buffer, request queue, reply state, AT…
  - More grained locks
    - Although they are local to each CPU, we still have cross CPU data access sometimes
- CPU affinity service threads pool
  - Local waitq for each CPU, otherwise all threads are serialized by the global waitq
  - LIFO wait queue can help to reduce active threads
- Cacheline optimization is always important

What we can improve

Ptlrpc performance





What we can improve

Hash tables and overprotected data

- Better hash for objects and ldlm resources
  - 1 million files tests, max search depth dropped from hundreds to less than 50
  - It not only reduces overhead of searching, also avoids cache pollution
    - One cache miss means hundreds of cycles on most processors
- Over-protected data
  - We protect the same data at different levels of stack
  - MDT takes 2 locks on create/unlink where as one would be enough (*survey still under* way)

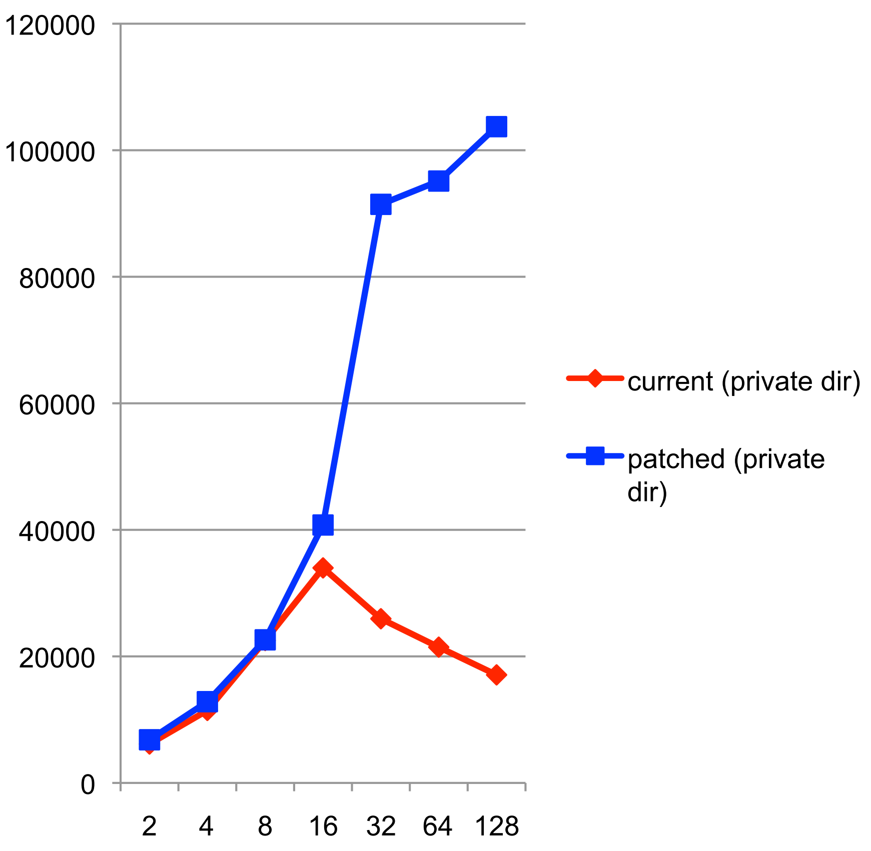
What we can improve

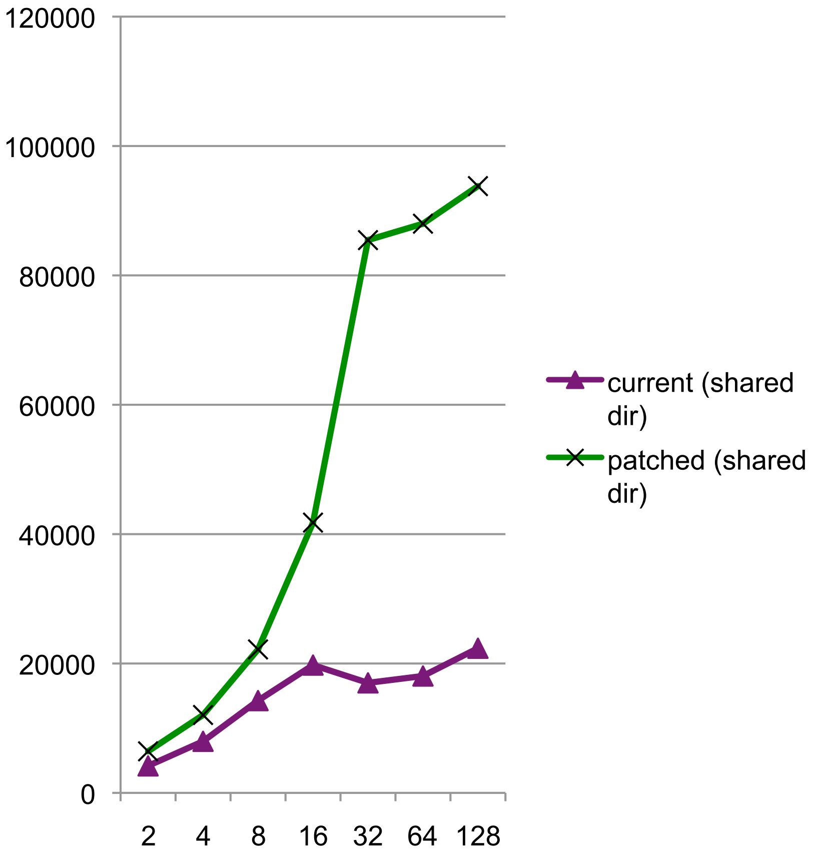
Everywhere

- Lazy update to globals
- Big reference count
- Per-CPU stats
- Code level improvement everywhere
  - Unnecessary lock dance
  - Wrong lock type
  - Redundant memset in our allocators

What we can improve

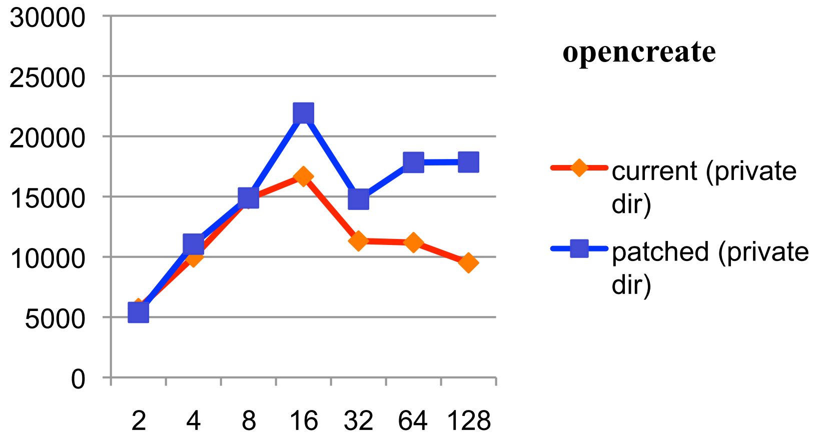
File stat (1-128 clients, 1 thread/client, 4K files/thread)

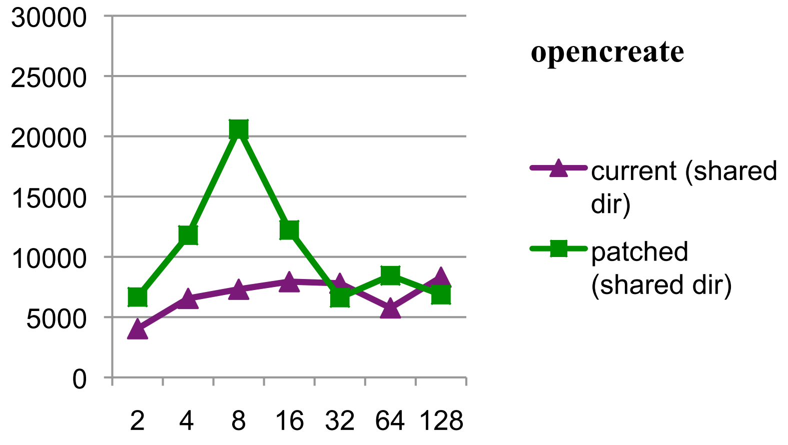


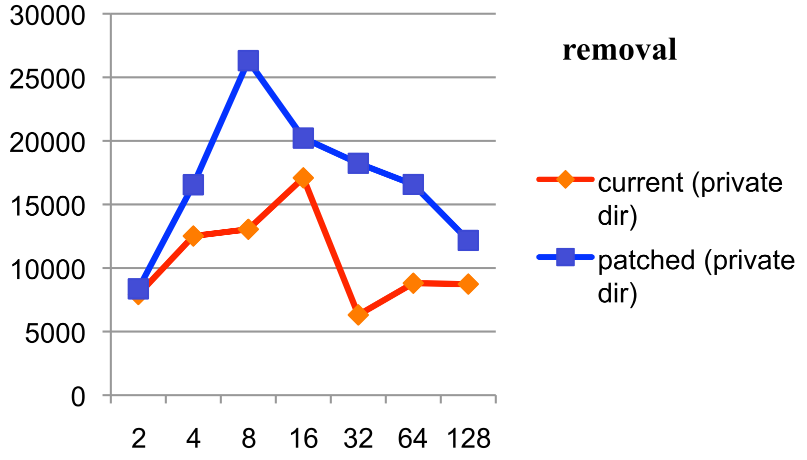


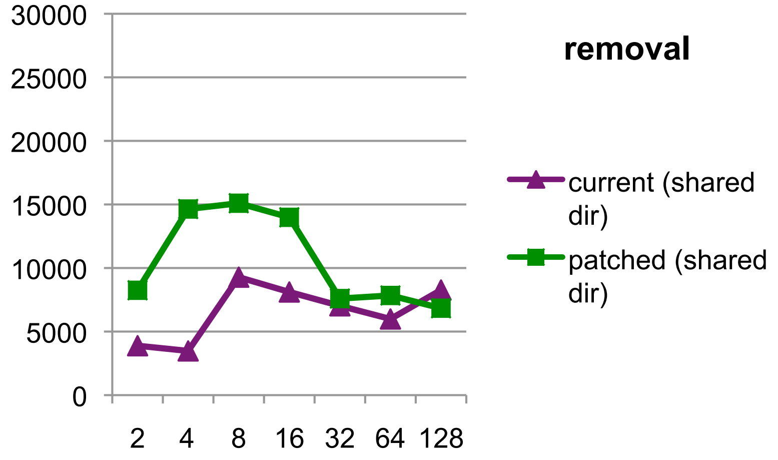
What we can improve

opencreate / removal
(1-128 clients, 1 thread/client, 4K files/thread)









Current status

- Implementation almost complete
- Initial tests show good result
- Need more survey on backend filesystem
- Metadata performance testing on Hyperion is underway
- BULL is helping us to test NUMIOA performance
- Changes are targeted for the Lustre 2 code branch

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