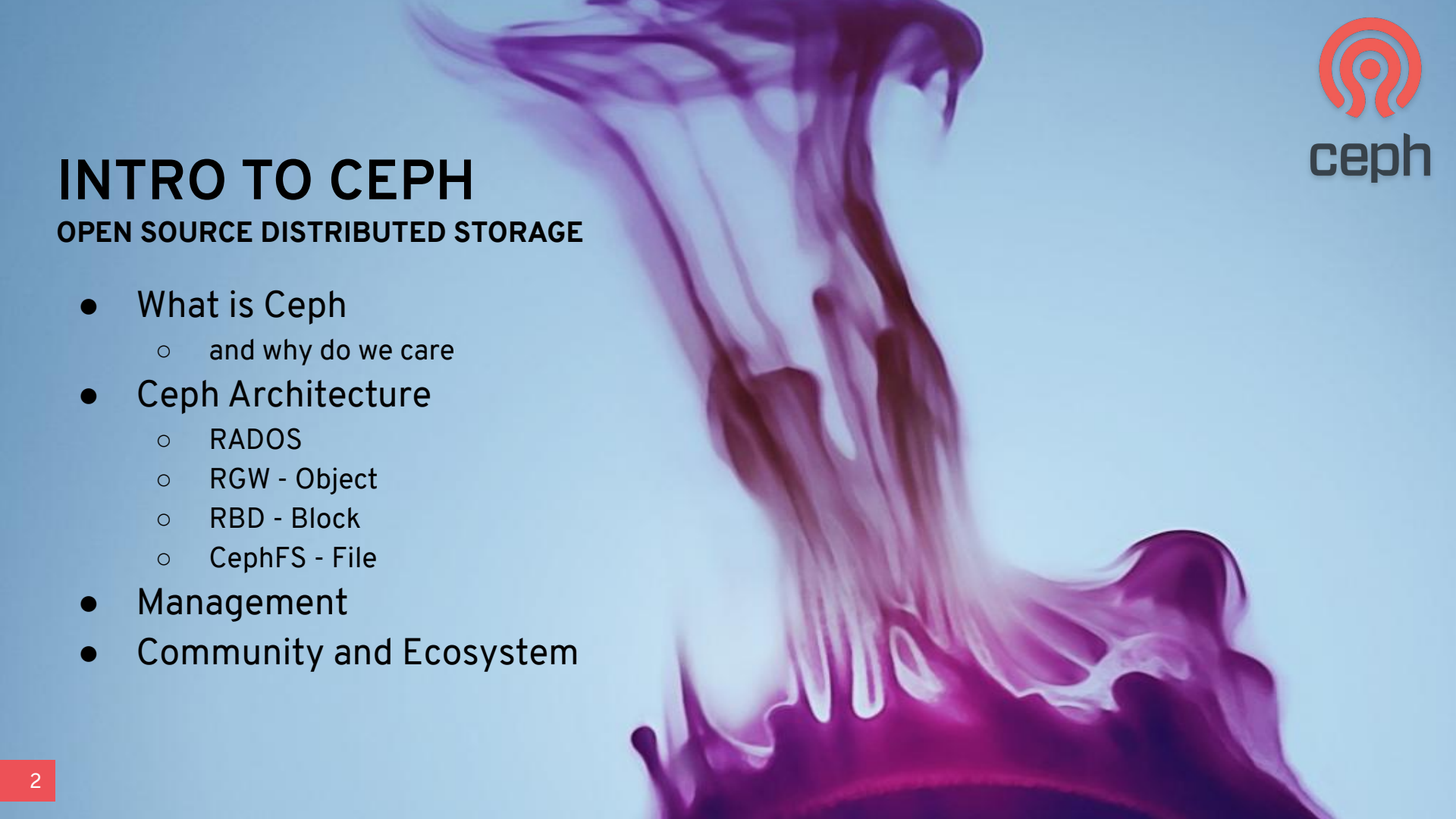
INTRO TO CEPH

OPEN SOURCE DISTRIBUTED STORAGE

Sage Weil
Ceph Tech Talk - 2019.06.27



INTRO TO CEPH

OPEN SOURCE DISTRIBUTED STORAGE

- What is Ceph
  - and why do we care
- Ceph Architecture
  - RADOS
  - RGW - Object
  - RBD - Block
  - CephFS - File
- Management
- Community and Ecosystem

WHAT IS CEPH?

The buzzwords

- “Software defined storage”
- “Unified storage system”
- “Scalable distributed storage”
- “The future of storage”
- “The Linux of storage”

The substance

- Ceph is open source **software**
- Runs on commodity hardware
  - Commodity servers
  - IP networks
  - HDDs, SSDs, NVMe, NV-DIMMs, …
- A single cluster can serve **object**, **block**, and **file** workloads

CEPH IS FREE AND OPEN SOURCE

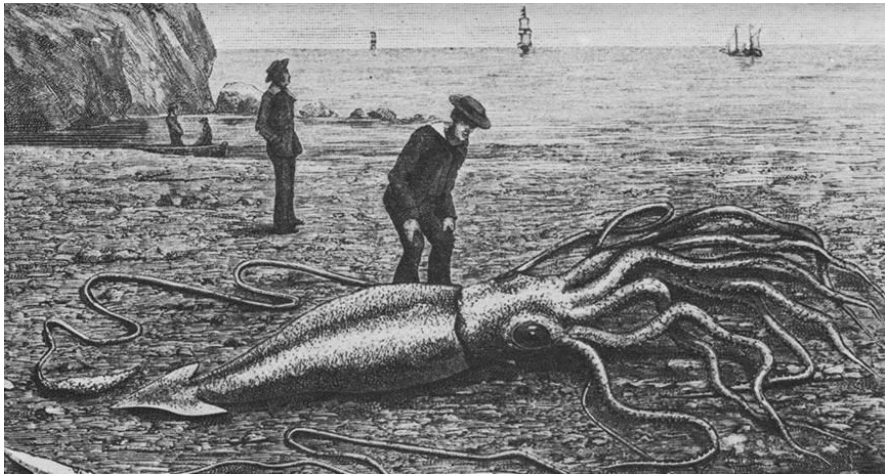
- Freedom to use (free as in beer)
- Freedom to introspect, modify, and share (free as in speech)
- Freedom from vendor lock-in
- Freedom to innovate

CEPH IS RELIABLE

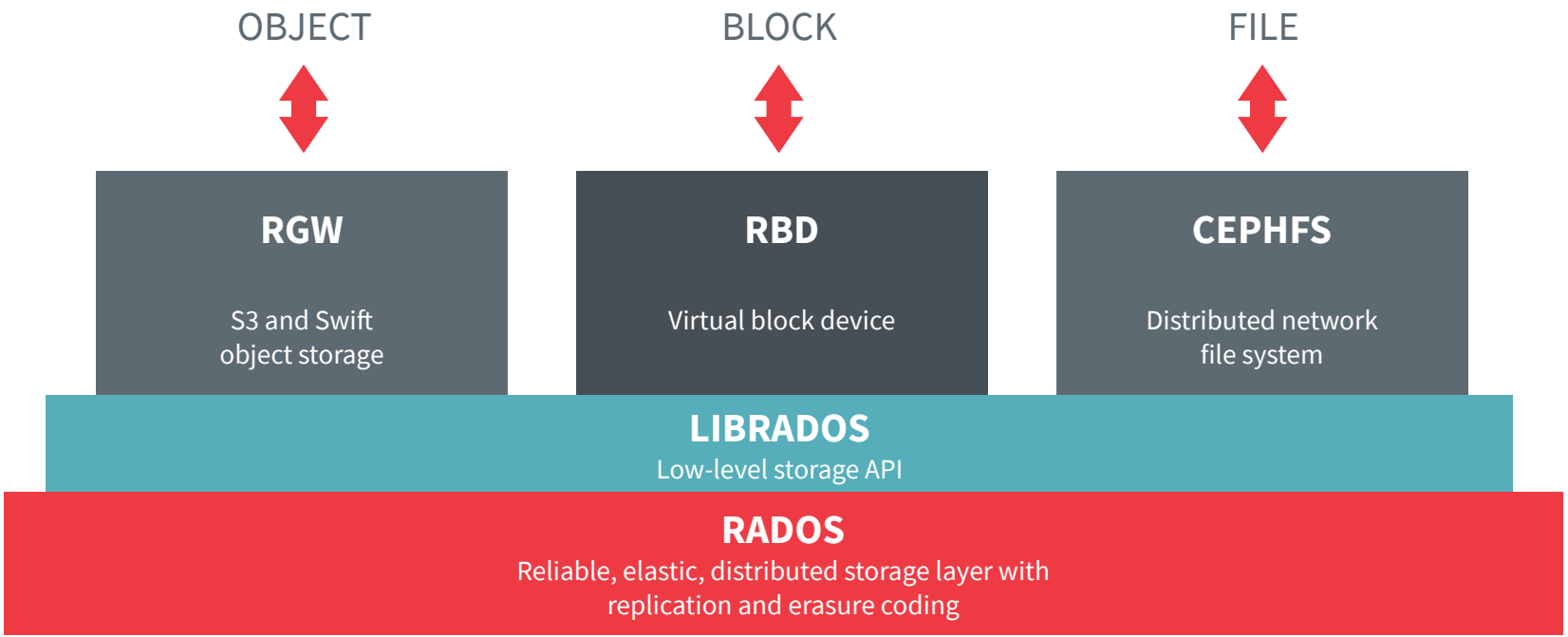
- **Reliable storage** service out of **unreliable components**
  - No single point of failure
  - Data durability via replication or erasure coding
  - No interruption of service from rolling upgrades, online expansion, etc.
- Favor consistency and correctness over performance

CEPH IS SCALABLE

- Ceph is elastic storage infrastructure
  - Storage cluster may grow or shrink
  - Add or remove hardware while system is online and under load
- Scale **up** with bigger, faster hardware
- Scale **out** within a single cluster for capacity and performance
- **Federate** multiple clusters across sites with asynchronous replication and disaster recovery capabilities



CEPH IS A UNIFIED STORAGE SYSTEM



RADOS

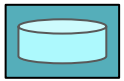
RADOS

- **R**eliable **A**utonomic **D**istributed **O**bject **S**torage
  - Common storage layer underpinning object, block, and file services
- Provides low-level data object storage service
  - Reliable and highly available
  - Scalable (on day 1 and day 1000)
  - Manages all replication and/or erasure coding, data placement, rebalancing, repair, etc.
- Strong consistency
  - CP, not AP
- Simplifies design and implementation of higher layers (file, block, object)

RADOS SOFTWARE COMPONENTS

ceph-mon

ceph-mgr



ceph-osd

Monitor

- Central authority for authentication, data placement, policy
- Coordination point for all other cluster components
- Protect critical cluster state with Paxos
- 3-7 per cluster

Manager

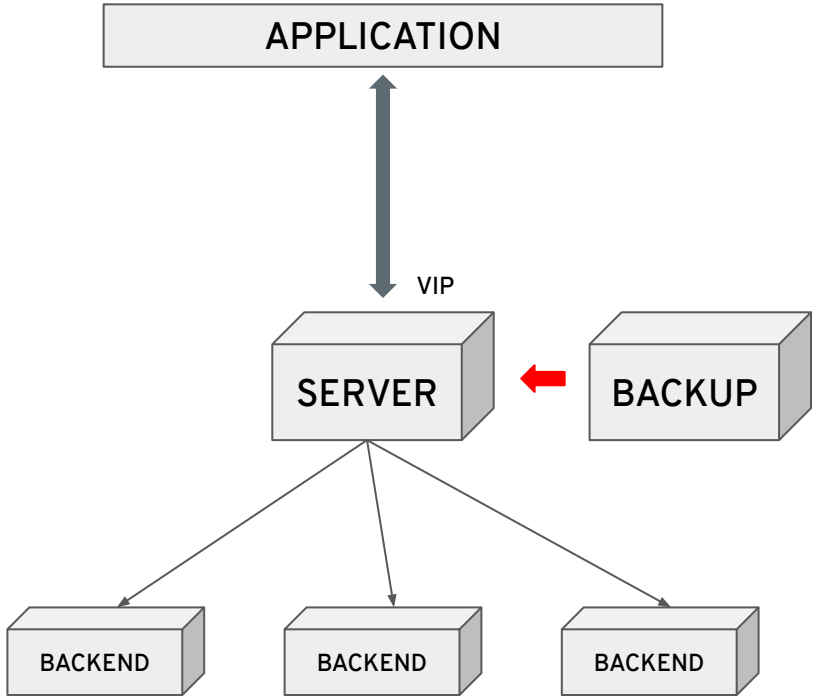
- Aggregates real-time metrics (throughput, disk usage, etc.)
- Host for pluggable management functions
- 1 active, 1+ standby per cluster

OSD (Object Storage Daemon)

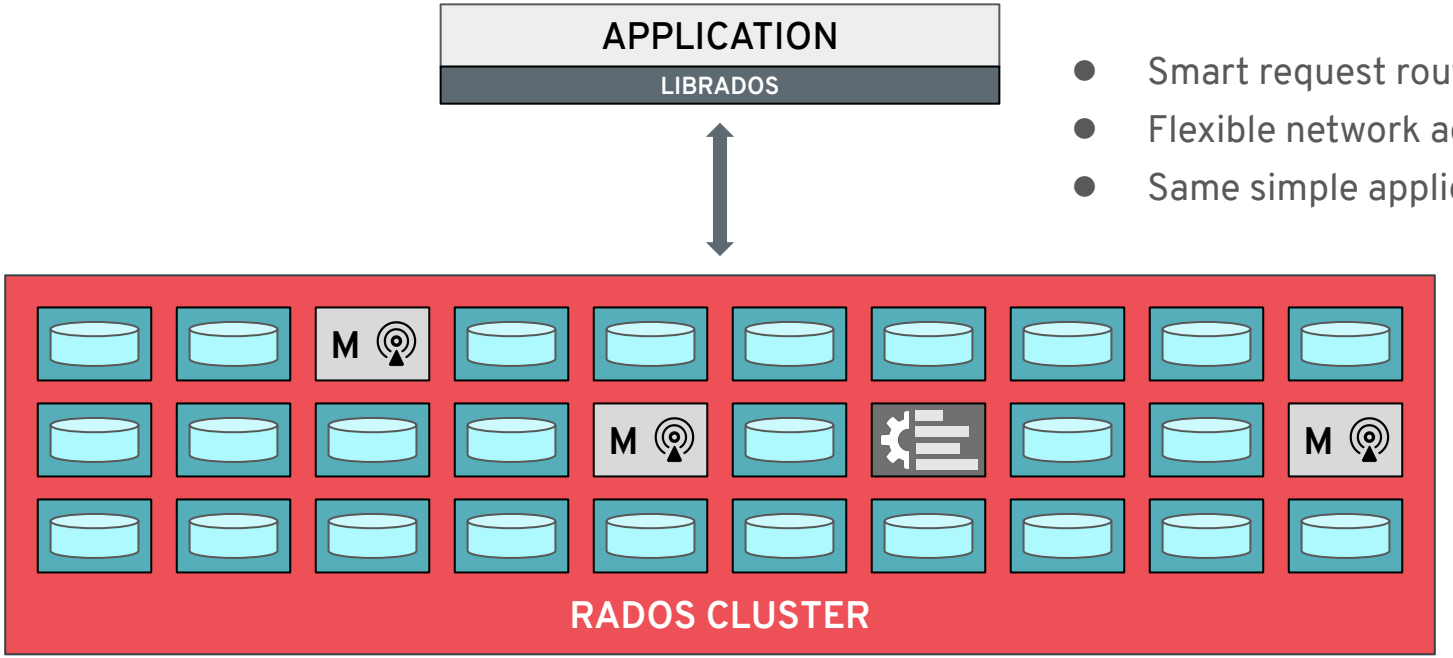
- Stores data on an HDD or SSD
- Services client IO requests
- Cooperatively peers, replicates, rebalances data
- 10s-1000s per cluster

LEGACY CLIENT/SERVER ARCHITECTURE

- Virtual IPs
- Failover pairs
- Gateway nodes

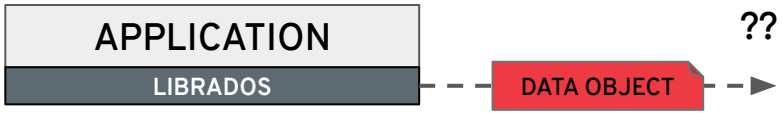


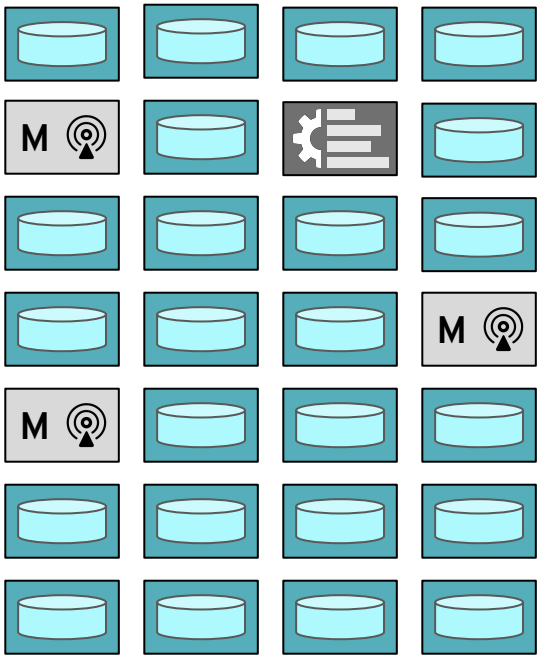
CLIENT/CLUSTER ARCHITECTURE



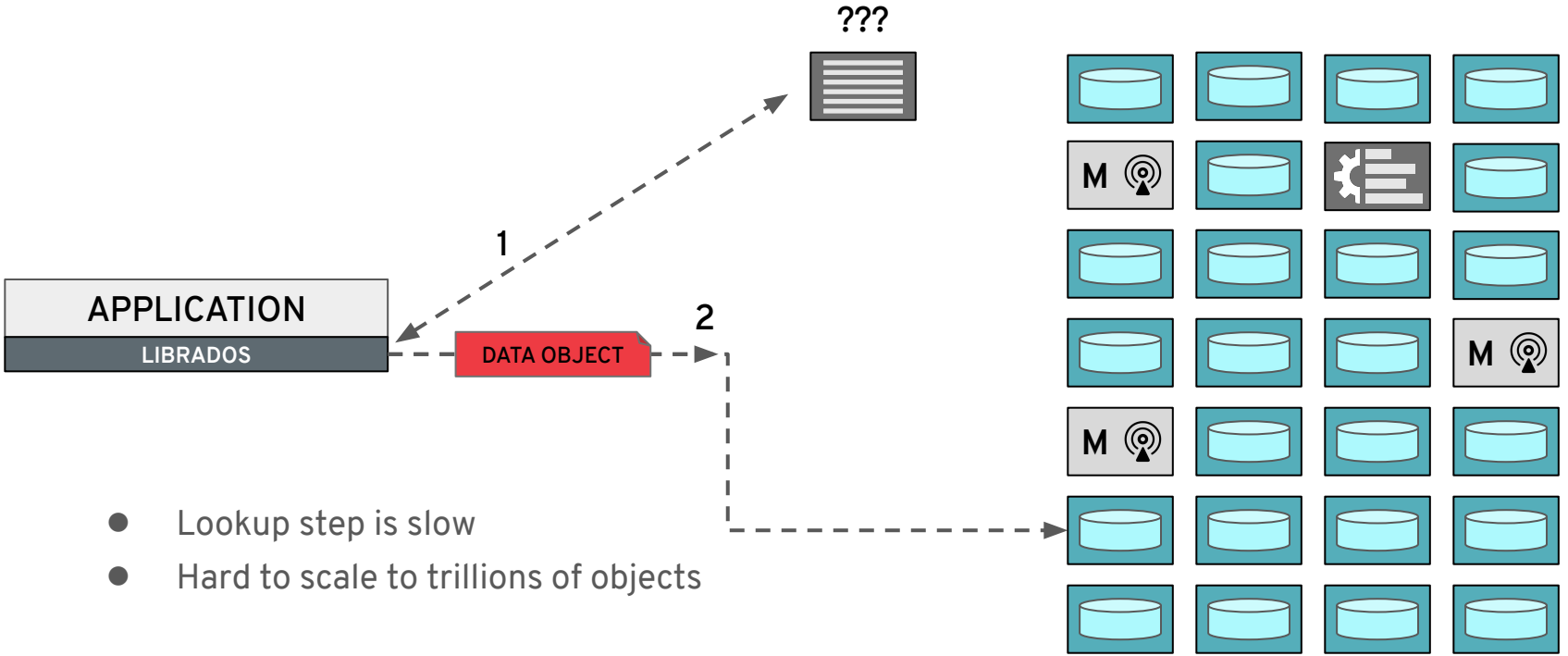
- Smart request routing
- Flexible network addressing
- Same simple application API

DATA PLACEMENT



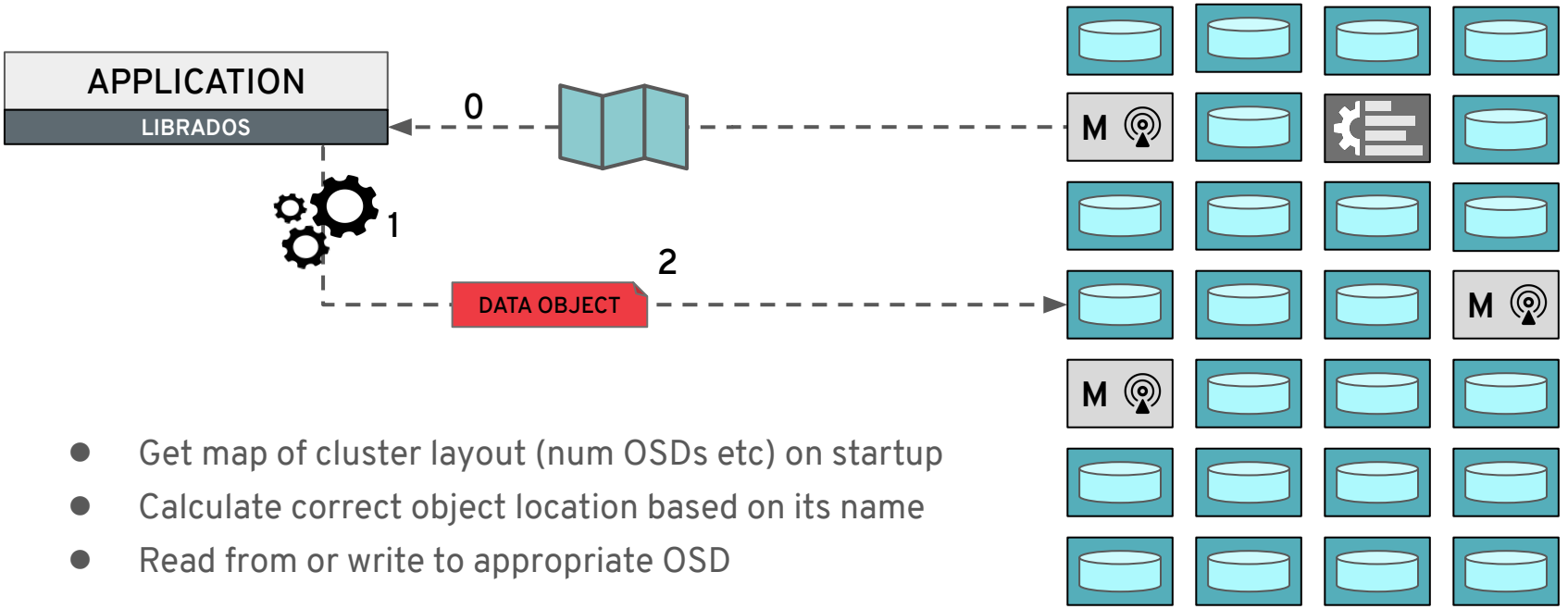


LOOKUP VIA A METADATA SERVER?



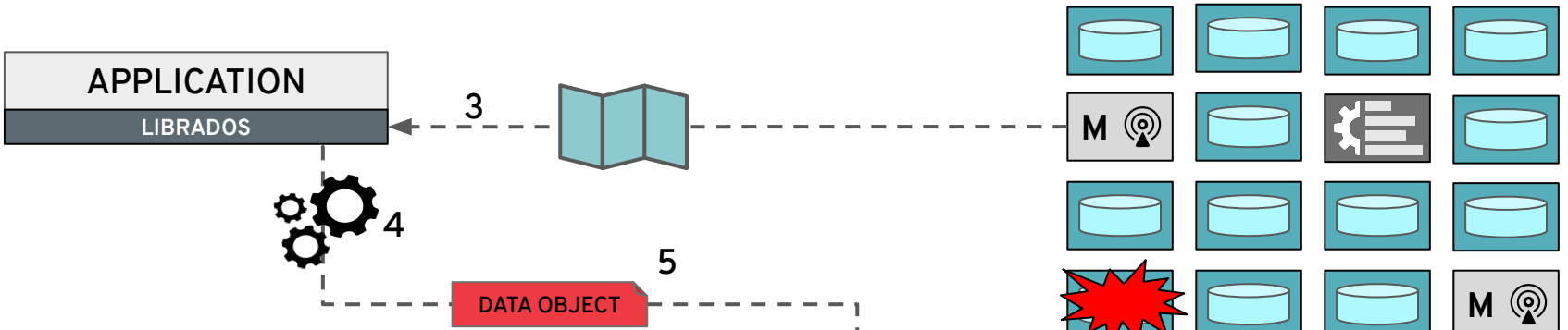
- Lookup step is slow
- Hard to scale to trillions of objects

CALCULATED PLACEMENT



- Get map of cluster layout (num OSDs etc) on startup
- Calculate correct object location based on its name
- Read from or write to appropriate OSD

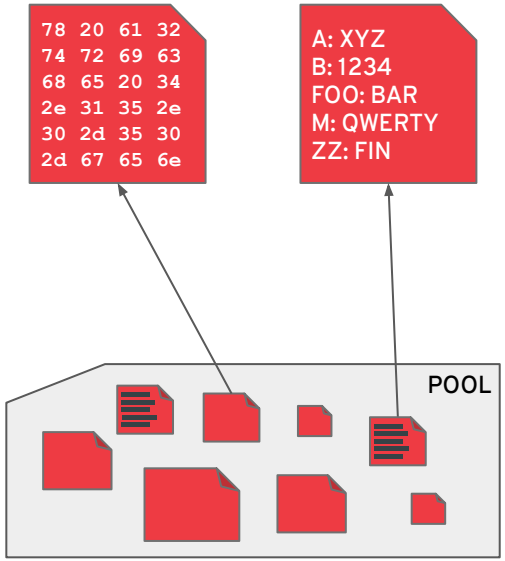
MAP UPDATES WHEN TOPOLOGY CHANGES



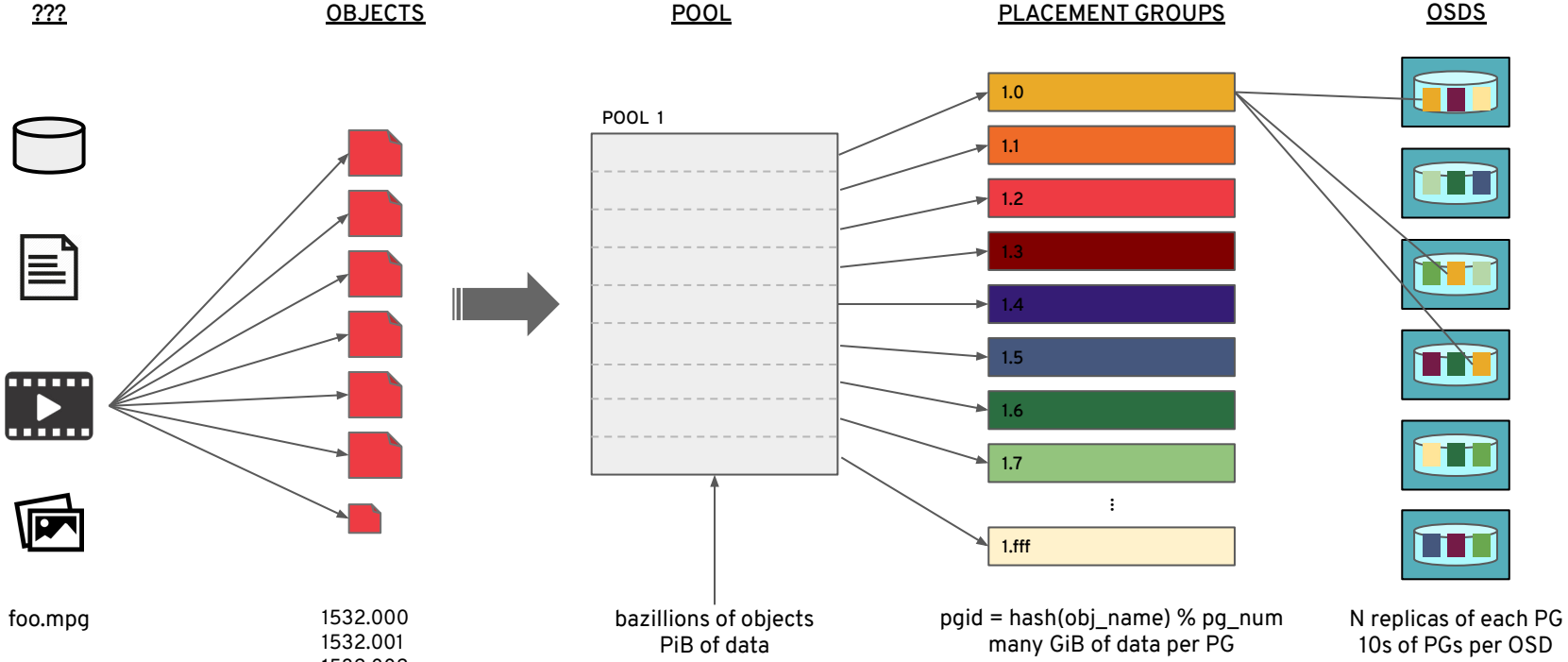
- Get updated map when topology changes
  - e.g., failed device; added node
- (Re)calculate correct object location
- Read from or write to appropriate OSD

RADOS DATA OBJECTS

- Name
  - 10s of characters
  - e.g., “rbd_header.10171e72d03d”
- Attributes
  - 0 to 10s of attributes
  - 0 to 100s of bytes each
  - e.g., “version=12”
- Byte data
  - 0 to 10s of megabytes
- Key/value data (“omap”)
  - 0 to 10,000s of items
  - 0 to 10,000s of bytes each
- Objects live in named “pools”

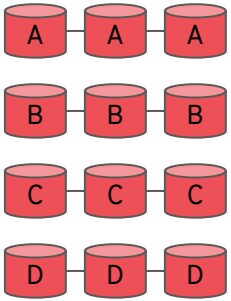


? → OBJECTS → POOLS → PGs → OSDs



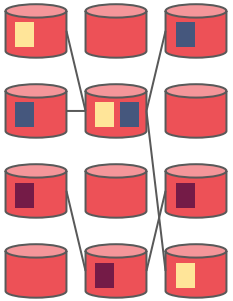
WHY PLACEMENT GROUPS?

REPLICATE DISKS



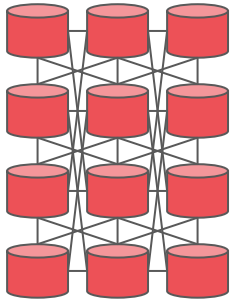
- Each device is mirrored
- Device sizes must match

REPLICATE PGS



- Each PG is mirrored
- PG placement is random

REPLICATE OBJECTS



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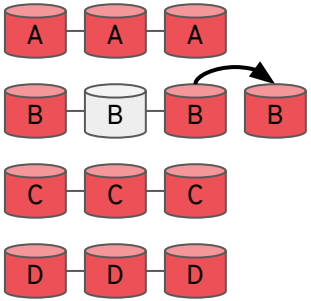
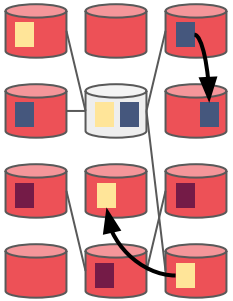
WHY PLACEMENT GROUPS?

REPLICATE DISKS



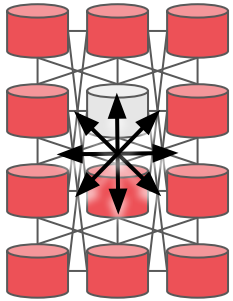
- Need an empty spare device to recover
- Recovery bottlenecked by single disk throughput

REPLICATE PGS



- New PG replicas placed on surviving devices
- Recovery proceeds in parallel, leverages many devices, and completes sooner

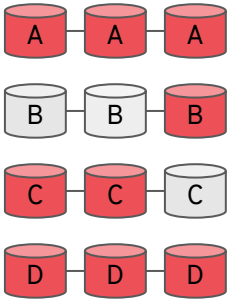
REPLICATE OBJECTS



- *Every* device participates in recovery

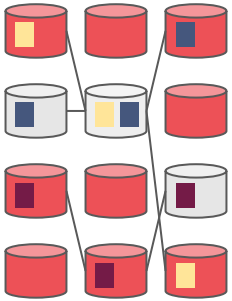
WHY PLACEMENT GROUPS?

REPLICATE DISKS



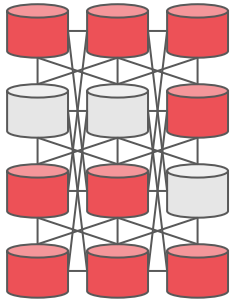
- Very few triple failures cause data loss (of an entire disk)

REPLICATE PGS



- Some triple failures cause data loss (of an entire PG)

REPLICATE OBJECTS



- **Every** triple failure causes data loss (of some objects)

PGs balance competing extremes

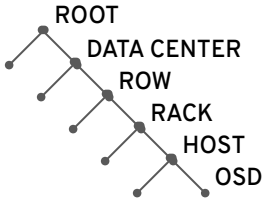
KEEPING DATA SAFE

"Declustered replica placement"

- More clusters
  - Faster recovery
  - More even data distribution
- Fewer clusters
  - Lower risk of concurrent failures affecting all replicas
- Placement groups a happy medium
  - No need for spare devices
  - Adjustable balance between durability (in the face of concurrent failures) and recovery time

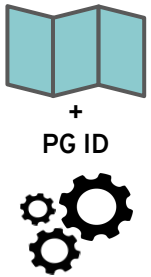
Avoiding concurrent failures

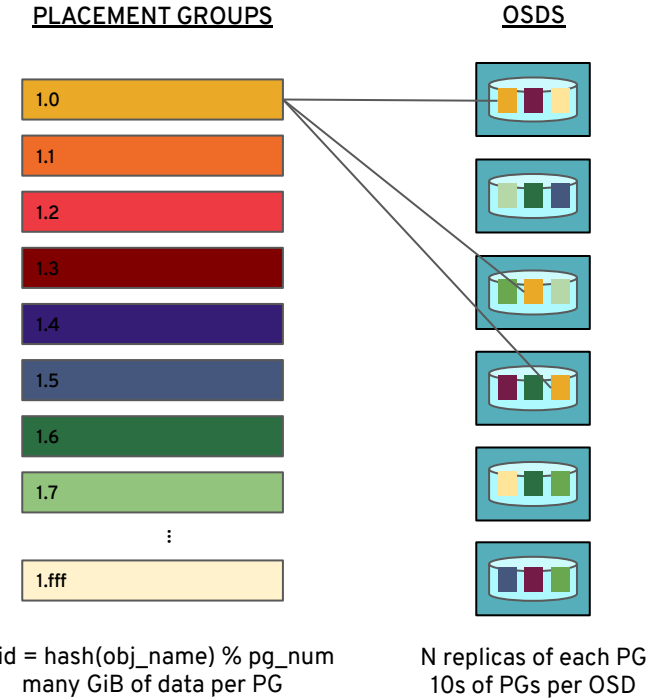
- Separate replicas across failure domains
  - Host, rack, row, datacenter
- Create a hierarchy of storage devices
  - Align hierarchy to physical infrastructure
- Express placement policy in terms hierarchy



PLACING PGs WITH CRUSH

- Pseudo-random placement algorithm
  - Repeatable, deterministic, calculation
  - Similar to “consistent hashing”
- Inputs:
  - Cluster topology (i.e., the OSD hierarchy)
  - Pool parameters (e.g., replication factor)
  - PG id
- Output: ordered list of OSDs
- Rule-based policy
  - “3 replicas, different racks, only SSDs”
  - “6+2 erasure code shards, 2 per rack, different hosts, only HDDs”
- Stable mapping
  - Limited data migration on change
- Support for varying device sizes
  - OSDs get PGs proportional to their weight



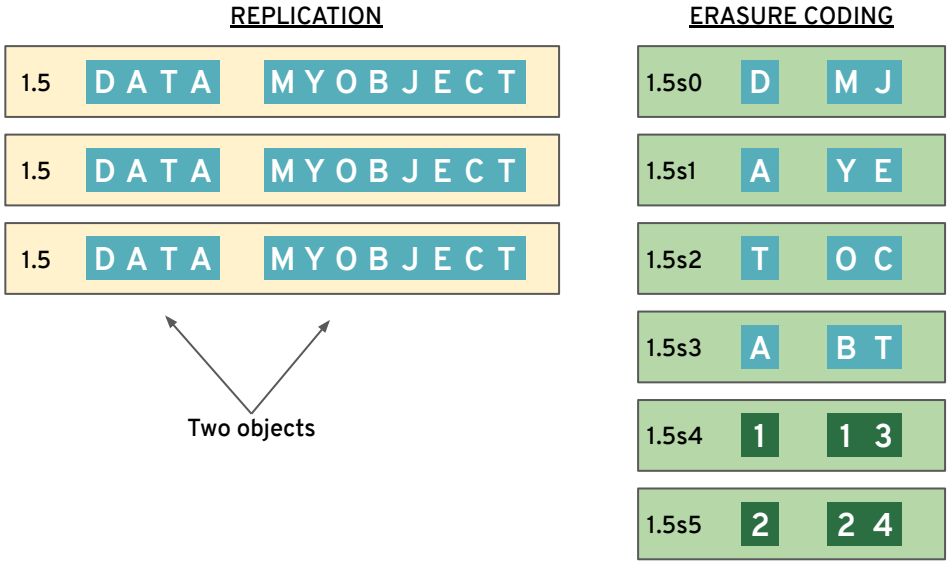


pgid = hash(obj_name) % pg_num
many GiB of data per PG

N replicas of each PG
10s of PGs per OSD

REPLICATION AND ERASURE CODING

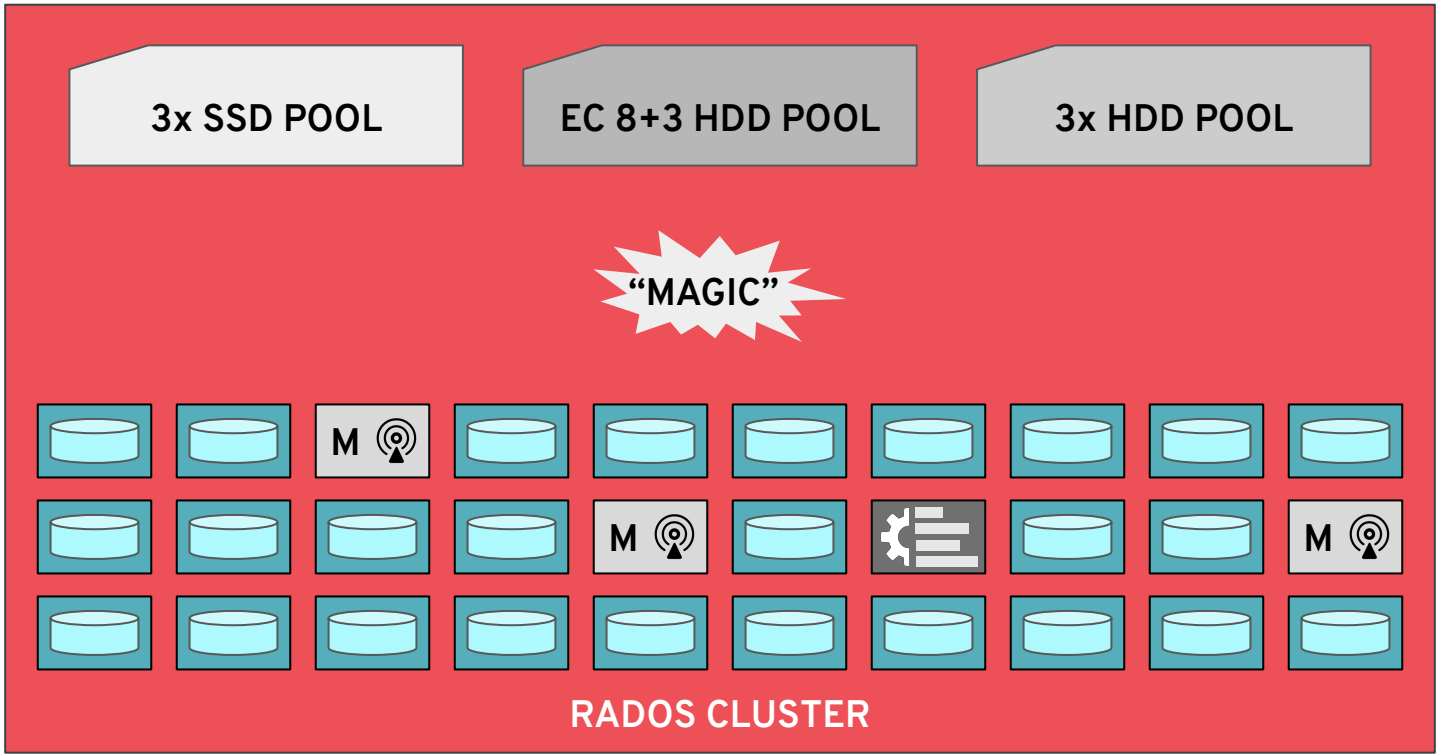
- Each RADOS pool must be durable
- Each PG must be durable
- Replication
  - Identical copies of each PG
  - Usually 3x (200% overhead)
  - Fast recovery--read any surviving copy
  - Can vary replication factor at any time
- Erasure coding
  - Each PG “shard” has different slice of data
  - Stripe object across **k** PG shards
  - Keep addition **m** shards with per-object parity/redundancy
  - Usually more like 1.5x (50% overhead)
  - Erasure code algorithm and **k+m** parameters set when pool is created
  - Better for large objects that rarely change



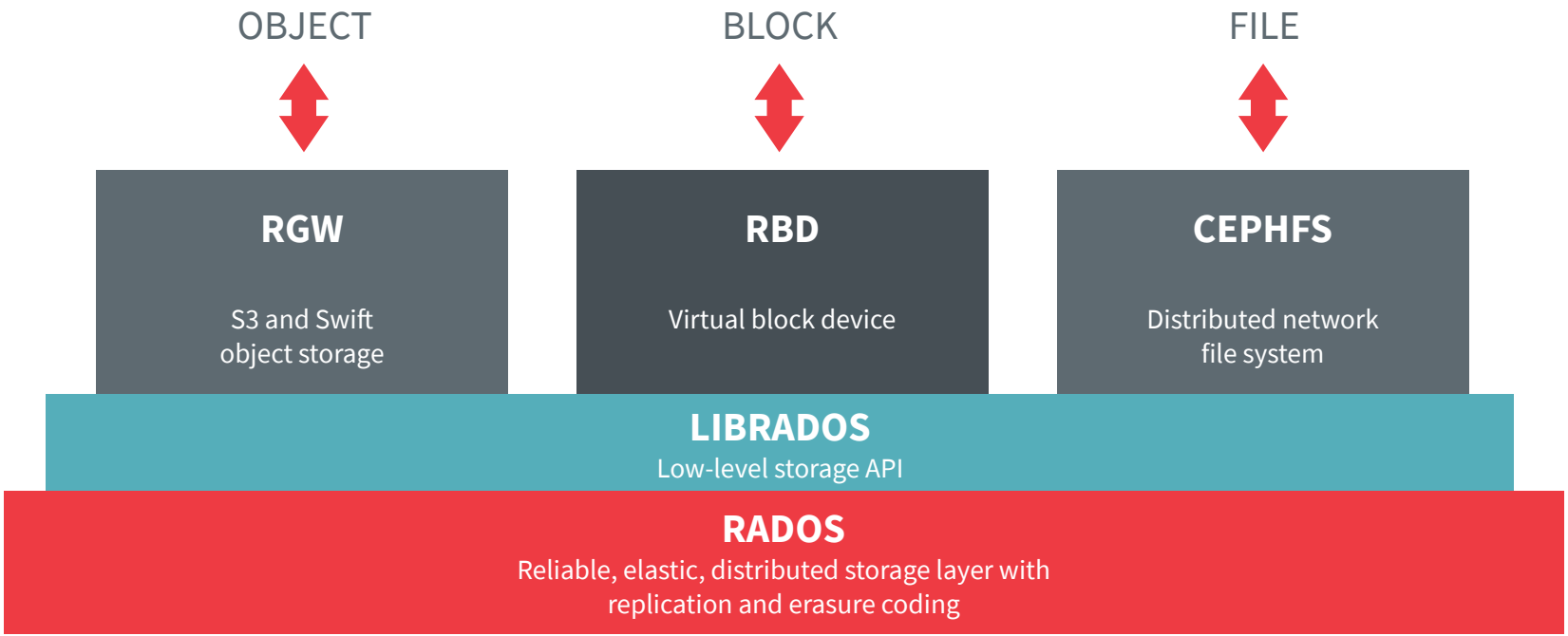
SPECIALIZED POOLS

- Pools usually share devices
  - Unless a pool's CRUSH placement policy spcifies a specific class of device
- Elastic, scalable provisioning
  - Deploy hardware to keep up with demand
- Uniform management of devices
  - Common "day 2" workflows to add, remove, replace devices
  - Common management of storage hardware resources

RADOS VIRTUALIZES STORAGE



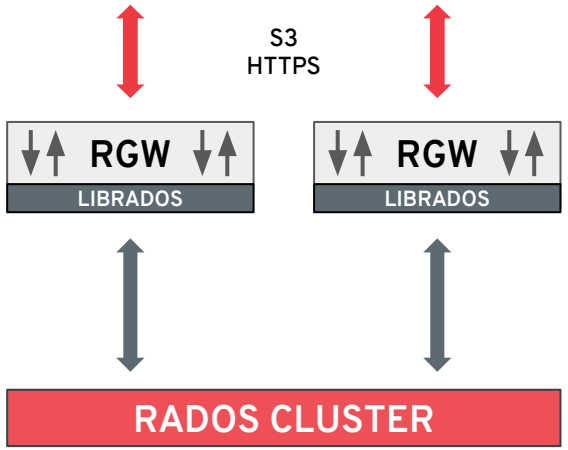
PLATFORM FOR HIGH-LEVEL SERVICES



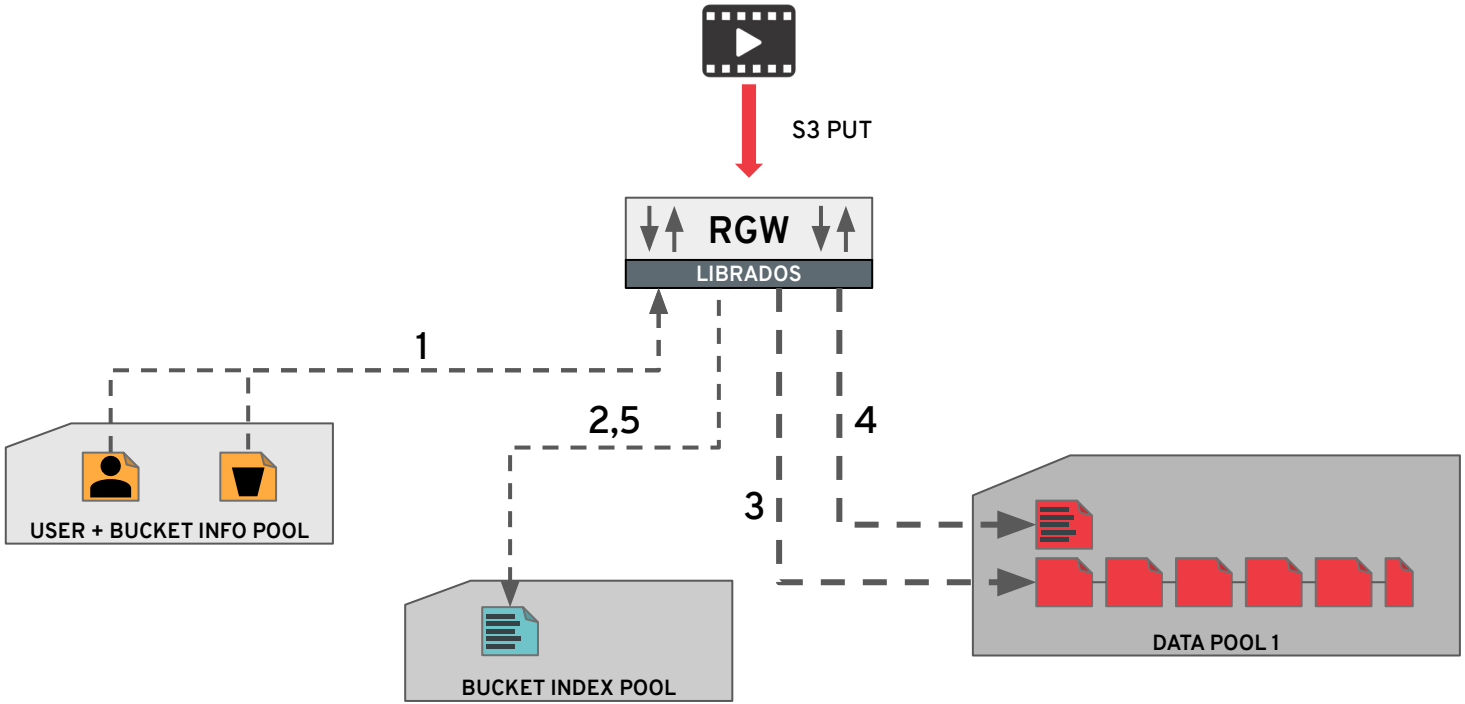
RGW: OBJECT STORAGE

RGW: RADOS GATEWAY

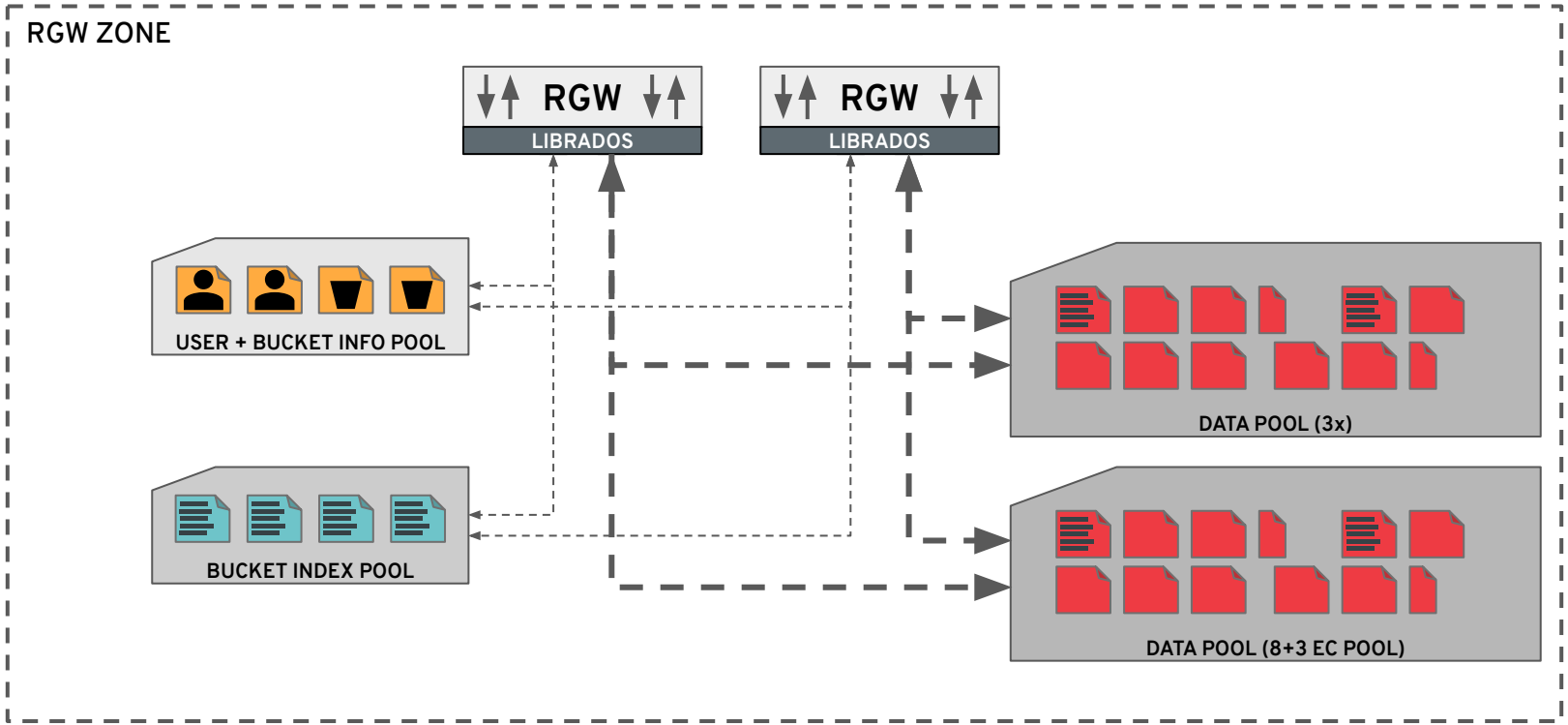
- S3 and Swift-compatible object storage
  - HTTPS/REST-based API
  - Often combined with load balancer to provide storage service to public internet
- Users, buckets, objects
  - Data and permissions model is based on a superset of S3 and Swift APIs
  - ACL-based permissions, enforced by RGW
- RGW objects not same as RADOS objects
  - S3 objects can be very big: GB to TB
  - RGW stripes data across RADOS objects



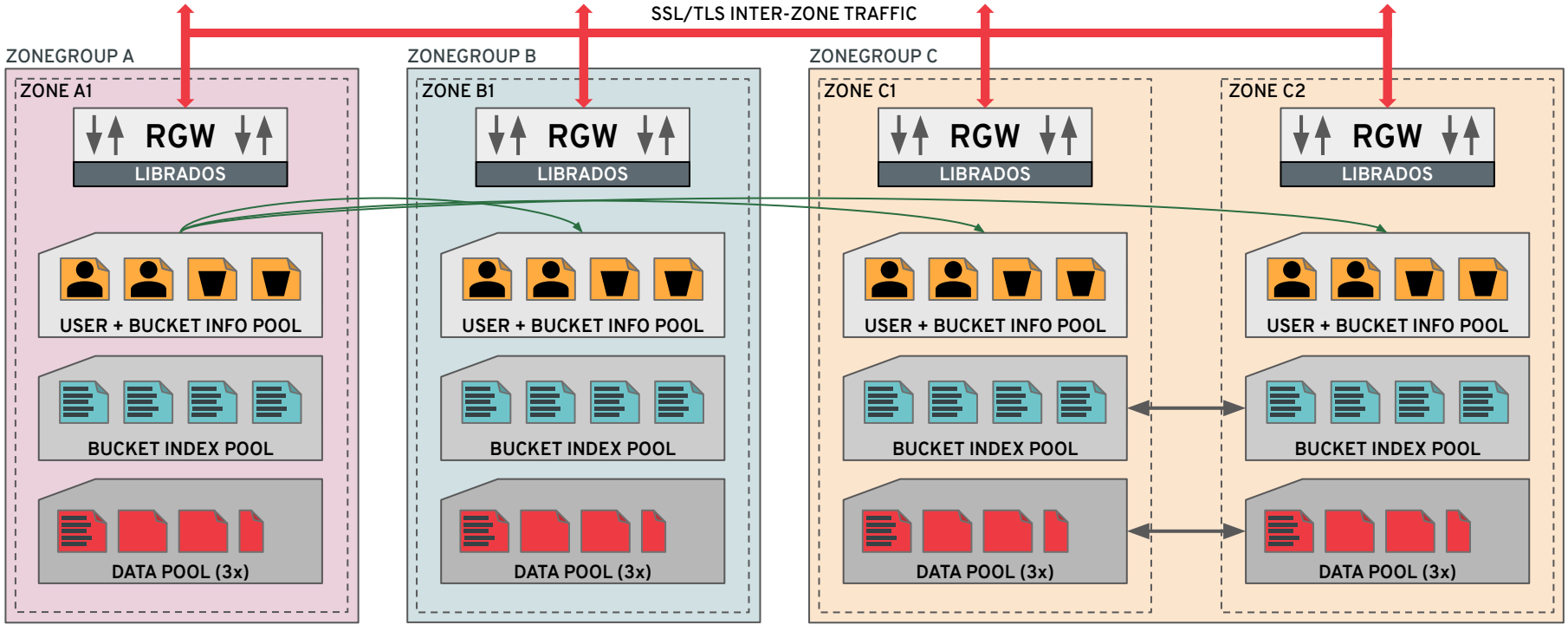
RGW STORES ITS DATA IN RADOS



RGW ZONE: POOLS + RGW DAEMONS



RGW FEDERATION AND GEO-REP



- Zones may be different clusters and/or sites
- Global view of users and buckets

- Each bucket placed in a ZoneGroup
- Data replicated between all Zones in a ZoneGroup

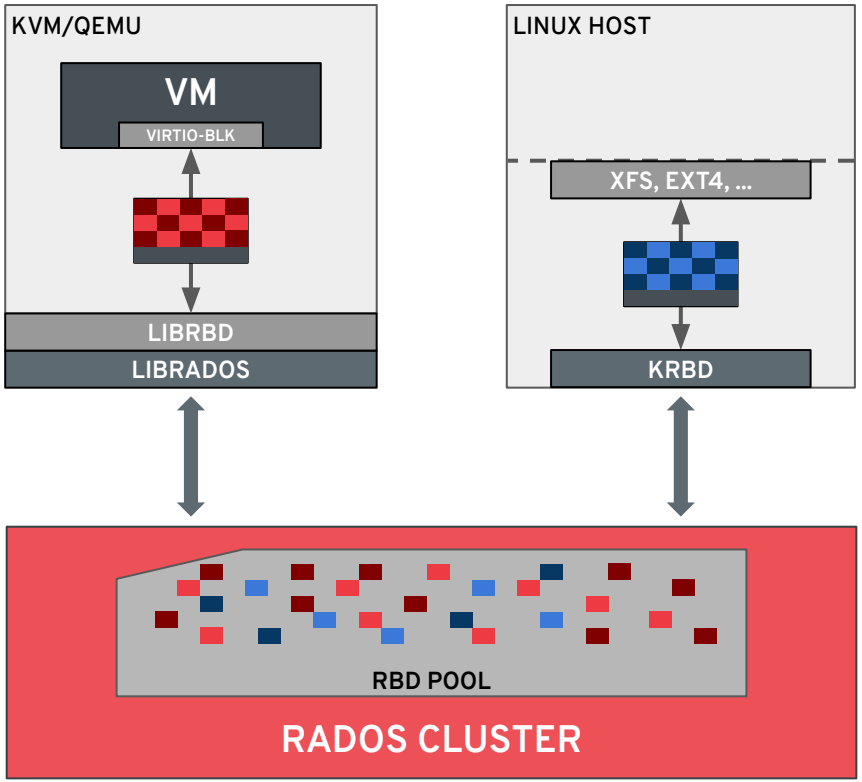
OTHER RGW FEATURES

- Very strong S3 API compatibility
  - https://github.com/ceph/s3-tests functional test suite
- STS: Security Token Service
  - Framework for interoperating with other authentication/authorization systems
- Encryption (various flavors of API)
- Compression
- CORS and static website hosting
- Metadata search with ElasticSearch
- Pub/sub event stream
  - Integration with knative serverless
  - Kafka
- Multiple storage classes
  - Map classes to RADOS pools
  - Choose storage for individual objects or set a bucket policy
- Lifecycle management
  - Bucket policy to automatically move objects between storage tiers and/or expire
  - Time-based
- Archive zone
  - Archive and preserve full storage history

RBD: BLOCK STORAGE

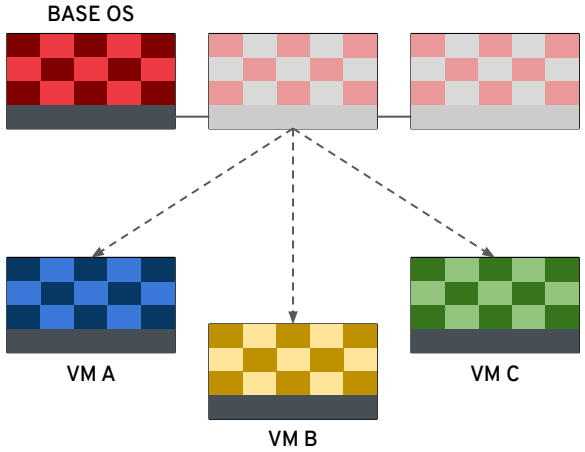
RBD: RADOS BLOCK DEVICE

- Virtual block device
  - Store disk images in RADOS
  - Stripe data across many objects in a pool
- Storage decoupled from host, hypervisor
  - Analogous to AWS's EBS
- Client implemented in KVM and Linux
- Integrated with
  - Libvirt
  - OpenStack (Cinder, Nova, Glace)
  - Kubernetes
  - Proxmox, CloudStack, Nebula, ...

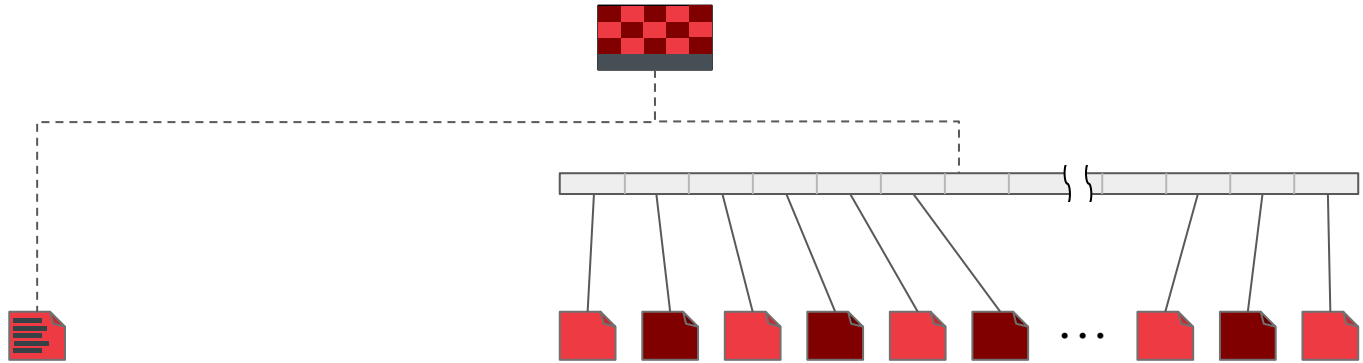


SNAPSHOTS AND CLONES

- Snapshots
  - Read-only
  - Associated with individual RBD image
  - Point-in-time consistency
- Clones
  - New, first-class image
  - Writeable overlay over an existing snapshot
  - Can be snapshotted, resized, renamed, etc.
- Efficient
  - O(1) creation time
  - Leverage copy-on-write support in RADOS
  - Only consume space when data is changed



RBD: DATA LAYOUT



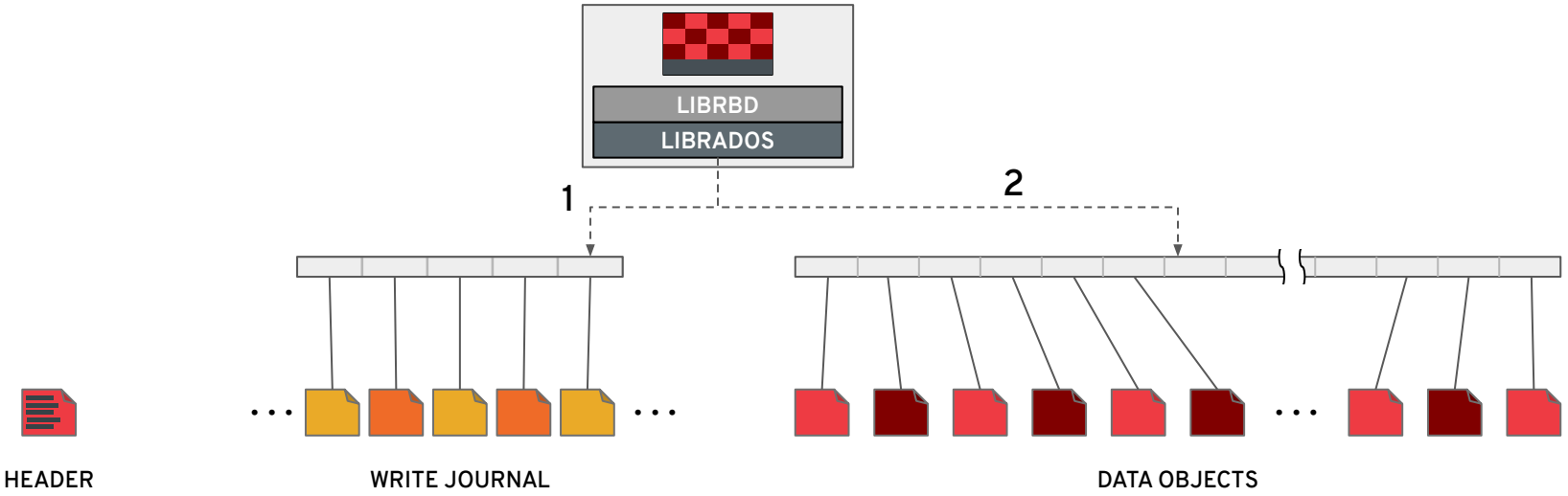
HEADER

DATA OBJECTS

- Image name
- Image size
- Striping parameters
- Snapshot metadata (names etc.)
- Options
- Lock owner
- …

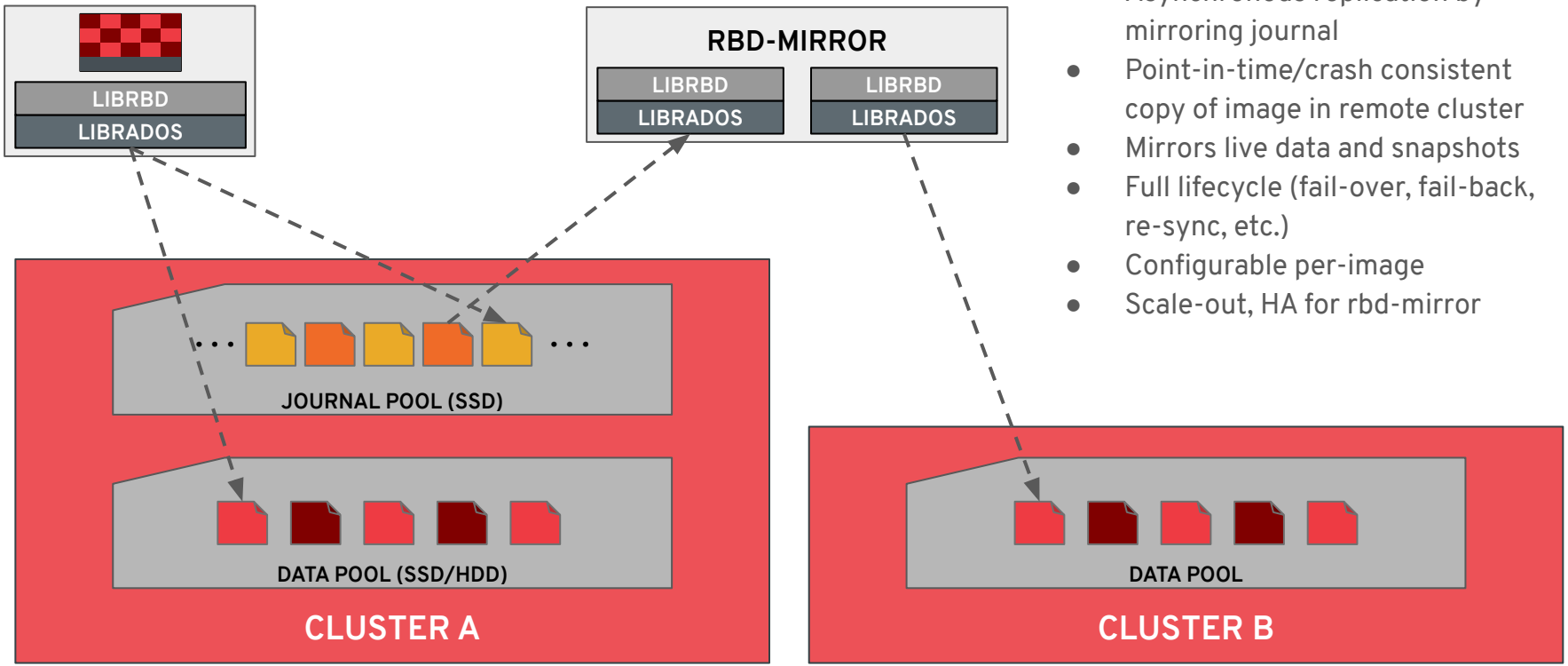
- Chunk of block device content
- 4 MB by default, but striping is configurable
- Sparse: objects only created if/when data is written
- Replicated or erasure coded, depending on the pool

RBD: JOURNALING MODE



- Recent writes
- Metadata changes

RBD MIRRORING



- Asynchronous replication by mirroring journal
- Point-in-time/crash consistent copy of image in remote cluster
- Mirrors live data and snapshots
- Full lifecycle (fail-over, fail-back, re-sync, etc.)
- Configurable per-image
- Scale-out, HA for rbd-mirror

OTHER RBD FEATURES

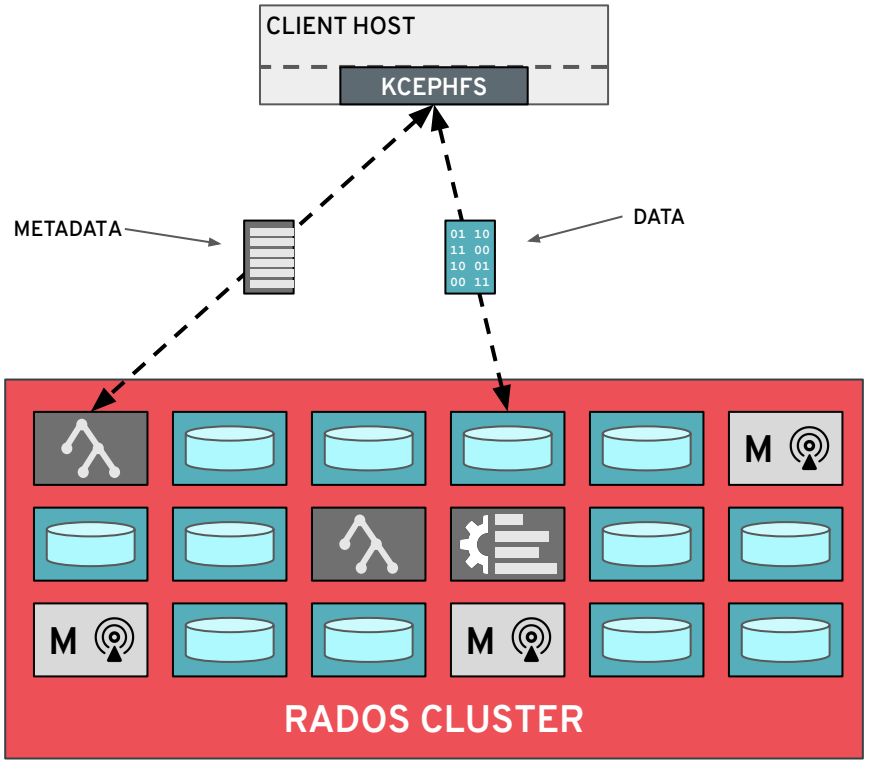
- ‘rbd top’
  - Real-time view of IO activity
- Quotas
  - Enforced at provisioning time
- Namespace isolation
  - Restrict access to a private namespace of RBD images
- Import and export
  - Full image import/export
  - Incremental diff (between snapshots)
- Trash
  - Keep deleted images around for a bit before purging

- Linux kernel client
  - ‘rbd map myimage’ → /dev/rbd*
- NBD
  - ‘rbd map -t nbd myimage’ → /dev/nbd*
  - Run latest userspace library
- iSCSI gateway
  - LIO stack + userspace tools to manage gateway configuration
- librbd
  - Dynamically link with application

CEPHFS: FILE STORAGE

CEPHFS: CEPH FILE SYSTEM

- Distributed network file system
  - Files, directories, rename, hard links, etc.
  - Concurrent shared access from many clients
- Strong consistency and coherent caching
  - Updates from one node visible elsewhere, immediately
- Scale metadata and data independently
  - Storage capacity and IO throughput scale with the number of OSDs
  - Namespace (e.g., number of files) scales with the number of MDS daemons



CEPH-MDS: METADATA SERVER

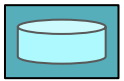
ceph-mds

MDS (Metadata Server)

- Manage file system namespace
- Store file system metadata in RADOS objects
  - File and directory metadata (names, inodes)
- Coordinate file access between clients
- Manage client cache consistency, locks, leases
- Not part of the data path
- 1s - 10s active, plus standbys

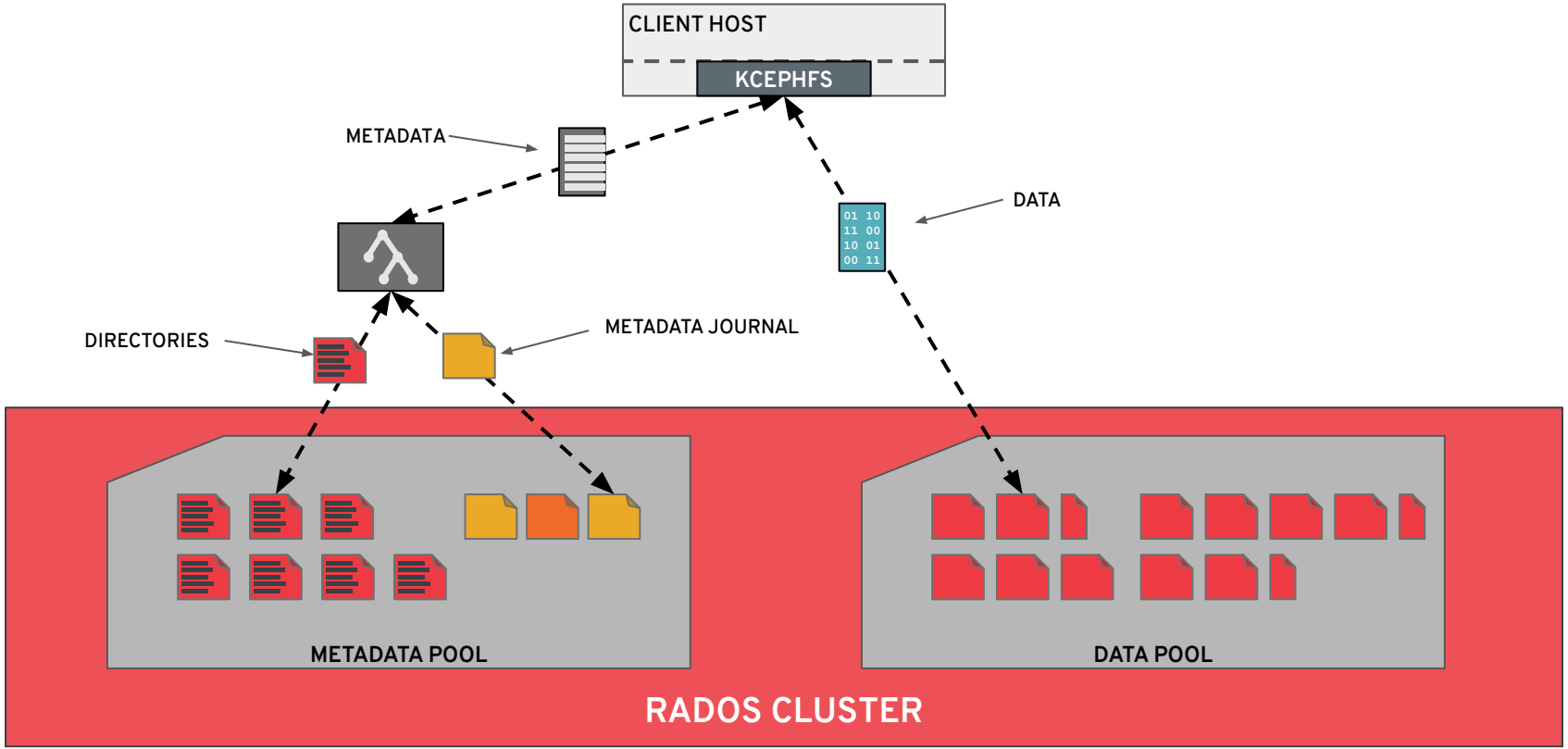
ceph-mon

ceph-mgr

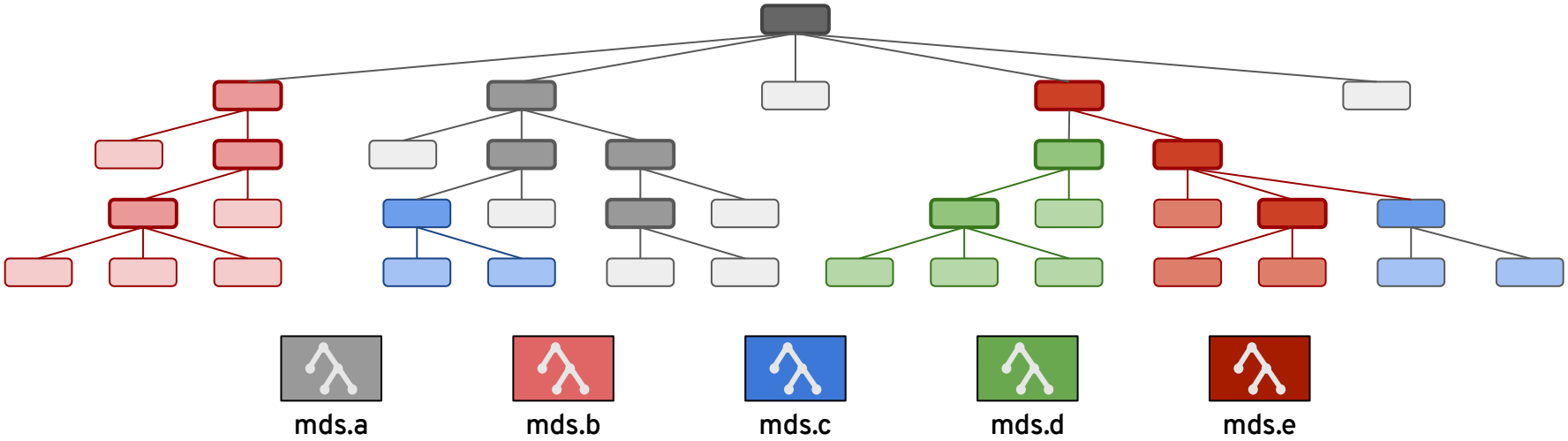


ceph-osd

METADATA IS STORED IN RADOS



SCALABLE NAMESPACE



- Partition hierarchy across MDSs based on workload
- Fragment huge directories across MDSs
- Clients learn overall partition as they navigate the namespace

- Subtree partition maintains directory locality
- Arbitrarily scalable by adding more MDSs

CEPHFS SNAPSHOTS

- Snapshot any directory
  - Applies to all nested files and directories
  - Granular: avoid “volume” and “subvolume” restrictions in other file systems
- Point-in-time consistent
  - from perspective of POSIX API at *client*
  - *not* client/server boundary
- Easy user interface via file system
- Efficient
  - Fast creation/deletion
  - Snapshots only consume space when changes are made

```
$ cd any/cephfs/directory
$ ls
foo bar baz/
$ ls .snap
$ mkdir .snap/my_snapshot
$ ls .snap/
my_snapshot/
$ rm foo
$ ls
bar baz/
$ ls .snap/my_snapshot
foo bar baz/
$ rmdir .snap/my_snapshot
$ ls .snap
$
```

CEPHFS RECURSIVE ACCOUNTING

- MDS maintains recursive stats across the file hierarchy
  - File and directory counts
  - File size (summation)
  - Latest **ctime**
- Visible via virtual xattrs
- Recursive bytes as directory size
  - If mounted with ‘rbytes’ option
  - Unfortunately this confuses rsync; off by default
  - Similar to ‘du’, but free

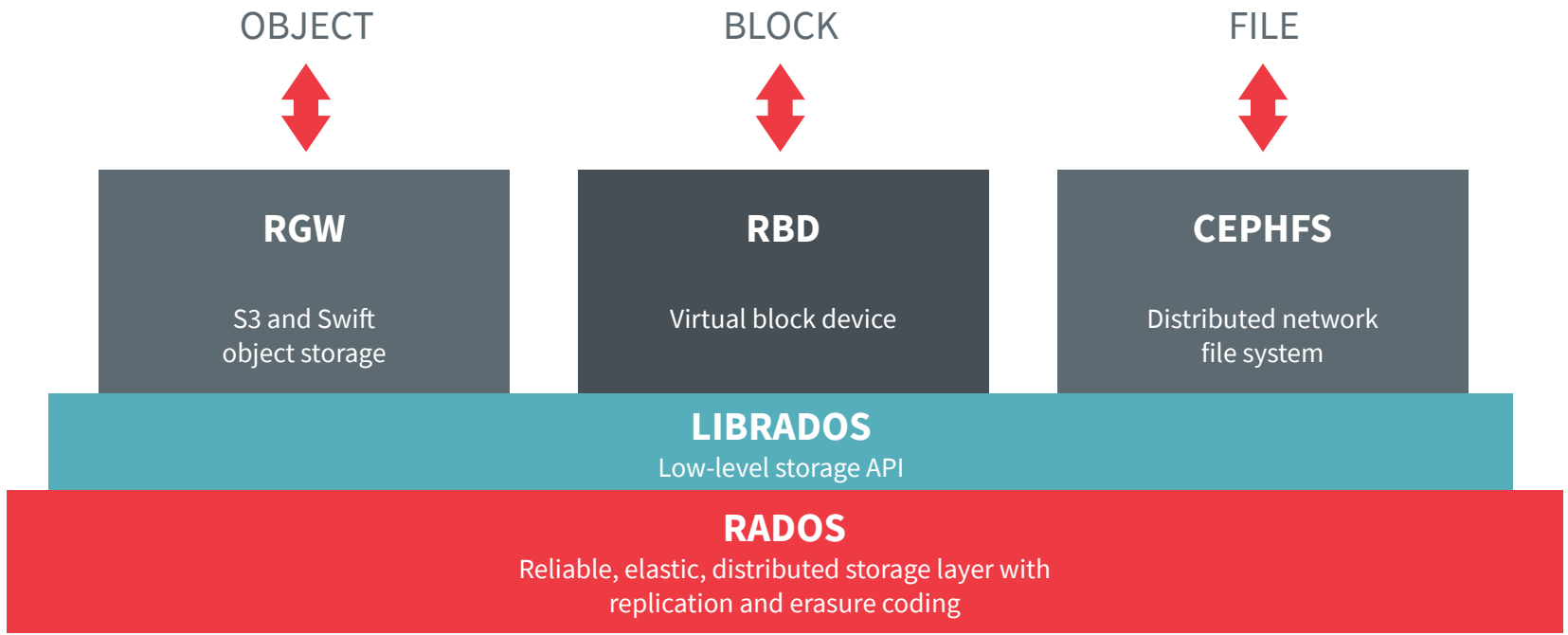
```
$ sudo mount -t ceph 10.1.2.10:/ /mnt/ceph \
-o name=admin,secretfile=secret,rbytes
$ cd /mnt/ceph/some/random/dir
$ getfattr -d -m - .
# file: .
ceph.dir.entries="3"
ceph.dir.files="2"
ceph.dir.subdirs="1"
ceph.dir.rbytes="512000"
ceph.dir.rctime="1474909482.0924860388"
ceph.dir.rentries="17"
ceph.dir.rfiles="16"
ceph.dir.rsubdirs="1"
$ ls -alh
total 12
drwxr-xr-x  3 sage sage 4.5M Jun 25 11:38 ./
drwxr-xr-x 47 sage sage  12G Jun 25 11:38 ../
-rw-r--r--  1 sage sage   2M Jun 25 11:38 bar
drwxr-xr-x  2 sage sage 500K Jun 25 11:38 baz/
-rw-r--r--  1 sage sage   2M Jun 25 11:38 foo
```

OTHER CEPHFS FEATURES

- Multiple file systems (volumes) per cluster
  - Separate ceph-mds daemons
- xattrs
- File locking (flock and fcntl)
- Quotas
  - On any directory
- Subdirectory mounts + access restrictions
- Multiple storage tiers
  - Directory subtree-based policy
  - Place files in different RADOS pools
  - Adjust file striping strategy
- Lazy IO
  - Optionally relax CephFS-enforced consistency on per-file basis for HPC applications

- Linux kernel client
  - e.g., mount -t ceph $monip:/ /ceph
- ceph-fuse
  - For use on non-Linux hosts (e.g., OS X) or when kernel is out of date
- NFS
  - CephFS plugin for nfs-ganesha FSAL
- CIFS
  - CephFS plugin for Samba VFS
- libcephfs
  - Dynamically link with your application

COMPLETE STORAGE PLATFORM



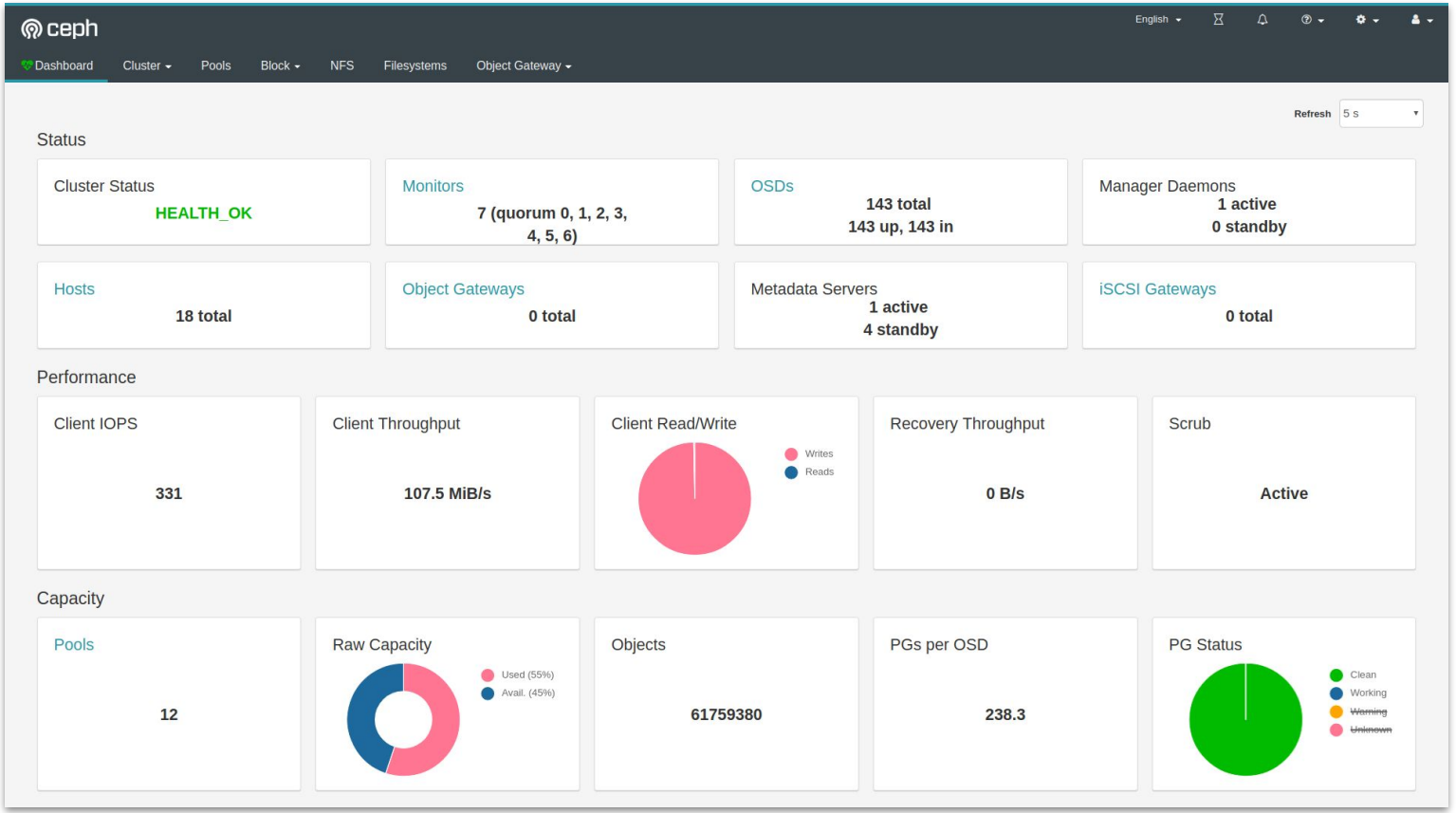
MANAGEMENT

INTEGRATED DASHBOARD

Monitoring
- Health
- IO and capacity utilization

Metrics
- Prometheus
- Grafana

Management
- Configuration
- Provisioning
- Day 2 tasks



A FEW OTHER MANAGEMENT FEATURES

- Internal health monitoring
  - Error and warning states
  - Alert IDs with documentation, mitigation steps, etc.
- Integrated configuration management
  - Self-documenting
  - History, rollback, etc.
- Device management
  - Map daemons to raw devices ($vendor_$model_$serial)
  - Scrape device health metrics (e.g. SMART)
  - Predict device life expectancy
  - Optionally preemptively evacuate failing devices
- Telemetry
  - Phone home anonymized metrics to Ceph developers
  - Cluster size, utilization, enabled features
  - Crash reports (version + stack trace)
  - Opt-in, obviously

INSTALLATION OPTIONS

- ceph-deploy
  - Bare-bones CLI-based deployment
  - https://github.com/ceph/ceph-deploy
  - Deprecated…
- ceph-ansible
  - Run Ceph on bare metal
  - https://github.com/ceph/ceph-ansible
- Rook
  - Run Ceph in Kubernetes
  - https://rook.io/
- DeepSea
  - SALT-based deployment tool
  - https://github.com/SUSE/DeepSea
- Puppet
  - https://github.com/openstack/puppet-ceph

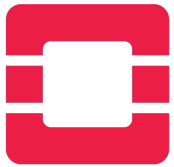
- Work in progress…
  - Integrated orchestration API
  - Unified CLI and GUI experience for day 2 ops
  - Pluggable integrations with deployment tools (Rook, ansible, …, and bare-bones ssh)

COMMUNITY AND ECOSYSTEM

OPEN DEVELOPMENT COMMUNITY

- Ceph is open source software!
  - Mostly LGPL2.1/LGPL3
- We collaborate via
  - GitHub: https://github.com/ceph/ceph
  - https://tracker.ceph.com/
  - E-mail: dev@ceph.io
  - #ceph-devel on irc.oftc.net
- We meet a lot over video chat
  - See schedule at http://ceph.io/contribute
- We publish ready-to-use packages
  - CentOS 7, Ubuntu 18.04
- We work with downstream distributions
  - Debian, SUSE, Ubuntu, Red Hat

WE INTEGRATE WITH CLOUD ECOSYSTEMS



openstack®

kubernetes

CEPH EVENTS

Ceph Days

- One-day regional event
- ~10 per year
- 50-200 people
- Normally a single track of technical talks
- Mostly user-focused

http://ceph.io/cephdays

Cephalocon

- Two-day global event
- Once per year, in the spring
- 300-1000 people
- Multiple tracks
- Users, developers, vendors

http://ceph.io/cephalocon

FOR MORE INFORMATION

- http://ceph.io/
- Twitter: **@ceph**
- Docs: http://docs.ceph.com/
- Mailing lists: http://lists.ceph.io/
  - ceph-announce@ceph.io → announcements
  - ceph-users@ceph.io → user discussion
  - dev@ceph.io → developer discussion
- IRC: irc.oftc.net
  - #ceph, #ceph-devel
- GitHub: https://github.com/ceph/
- YouTube 'Ceph' channel

CEPH FOUNDATION

- Organization of industry members supporting the Ceph project and community
- 35 members
  - Vendors
  - Cloud companies
  - Major users
  - Academic and government institutions
- Event planning
- Upstream CI infrastructure
- Community hardware test lab

CEPH FOUNDATION MEMBERS

AMIHAN
中国移动 China Mobile | 中移软件 CMSoft
DigitalOcean
intel
OVH
ProphetStor
Red Hat
SOFTIRON
SUSE We adapt. You succeed.
ubuntu Delivered by Canonical
Western Digital
XSKY
ZTE

Ambedded
arm
博云 BoCloud
catalyst cloud
clyso cloud system solutions
croit
DiDi
EasyStack
Intelligent Systems Services
中国平安 平安科技 PING AN TECHNOLOGY
QCT
SRIE

BOSTON UNIVERSITY
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MONASH University
NRF SARAO
Science & Technology Facilities Council
SWITCH