CephFS: The Stable Distributed Filesystem

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Hi, I'm Greg

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Overview

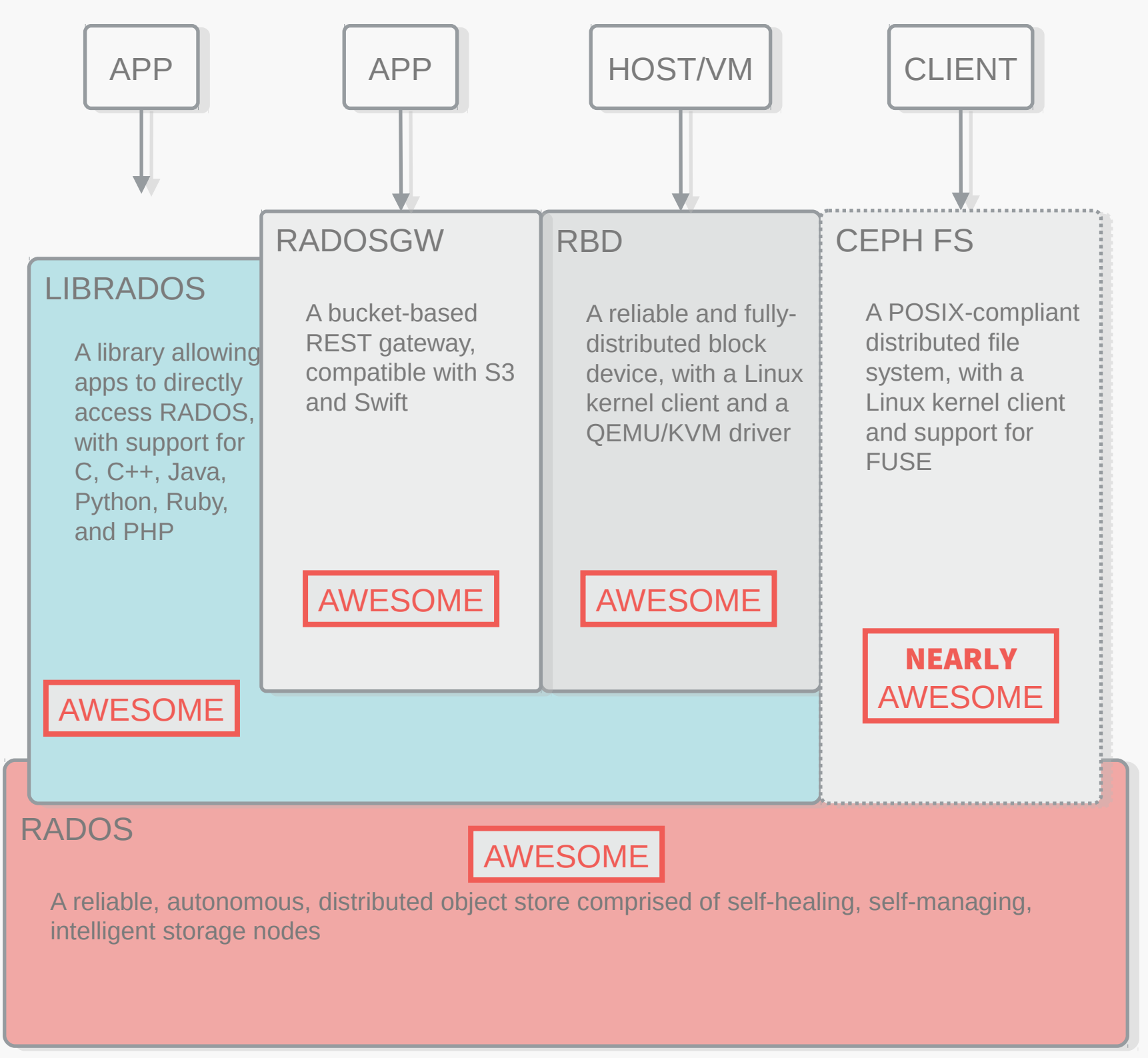
- What is Ceph/Cephfs
- CephFS: What Works
  - It's a distributed POSIX filesystem!
  - There are many niceties that go with that
- CephFS: What Doesn't Work (Yet)
  - Directory fragmentation
  - Erasure Coding
  - Multi-Active MDS
  - Snapshots
- Pain Points & Use Cases

Where Does Ceph Come From?

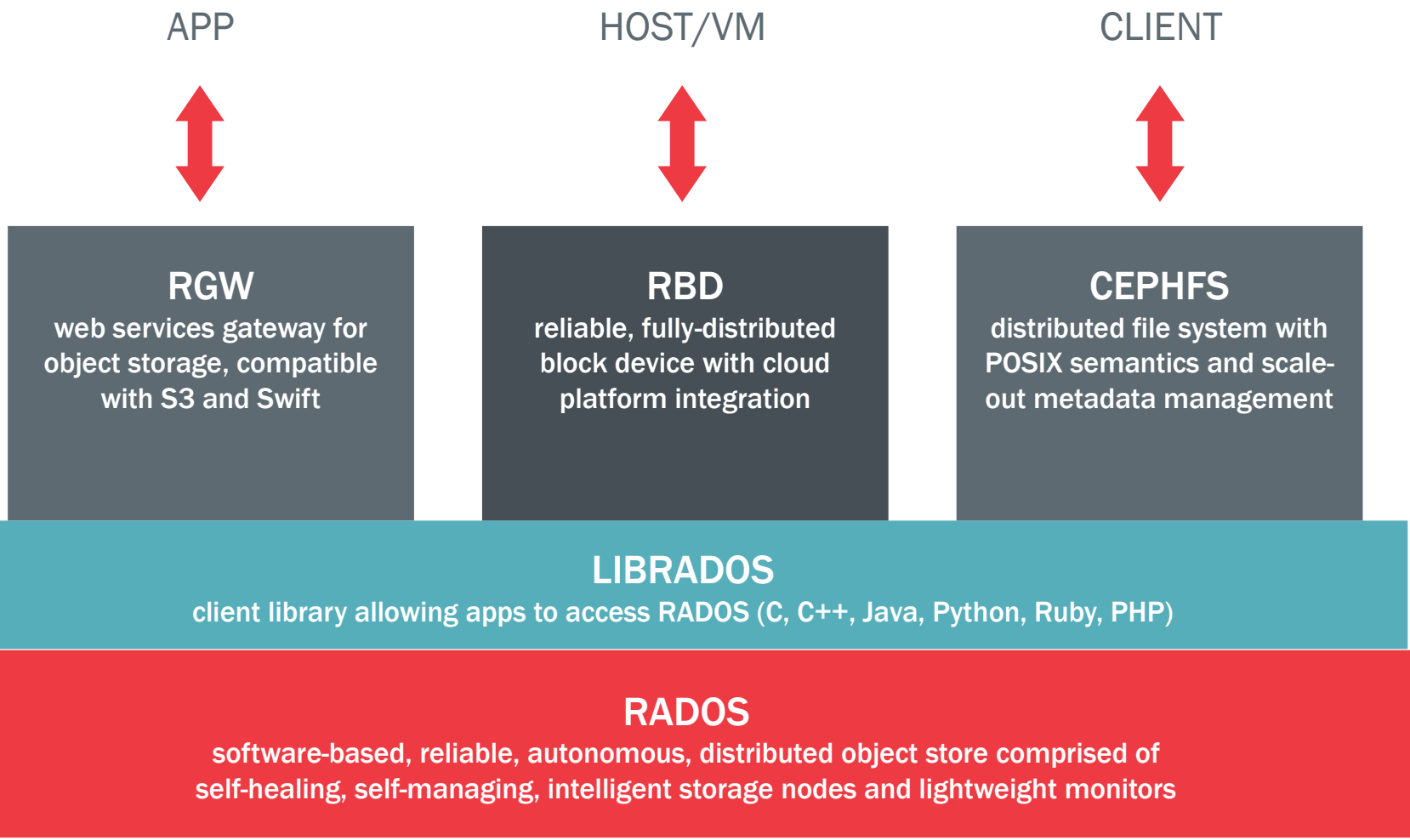
- Then: UC Santa Cruz Storage Research Systems Center
- Long-term research project in petabyte-scale storage
- trying to develop a Lustre successor.

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

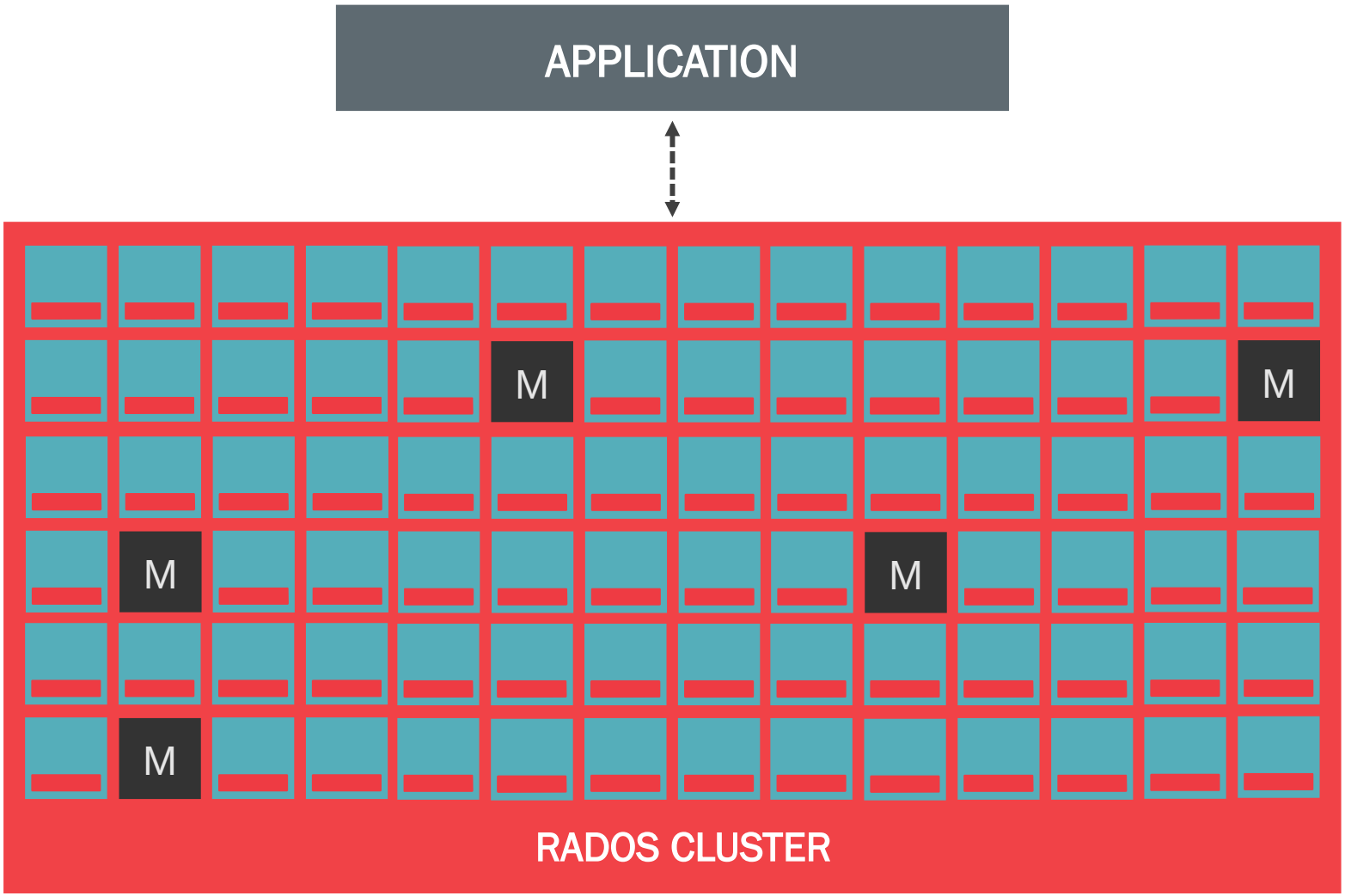
  (Mirantis, SuSE, Canonical, 42on, Hastexo, ...)
- Building a business; customers in virtual block devices and object storage
- ...and reaching for filesystem users!


APP
APP
HOST/VM
CLIENT
LIBRADOS
A library allowing apps to directly access RADOS, with support for C, C++, Java, Python, Ruby, and PHP
AWESOME
RADOSGW
A bucket-based REST gateway, compatible with S3 and Swift
AWESOME
RBD
A reliable and fully-distributed block device, with a Linux kernel client and a QEMU/KVM driver
AWESOME
CEPH FS
A POSIX-compliant distributed file system, with a Linux kernel client and support for FUSE
NEARLY AWESOME
RADOS
AWESOME
A reliable, autonomous, distributed object store comprised of self-healing, self-managing, intelligent storage nodes

Now: Fully Awesome



RADOS CLUSTER



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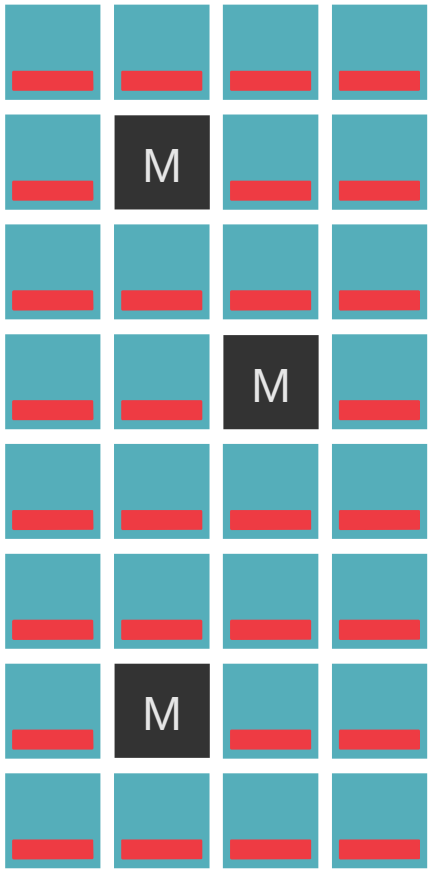
WHERE DO OBJECTS LIVE?



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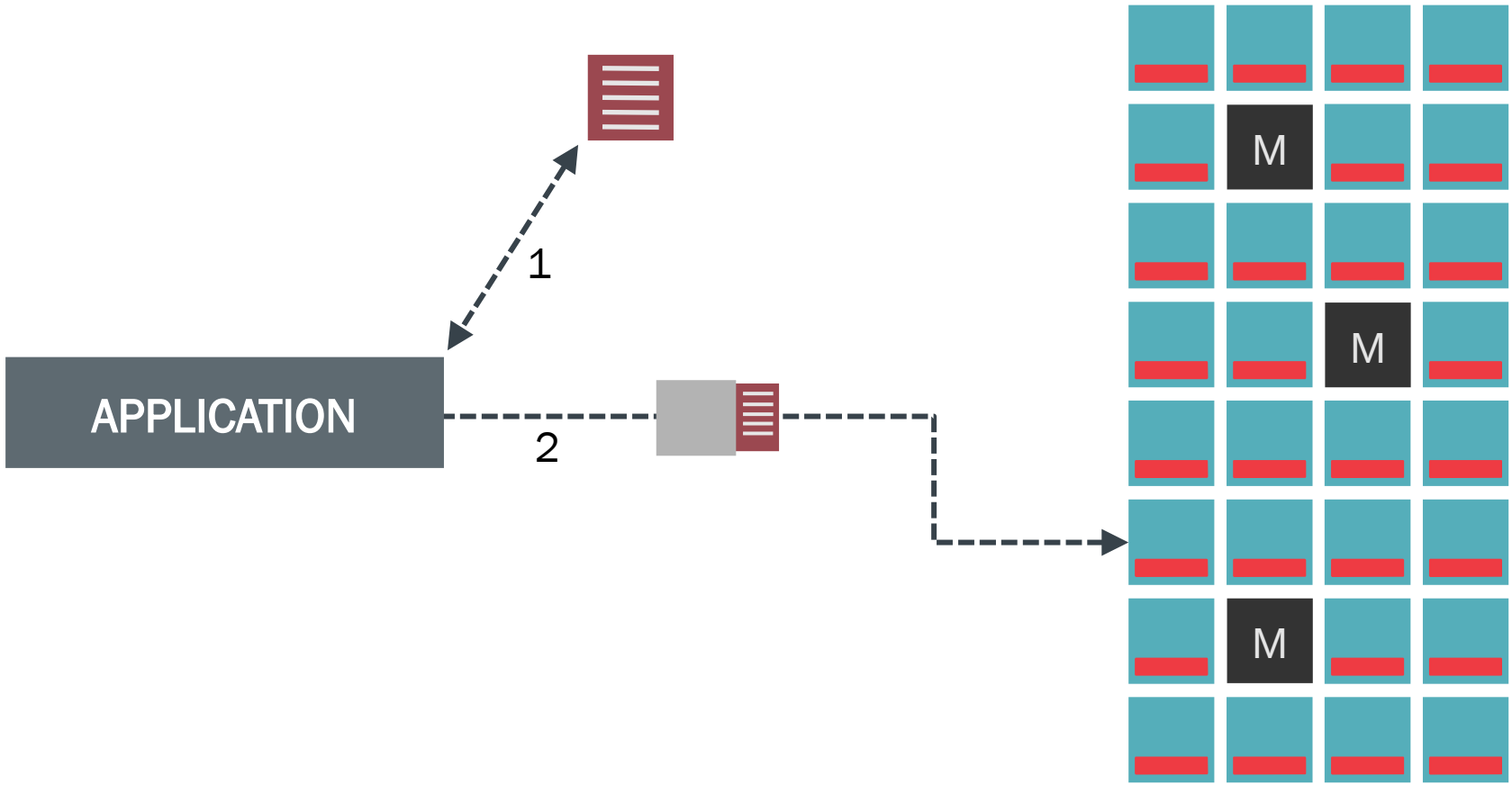
A METADATA SERVER?



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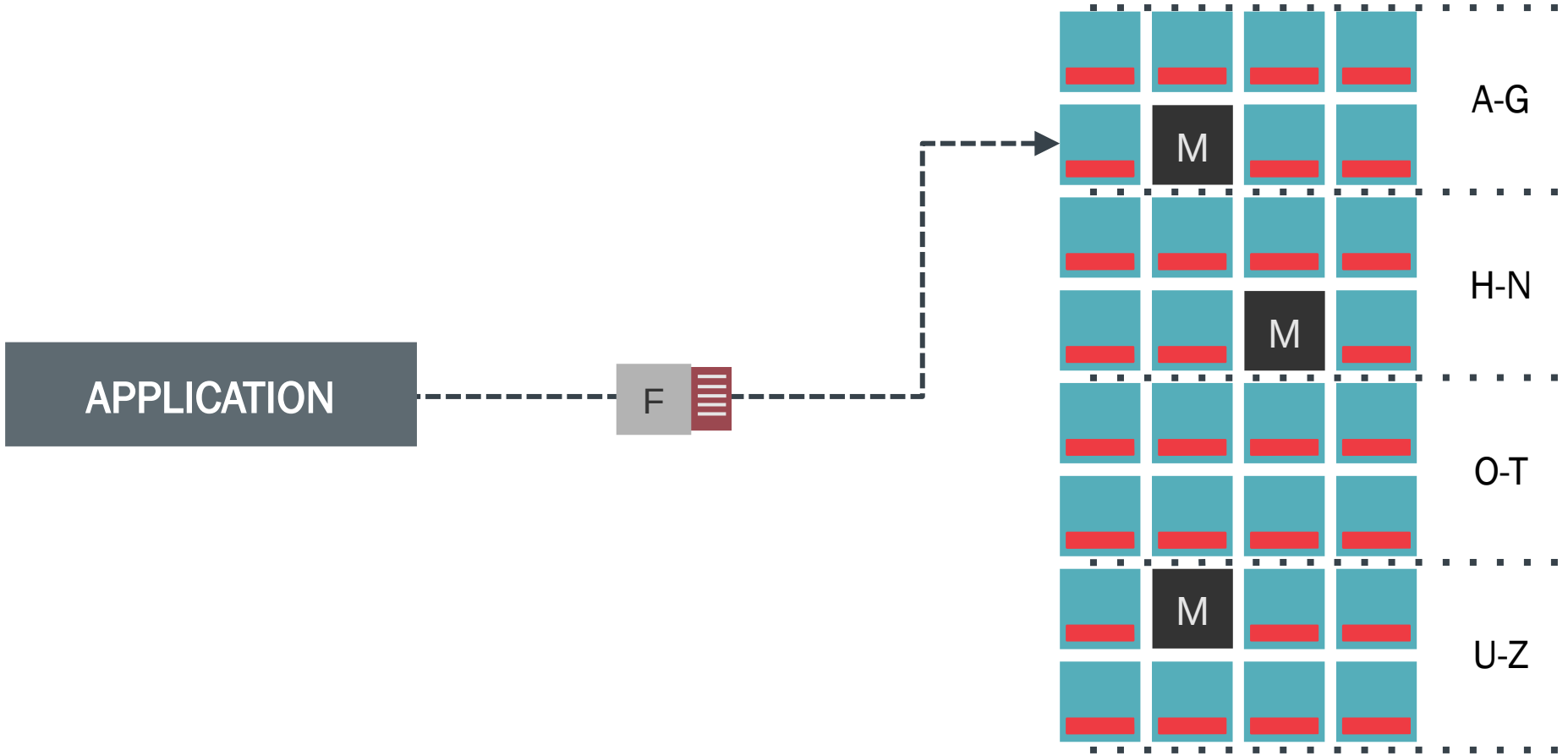
CALCULATED PLACEMENT



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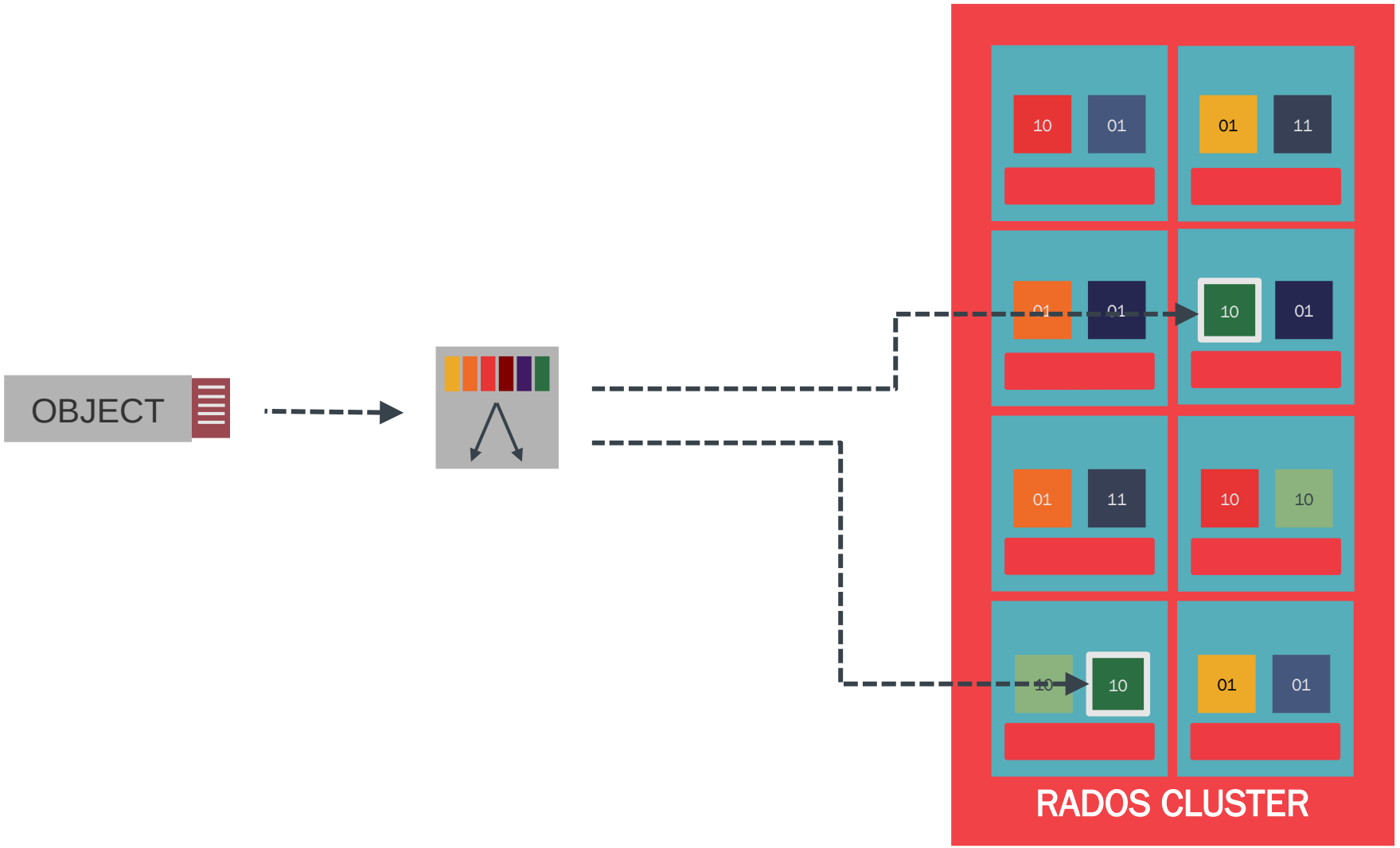
CRUSH IS A QUICK CALCULATION



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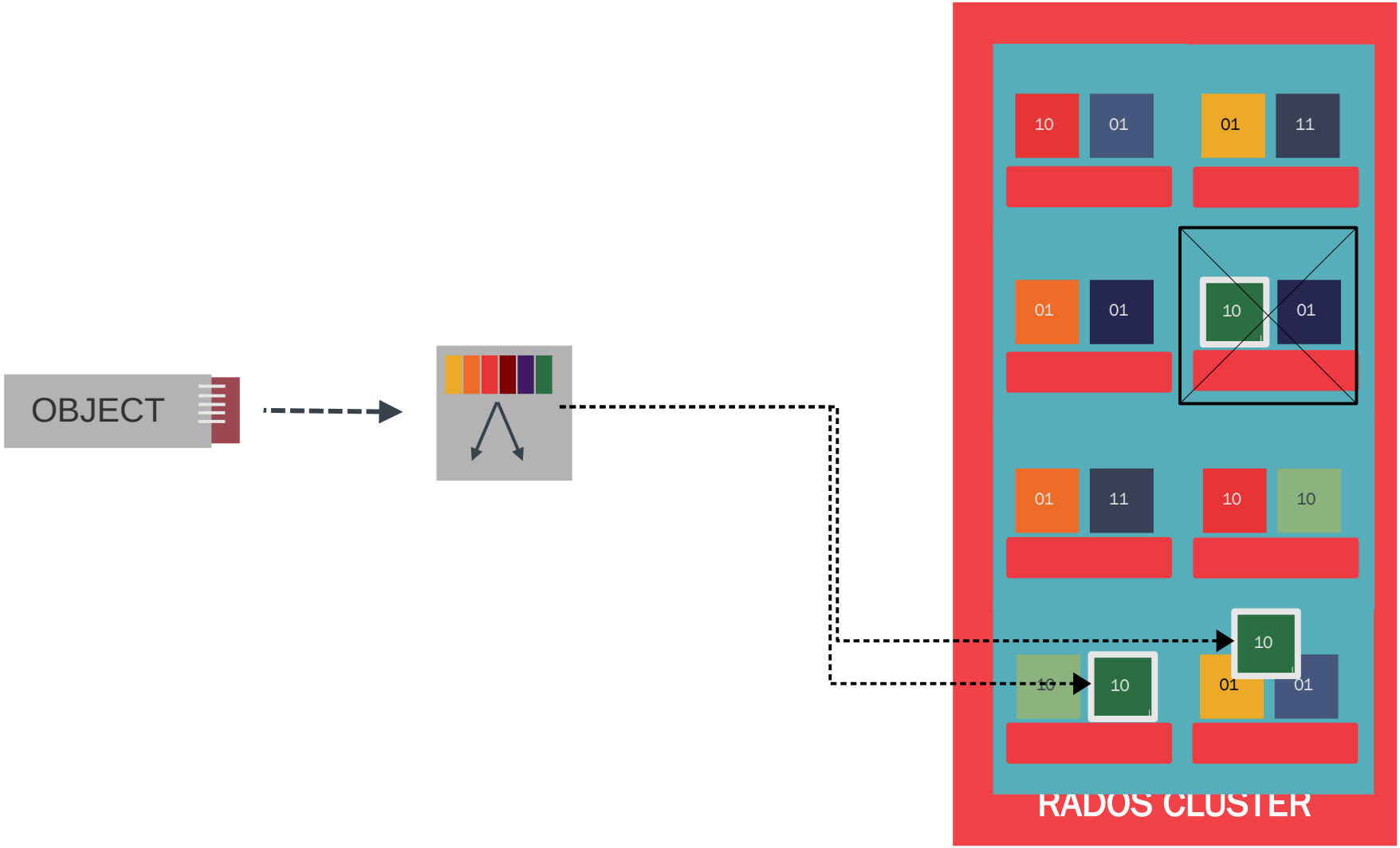
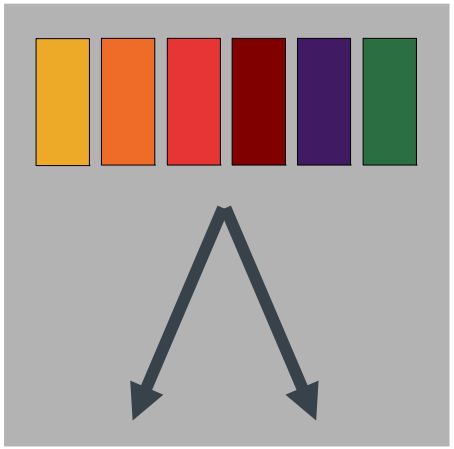
CRUSH AVOIDS FAILED DEVICES



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

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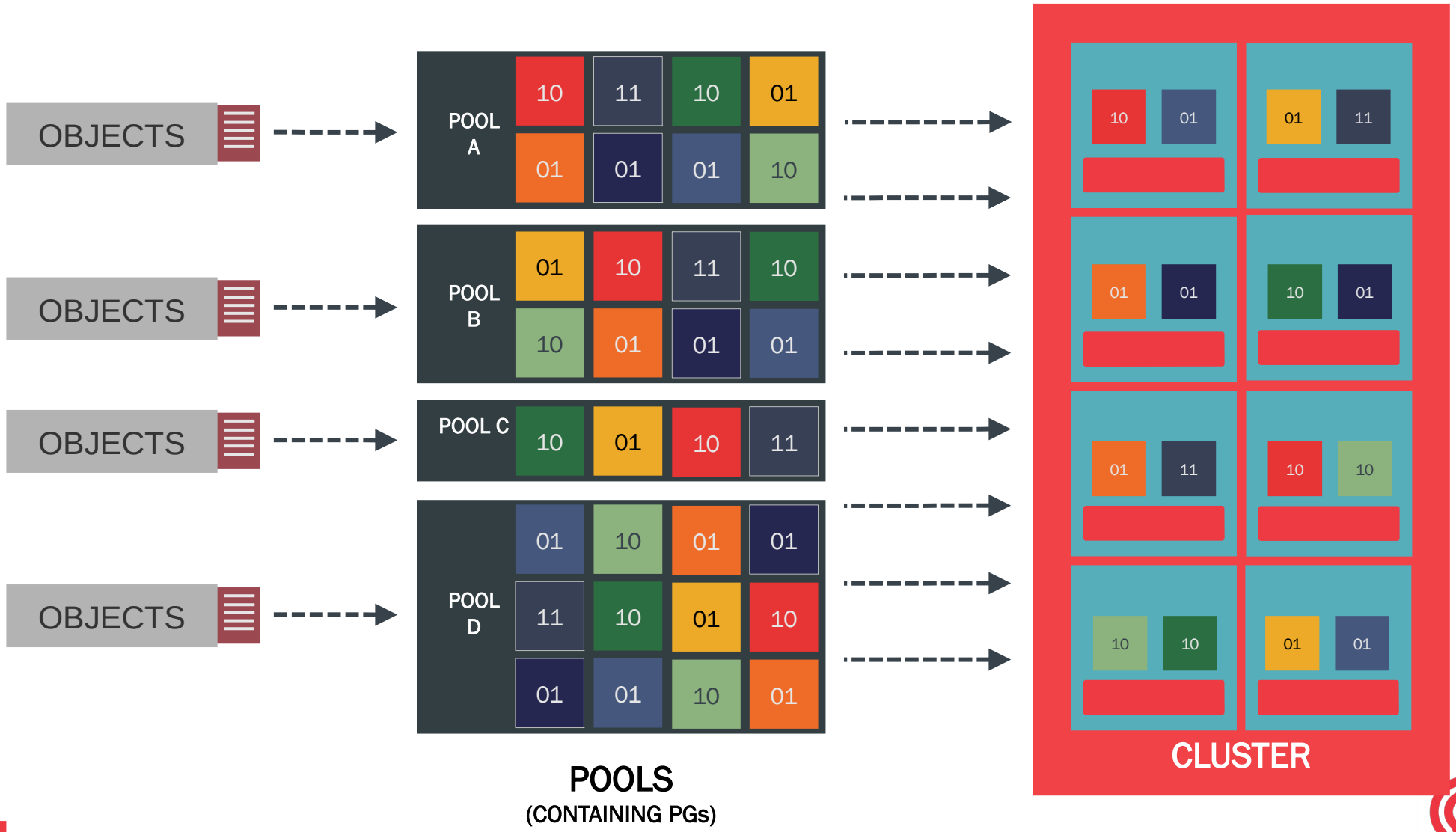
DATA IS ORGANIZED INTO POOLS



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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

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RADOS: FAILURE RECOVERY

- Each OSDMap is numbered with an epoch number
- The Monitors and OSDs store a history of OSDMaps
- Using this history, an OSD which becomes a new member of a PG can deduce every OSD which could have received a write which it needs to know about
- The process of discovering the authoritative state of the objects stored in the PG by contacting old PG members is called **Peering**

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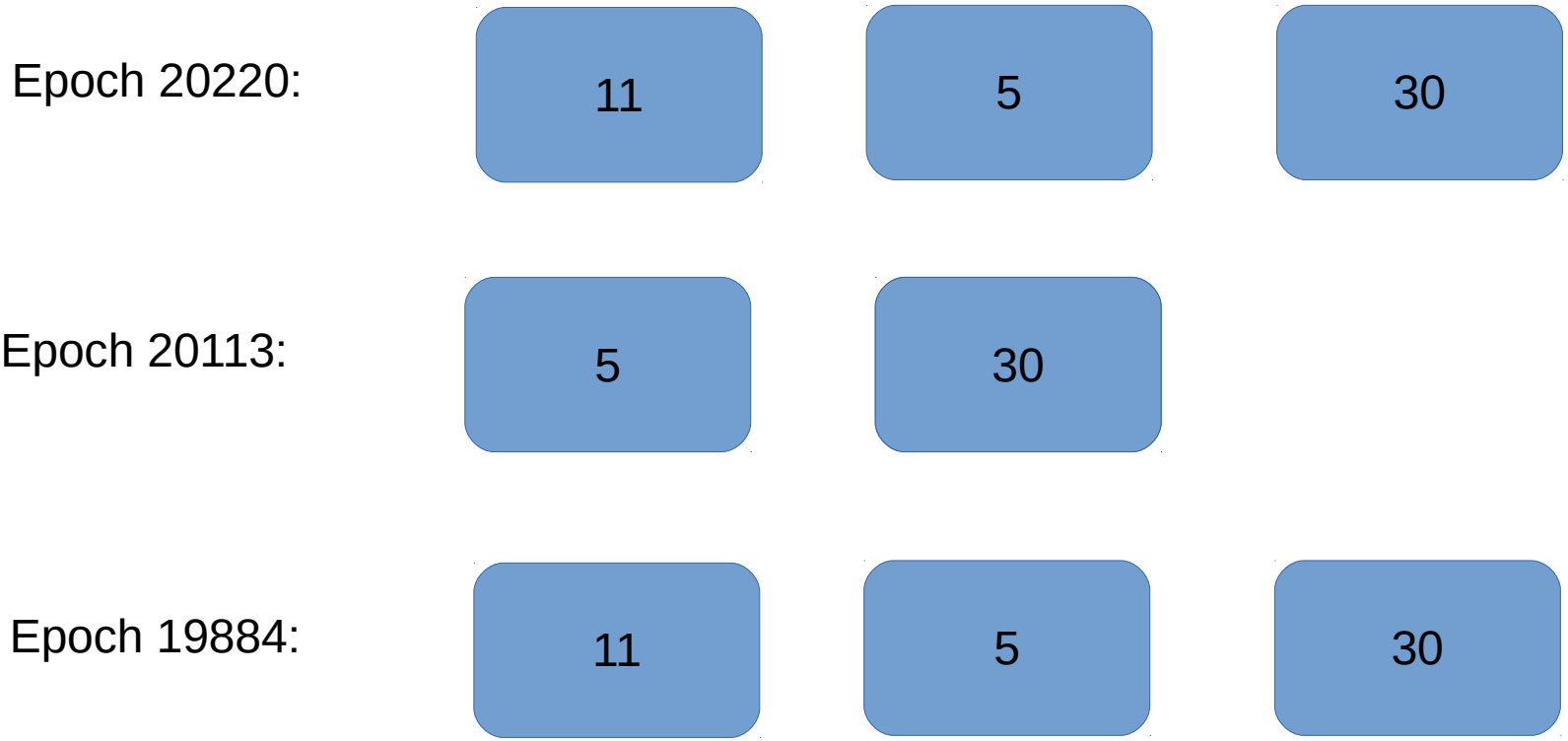
RADOS: FAILURE RECOVERY

RADOS: FAILURE RECOVERY



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)

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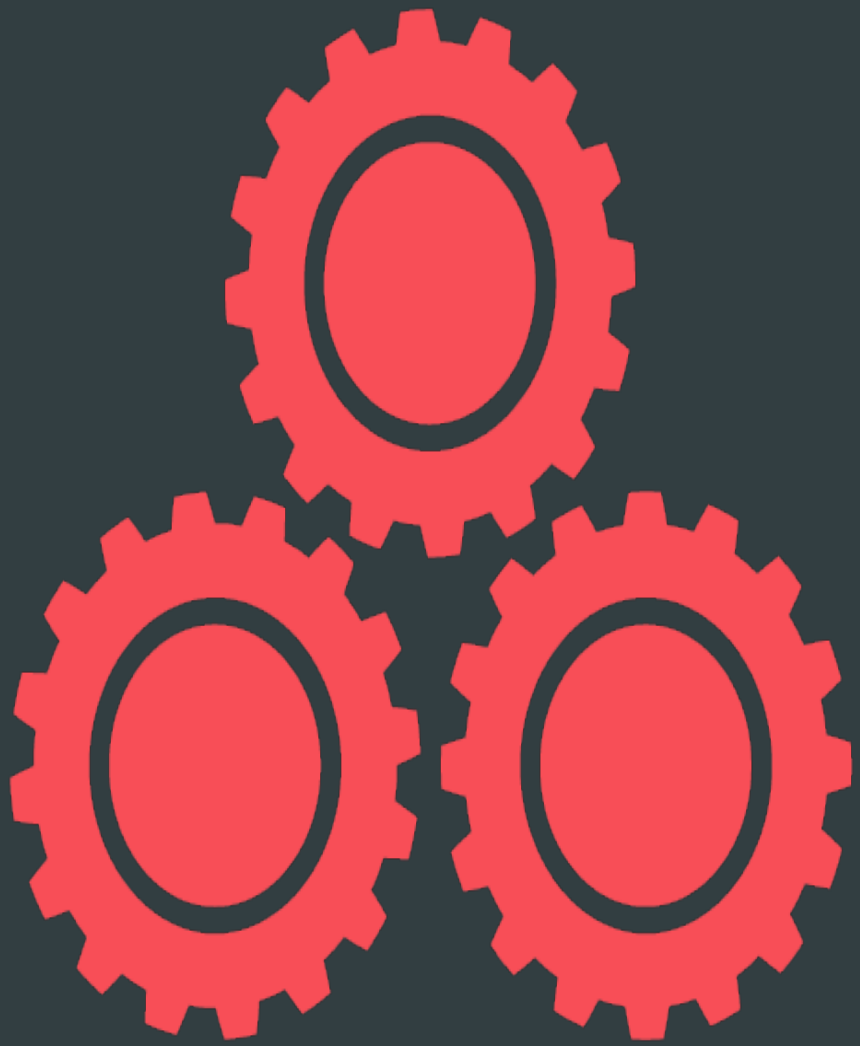
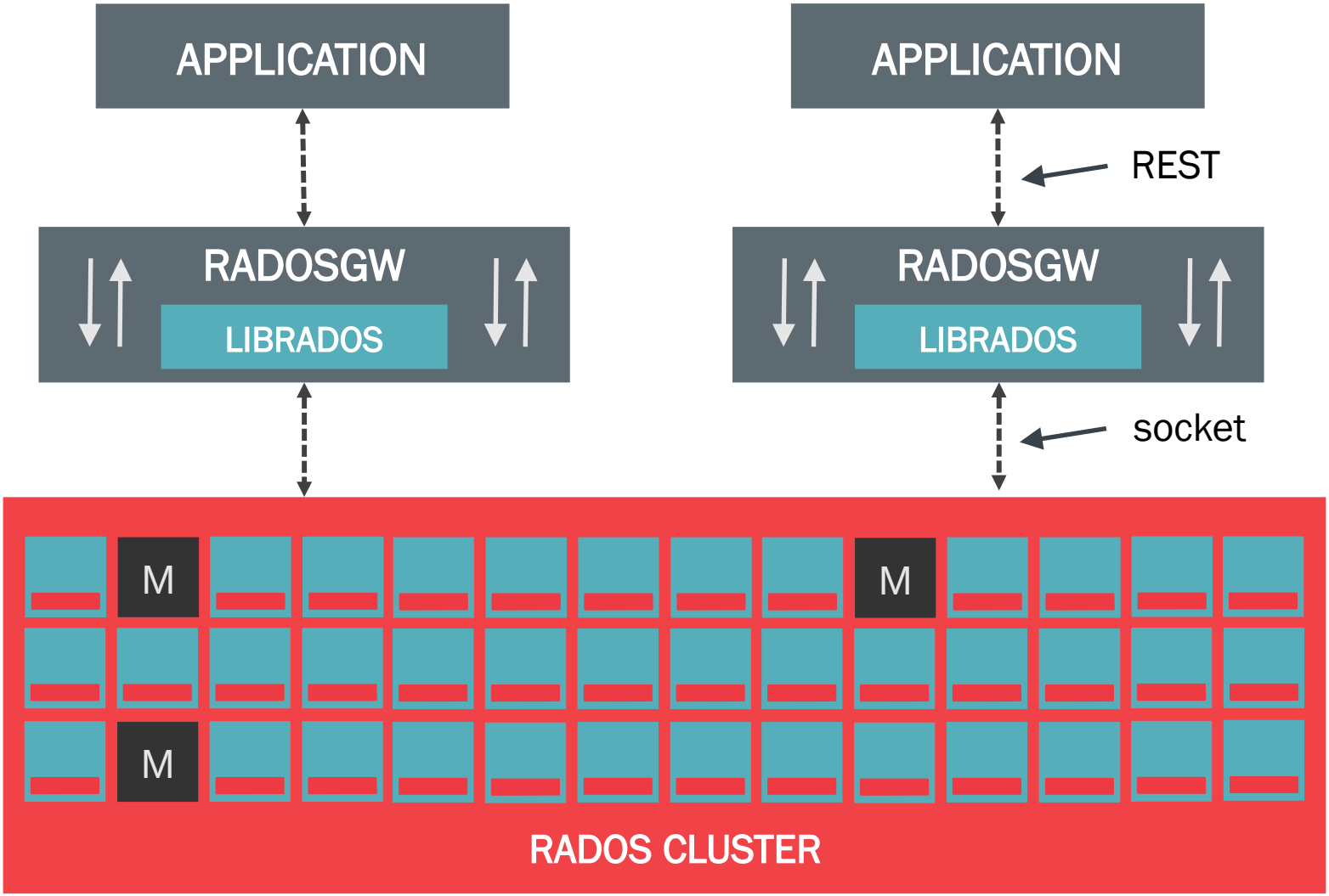


Existing Awesome Ceph Stuff

THE RADOS GATEWAY



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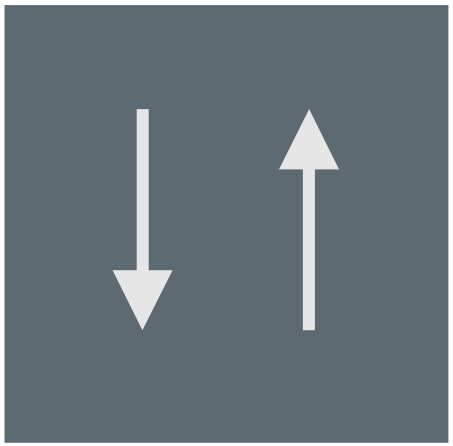
RADOSGW MAKES RADOS WEBBY



RADOSGW:

- REST-based object storage proxy
- Uses RADOS to store objects
- API supports buckets, accounts
- Usage accounting for billing
- Compatible with S3 and Swift applications

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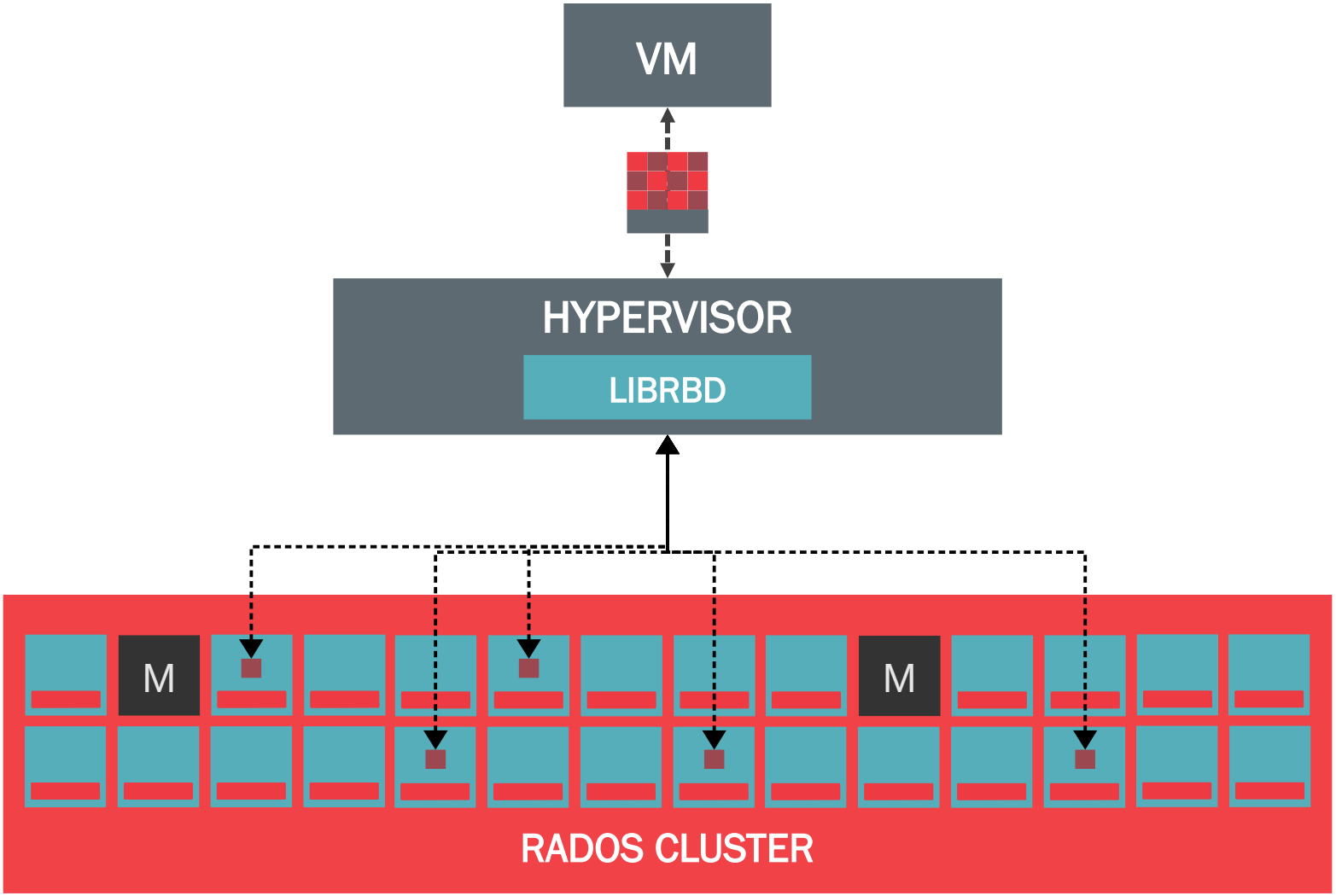
STORING VIRTUAL DISKS



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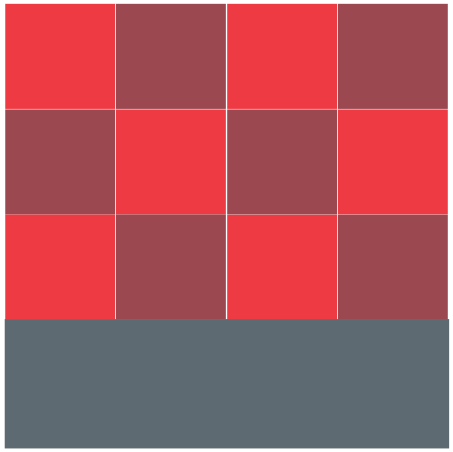
RBD STORES VIRTUAL DISKS



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
  - OpenStack, CloudStack, Nebula, Proxmox

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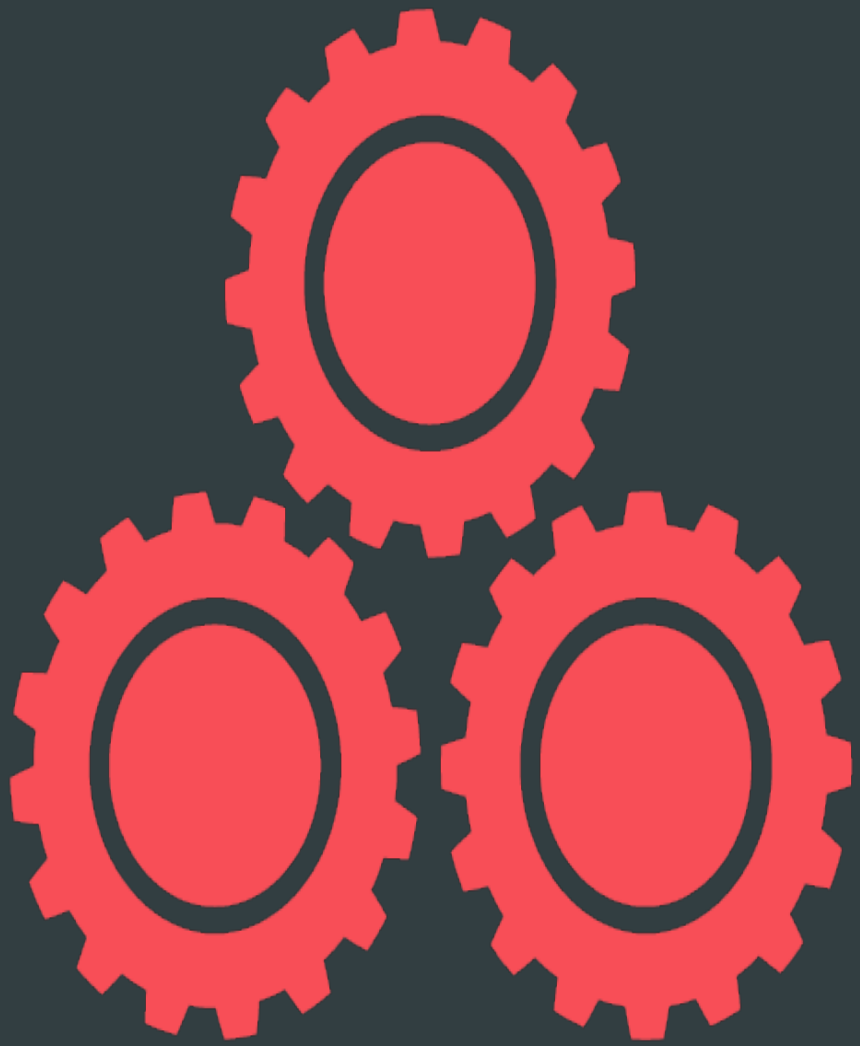
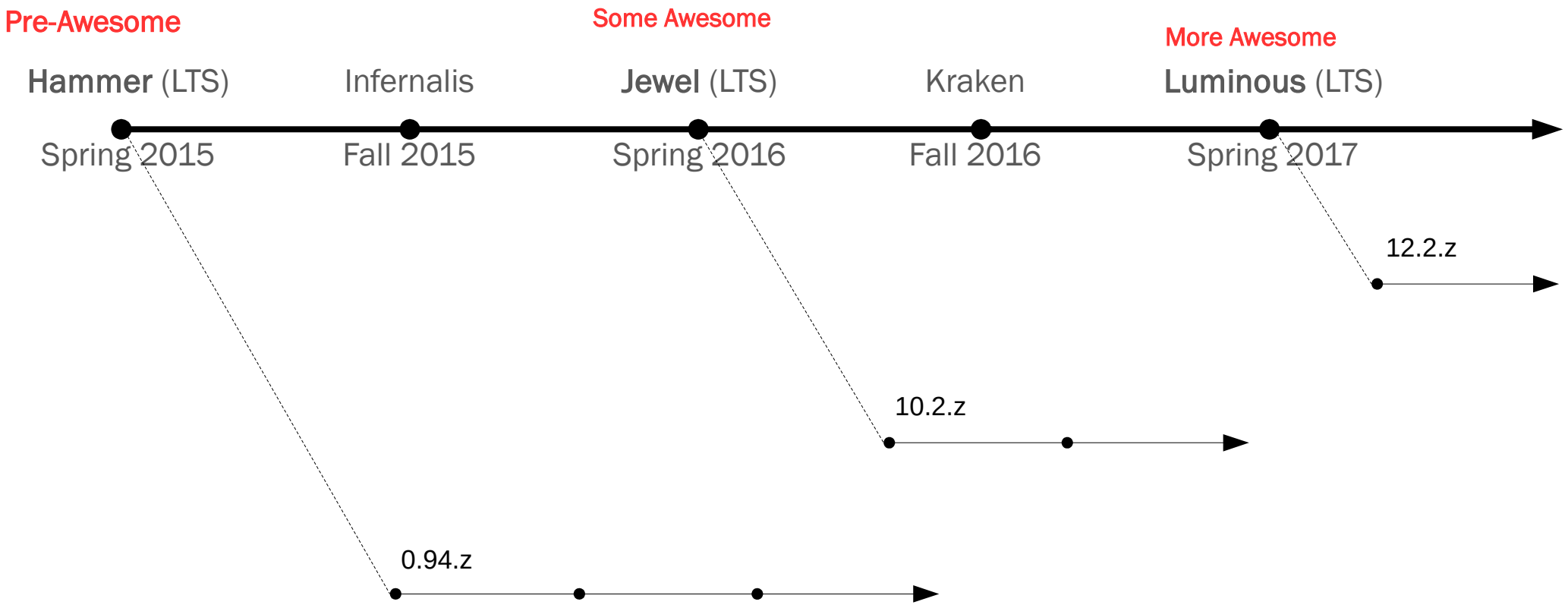
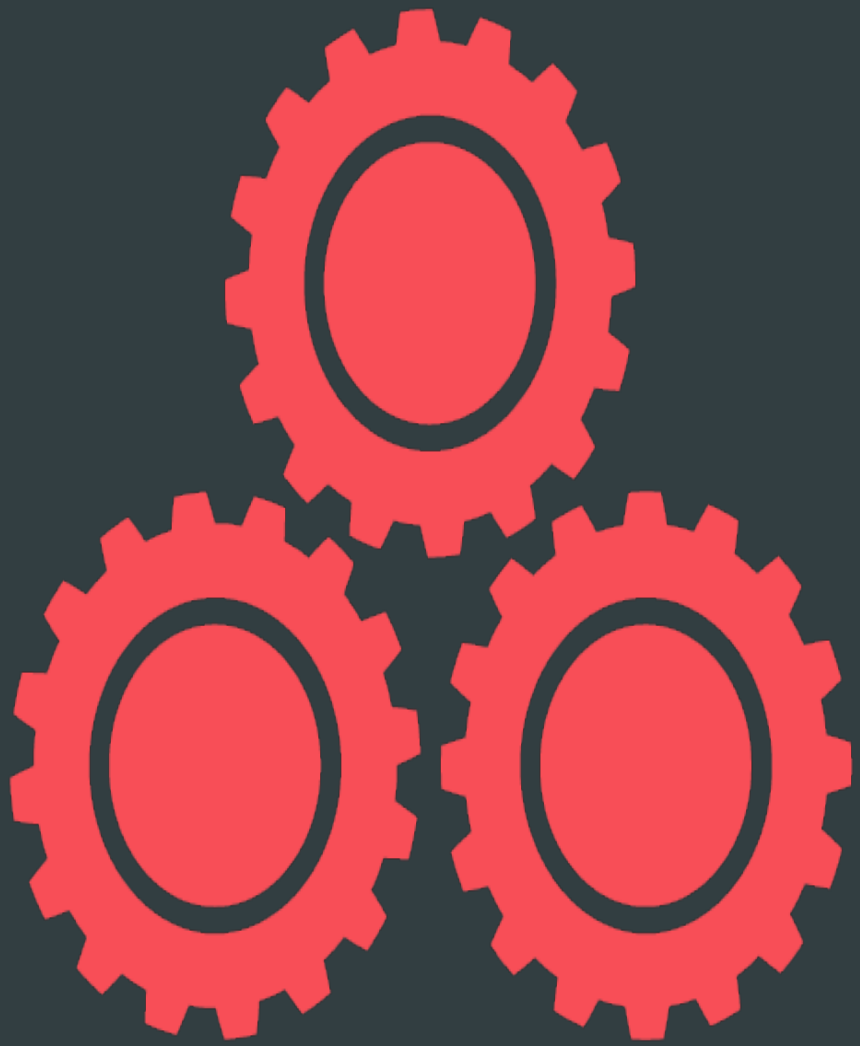


CephFS, The Awesome Parts

Awesomeness Timeline

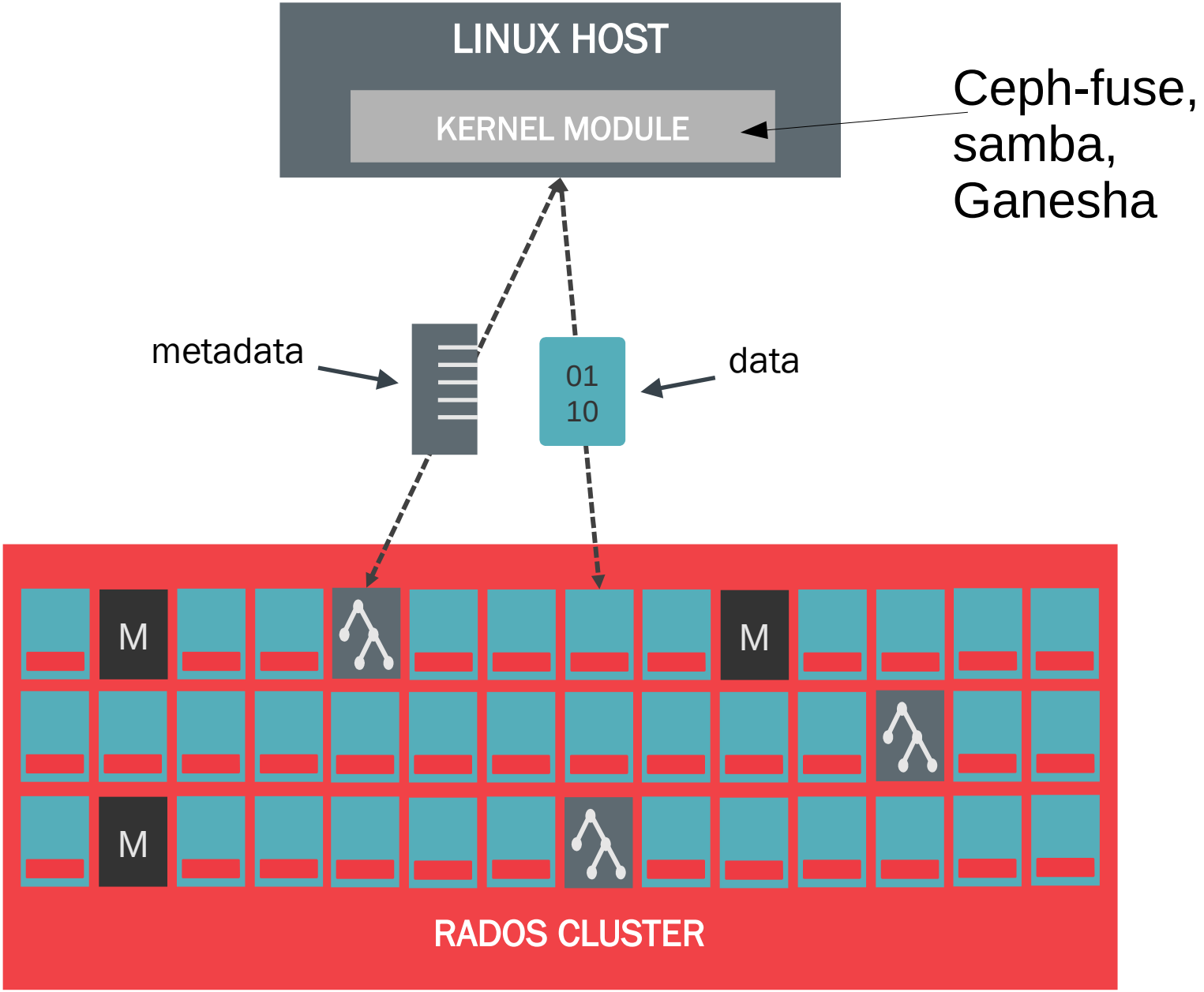




Awesome: It's A Filesystem!

POSIX Filesystem

- Mounting, from multiple clients
  - Not much good without that!
- POSIX-y goodness:
  - Atomic updates
  - Files, with names and directories and rename
- Coherent caching
  - Updates from one node are visible elsewhere, immediately


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

POSIX Filesystem: Consistency

- CephFS has “consistent caching”
- Clients are allowed to cache, and the server invalidates them before making changes
  - This means clients never see stale data of any kind!
  - And there's no opportunity for any kind of split brain situation

POSIX Filesystem: Scaling Data

- All data is stored in RADOS
- Filesystem clients write directly to RADOS

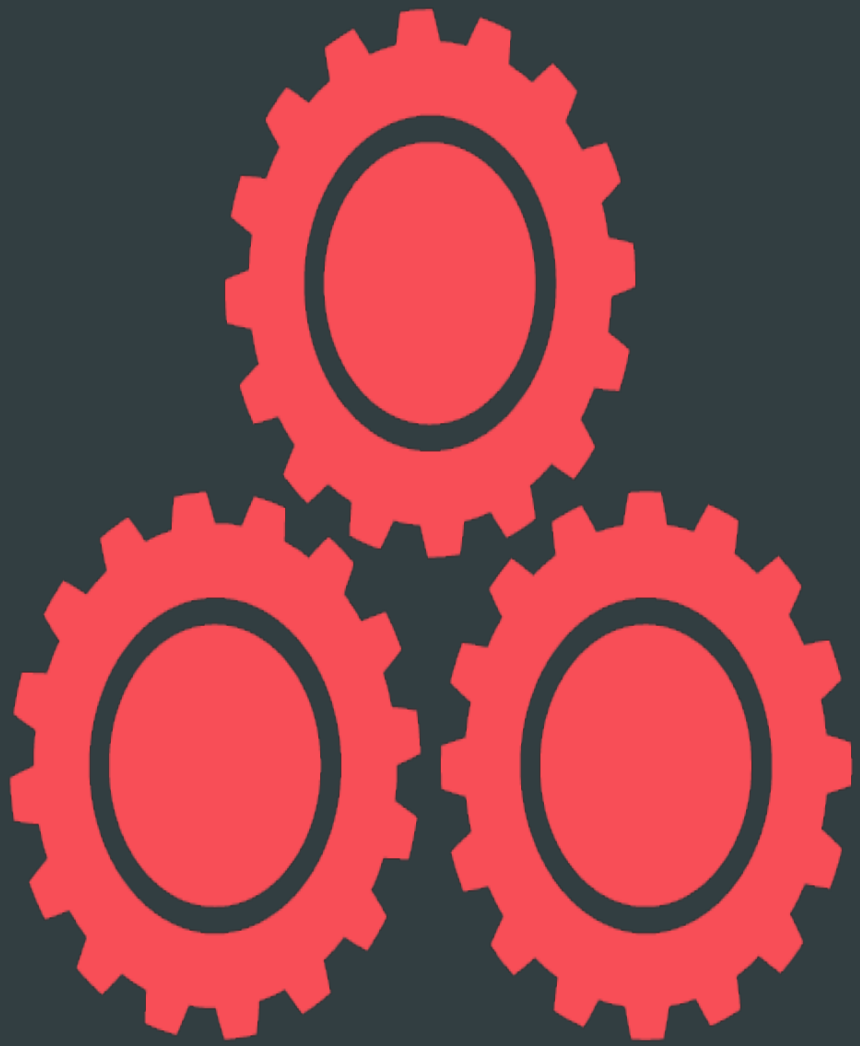
- Need more data space? Add more OSDs!
- Faster throughput?
  - Faster SSDs!
  - Wider striping of files across objects!
  - ...at least, up until you're limited by latency instead of throughput

POSIX Filesystem: Scaling Metadata

- Only **active** metadata is stored in memory
- Size your metadata server (MDS) by active set size, not total metadata

rstats are cool

```
# ext4 reports dirs as 4K

ls -lhd /ext4/data

drwxrwxr-x. 2 john john 4.0K Jun 25 14:58
/home/john/data


# cephfs reports dir size from contents

$ ls -lhd /cephfs/mydata

drwxrwxr-x. 1 john john 16M Jun 25 14:57 ./mydata
```



Awesome: A Security Model

CephX security capabilities

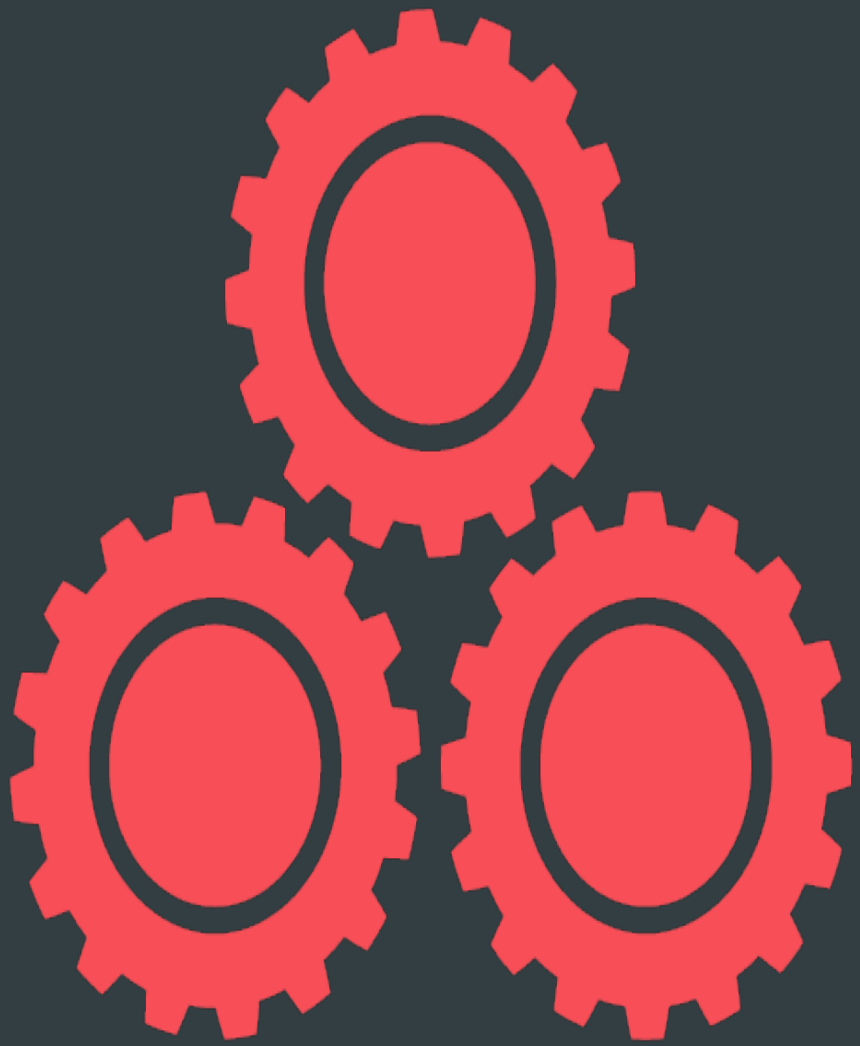
- Clients start out unable to access the MDS.
  - Incrementally granted permissions for subtrees (or the whole tree)
  - To act as a specific user
  - Etc
- For real security, these must be coordinated with OSD caps:

```
ceph auth get-or-create client.foo \
  mds “allow rw path=/foodir” \
  osd “allow rw pool=foopool” \
  mon “allow r”
```

CephX security capabilities: Protection

- The security capabilities are encrypted by the server; can't be changed by client
- MDS only examines MDS grants
  - Protects against acting as an unauthorized user
  - Prevents all access to inodes/dentries not under granted path
- OSDs independently examine OSD grants
  - Protects against access to unauthorized pools and namespaces

- Possible hole: if clients share namespace+pool, they can trample on raw file data
  - If you don't trust your clients, give them each their own namespace (free for RADOS) and specify it in CephFS layout for their directory hierarchy



Awesome: Hot standby MDS

Standby servers

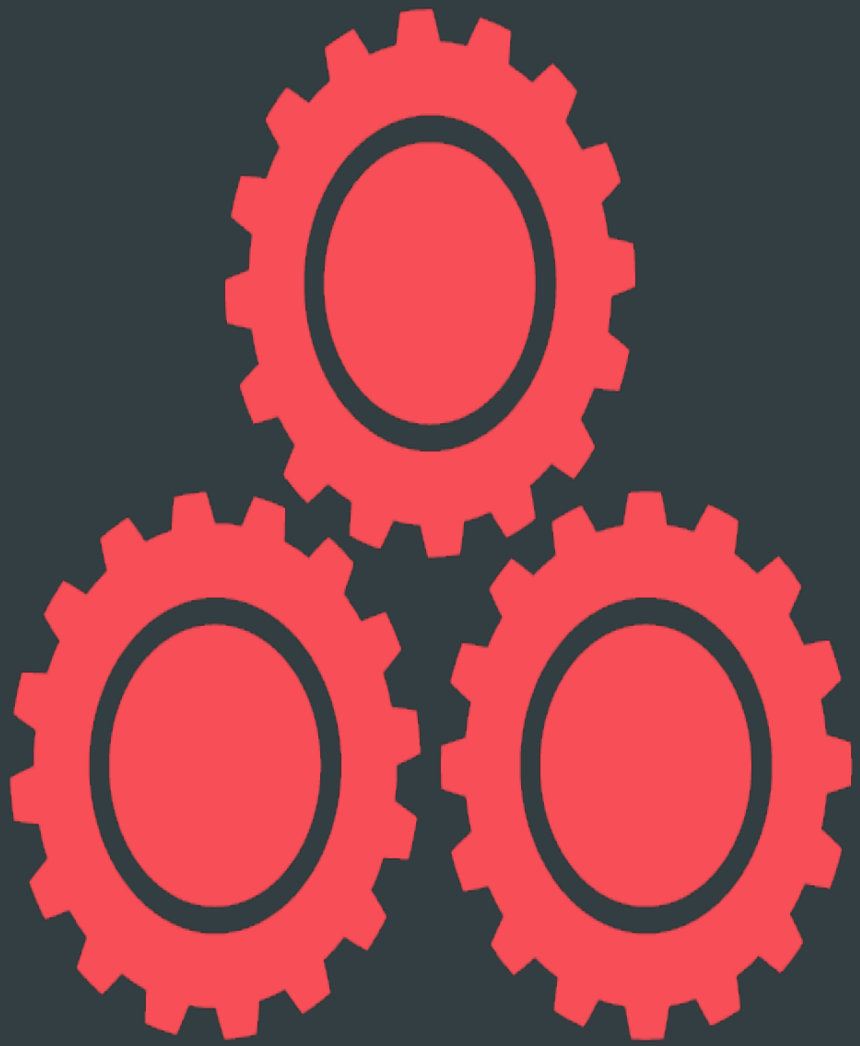
- Nothing ties metadata to a particular server!

- Spin up an arbitrary number of “standby” and “standby-replay” servers
  - Standby: just waiting around; can be made active
  - Standby-replay: actively replaying the MDS log
    - Warms up the cache for fast takeover

rename /tmp/file1 -> /home/greg/foo
rename /tmp/file2 -> /home/greg/bar
create /home/greg/baz

Standby servers: reconnect

- Replay log, load all necessary file data from RADOS
- Let clients replay uncommitted operations, process them
- Synchronize caching states between clients and MDS
- Go active!



Mostly Awesome: Scrub/Repair

Forward Scrub

- Forward scrubbing, to ensure consistency

ceph daemon mds.<id> scrub_path

ceph daemon mds.<id> scrub_path recursive

ceph daemon mds.<id> scrub_path repair

ceph daemon mds.<id> tag path

- You have to run this manually right now, no automatic background scrub :(
  - Fix: targeted for Luminous! With multi-MDS support!

Repair tools: cephfs-journal-tool

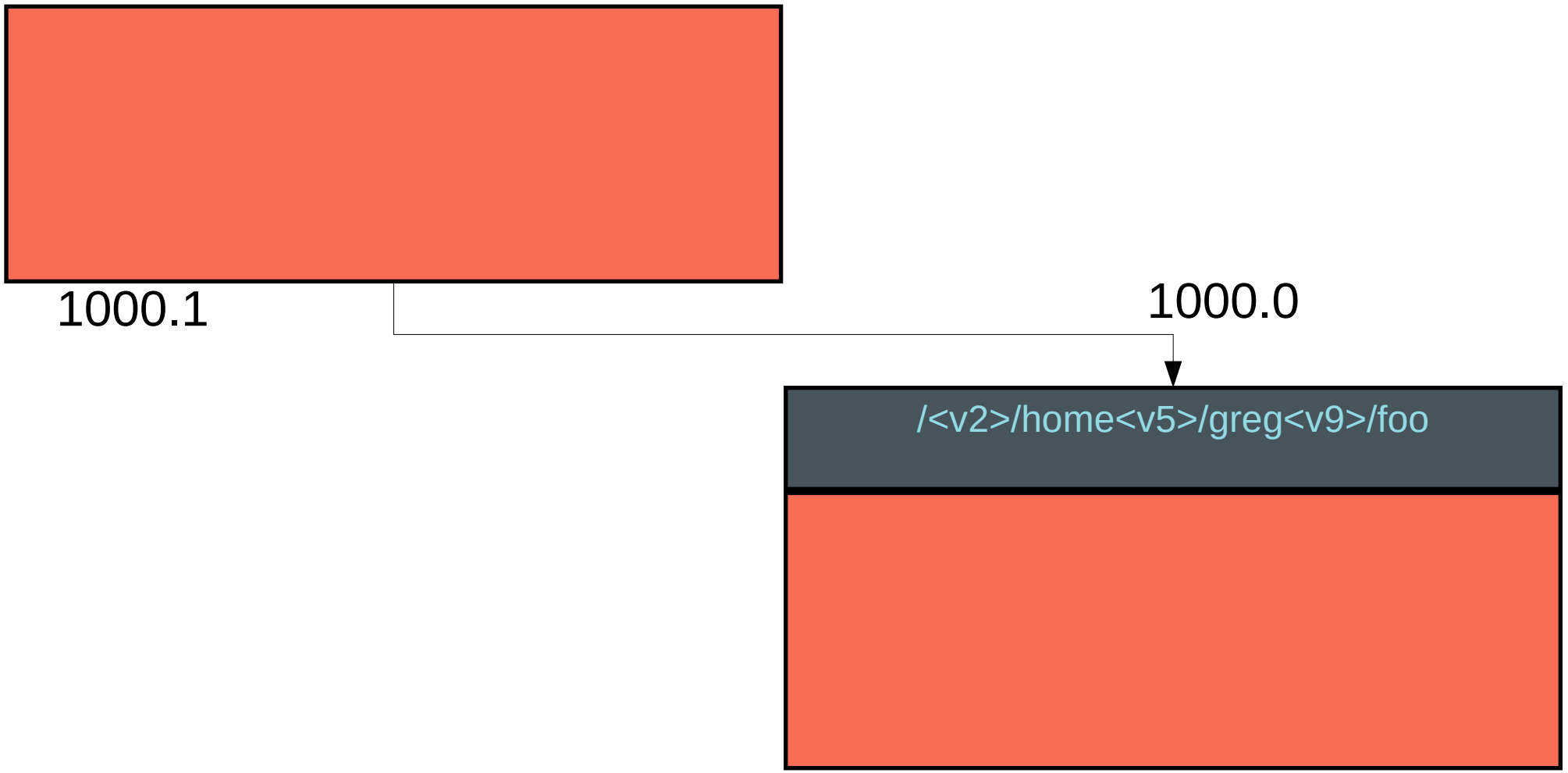
- Disaster recovery for damaged journals:
  - inspect/import/export/reset
  - header get/set
  - event recover_dentries
- Allows rebuild of metadata that exists in journal but is lost on disk
- Companion **cephfs-table-tool** exists for resetting session/inode/snap tables as needed afterwards.

Repair tools: cephfs-data-scan

- “Backwards scrub”
- Iterate through all RADOS objects and tie them back to the namespace
- Parallel workers, thanks to new RADOS functionality
  - cephfs-data-scan scan_extents
  - cephfs-data-scan scan_inodes

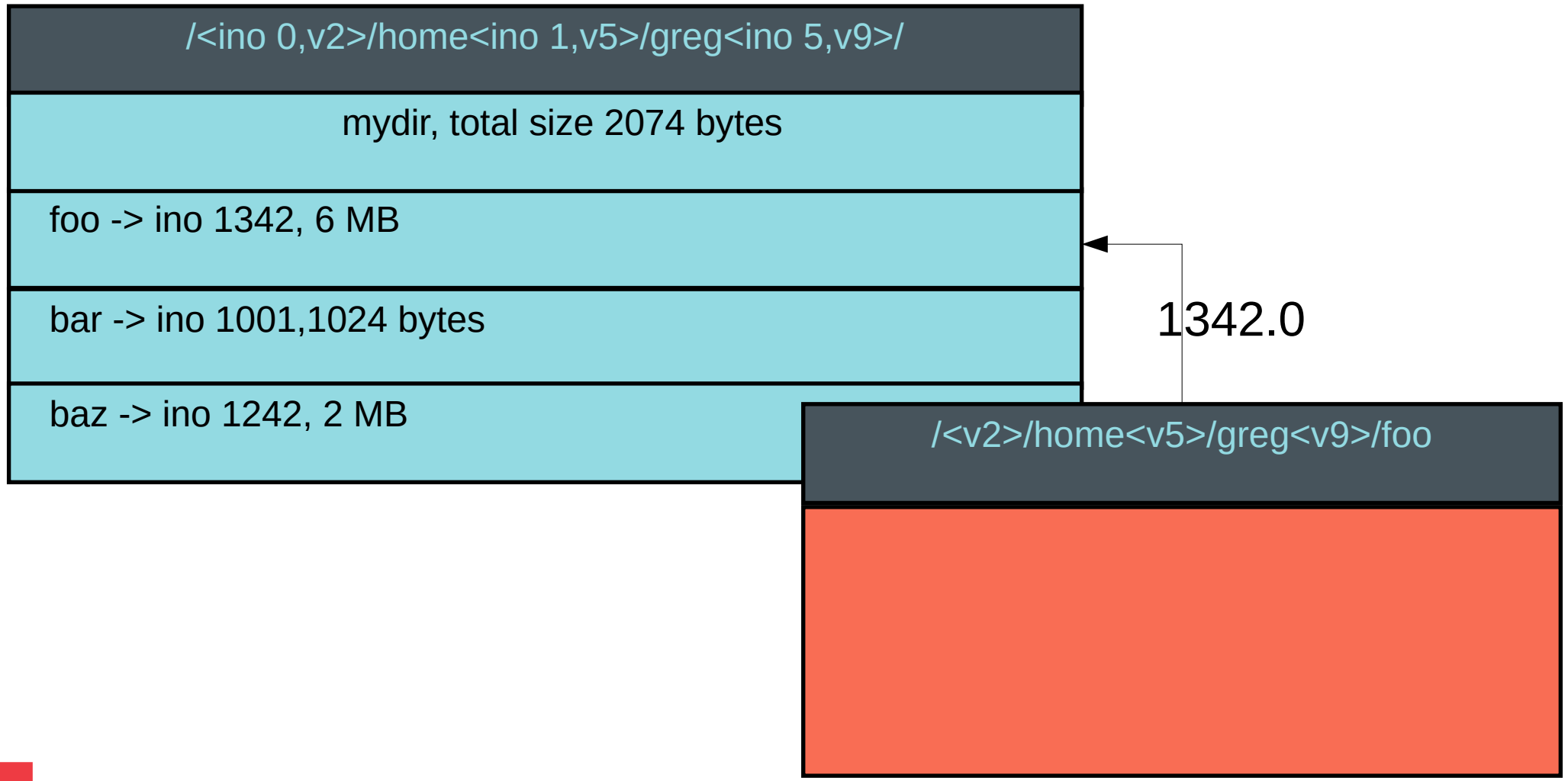
Repair tool methods

- Examine object names and send inferred stat info to “root” object



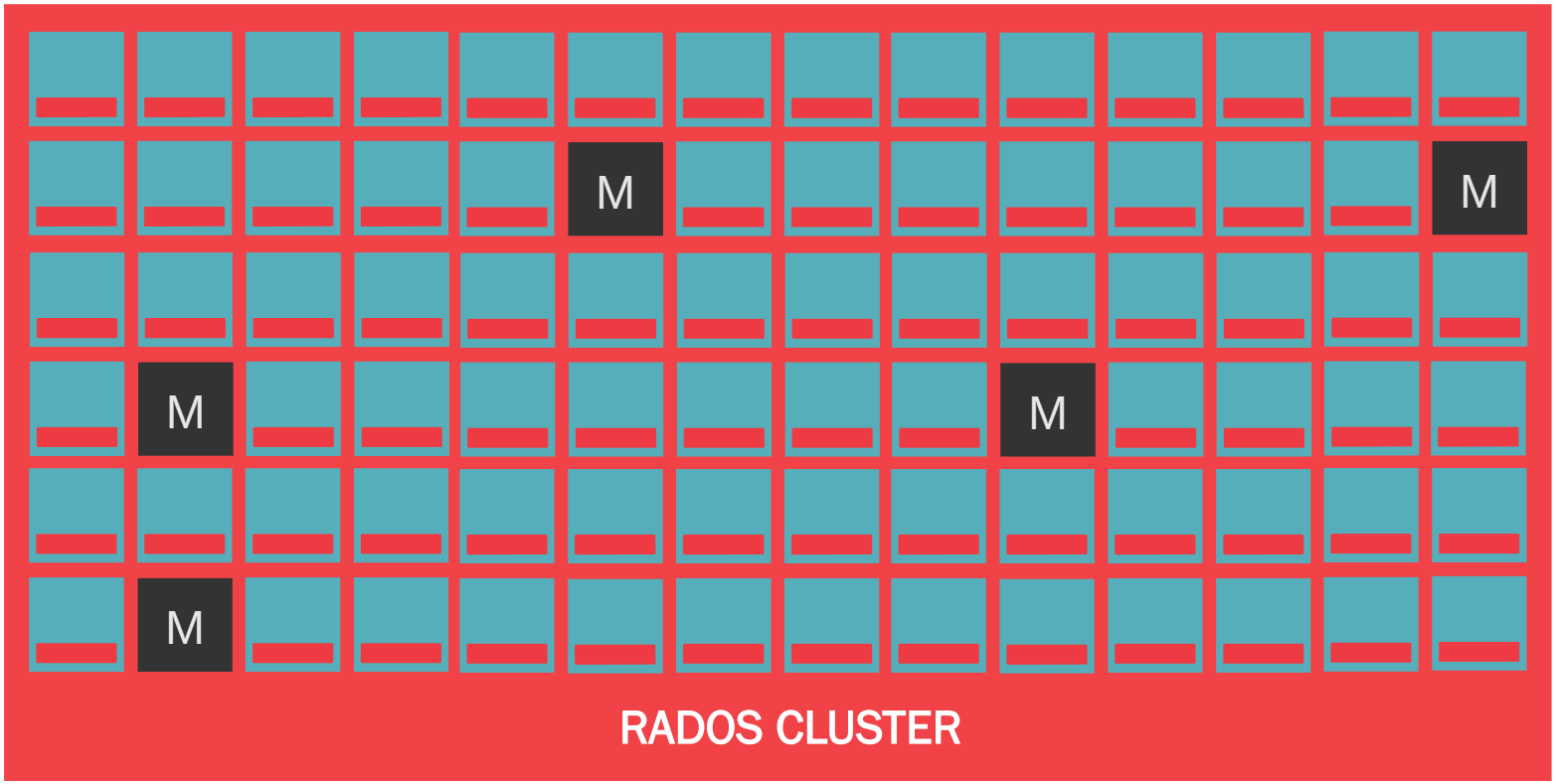
Repair tool methods

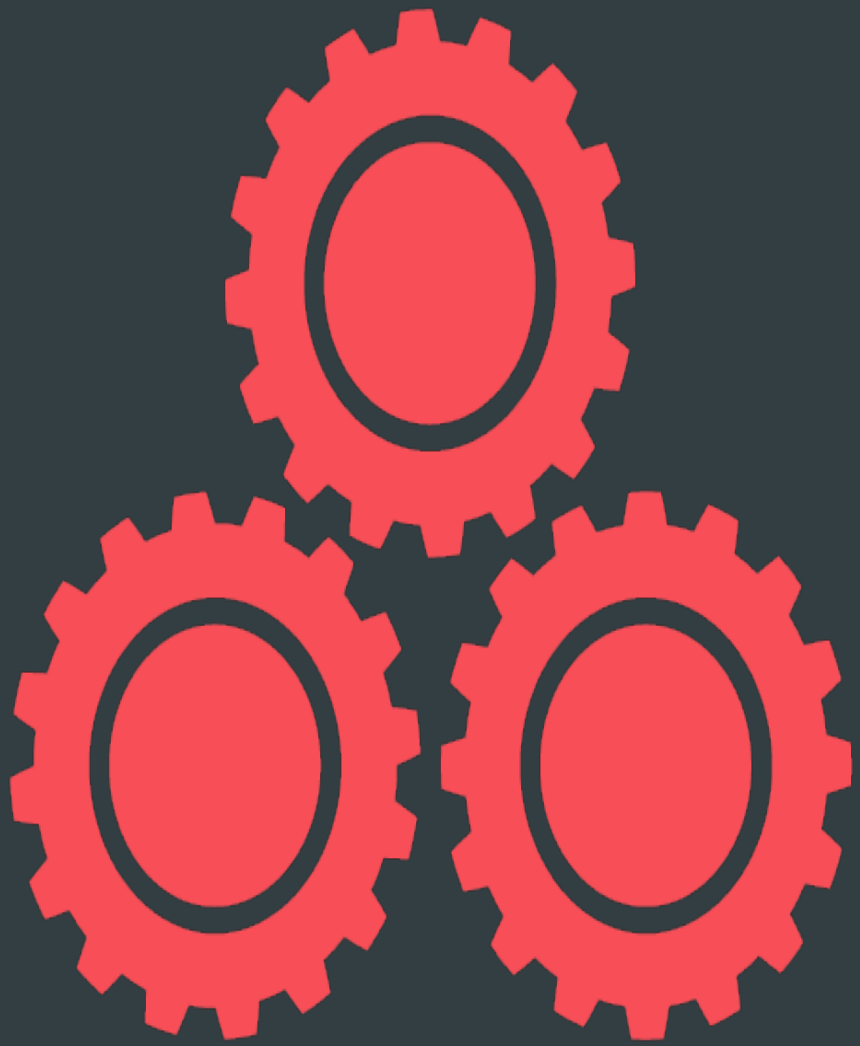
- Assemble tree information from backtrace and inferred stat



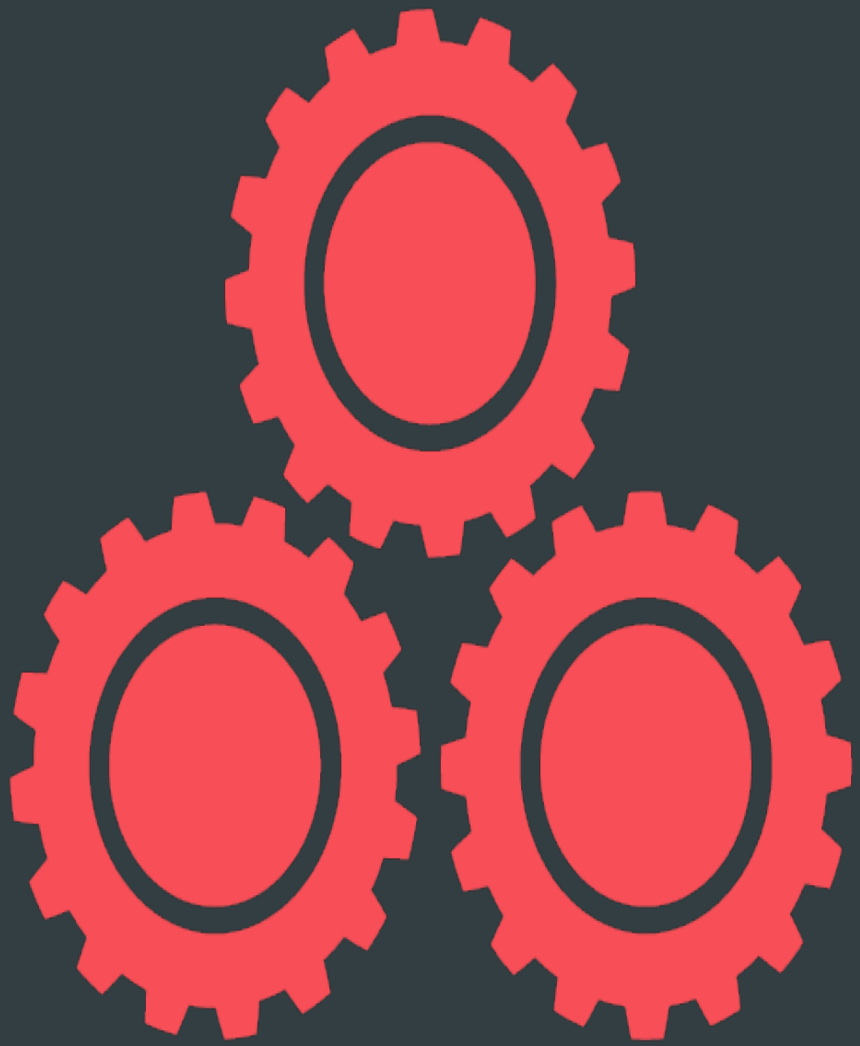
Repair tool methods

- Do inference and then insertion in parallel across the cluster





CephFS: The Parts You Don't Get



Almost Awesome: Directory Frags

Directory Fragmentation

- Directories are generally loaded from disk as a unit
  - But sometimes that's too much data at once!
  - Or you want to spread a hot directory over many active MDSes

/<ino 0,v2>/home<ino 1,v5>/greg<ino 5,v9>/	/<ino 0,v2>/home<ino 1,v5>/greg<ino 5,v9>/
Mydir[01], total size 7MB	Mydir[10], total size 8MB
foo -> ino 1342, 4 MB	hi -> ino 1000, 6 MB
bar -> ino 1001, 1024 KBytes	hello -> ino 6743, 1024 KB
baz -> ino 1242, 2 MB	whaddup -> ino 9872, 1 MB

Directory Fragmentation: What's Short

- It's not well-tested
  - Just need to do the QA work
  - Expected in Luminous

/<ino 0,v2>/home<ino 1,v5>/greg<ino 5,v9>/	/<ino 0,v2>/home<ino 1,v5>/greg<ino 5,v9>/
Mydir[01], total size 7MB	Mydir[10], total size 8MB
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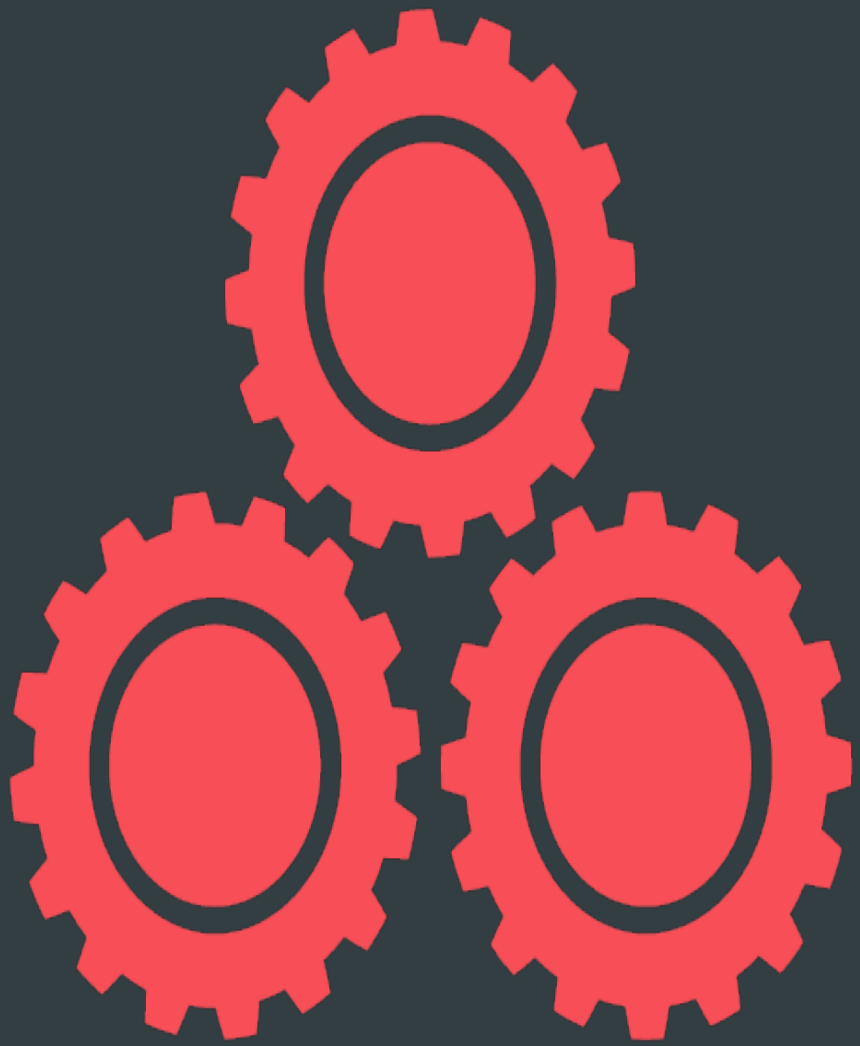
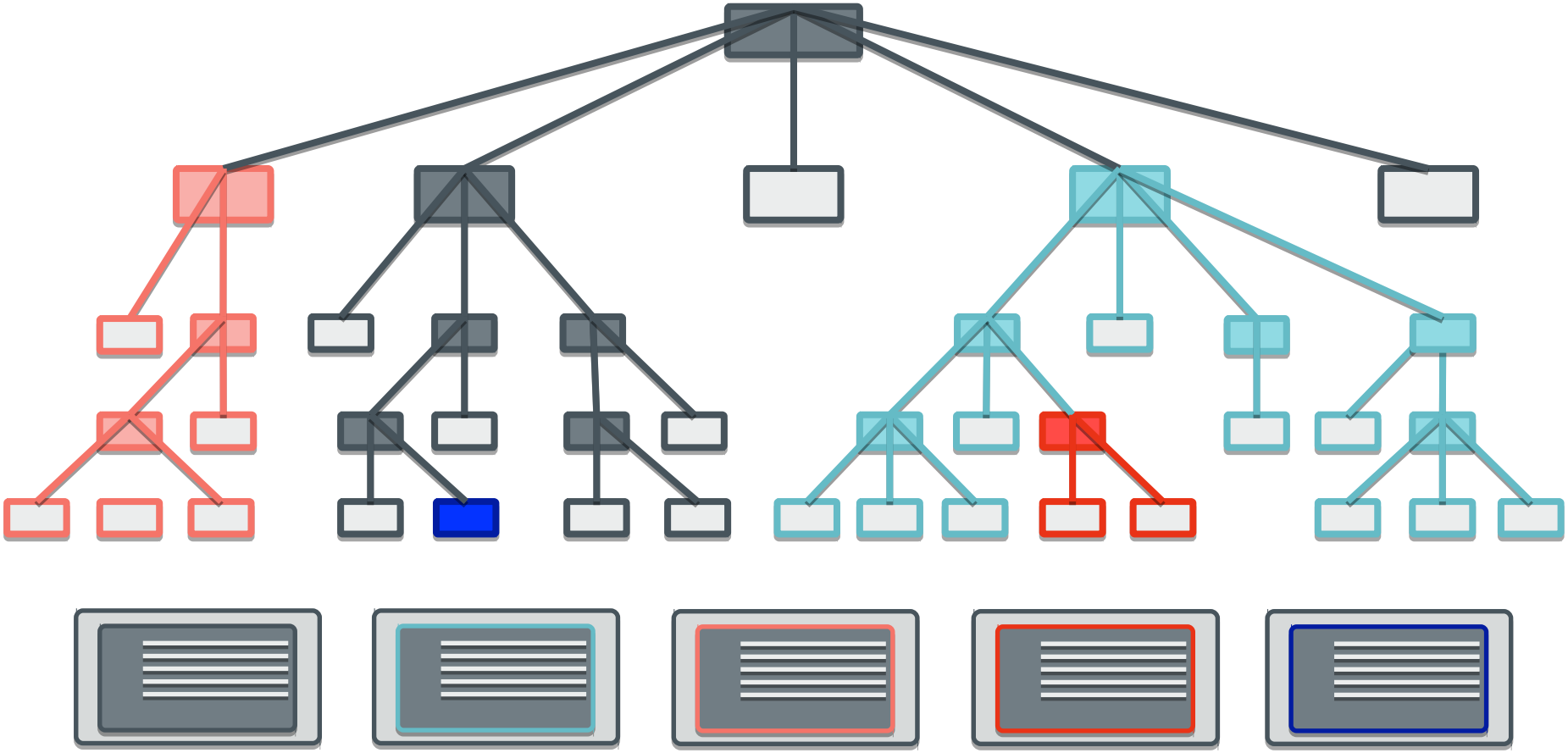


Almost Awesome: Active Multi-MDS

Active Multi-MDS

- Because no metadata is stored on MDS servers, migrating it is "easy"!



Active Multi-MDS

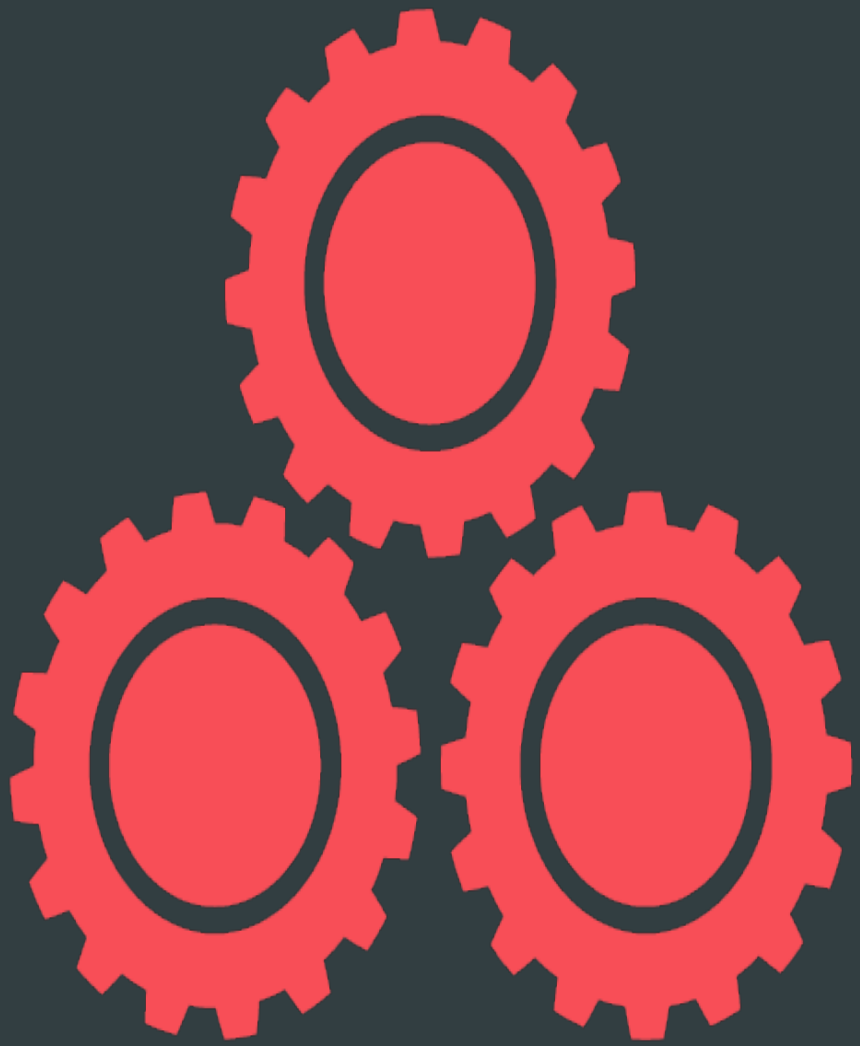
Cooperative Partitioning between servers:

- Keep track of how hot metadata is
- Migrate subtrees to keep heat distribution similar
  - Cheap because all metadata is in RADOS
- Maintains locality

Active Multi-MDS: What's short

- MDS failure/recovery in general is more complicated with >1 active MDS
  - The coding is detailed and takes time to get right
- Testing
- Targeted for Luminous

  ...but we'll see



Almost Awesome: Snapshots

Snapshots: Disk Data Structures

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

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

Snapshots

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

1342.0/1

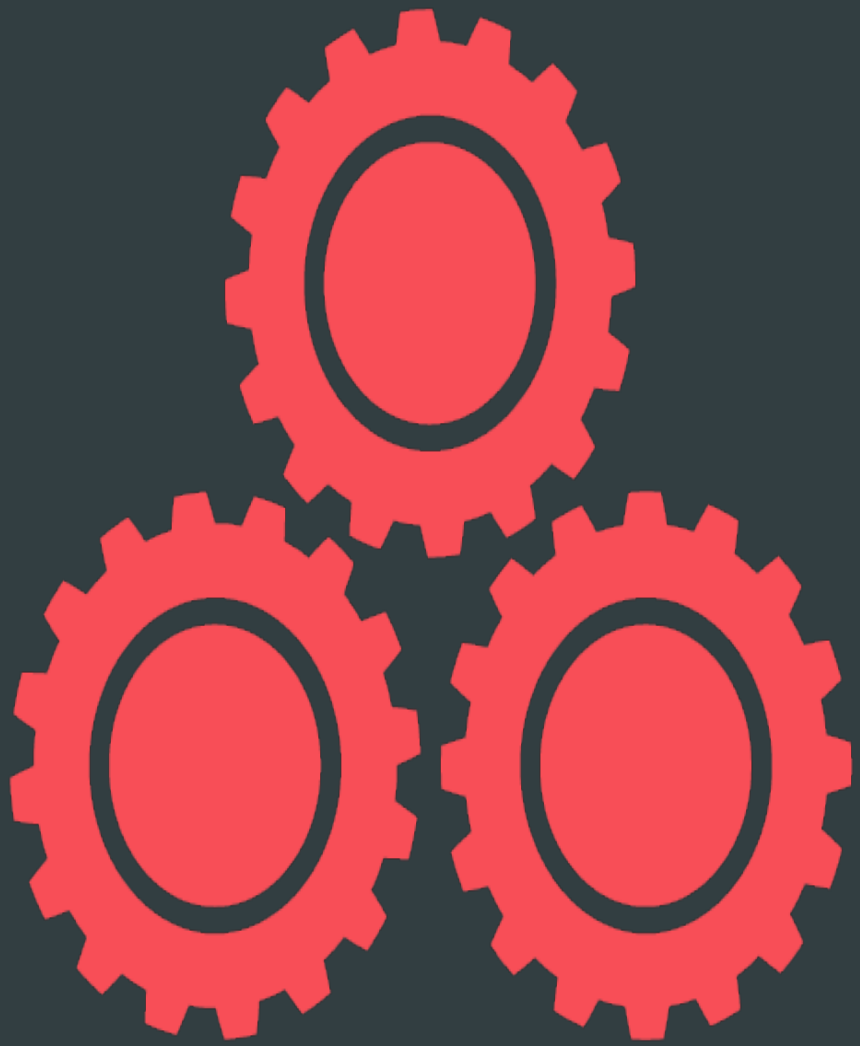
/<v1>/home<v3>/greg<v7>/foo

1342.0/HEAD

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

Snapshots: What's Short

- Testing. So much testing.
- The exciting combinatorial explosion of tracking all this across different metadata servers!
  - Much of this exists; it's incomplete in various ways
  - As always, recovering from other failures which impact our state transitions
- Targeted for after Luminous
  - It works pretty well on single-MDS systems, but that’s boring



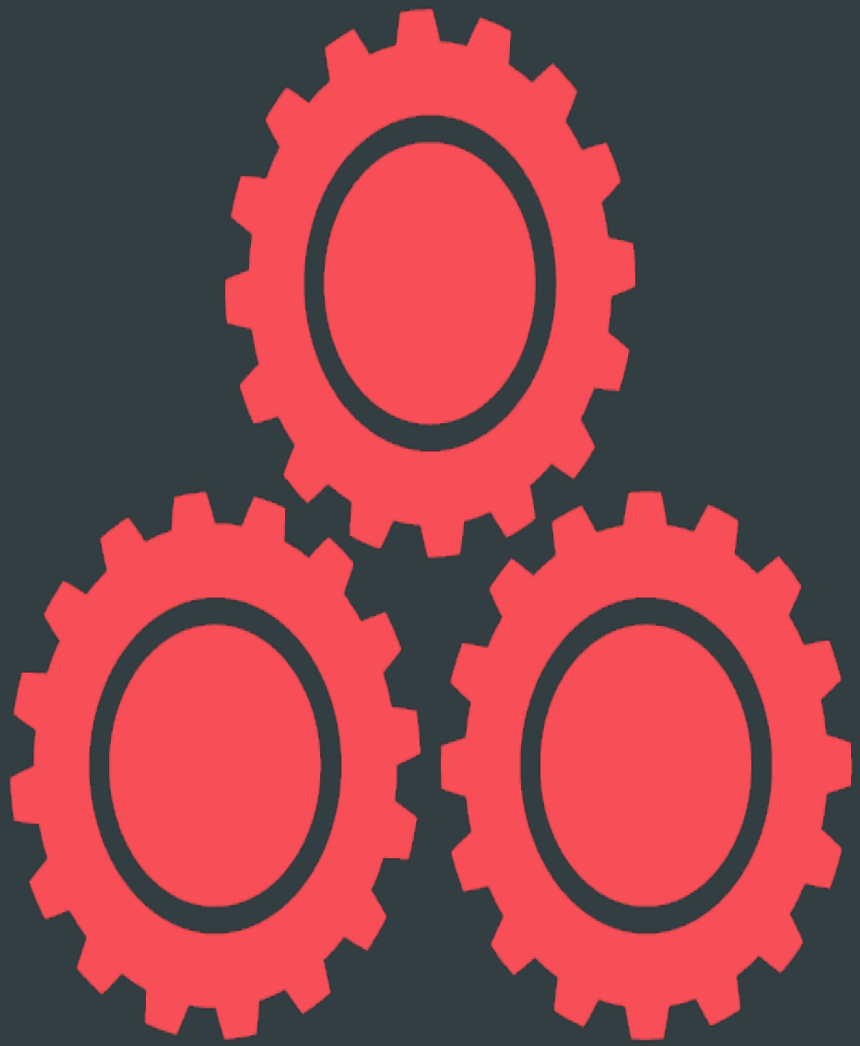
Almost Awesome: Multi-FS

MultiFS: What's Present

- You can create multiple filesystems within a RADOS cluster
  - Different pools or namespaces
- Each FS gets its own MDS and has to be connected to independently

MultiFS: What's Missing

- Testing: This gets limited coverage in our test suite
- Security model: we know where we're going, but it's not done
  - Can't expose filesystem existence to users who aren't allowed to see it
- Post-luminous



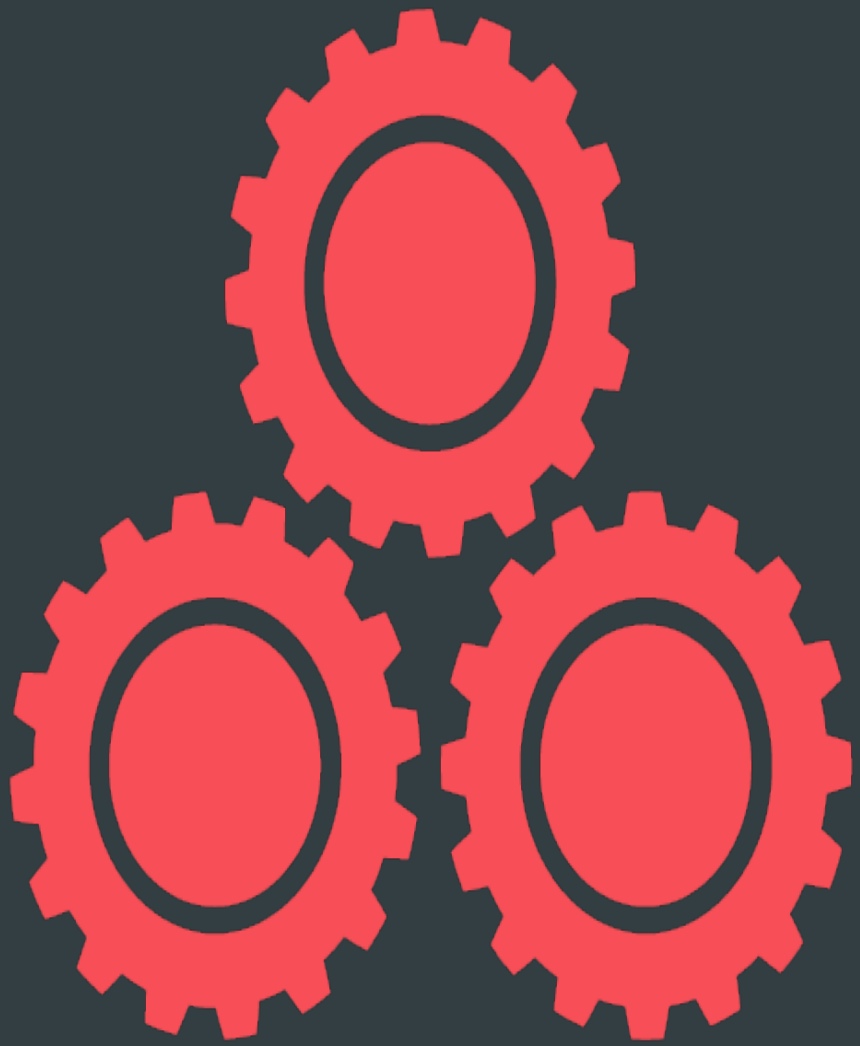
Pain Point: File Deletion

File Deletion

- The MDS deletes RADOS objects in the background after files are unlinked
- This requires “pinning” the inode in memory
- Usually not a problem, unless you have so many deleting files your MDS memory cache fills up!

File Deletion: The Fix

- Pull request pending: build a queueing system in RADOS
  - https://github.com/ceph/ceph/pull/12786
  - Add files to delete queue
  - Pull them off and delete, in constant memory space
- This will be done for Luminous

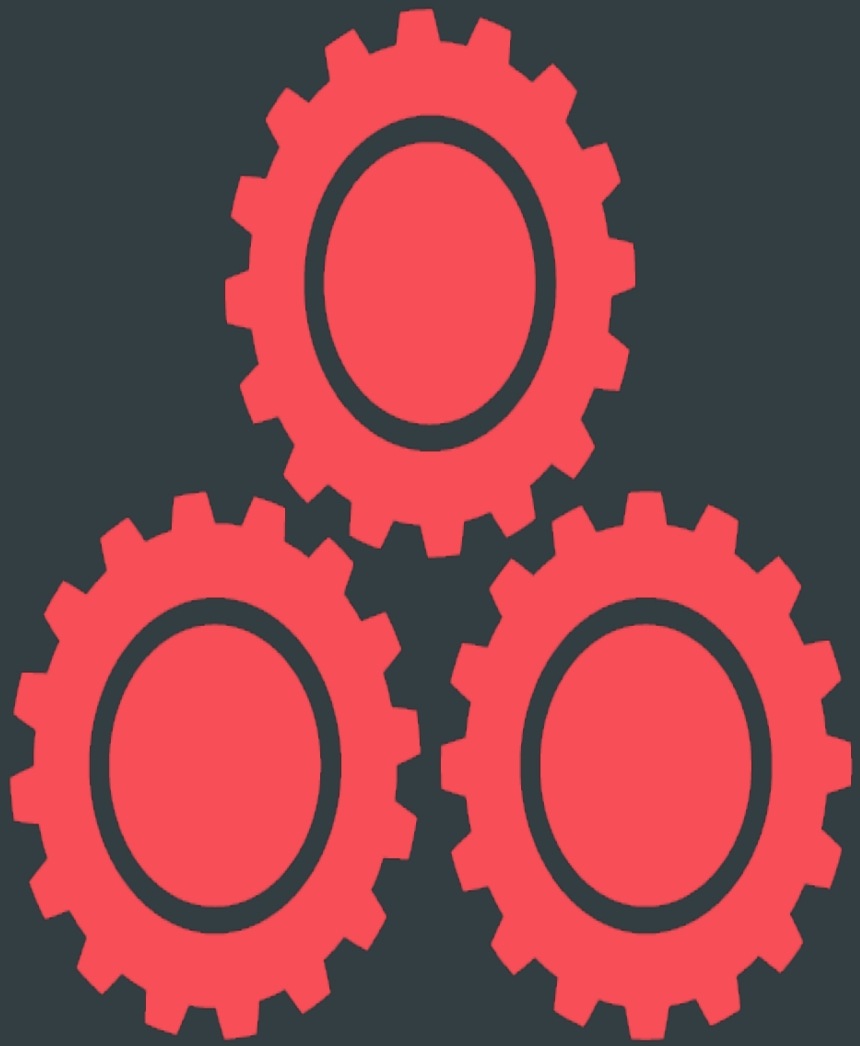


Pain Point: Client Trust

Client Trust

- Clients can trash anything they can write
  - Give clients separate namespaces!
- Clients can deny writes to anything they can read
  - Don't share stuff across tenants
- Clients can DoS the MDS they attach to
  - ...Multiple FSes in a cluster will fix this

- This is pretty fundamental. If you actively don't trust your clients, put them behind an NFS gateway.



Pain Point: Debugging Live Systems

Exposing State: What's available

```
ceph daemon mds.a dump_ops_in_flight
{
    "ops": [
        {
            "description": "client_request(client.
            "initiated_at": "2015-03-10 22:26:17.4
            "age": 0.052026,
            "duration": 0.001098,
            "type_data": [
                "submit entry: journal_and_reply",
                "client.4119:21120",
...
```

Exposing State: What's available

```
# ceph daemon mds.a session ls
...
  "client_metadata": {
    "ceph_sha1": "a19f92cf...",
    "ceph_version": "ceph version 0.93...",
    "entity_id": "admin",
    "hostname": "claystone",
    "mount_point": "\/home\/john\/mnt"
  }
```

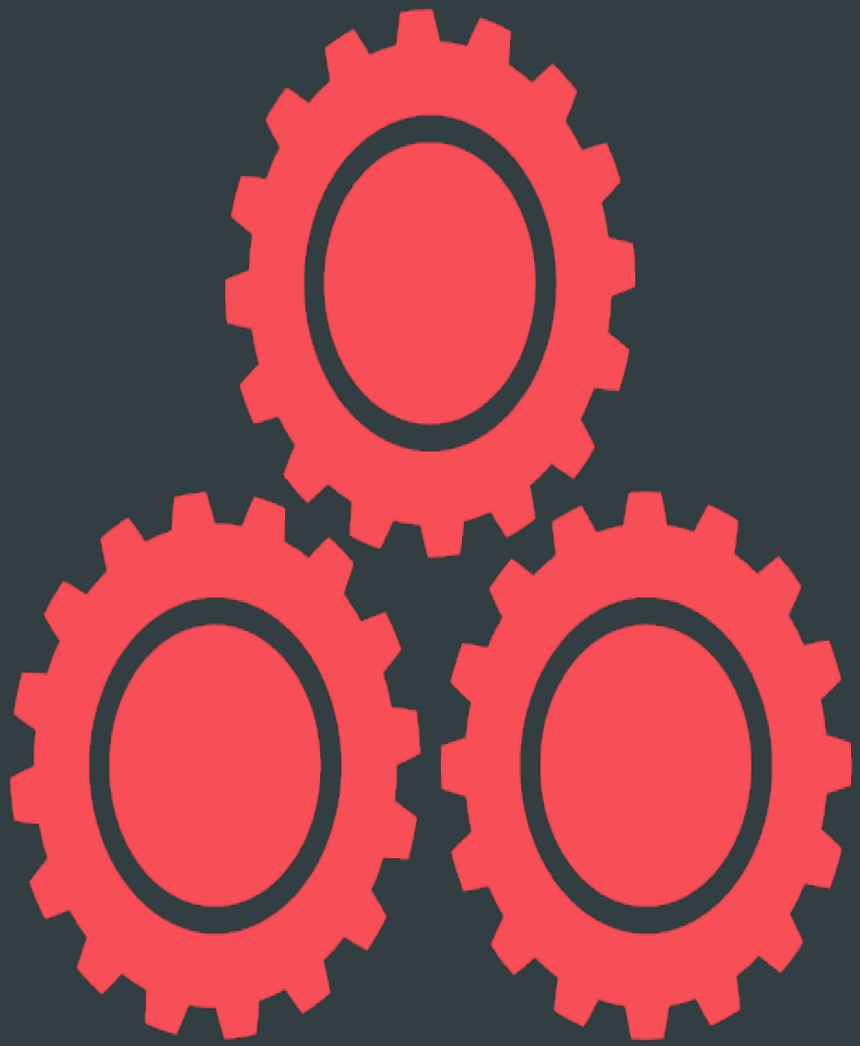
Exposing State: What's available

- ceph mds tell 0 dumpcache /path/to/dump/to

- Yes, it seriously dumps the full cache to a file

Exposing State: What's missing

- Dumping individual dirs/dentries/inodes
- Good ways of identifying why things are blocked
- Tracking accesses to a file
- ...and other things we haven't thought of yet?



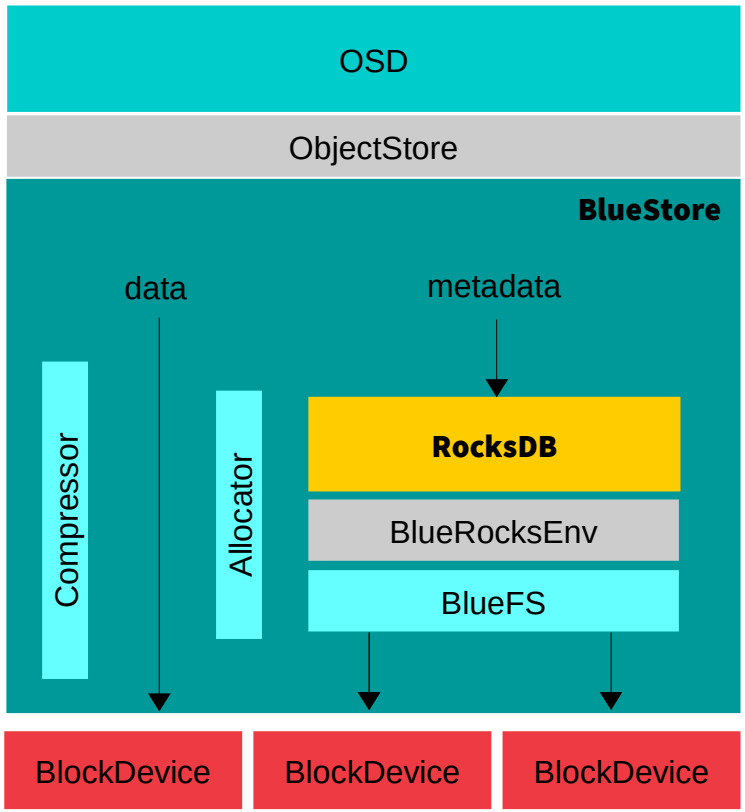
Upcoming Stuff

Erasure Coding (Overwrites)

- Instead of replicating across OSDs, give them shards and parity blocks
- Current EC RADOS pools are append only
  - simple, stable suitable for RGW, or behind a cache tier
- Coming in Luminous: EC with overwrite support
  - This will be slow at first, as it requires a two-phase commit and optimizations to be remotely efficient will follow
  - Means you can store CephFS and RBD data at 1.5x instead of 3x cost, with same (or larger) number of node failures

OSD: BLUESTORE

- BlueStore = **Bl**ock + N**ewStore**
  - key/value database (RocksDB) for metadata
  - all data written directly to raw block device(s)
  - can combine HDD, SSD, NVMe, NVRAM
- Full data checksums (crc32c, xxhash)
- Inline compression (zlib, snappy, zstd)
- ~2x faster than FileStore
  - better parallelism, efficiency on fast devices
  - no double writes for data
  - performs well with very small SSD journals



ASYNCMESSENGER

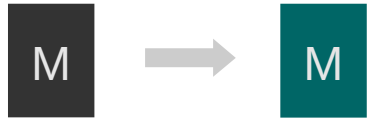
- New implementation of network layer
  - replaces aging SimpleMessenger
  - fixed size thread pool (vs 2 threads per socket)
  - scales better to larger clusters
  - more healthy relationship with tcmalloc
  - now the default!

- Pluggable backends
  - PosixStack – Linux sockets, TCP (default, supported)
  - Two experimental backends!

X·SKY

CEPH-MGR

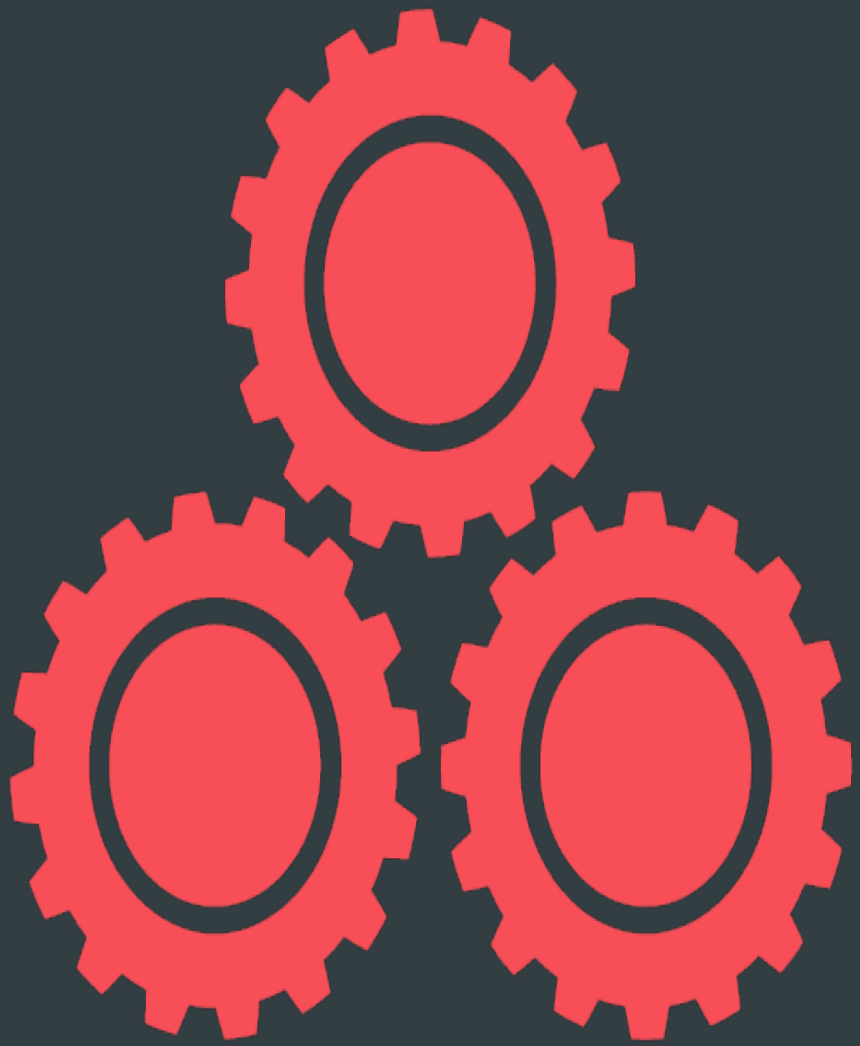
- ceph-mon monitor daemons currently do a lot
  - more than they need to (PG stats to support things like 'df')
  - this limits cluster scalability
- ceph-mgr moves non-critical metrics into a separate daemon
  - that is more efficient
  - that can stream to graphite, influxdb
  - that can efficiently integrate with external modules (even Python!)
- Good host for
  - integrations, like Calamari REST API endpoint
  - coming features like 'ceph top' or 'rbd top'
  - high-level management functions and policy



???

(time for new iconography)

redhat. SUSE



Who Should Use CephFS?

CephFS Users

- Some vendors are targeting it at OpenStack users, since it pairs so well with RBD
- CephFS is good at large files
  - It does well with small files for a distributed FS, but there's no comparing to a local FS
- CephFS for home directories?
  - If your users are patient or metadata can all be cached, but remember you want very new clients to get all the bug fixes
- Anybody who likes exploring: go for it!

FOR MORE INFORMATION

- docs
  - http://docs.ceph.com/
  - https://github.com/ceph
- help
  - ceph-users@ceph.com, ceph-devel@vger.kernel.org
  - #ceph, #ceph-devel on irc.oftc.net

THANK YOU!

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