Ceph Snapshots: Diving into Deep Waters

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Hi, I'm Greg

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Outline

- RADOS, RBD, CephFS: (Lightning) overview and how writes happen
- The (self-managed) snapshots interface
- A diversion into pool snapshots
- Snapshots in RBD, CephFS
- RADOS/OSD Snapshot implementation, pain points

Ceph's Past & Present

- Then: UC Santa Cruz Storage Research Systems Center
- Long-term research project in petabyte-scale storage
- trying to develop a Lustre successor.

- Now: Red Hat, a commercial open-source software & support provider you might have heard of :)

  (Mirantis, SuSE, Canonical, 42on, Hastexo, ...)
- Building a business; customers in virtual block devices and object storage
- ...and reaching for filesystem users!

Ceph Projects

OBJECT	BLOCK	FILE
RGW S3 and Swift compatible object storage with object versioning, multi-site federation, and replication	**RBD** A virtual block device with snapshots, copy-on-write clones, and multi-site replication	**CEPHFS** A distributed POSIX file system with coherent caches and snapshots on any directory

LIBRADOS

A library allowing apps to direct access RADOS (C, C++, Java, Python, Ruby, PHP)

RADOS

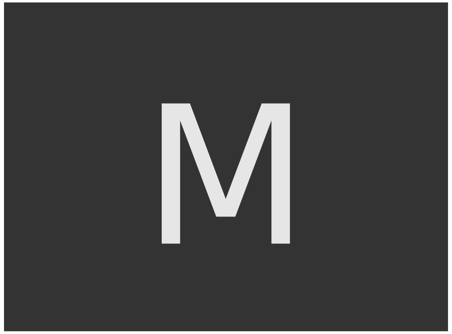
A software-based, reliable, autonomic, distributed object store comprised of self-healing, self-managing, intelligent storage nodes (OSDs) and lightweight monitors (Mons)

RADOS: Overview

RADOS Components

OSDs:

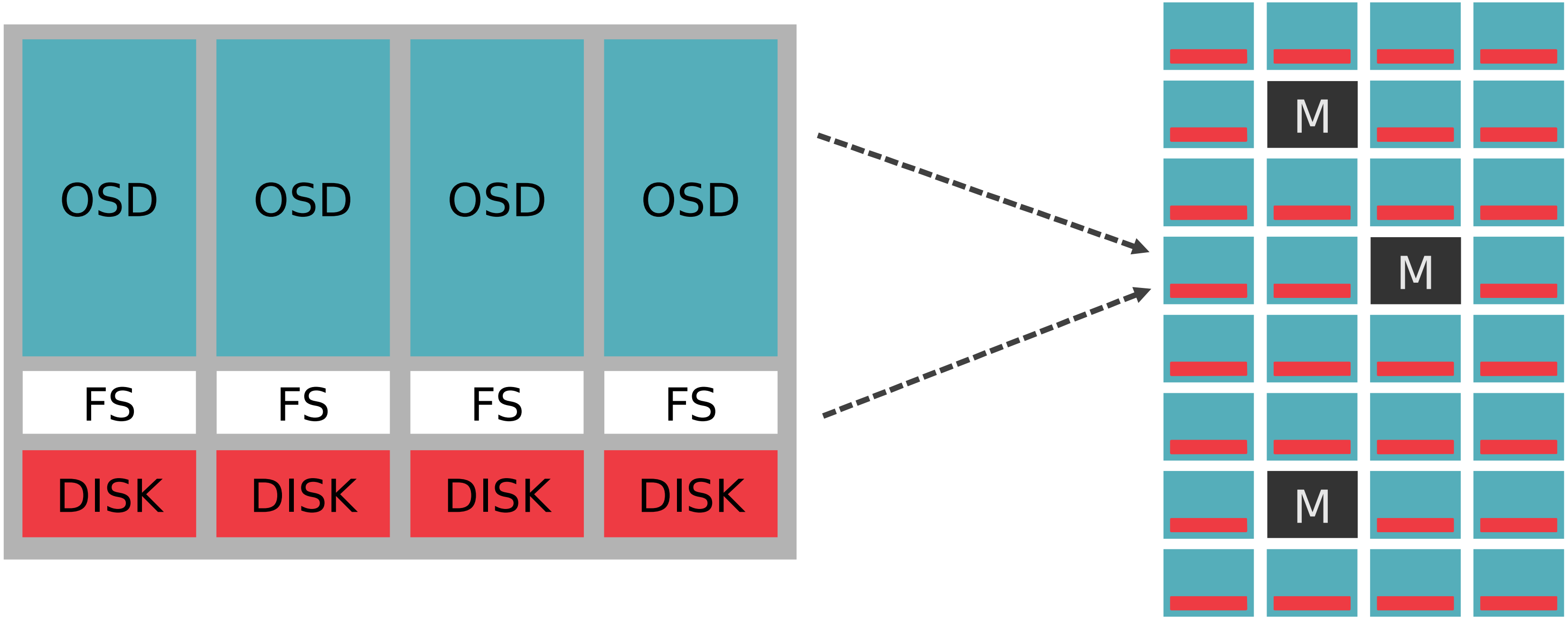
- 10s to 10000s in a cluster
- One per disk (or one per SSD, RAID group…)
- Serve stored objects to clients
- Intelligently peer for replication & recovery



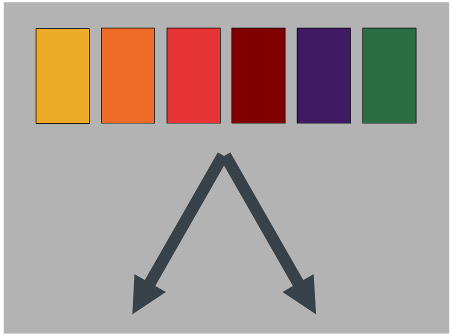
Monitors:

- Maintain cluster membership and state
- Provide consensus for distributed decision-making
- Small, odd number
- These do not serve stored objects to clients

Object Storage Daemons



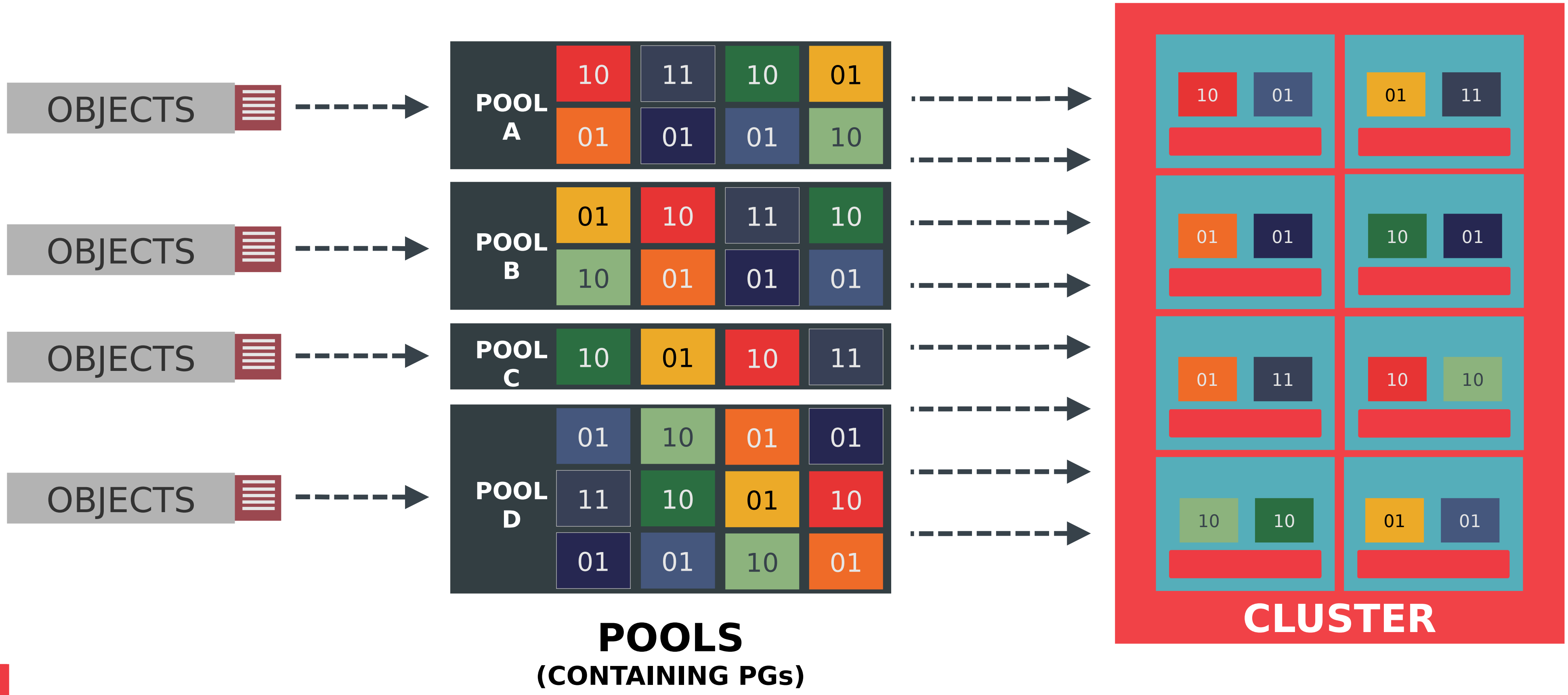
CRUSH: Dynamic Data Placement



CRUSH:

- Pseudo-random placement algorithm
  - Fast calculation, no lookup
  - Repeatable, deterministic
- Statistically uniform distribution
- Stable mapping
  - Limited data migration on change
- Rule-based configuration
  - Infrastructure topology aware
  - Adjustable replication
  - Weighting

DATA IS ORGANIZED INTO POOLS



librados: RADOS Access for Apps

LIBRADOS:

- Direct access to RADOS for applications
- C, C++, Python, PHP, Java, Erlang
- Direct access to storage nodes
- No HTTP overhead

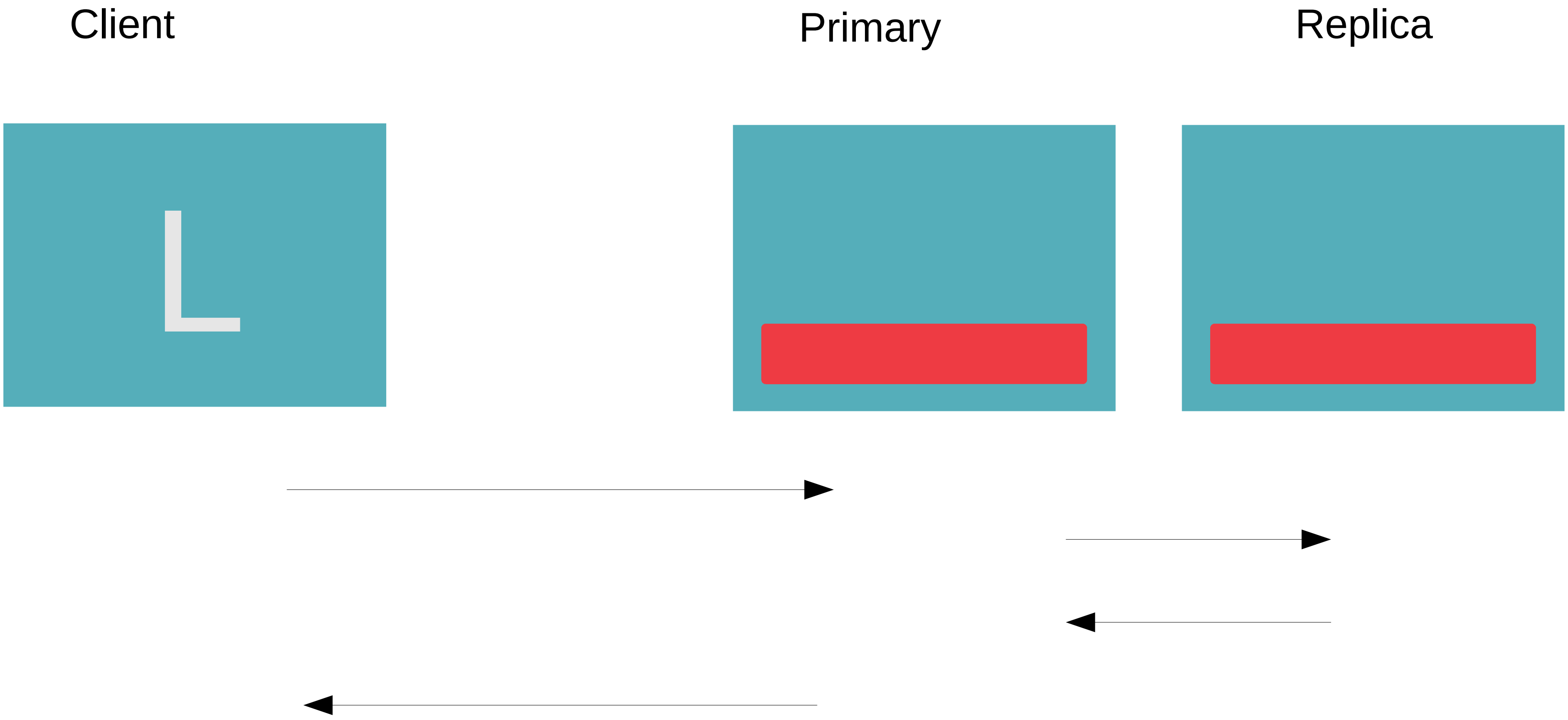
- Rich object API
- Bytes, attributes, key/value data
- Partial overwrite of existing data
- Single-object compound atomic operations
- RADOS classes (stored procedures)

RADOS: The Write Path (user)

```
aio_write(const object_t &oid, AioCompletionImpl *c,
          const bufferlist& bl, size_t len, uint64_t off);
c->wait_for_safe();
```

```
write(const std::string& oid, bufferlist& bl, size_t len, uint64_t off)
```

RADOS: The Write Path (Network)

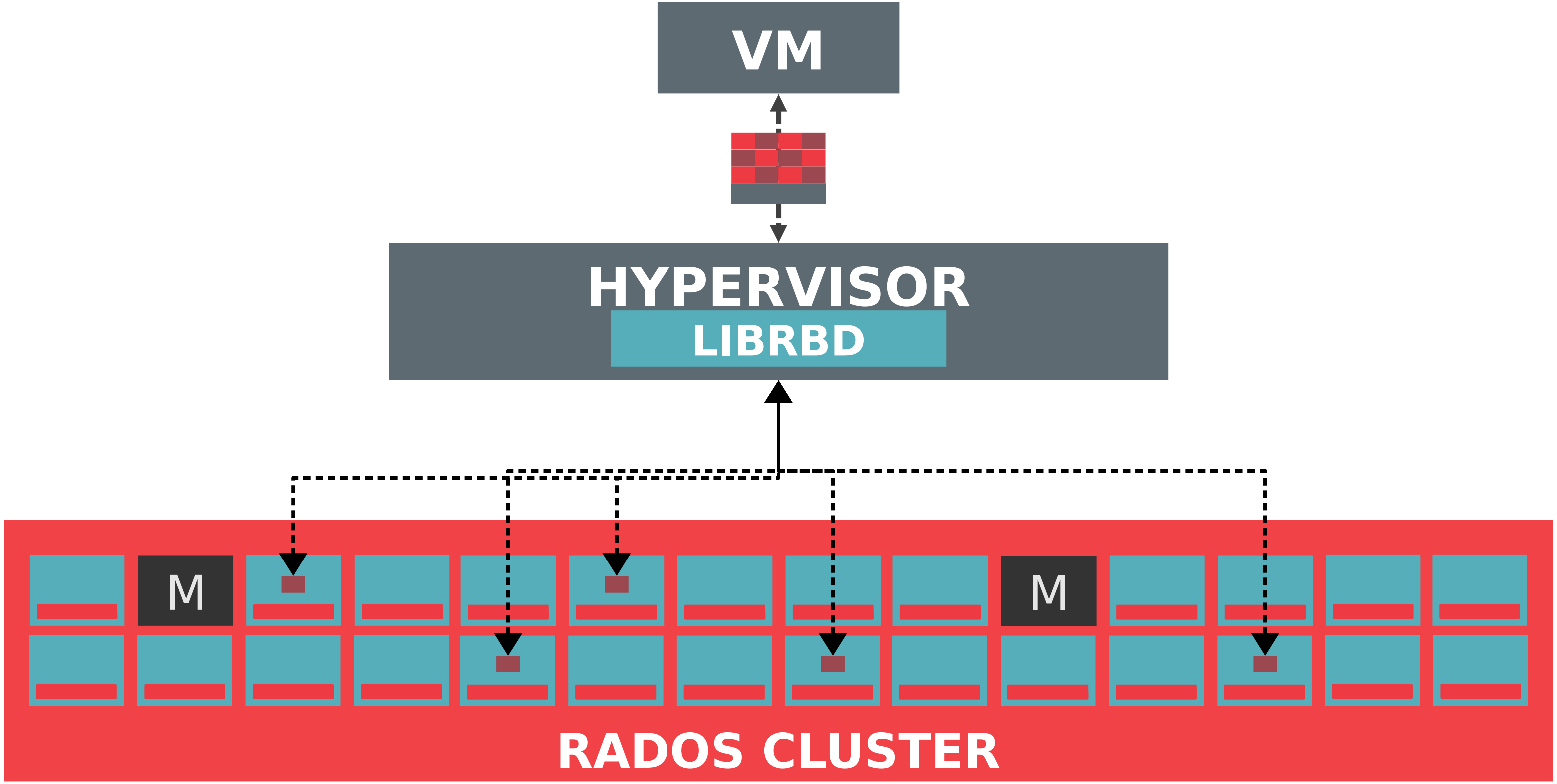


RADOS: The Write Path (OSD)

- Queue write for PG
- Lock PG
- Assign order to write op
- Package it for persistent storage
  - Find current object state, etc
- Send to replica op
- Send to local persistent storage
- Unlock PG
- Wait for commits from persistent storage and replicas
- Send commit back to client

RBD: Overview

STORING VIRTUAL DISKS



RBD STORES VIRTUAL DISKS

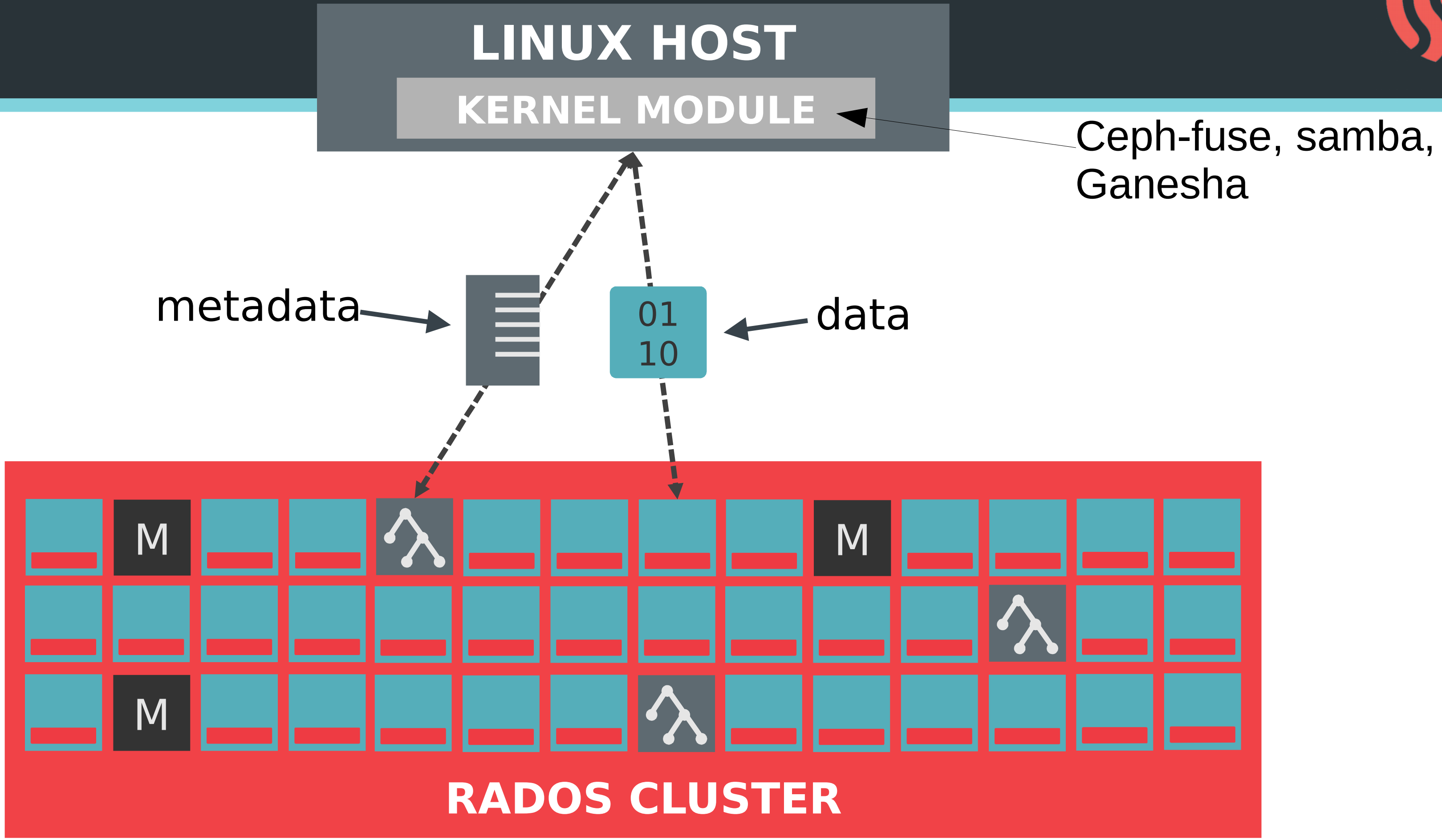
RADOS BLOCK DEVICE:

- Storage of disk images in RADOS
- Decouples VMs from host
- Images are striped across the cluster (pool)
- Snapshots
- Copy-on-write clones
- Support in:
    - Mainline Linux Kernel (2.6.39+)
    - Qemu/KVM, native Xen coming soon
    - OpenStack, CloudStack, Nebula, Proxmox

RBD: The Write Path

```
ssize_t Image::write(uint64_t ofs, size_t len, bufferlist& bl)



int Image::aio_write(uint64_t off, size_t len, bufferlist& bl,
                     RBD::AioCompletion *c)
```

CephFS: Overview


LINUX HOST
KERNEL MODULE
Ceph-fuse, samba,
Ganesha
metadata
01
10
data
M
M
M
RADOS CLUSTER

CephFS: The Write Path (User)

```
extern "C" int ceph_write(struct ceph_mount_info *cmount, int fd, const char *buf, int64_t size, int64_t offset)
```

CephFS: The Write Path (Network)

CephFS: The Write Path

- Request write capability from MDS if not already present
- Get “cap” from MDS
- Write new data to “ObjectCacher”
- (Inline or later when flushing)
  - Send write to OSD
  - Receive commit from OSD
- Return to caller

The Origin of Snapshots

```
[john@schist backups]$ touch history
[john@schist backups]$ cd .snap
[john@schist .snap]$ mkdir snap1
[john@schist .snap]$ cd ..
[john@schist backups]$ rm -f history
[john@schist backups]$ ls
[john@schist backups]$ ls .snap/snap1
history
# Deleted file still there in the snapshot!
```

Snapshot Design: Goals & Limits

- For CephFS
  - Arbitrary subtrees: lots of seemingly-unrelated objects snapshotting together
- Must be cheap to create
- We have external storage for any desired snapshot metadata

Snapshot Design: Outcome

- Snapshots are per-object
- Driven on object write
  - So snaps which logically apply to any object don’t touch it if it’s not written
- Very skinny data
  - per-object list of existing snaps
  - Global list of deleted snaps

RADOS: “Self-managed” snapshots

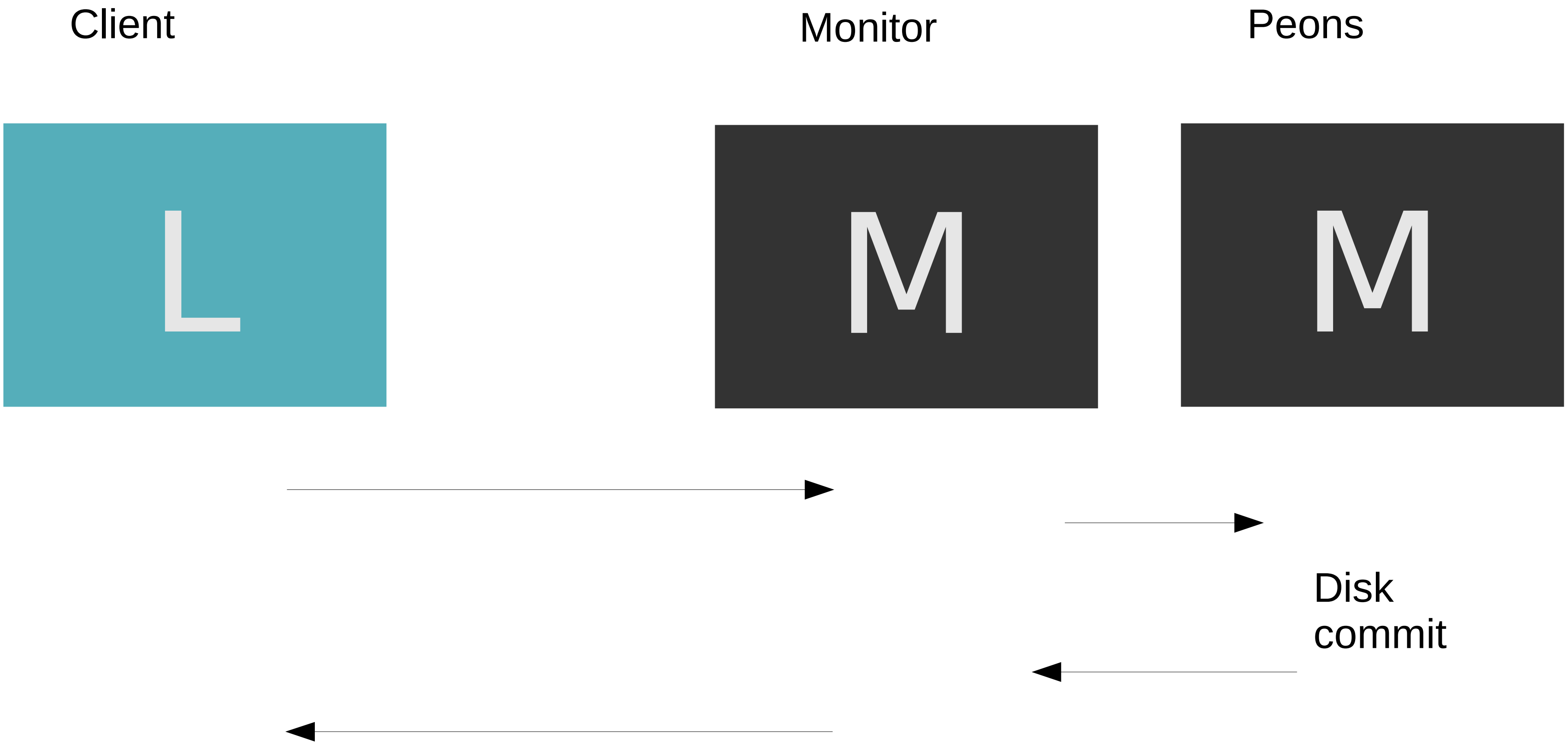
Librados snaps interface

```
int set_snap_write_context(snapid_t seq, vector<snapid_t>& snaps);

int selfmanaged_snap_create(uint64_t *snapid);

void aio_selfmanaged_snap_create(uint64_t *snapid, AioCompletionImpl
*c);

int selfmanaged_snap_remove(uint64_t snapid);

void aio_selfmanaged_snap_remove(uint64_t snapid, AioCompletionImpl
*c);

int selfmanaged_snap_rollback_object(const object_t& oid,
::SnapContext& snapc, uint64_t snapid);
```

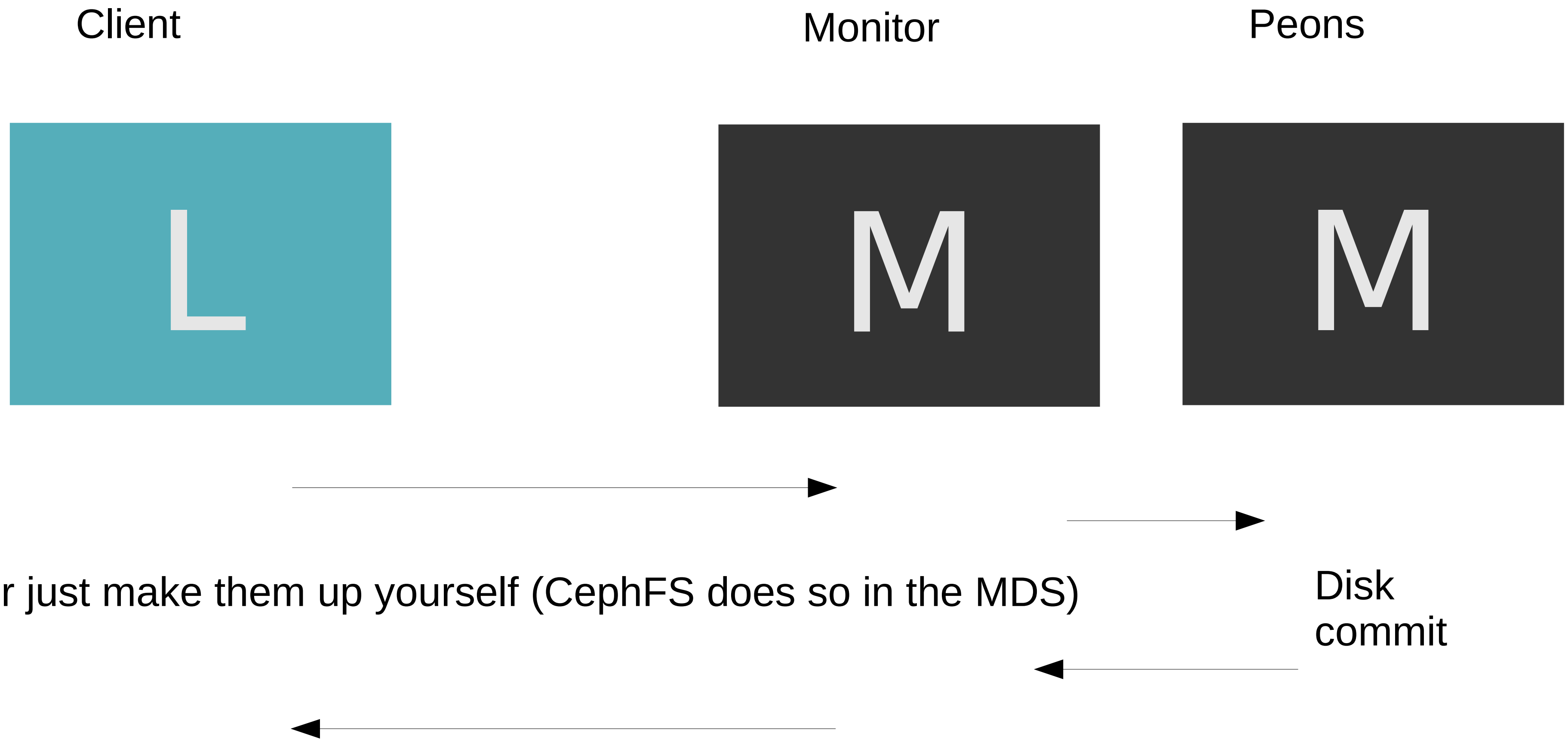
Allocating Self-managed Snapshots

“snapids” are allocated by incrementing the “snapid” and “snap_seq” members of the per-pool “pg_pool_t” OSDMap struct

Allocating Self-managed Snapshots



Allocating Self-managed Snapshots



...or just make them up yourself (CephFS does so in the MDS)

Librados snaps interface

int set_snap_write_context(snapid_t seq, vector<snapid_t>& snaps);

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void aio_selfmanaged_snap_create(uint64_t *snapid, AioCompletionImpl *c);

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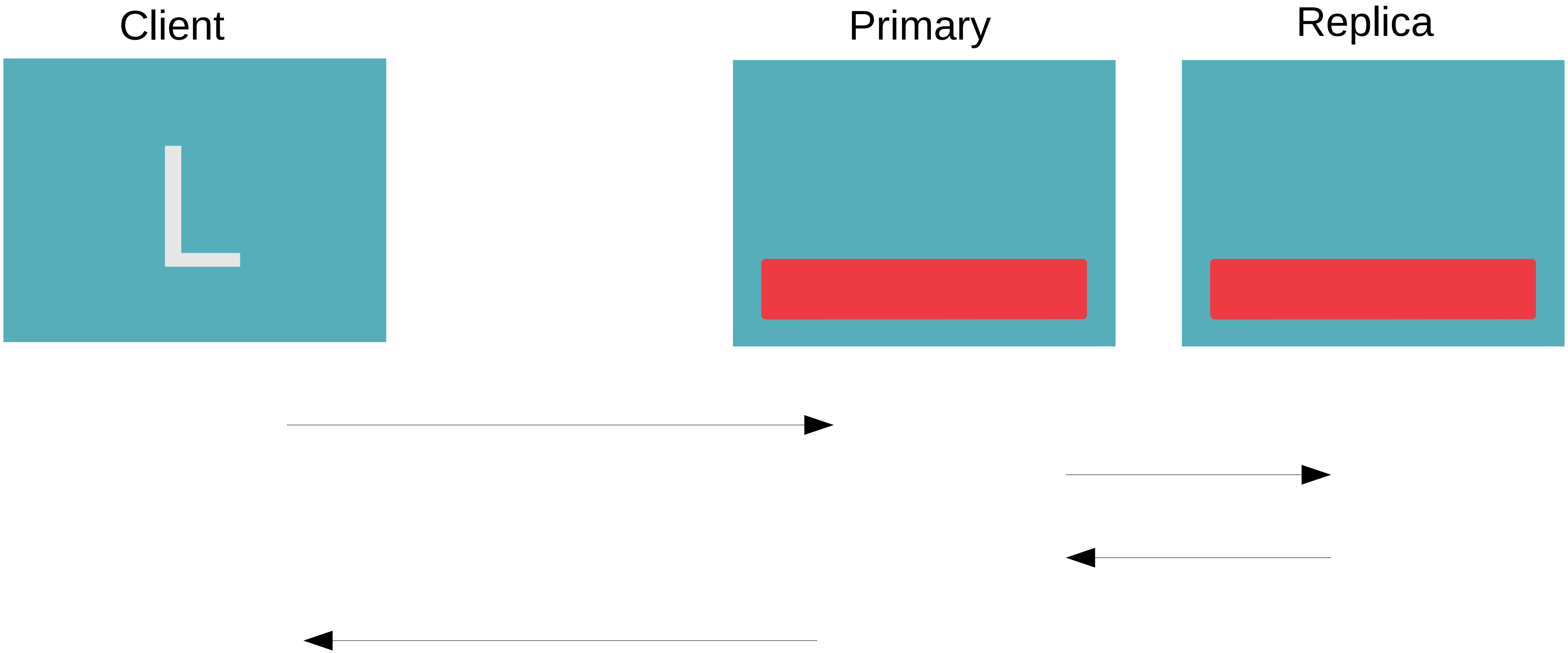
void aio_selfmanaged_snap_remove(uint64_t snapid, AioCompletionImpl *c);

int selfmanaged_snap_rollback_object(const object_t& oid, ::SnapContext& snapc, uint64_t snapid);

Writing With Snapshots

write(const std::string& oid, bufferlist& bl, size_t len, uint64_t off)



Snapshots: The OSD Path

- Queue write for PG
- Lock PG
- Assign order to write op
- Package it for persistent storage
  - Find current object state, etc
  - **make_writeable()**
- Send to replica op
- Send to local persistent storage
- Wait for commits from persistent storage and replicas
- Send commit back to client

Snapshots: The OSD Path

- The PrimaryLogPG::make_writeable() function
  - Is the “SnapContext” newer than the object already has on disk?
  - (Create a transaction to) clone the existing object
  - Update the stats and clone range overlap information
- PG::append_log() calls update_snap_map()
  - Updates the “SnapMapper”, which maintains LevelDB entries from:
    - snapid → object
    - And Object → snapid

Snapshots: OSD Data Structures

```
struct SnapSet {
  snapid_t seq;
  bool head_exists;
  vector<snapid_t> snaps;    // descending
  vector<snapid_t> clones;   // ascending
  map<snapid_t, interval_set<uint64_t> > clone_overlap;
  map<snapid_t, uint64_t> clone_size;
}
```

- This is attached to the “HEAD” object in an xattr

RADOS: Pool Snapshots :(

Pool Snaps: Desire

- Make snapshots “easy” for admins
- Leverage the existing per-object implementation
  - Overlay the correct SnapContext automatically on writes
  - Spread that SnapContext via the OSDMap

Librados pool snaps interface

```
int snap_list(vector<uint64_t> *snaps);
int snap_lookup(const char *name, uint64_t *snapid);
int snap_get_name(uint64_t snapid, std::string *s);
int snap_get_stamp(uint64_t snapid, time_t *t);
int snap_create(const char* snapname);
int snap_remove(const char* snapname);
int rollback(const object_t& oid, const char *snapName);
```

- Note how that’s still per-object!

Pool Snaps: Reality

- “Spread that SnapContext via the OSDMap”
  - It’s *not* a point-in-time snapshot
  - SnapContext spread virally as OSDMaps get pushed out
  - *No* guaranteed temporal order between two different RBD volumes in the pool – even when attached to the same VM :(
- Inflates the OSDMap size:

  per-pool map<snapid_t, pool_snap_info_t> snaps;

  struct pool_snap_info_t { snapid_t snapid; utime_t stamp; string name; }

- They are unlikely to solve a problem you want

Pool Snaps: Reality

- “Overlay the correct SnapContext automatically on writes”
  - No sensible way to merge that with a self-managed SnapContext
  - ...so we don’t: pick one or the other for a pool

All in all, pool snapshots are unlikely to usefully solve any problems.

RBD: Snapshot Structures

RBD Snapshots: Data Structures

```
struct cls_rbd_snap {
  snapid_t id;
  string name;
  uint64_t image_size;
  uint64_t features;
  uint8_t protection_status;
  cls_rbd_parent parent;
  uint64_t flags;
  utime_t timestamp;
  cls::rbd::SnapshotNamespaceOnDisk snapshot_namespace;
}
```

RBD Snapshots: Data Structures

- cls_rbd_snap for every snapshot
- Stored in “omap” (read: LevelDB) key-value space on the RBD volume’s header object
- RBD object class exposes get_snapcontext() function, called on mount
- RBD clients “watch” on the header, get “notify” when a new snap is created to update themselves

CephFS: Snapshot Structures

CephFS Snapshots: Goals & Limits

- For CephFS
  - Arbitrary subtrees: lots of seemingly-unrelated objects snapshotting together
- Must be cheap to create
- We have external storage for any desired snapshot metadata

CephFS Snapshots: Memory

- Directory “Cinodes” have “SnapRealms”
- Important elements:

snapid_t seq; // a version/seq # for changes to _this_ realm.

snapid_t created; // when this realm was created.

snapid_t last_created; // last snap created in _this_ realm.

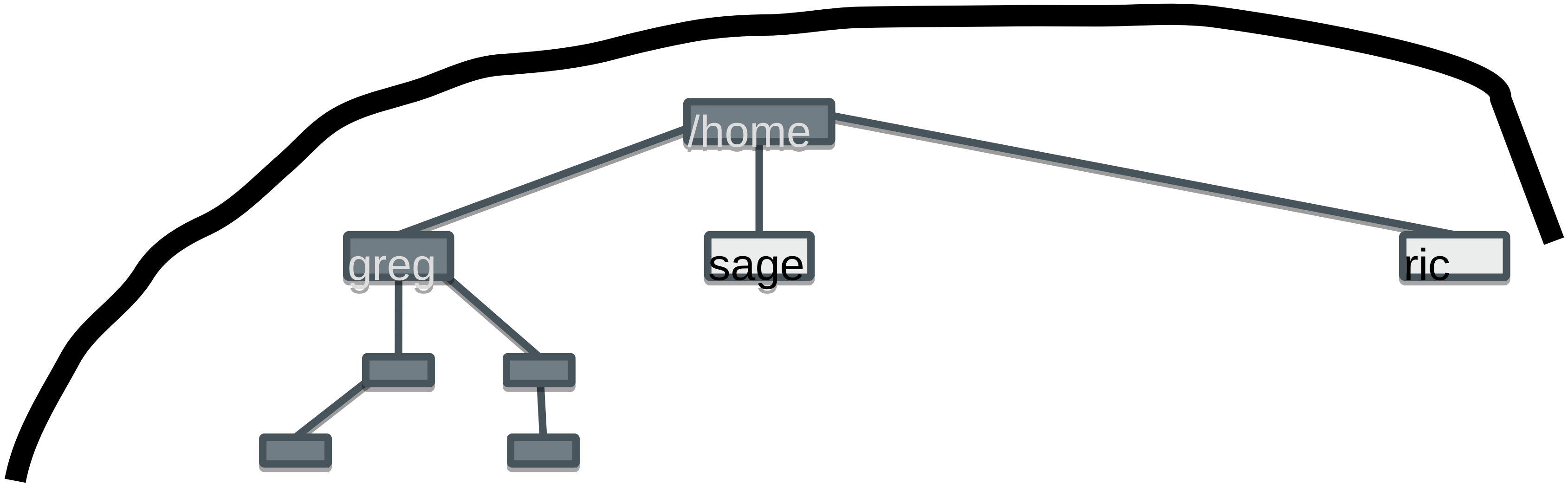
snapid_t last_destroyed; // seq for last removal

snapid_t current_parent_since;

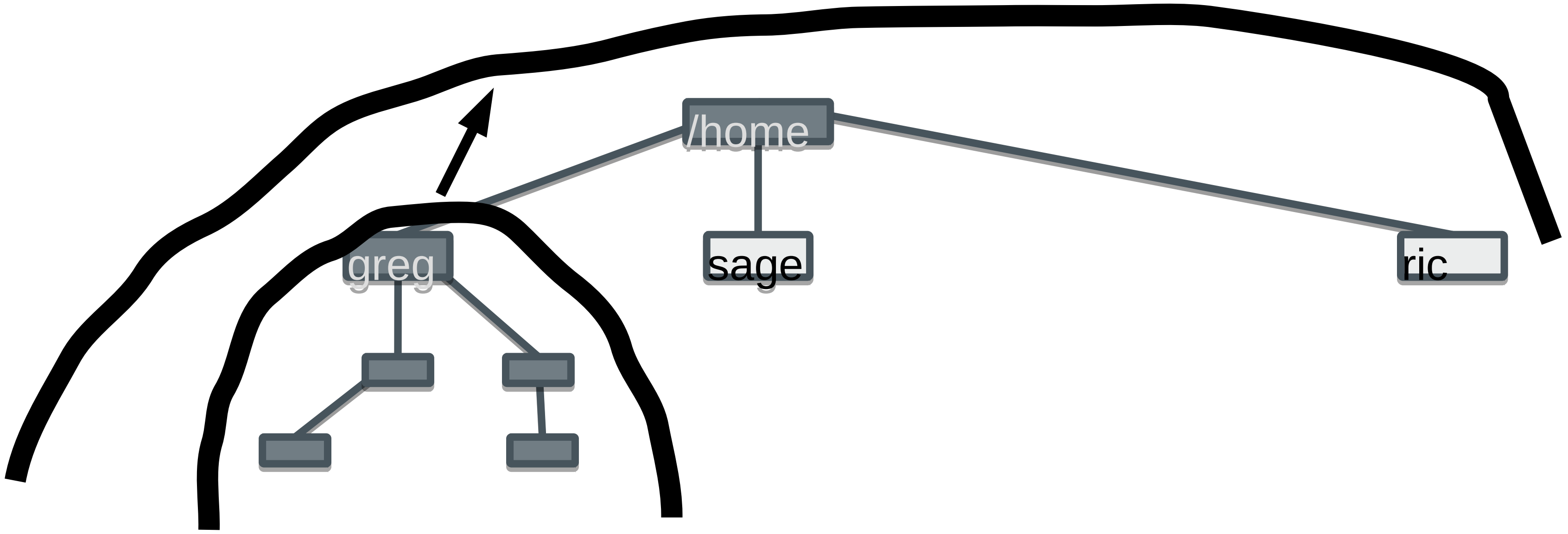
map<snapid_t, SnapInfo> snaps;

map<snapid_t, snaplink_t> past_parents; // key is "last" (or NOSNAP)

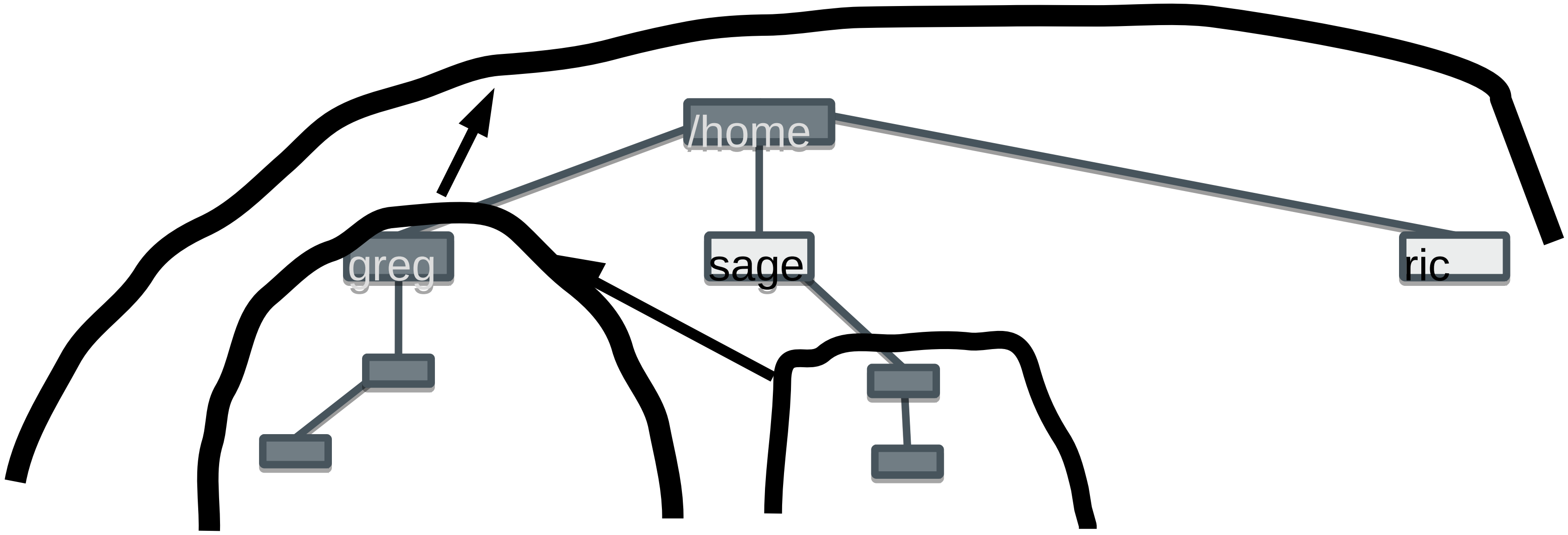
CephFS Snapshots: SnapRealms



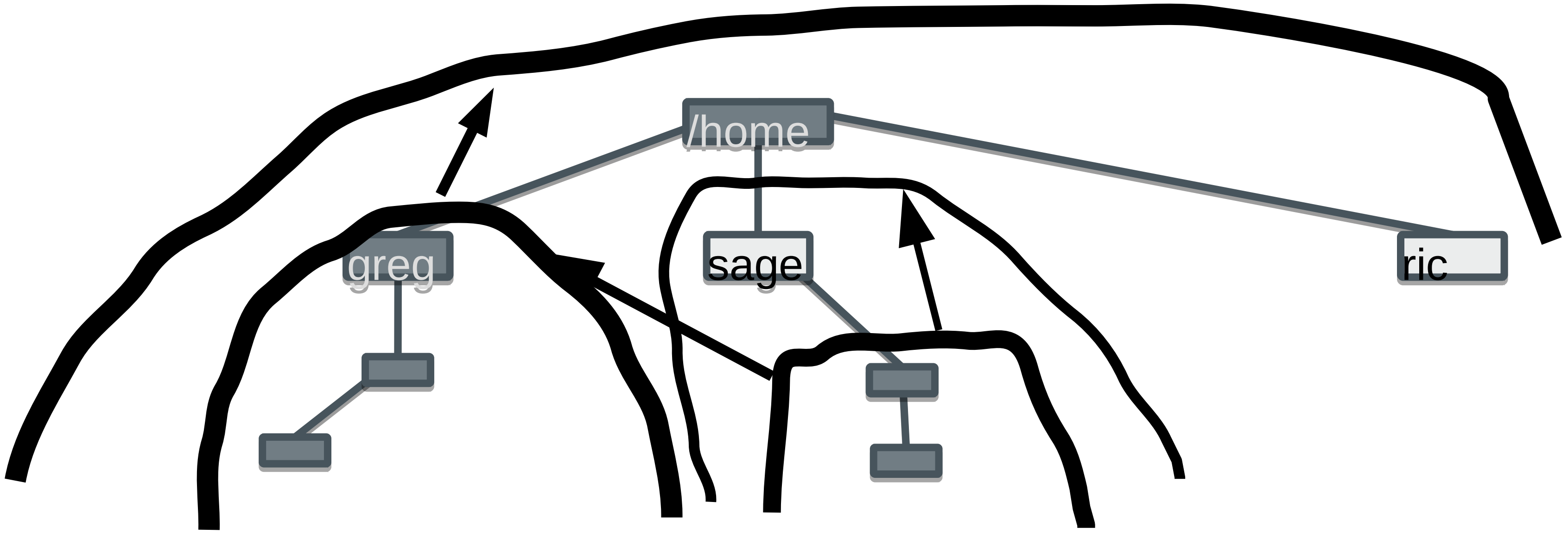
CephFS Snapshots: SnapRealms



CephFS Snapshots: SnapRealms



CephFS Snapshots: SnapRealms



CephFS Snapshots: SnapRealms

- Directory “Cinodes” have “SnapRealms”
- Important elements:

```
snapid_t seq;                      // a version/seq # for changes to _this_ realm.
snapid_t created;                  // when this realm was created.
snapid_t last_created;             // last snap created in _this_ realm.
snapid_t last_destroyed;           // seq for last removal
snapid_t current_parent_since;
map<snapid_t, SnapInfo> snaps;
map<snapid_t, snaplink_t> past_parents;  // key is "last" (or NOSNAP)
```

Construct the SnapContext!

CephFS Snapshots: Memory

- All “CInodes” have “old_inode_t” map representing its past states for snapshots

```
struct old_inode_t {
  snapid_t first;
  inode_t inode;
  std::map<string,bufferptr> xattrs;
}
```

CephFS Snapshots: Disk

- SnapRealms are encoded as part of inode
- Snapshotted metadata stored as old_inode_t map in memory/disk
- Snapshotted data stored in RADOS object self-managed snapshots

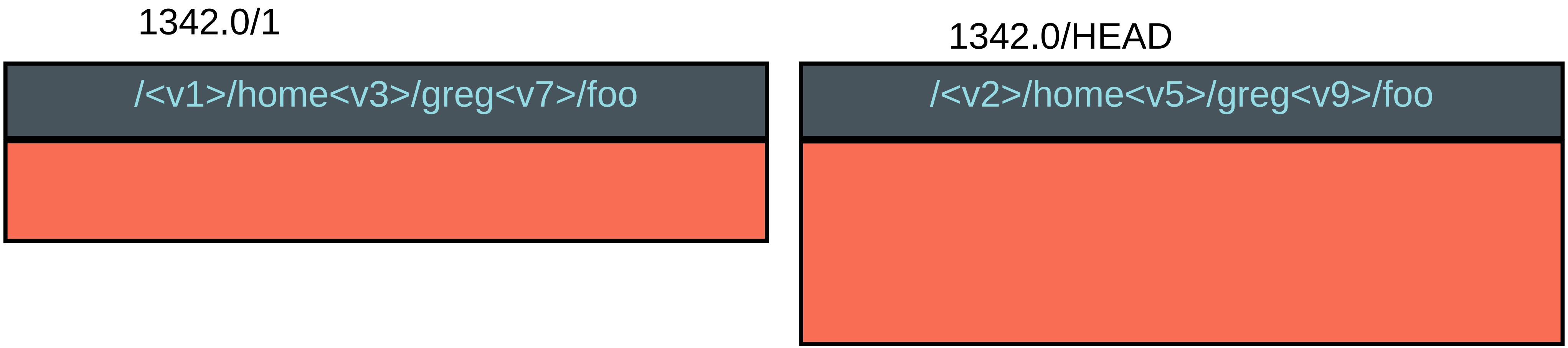
/<ino 0,v2>/home<ino 1,v5>/greg<ino 5,v9>/
Mydir[01], total size 7MB
foo -> ino 1342, 4 MB, [<1>,<3>,<10>]
bar -> ino 1001, 1024 KBytes
baz -> ino 1242, 2 MB

1342.0/HEAD

/<v2>/home<v5>/greg<v9>/foo

CephFS Snapshots

- Arbitrary sub-tree snapshots of the hierarchy
- Metadata stored as old_inode_t map in memory/disk
- Data stored in RADOS object snapshots



CephFS: Snapshot Pain

CephFS Pain: Opening past parents

- Directory "Cinodes" have "SnapRealms"
- Important elements:

snapid_t seq; // a version/seq # for changes to _this_ realm.

snapid_t created; // when this realm was created.

snapid_t last_created; // last snap created in _this_ realm.

snapid_t last_destroyed; // seq for last removal

snapid_t current_parent_since;

map<snapid_t, SnapInfo> snaps;

map<snapid_t, snaplink_t> past_parents;

CephFS Pain: Opening past parents

- To construct the SnapContext for a write, we need the all the SnapRealms it has **ever** participated in
  - Because it could have been logically snapshotted in an old location but not written to since, and a new write must reflect that old location's snapid
- So we must open all the directories the file has been a member of!
  - With a single MDS, this isn't too hard
  - With multi-MDS, this can be very difficult in some scenarios
    - We may not know who is "authoritative" for a directory under all failure and recovery scenarios
    - If there's been a disaster metadata may be inaccessible, but we don't have mechanisms for holding operations and retrying when "unrelated" metadata is inaccessible

CephFS Pain: Opening past parents

- Directory “Cinodes” have “SnapRealms”
- Important elements:

```
snapid_t seq;                    // a version/seq # for changes to _this_ realm.
snapid_t created;                // when this realm was created.
snapid_t last_created;           // last snap created in _this_ realm.
snapid_t last_destroyed;         // seq for last removal
snapid_t current_parent_since;
map<snapid_t, SnapInfo> snaps;
map<snapid_t, snaplink_t> past_parents;
```

Why not store snaps in all descendants
Instead of maintaining ancestor links?

CephFS Pain: Eliminating past parents

- The MDS opens an inode for any operation performed on it
  - This includes its SnapRealm
- So we can merge snapid lists down whenever we open an inode that has a new SnapRealm
- So if we rename a directory/file into a new location; its SnapRealm already contains all the right snapids and then we don't need a link to the past!

- I got this almost completely finished
  - Reduced code line count
  - Much simpler snapshot tracking code
  - But….

CephFS Pain: Hard links

- Hard links and snapshots **do not** interact :(
- They should!
- That means we need to merge SnapRealms from all the linked parents of an inode
  - And this is the exact same problem we have with past_parents
  - Since we need to open “remote” inodes correctly, avoiding it in the common case doesn’t help us
- So, back to debugging and more edge cases

RADOS: Deleting Snapshots

Librados snaps interface

int set_snap_write_context(snapid_t seq, vector<snapid_t>& snaps);

int selfmanaged_snap_create(uint64_t *snapid);

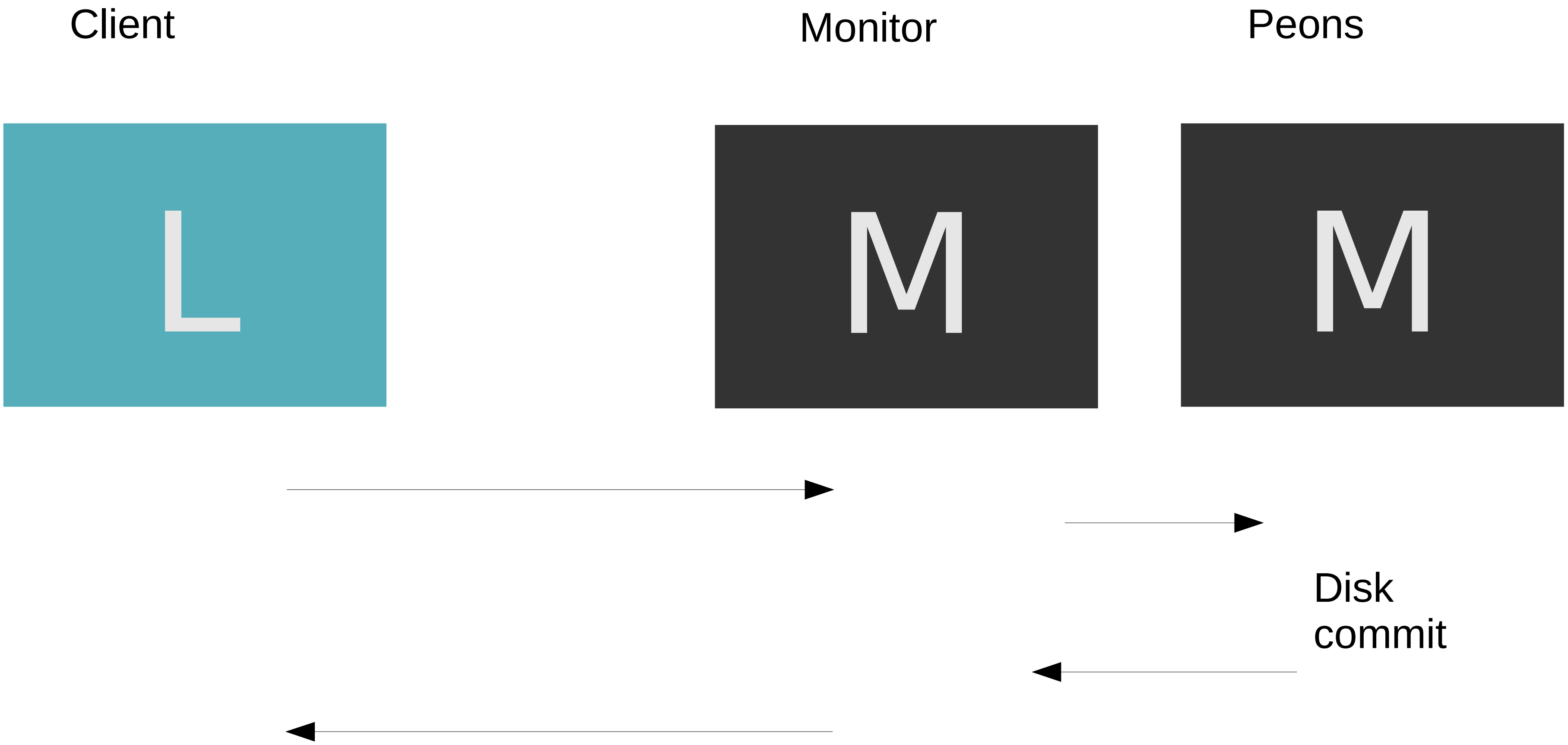
void aio_selfmanaged_snap_create(uint64_t *snapid, AioCompletionImpl *c);

int selfmanaged_snap_remove(uint64_t snapid);

void aio_selfmanaged_snap_remove(uint64_t snapid, AioCompletionImpl *c);

int selfmanaged_snap_rollback_object(const object_t& oid, ::SnapContext& snapc, uint64_t snapid);

“Deleting” Snapshots (Client)



Deleting Snapshots (Monitor)

- Generate new OSDMap updating pg_pool_t

```
interval_set<snapid_t> removed_snaps;
```

- This is really space-efficient if you consistently delete your oldest snapshots!
  - Rather less so if you keep every other one forever
    - ...and this looks sort of like some sensible RBD snapshot strategies (daily for a week, weekly for a month, monthly for a year)

Deleting Snapshots (OSD)

- OSD advances its OSDMap
- Asynchronously:
  - List objects with that snapshot via “SnapMapper”
    - int get_next_objects_to_trim(snapid_t snap, unsigned max, vector<hobject_t> *out);
  - For each object:
    - “unlink” object clone for that snapshot – 1 coalescable IO
      - Sometimes clones belong to multiple snaps so we might not delete right away
    - Update object HEAD’s “SnapSet” xattr – 1+ unique IO
    - Remove SnapMapper’s LevelDB entries for that object/snap pair – 1 coalescable IO
    - Write down “PGLog” entry recording clone removal – 1 coalescable IO
  - Note that if you trim a bunch of snaps, you do this for each one – no coalescing it down to one pass on each object :(

Deleting Snapshots (OSD)

- So that's at least 1 IO per object in a snap
  - potentially a lot more if we needed to fetch KV data off disk, didn't have directories cached, etc
  - This will be a *lot* better in BlueStore! It's just coalescable metadata ops
- Ouch!
- Even worse: throttling is hard
  - Why is a whole talk on its own
  - It's very difficult to not overwhelm clusters if you do a lot of trimming at once

RADOS: Alternate Approaches

Past: Deleting Snapshots

- Maintain a per snapid directory with hard links!
  - Every clone is linked into (all) its snapid directory(s)
  - Just list the directory to identify them, then
    - update the object’s SnapSet
    - Unlink from all relevant directories

- Turns out this destroys locality, in addition to being icky code

Present: Why per-object?

- For instance, LVM snapshots?
- We don't want to snapshot everything on an OSD at once
  - No implicit "consistency groups" across RBD volumes, for instance
- So we ultimately need a snap→object mapping, since each snap touches so few objects

Future: Available enhancements

- Update internal interfaces for more coalescing
  - There’s no architectural reason we need to scan each object per-snapshot
  - Instead, maintain iterators for each snapshot we are still purging and advance them through the keyspace in step so we can do all snapshots of a particular object in one go

- Change deleted snapshots representation so it doesn’t inflate ODSMaps
  - “deleting_snapshots” instead, which can be trimmed once all OSDs report they’ve been removed
  - Store the full list of deleted snapshots in config-keys or similar, handle it with ceph-mgr

Future: Available enhancements

- BlueStore: It makes everything better
  - Stop having to map our semantics onto a filesystem
  - Snapshot deletes still require the snapid→object mapping, but the actual delete is a few key updates rolled into RocksDB – easy to coalesce
- Better throttling for users
  - Short-term: hacks to enable sleeps so we don’t overwhelm the local FS
  - Long-term: proper cost estimates for BlueStore that we can budget correctly (not really possible in Fses since they don’t expose number of IOs needed to flush current dirty state)

THANK YOU!

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ceph