Lecture 15: storage for HPC systems: part 3

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Agenda of this lecture (part 3)

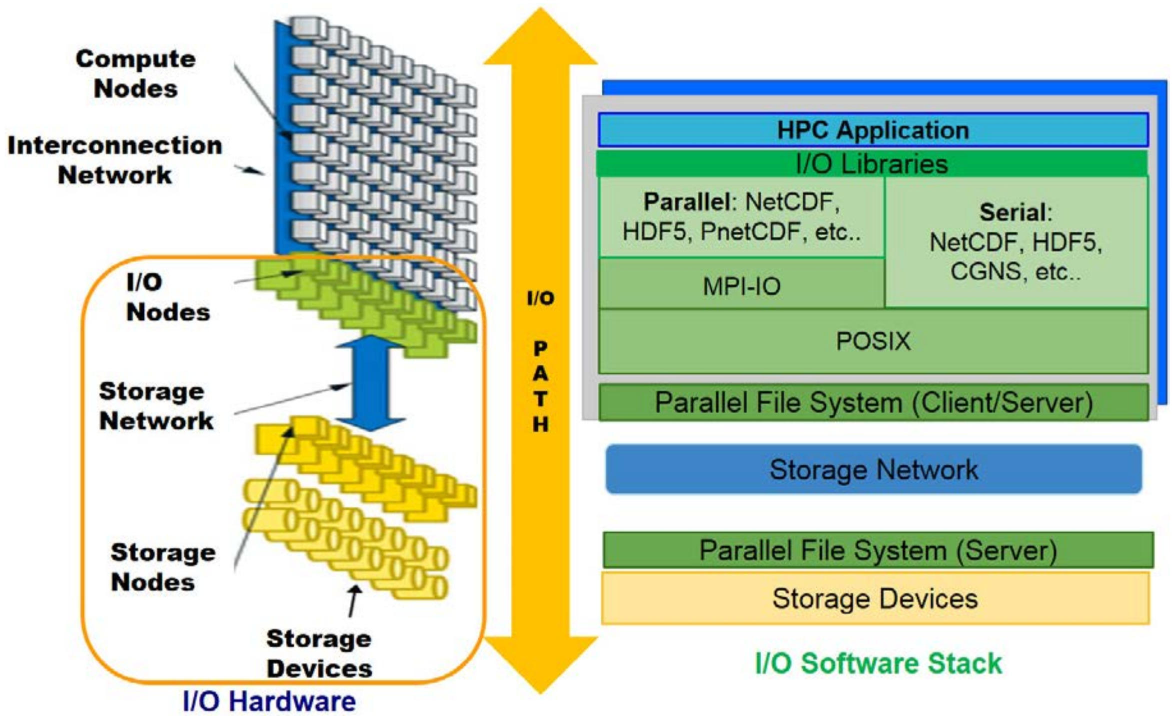
- Parallel FS
- CEPH fs
- ORFEO storage
- Benchmarking I/O storage on ORFEO…

Parallel File System

Elements of a PFS

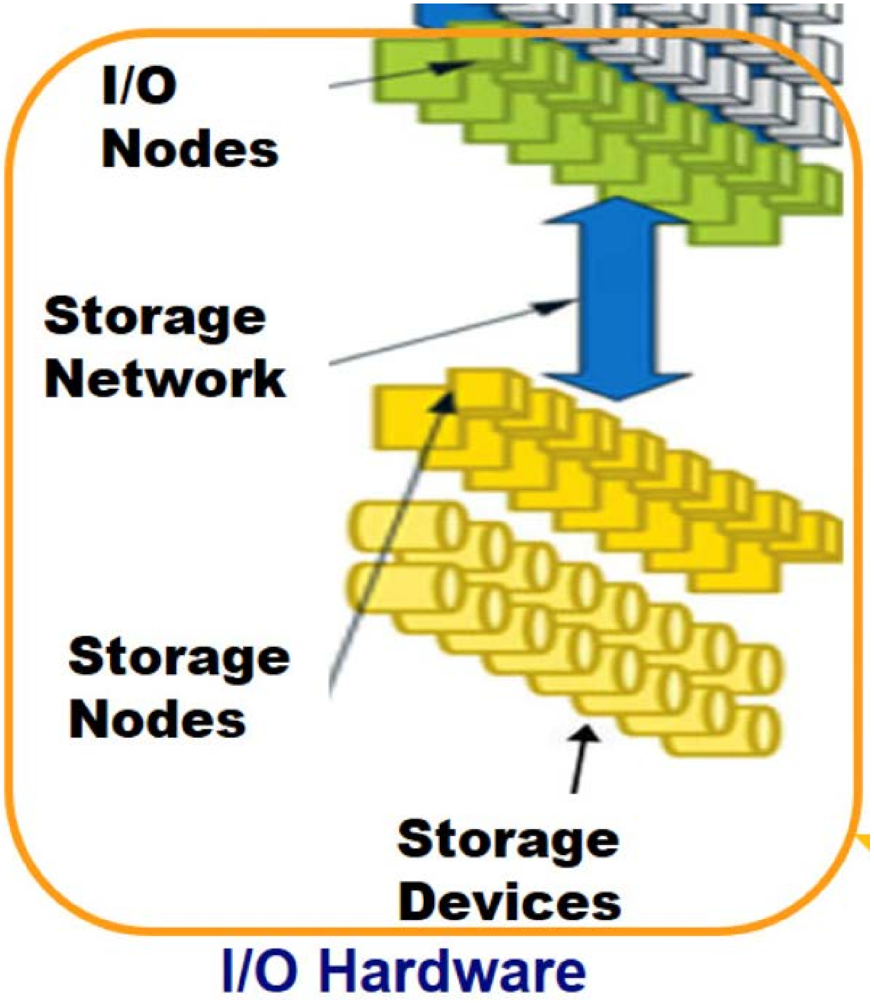
- A parallel solution usually is made of
  - several Storage Servers that hold the actual filesystem data
  - one or more Metadata Servers that help clients to identify/manage data stored in the file system
  - a redundancy layer that replicates in some way information in the storage cluster, so that the file system can survive the loss of some component server
- and optionally:
  - monitoring software that ensures continuous availability of all needed components

A graphical view:



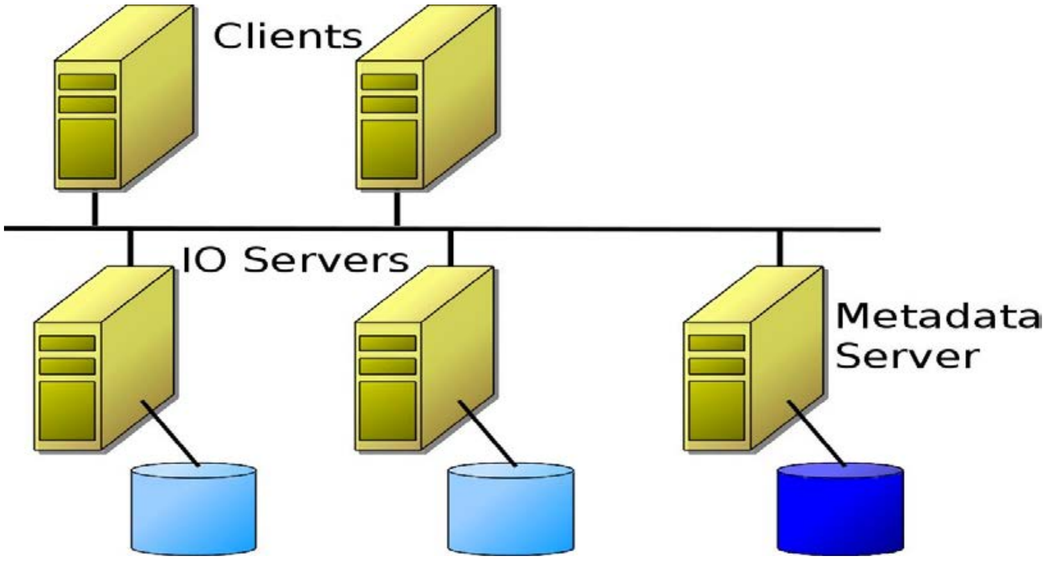
Picture from: http://www.prace-ri.eu/best-practice-guide-parallel-i-o/#id-1.3.5

Parallel File System: I/O hardware



Parallel File System: components

- In general, a Parallel File Systems has the following components
  - Metadata Server
  - I/O Servers
  - Clients



Hardware to build a PFS:

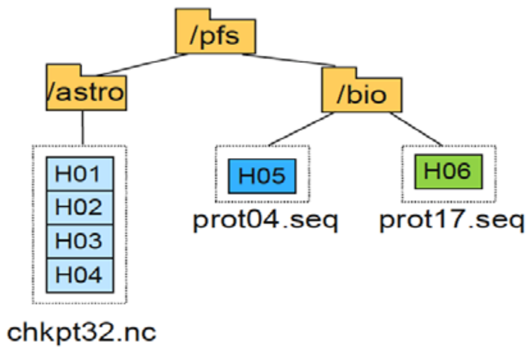
- Nodes, Disks, controllers, and interconnects
- Hardware defines the peak performance of the I/O system:
  - raw bandwidth
  - Minimum latency
- At the hardware level, data is accessed at the granularity of blocks, either physical disk blocks or logical blocks spread across multiple physical devices such as in a RAID array
- Parallel File Systems takes care of
  - managing data on the storage hardware,
  - presenting this data as a directory hierarchy,
  - coordinating access to files and directories in a consistent manner

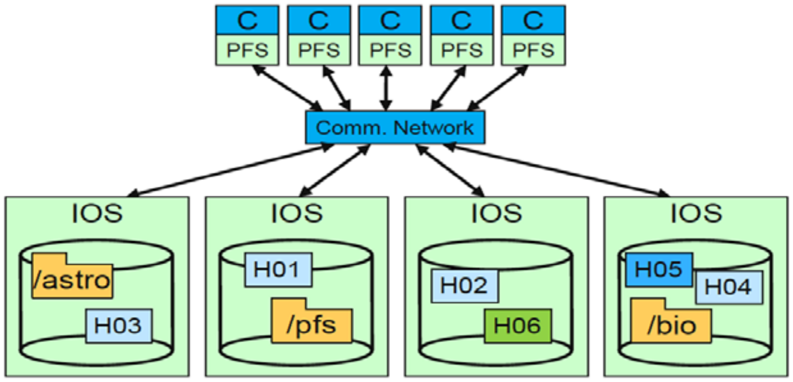
An important disclaimer..

- Parallel File Systems are usually optimized for high performance rather than general purpose use,
- Optimization criteria:
  - Large block sizes (≥ 64kB)
  - Relatively slow metadata operations (eg. fstat()) compared to reads and writes..)
  - Special APIs for direct access and additional optimizations. i.e. no Posix sometime/somewhere

Parallel FS approaches..

- An example parallel file system, with large astrophysics checkpoints distributed across multiple I/O servers (IOS) while small bioinformatics files are each stored on a single IOS

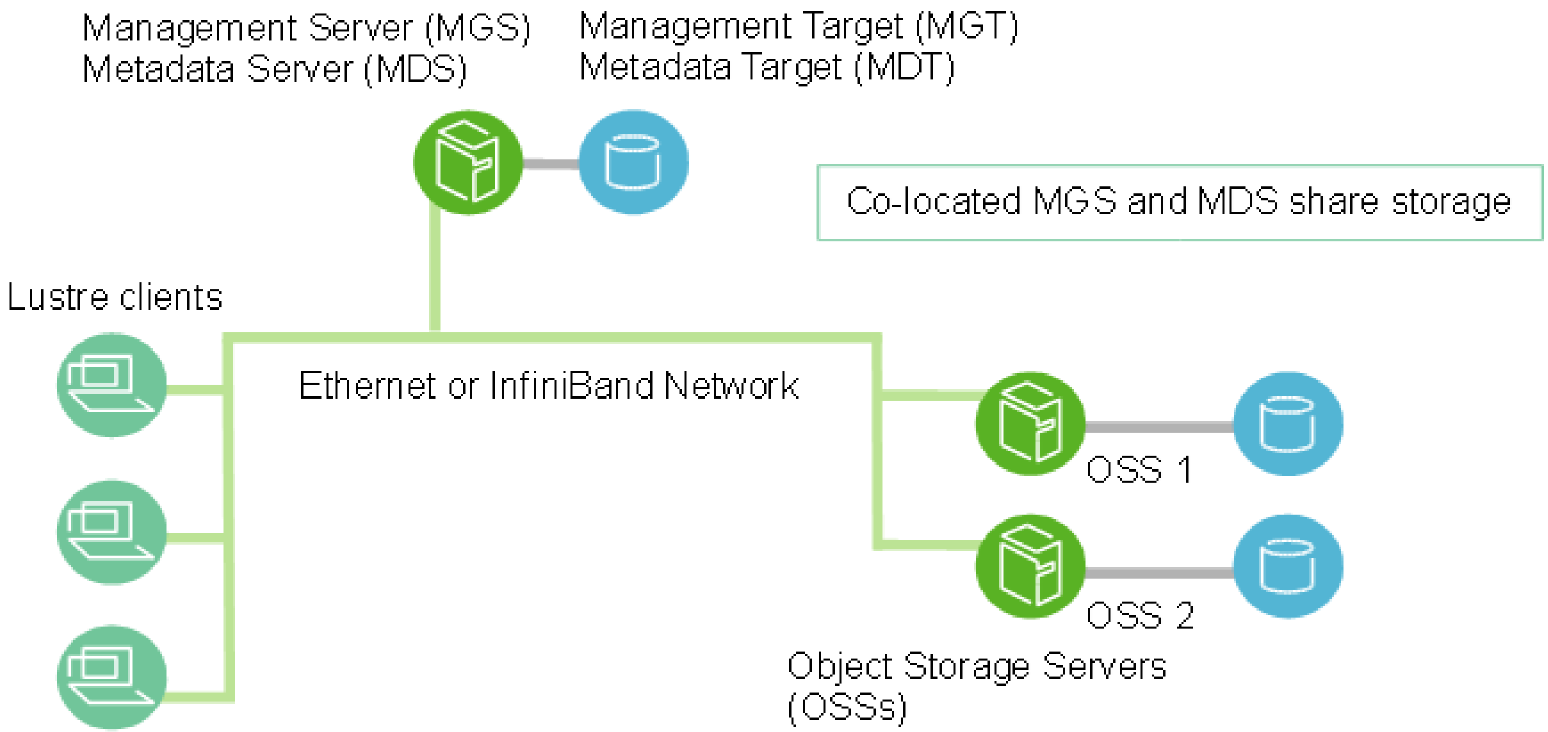




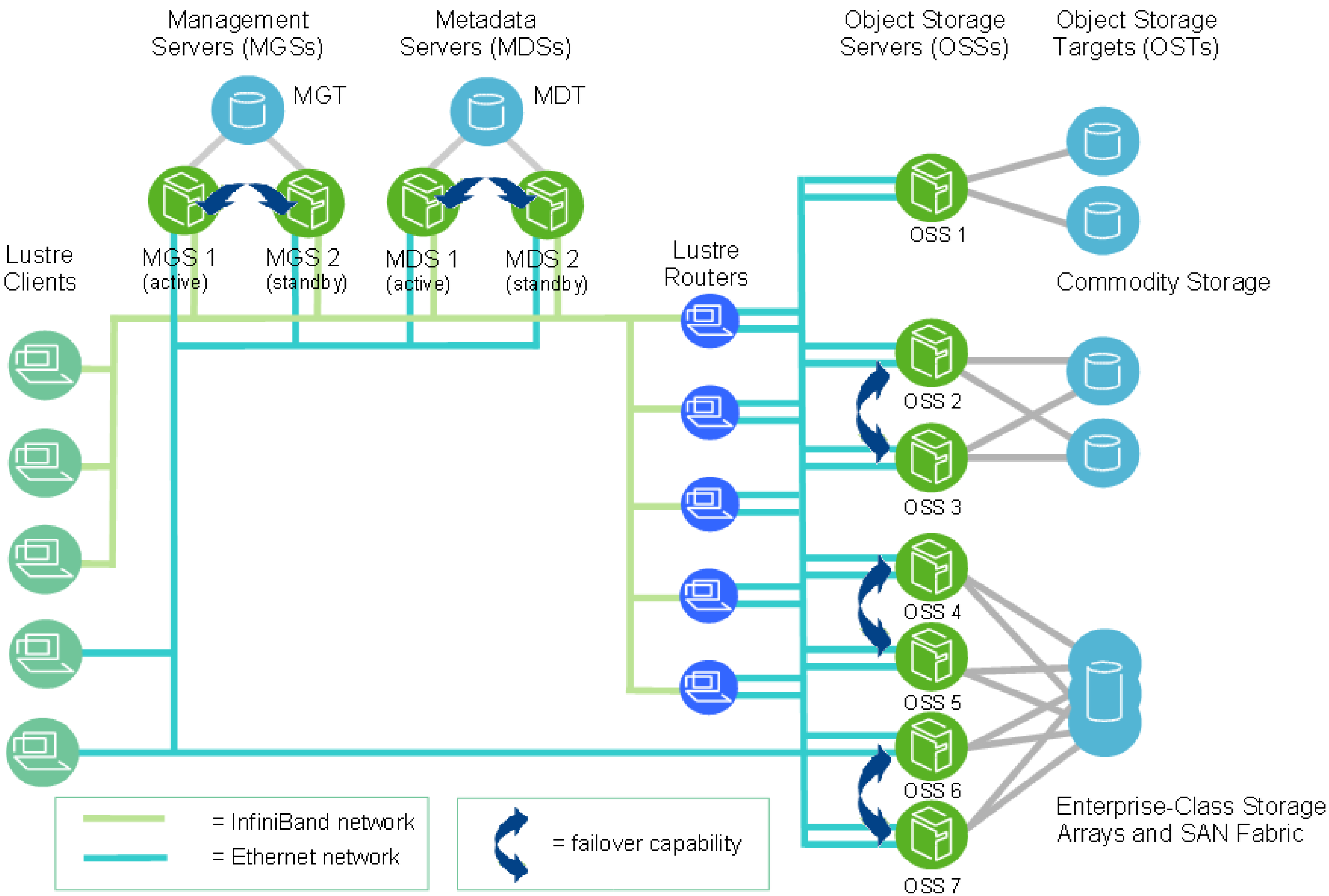
What is available on the market ?

- BeeGFS
  - Developed at Fraunhofer Institute, freely available not open
  - http://www.fhgfs.com/cms/
- Lustre
  - open and Free owned by Intel DDN
  - Intel no longer sells tools to manage and support ($$$)
  - http://lustre.opensfs.org/
- GPFS (now known as Spectrum Scale)
  - IBM proprietary $$$
  - Very nice solution and expensive ones !
- And many others (WekaIO/MooseFS/Panasas... etc)

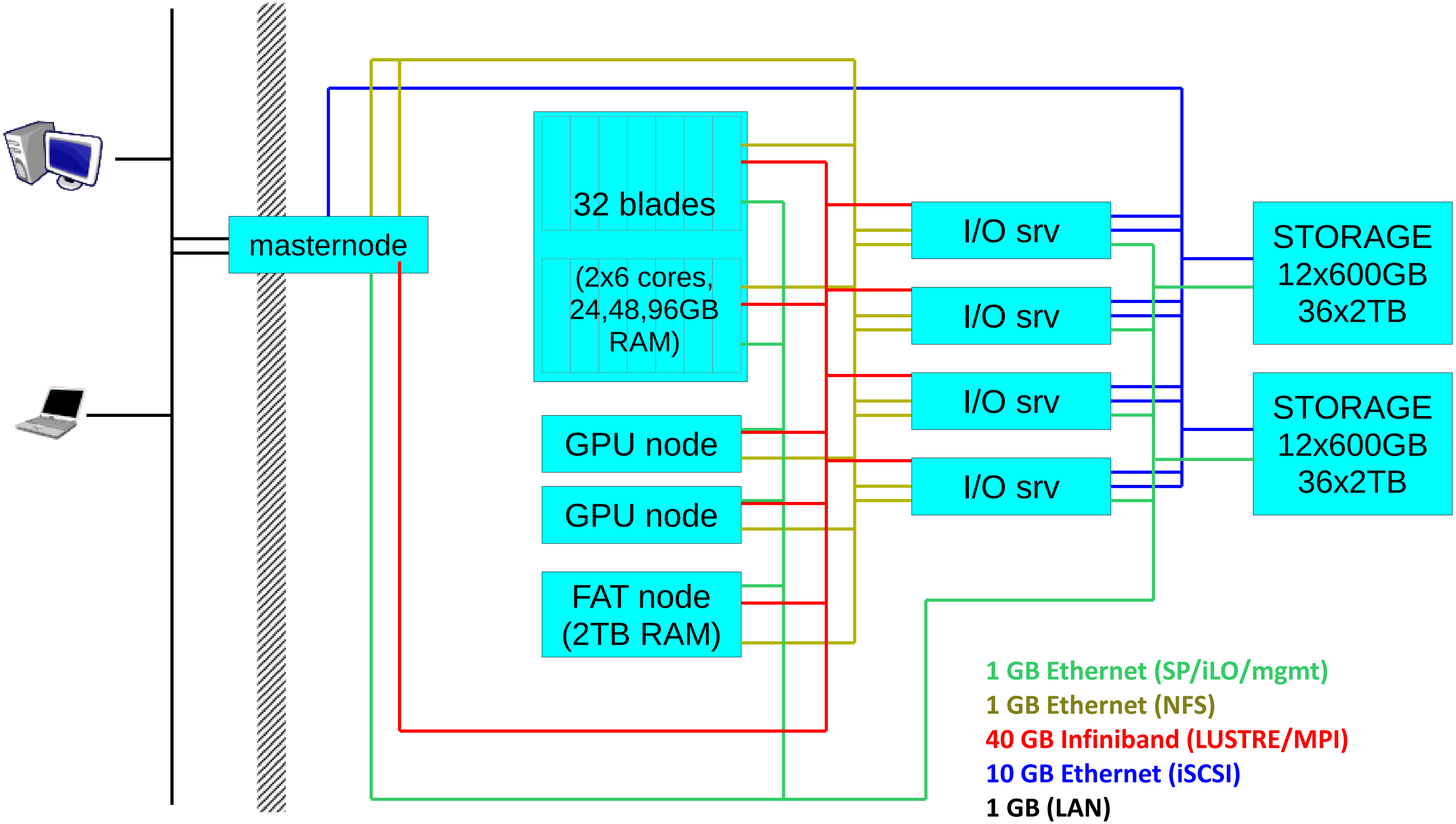
Lustre in two pictures: simple one



Lustre in two pictures: complex one

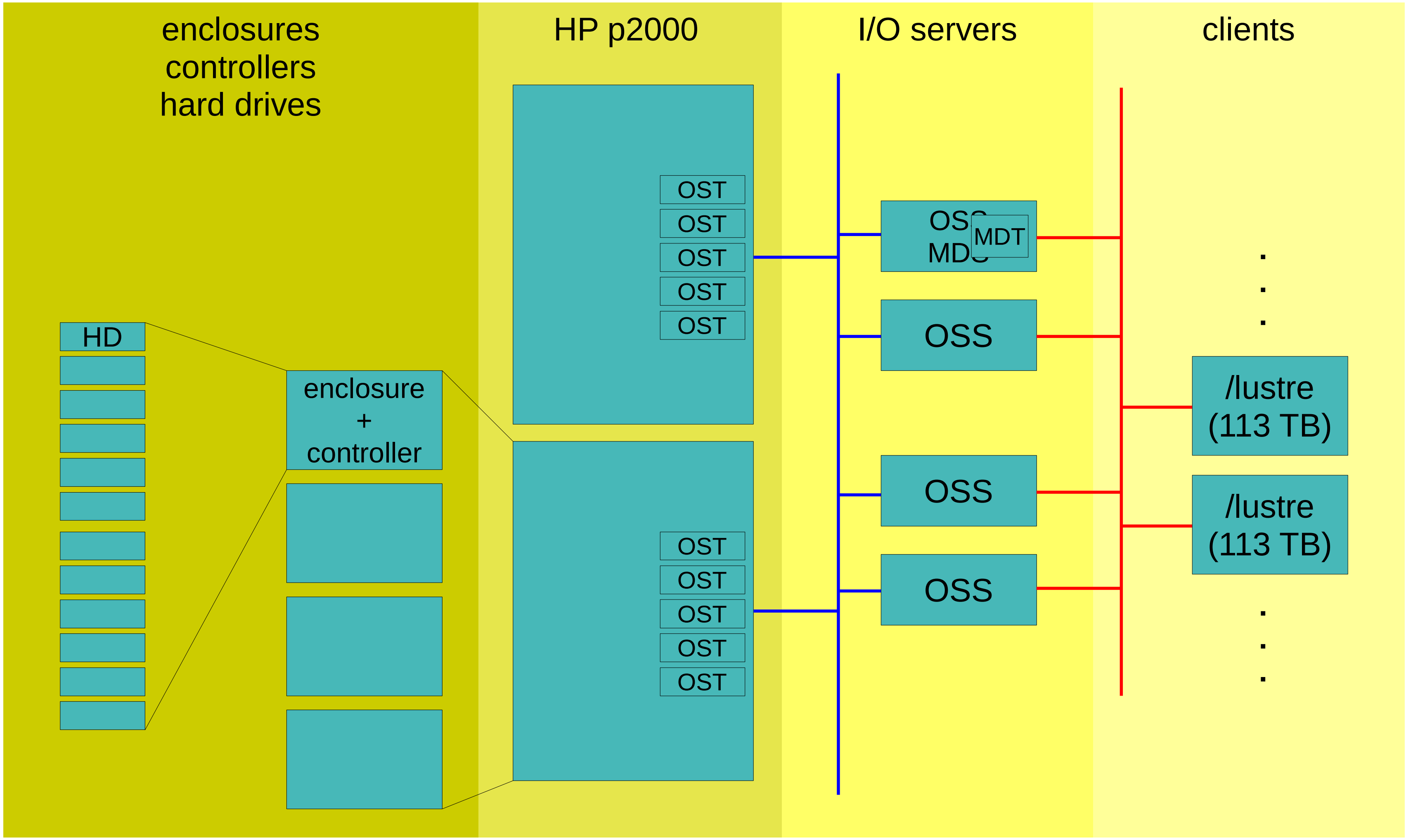


HPC infrastructure @ CRIBI

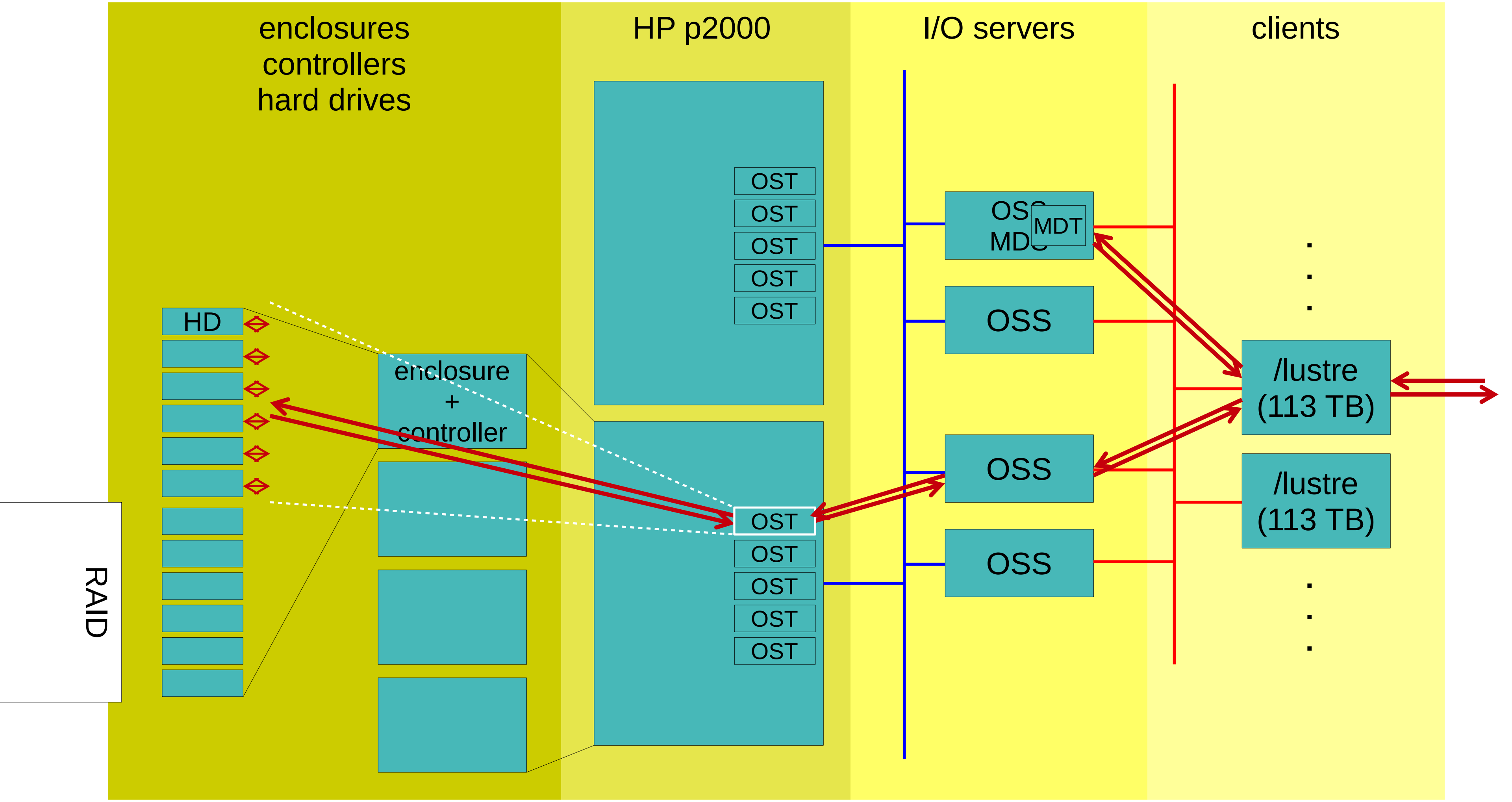


1 GB Ethernet (SP/iLO/mgmt)
1 GB Ethernet (NFS)
40 GB Infiniband (LUSTRE/MPI)
10 GB Ethernet (iSCSI)
1 GB (LAN)

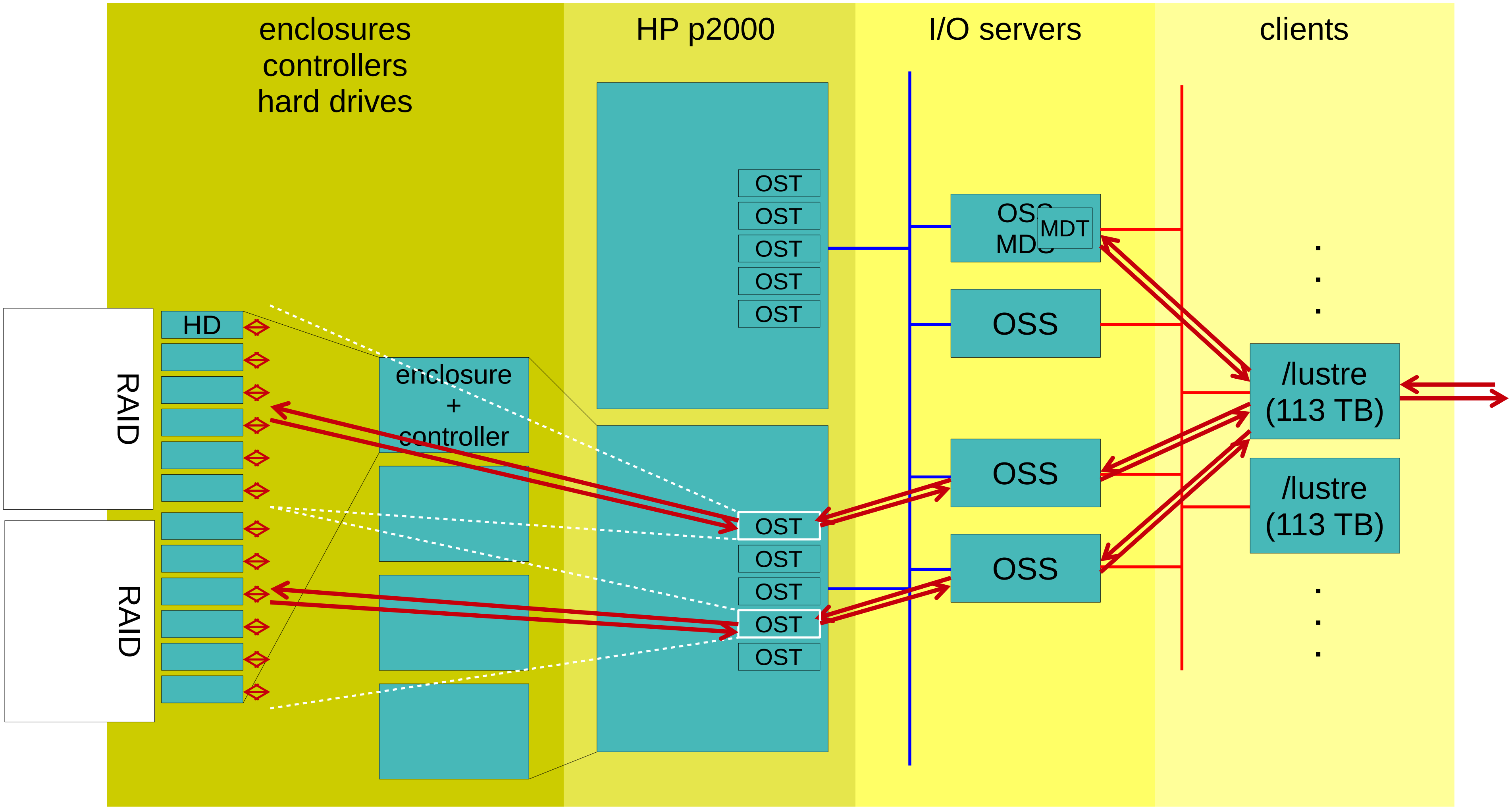
LUSTRE@CRIBI as storage solution



accessing LUSTRE filesystem



why "parallel" filesystem?



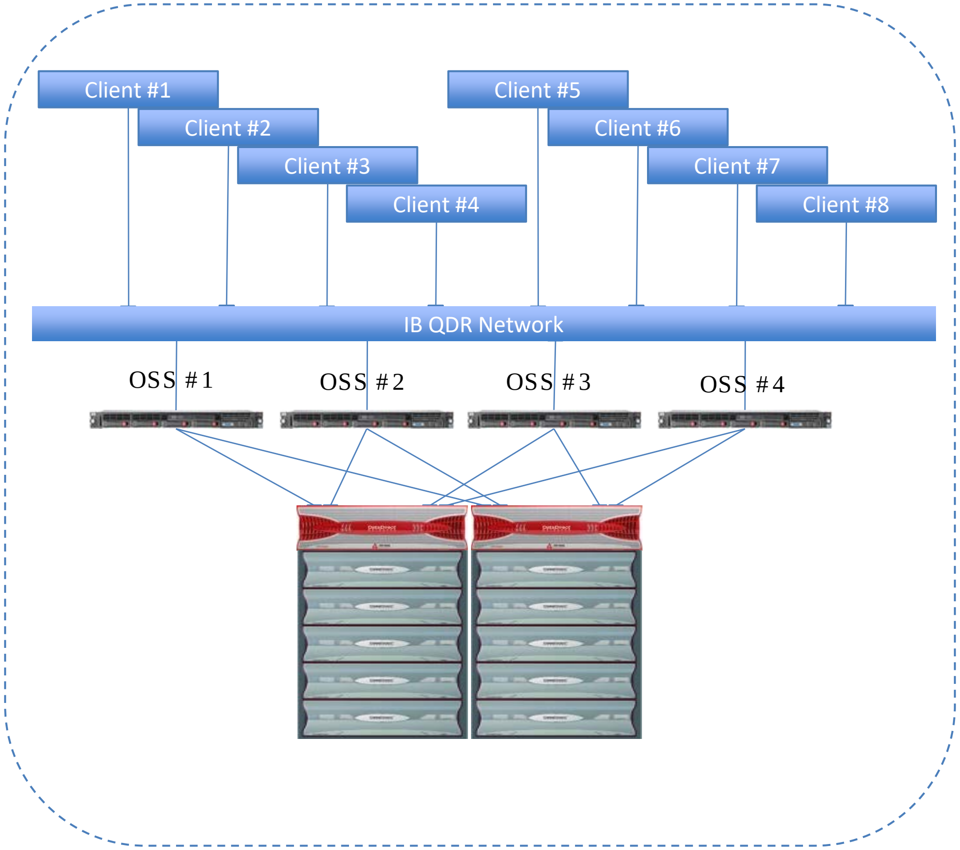
Expected performance

- Elements of the infrastructure:

  - Network Speed: Infiniband QDR :3.2GB/sec for server
    --> Network aggregate bandwith: 3.2 x 4 ~ 12GB/se
  - 4 IO-SRV two OST each
    - Each OST: RAID 6 6 disks
    - OST Aggregate bandwith: (6-2)*100 = 400 Mb/seconds
      - [Disk speed: 100 Mb/seconds]
  - Node Aggregate bandwith 400x 2 = 800 Mb/sec

Peak performance : 4 x 800 = 3.2 GB/sec read/write

overall LUSTRE performance

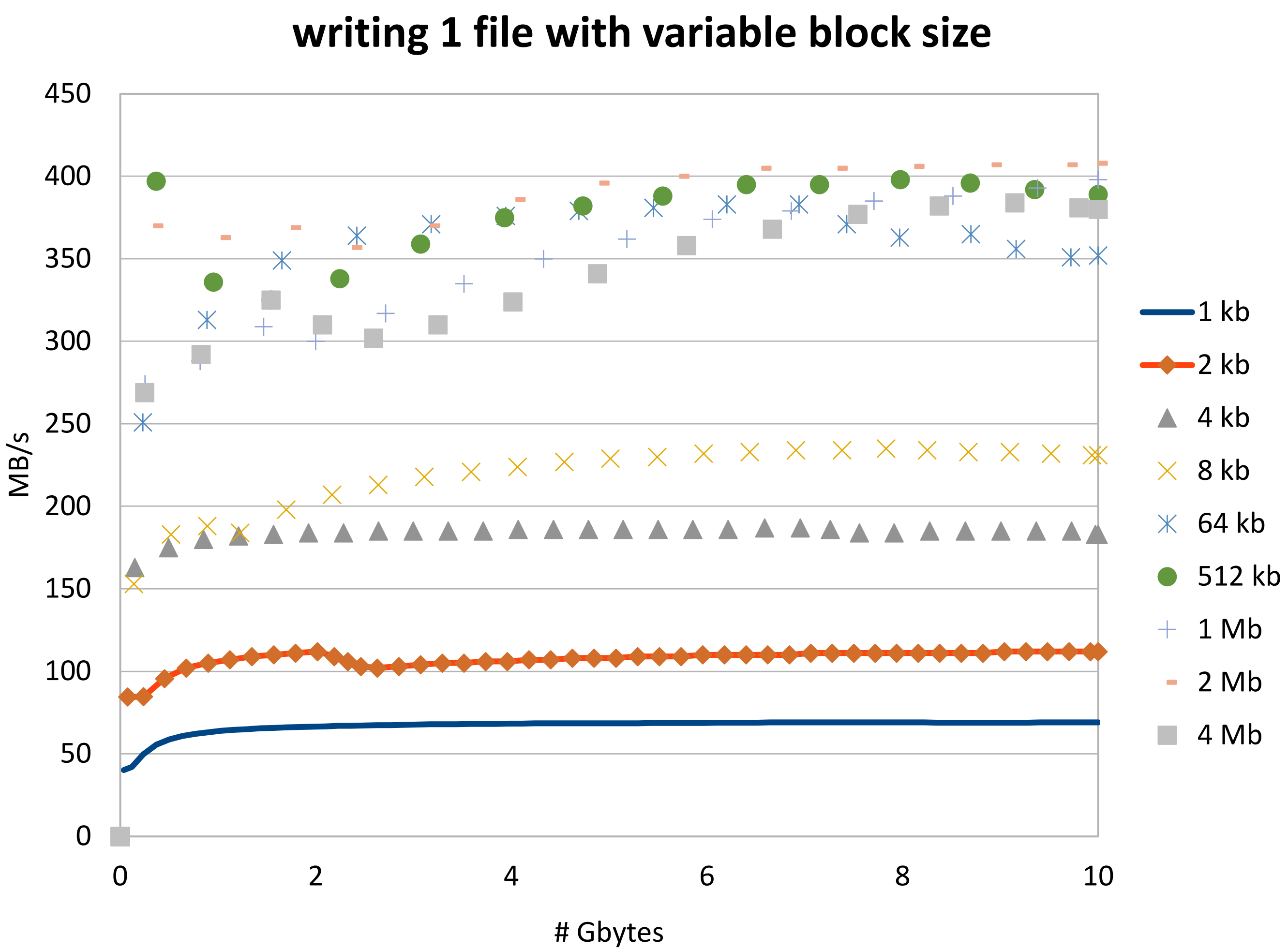


- ➢ sequential write/read by iozone
- ➢ 1 ~ 8 clients, 1 ~ 4 proc/client
- ➢ 32 GB files writing
- ➢ 64 GB files reading

- **~ 1.7 GB/sec writing**
- **32 clients, 32 GB files**

- **~ 1.2 GB/sec reading**
- **32 clients, 64 GB files**

LUSTRE can be disappointing too...



ORFEO choice: CEPH

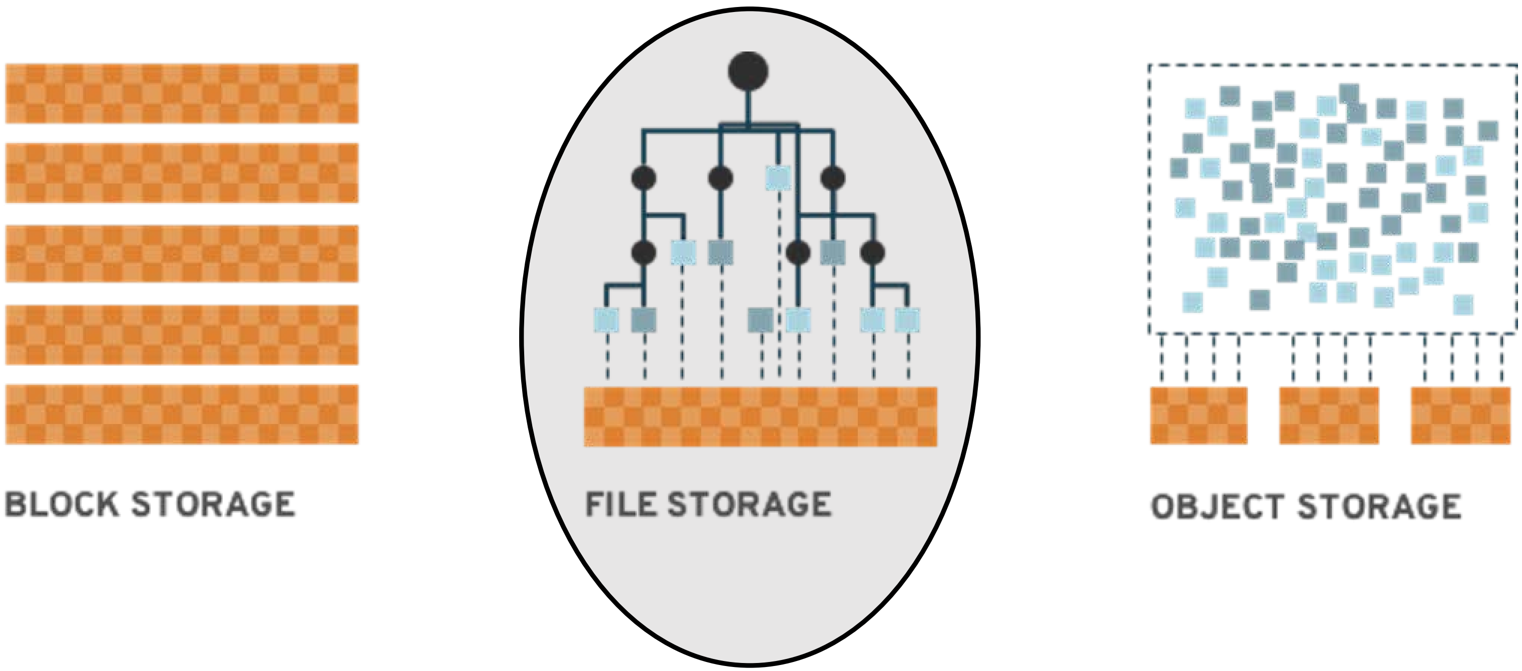
- A unique storage solution for both HPC and Cloud infrastructure
- Main Users: Bioinformatics with many files
- Open and free
- Scalable..

A short introduction to CEPH

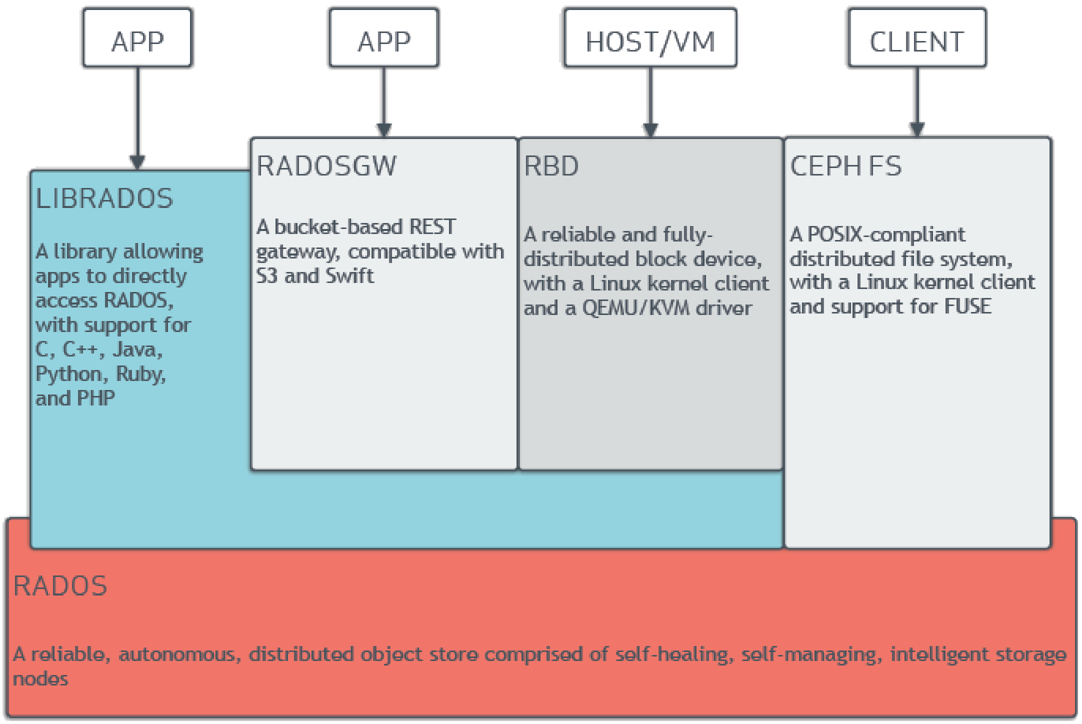
CEPH storage

- Open-source distributed storage solution
- Object based storage
- Highly scalable
- Built around the CRUSH algorithm, by Sage Weil – http://ceph.com/papers/weil-crush-sc06.pdf
- Supports multiple access methods [File, Block, Object]

Access methods:



CEPH Storage Architecture



CEPH storage cluster: RADOS

- **RADOS** (Reliable Autonomic Distributed Object Store)
  - This layer provides the CEPH software defined storage with the ability to store data (serve IO requests, protect the data, check the consistency and the integrity of the data through built-in mechanisms).
- The RADOS layer is composed of the following daemons:
  - MONs or Monitors
  - OSDs or Object Storage Devices
  - MGRs or Managers
  - MDSs or Meta Data Servers (only for CEPHfs)

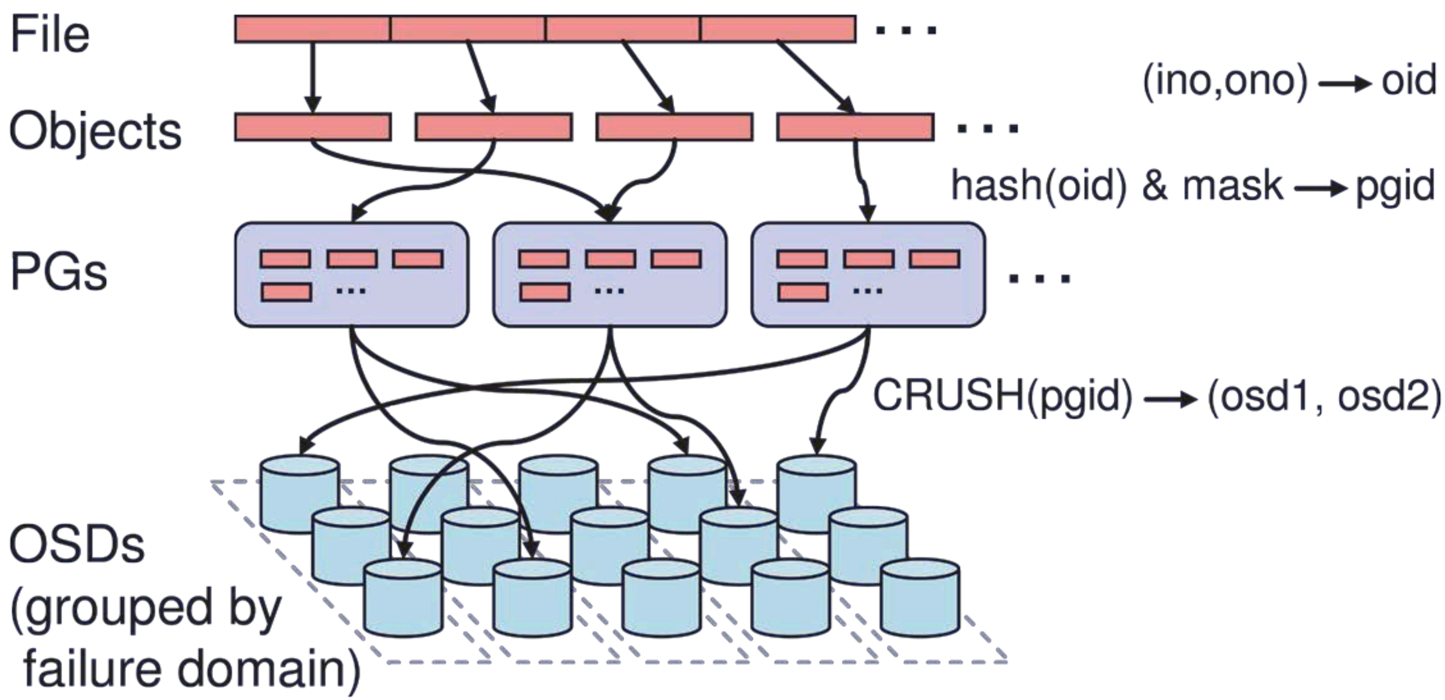
What are they doing ?

- A CEPH Monitor maintains a master copy of the cluster map. A cluster of CEPH monitors ensures high availability should a monitor daemon fail. Storage cluster clients retrieve a copy of the cluster map from the CEPH Monitor.
- A CEPH OSD Daemon checks its own state and the state of other OSDs and reports back to monitors.
- A CEPH Manager acts as an endpoint for monitoring, orchestration, and plug-in modules.
- A CEPH Metadata Server (MDS) manages file metadata when CephFS is used to provide file services.

Distributed Object Storage

- Files are split across objects
- Objects are members of placement groups
- Placement groups (PG) are distributed across OSDs.
- CRUSH (Controlled Replication Under Scalable Hashing) algorithm takes care of distributing objects and uses rules to determine the mapping of the PGs to the OSDs.

Distributed Object Storage



CRUSH

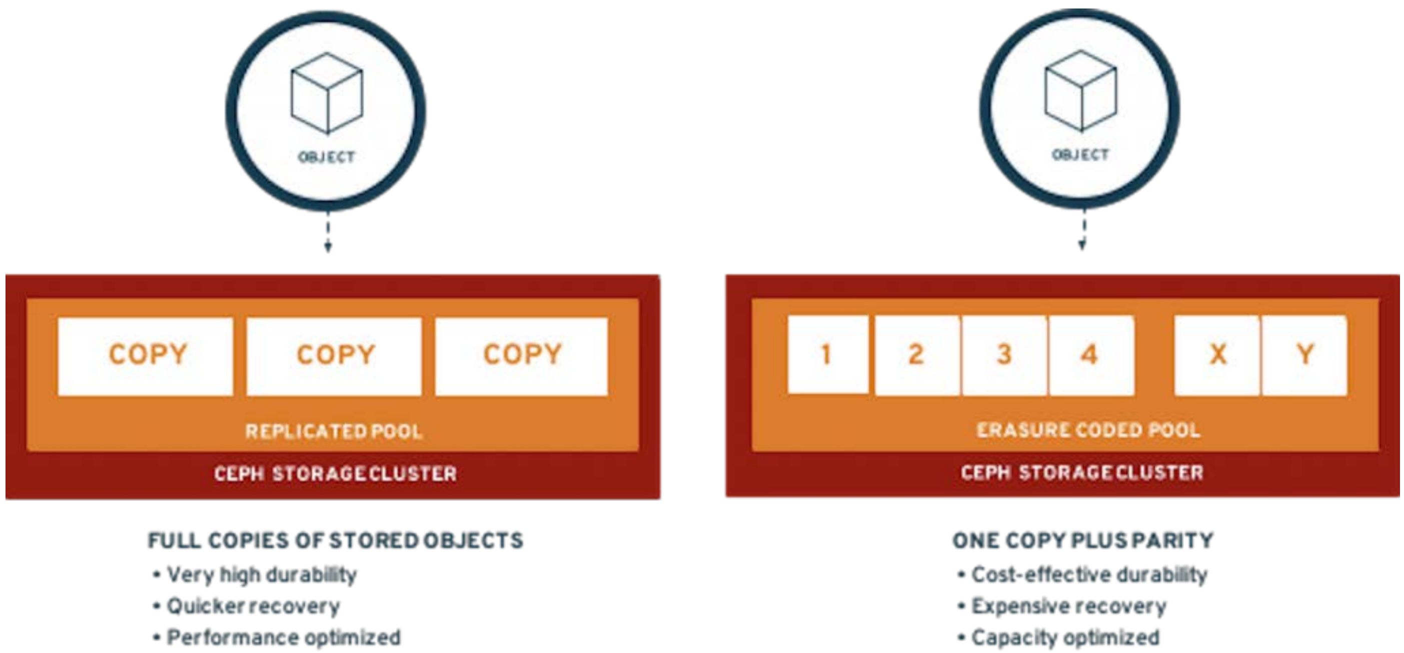
- CRUSH(x) -> (osdn1, osdn2, osdn3)
  - Inputs
    - x is the placement group
    - Hierarchical cluster map
    - Placement rules
  - Outputs a list of OSDs
- Advantages
  - Anyone can calculate object location
  - Cluster map infrequently updated

Cluster partitions

- The CEPH cluster is separated into logical partitions, known as pools. Each pool has the following properties that can be adjusted:
  - An ID (immutable)
  - A name
  - A number of PGs to distribute the objects across the OSDs
  - A CRUSH rule to determine the mapping of the PGs for this pool
  - Parameters associated with the type of protection
    - Number of copies for replicated pools
    - K and M chunks for Erasure Coding

Data protection

- Support two types: redundancy and erasure code

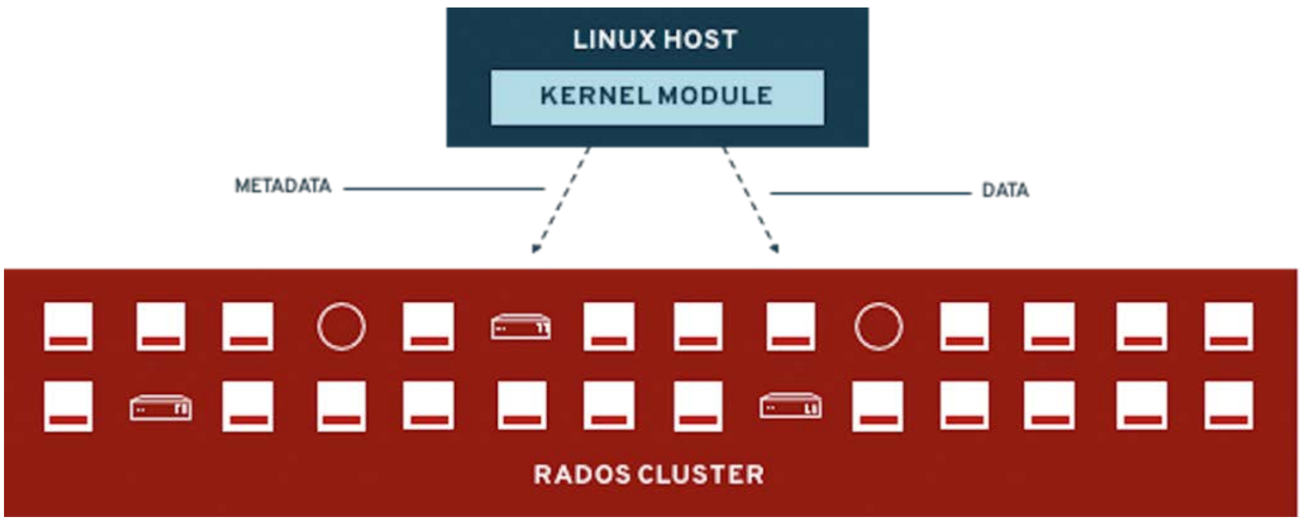


Erasure code vs replication

- Replicated pools provide better performance in almost all cases at the cost of a lower usable to raw storage ratio (1 usable byte is stored using 3 bytes of raw storage by default)
- Erasure Coding provides a cost-efficient way to store data with less performance.
- Standard Erasure Coding profiles
  - 4+2 (1:1.666 ratio)
  - 8+3 (1:1.375 ratio)
  - 8+4 (1:1.666 ratio)

CEPHfs

- clients access a shared POSIX compliant filesystem.



Client access example:

1. Client sends *open* request to MDS
2. MDS returns capability, file inode, file size and stripe information
3. Client read/write directly from/to OSDs
4. MDS manages the capability
5. Client sends *close* request, relinquishes capability, provides details to MDS

Synchronization

- Adheres to POSIX
- Includes HPC oriented extensions
  - Consistency / correctness by default
  - Optionally relax constraints via extensions
  - Extensions for both data and metadata
- Synchronous I/O used with multiple writers or mix of readers and writers

ORFEO storage

ORFEO storage: hardware

	FAST storage (NVMe)	FAST storage (SSD)	Standard storage (HDD)	Long term preservation
# of server	4		6	1
RAM	6 x 16GB		6 x 16GB	6 x 16GB
Disk per node	2x 1.6TB NVMe PCIe card	20 x 3.84TB	15 x 12TB	84 x 12TB + 42 x 12TB
Storage provider	CEPH parallel FS	CEPH parallel FS	CEPH parallel FS	Network FS (NFS)
RAW storage	**12TB**	**320 TB**	**1080 TB**	**1,512 TB**

ORFEO CEPH storage cluster

- 10 nodes

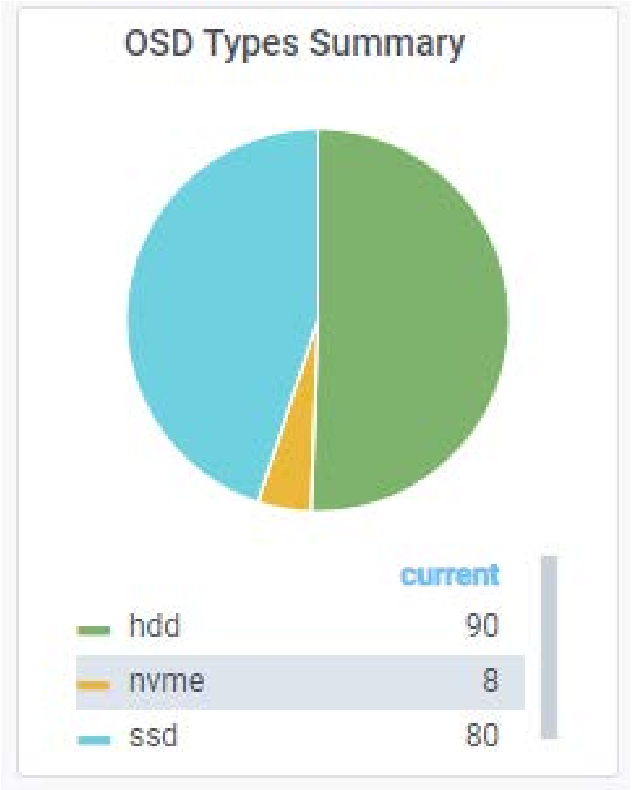
Hosts List | Overall Performance

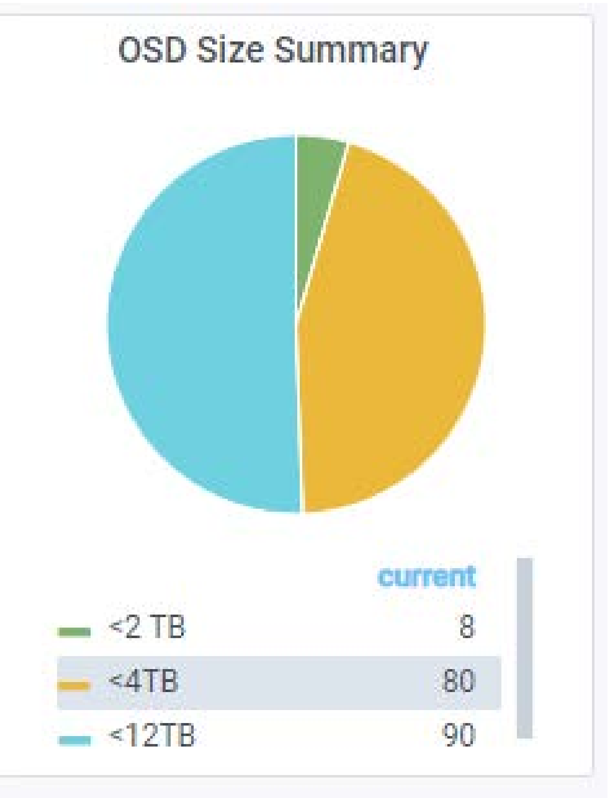
Hostname	Services
ct1ps-ceph005	osd.63 , osd.64 , osd.65 , osd.66 , osd.67 , osd.68 , osd.69 , osd.70 , osd.71 , osd.72 , osd.73 , osd.74 , osd.75 , osd.76 , osd.77
ct1ps-ceph006	osd.78 , osd.79 , osd.80 , osd.81 , osd.82 , osd.83 , osd.84 , osd.85 , osd.86 , osd.87 , osd.88 , osd.89 , osd.90 , osd.91 , osd.92
ct1ps-ceph007	osd.100 , osd.101 , osd.102 , osd.103 , osd.104 , osd.105 , osd.106 , osd.107 , osd.93 , osd.94 , osd.95 , osd.96 , osd.97 , osd.98 , osd.99
ct1ps-ceph008	osd.108 , osd.109 , osd.110 , osd.111 , osd.112 , osd.113 , osd.114 , osd.115 , osd.116 , osd.117 , osd.118 , osd.119 , osd.120 , osd.121 , osd.122
ct1ps-ceph009	osd.148 , osd.149 , osd.150 , osd.151 , osd.152 , osd.153 , osd.154 , osd.155 , osd.156 , osd.157 , osd.158 , osd.159 , osd.160 , osd.161 , osd.162
ct1ps-ceph010	osd.163 , osd.164 , osd.165 , osd.166 , osd.167 , osd.168 , osd.169 , osd.170 , osd.171 , osd.172 , osd.173 , osd.174 , osd.175 , osd.176 , osd.177
ct1ps-ceph001	mds.ct1ps-ceph001 , mgr.ct1ps-ceph001 , mon.ct1ps-ceph001 , osd.0 , osd.1 , osd.10 , osd.11 , osd.12 , osd.124 , osd.125 , osd.126 , osd.127 , osd.128 , osd.129 , osd.13 , osd.2 , osd.3 , osd.4 , osd.5 , osd.56 , osd.6 , osd.60 , osd.7 , osd.8 , osd.9 , rgw.ct1ps-ceph001
ct1ps-ceph002	mds.ct1ps-ceph002 , mgr.ct1ps-ceph002 , mon.ct1ps-ceph002 , osd.130 , osd.131 , osd.132 , osd.133 , osd.134 , osd.135 , osd.14 , osd.15 , osd.16 , osd.17 , osd.18 , osd.19 , osd.20 , osd.21 , osd.22 , osd.23 , osd.24 , osd.25 , osd.26 , osd.27 , osd.57 , osd.61 , rgw.ct1ps-ceph002
ct1ps-ceph003	mds.ct1ps-ceph003 , mgr.ct1ps-ceph003 , mon.ct1ps-ceph003 , osd.136 , osd.137 , osd.138 , osd.139 , osd.140 , osd.141 , osd.28 , osd.29 , osd.30 , osd.31 , osd.32 , osd.33 , osd.34 , osd.35 , osd.36 , osd.37 , osd.38 , osd.39 , osd.40 , osd.41 , osd.58 , osd.62 , rgw.ct1ps-ceph003
ct1ps-ceph004	mds.ct1ps-ceph004 , mgr.ct1ps-ceph004 , mon.ct1ps-ceph004 , osd.123 , osd.142 , osd.143 , osd.144 , osd.145 , osd.146 , osd.147 , osd.42 , osd.43 , osd.44 , osd.45 , osd.46 , osd.47 , osd.48 , osd.49 , osd.50 , osd.51 , osd.52 , osd.53 , osd.54 , osd.55 , osd.59 , rgw.ct1ps-ceph004

0 selected / 10 total

ORFEO CEPH storage cluster

- 178 OSDs





ORFEO CEPH Crush map

Cluster » CRUSH map

CRUSH map viewer

- default (root)
  - ct1ps-ceph005 (host)
  - ct1ps-ceph006 (host)
  - ct1ps-ceph007 (host)
  - ct1ps-ceph001 (host)
    - up osd.0 (osd)
    - up osd.1 (osd)
    - up osd.10 (osd)
    - up osd.11 (osd)
    - up osd.12 (osd)
    - up osd.124 (osd)
    - up osd.125 (osd)
    - up osd.126 (osd)
    - up osd.127 (osd)
    - up osd.128 (osd)
    - up osd.129 (osd)
    - up osd.13 (osd)
    - up osd.2 (osd)
    - up osd.3 (osd)
    - up osd.4 (osd)
    - up osd.5 (osd)
    - up osd.56 (osd)

osd.56 (osd)

crush_weight	1.454986572265625
depth	2
device_class	nvme
exists	1
id	56
primary_affinity	1
reweight	1
type_id	0

ORFEO CEPH storage cluster

- 4 monitors:

In Quorum

10

Name	Rank	Public Address	Open Sessions
ct1ps-ceph001	0	10.128.6.211:6789/0	
ct1ps-ceph002	1	10.128.6.212:6789/0	
ct1ps-ceph003	2	10.128.6.213:6789/0	
ct1ps-ceph004	3	10.128.6.214:6789/0	

4 total

Not In Quorum

10

Name	Rank	Public Address
No data to display		

0 total

ORFEO CEPH pools..

- 17 different pools

Pools List | Overall Performance

+ Create

10

Name	Type	Applications	PG Status	Replica Size	Erasure Coded Profile	Crush Ruleset	Usage	Read bytes	Write bytes
cephfs_data	replicated	cephfs	2048 active+clean	3		repl_ssd	17%		
cephfs_metadata	replicated	cephfs	256 active+clean	3		repl_ssd	0%		
cephfs_spin_data	erasure	cephfs	2 active+clean+scrubbing+dee 1 active+clean+scrubbing, 1021 active+clean	6	ec_hdd_4km2	cephfs_spin_data	23%		
cephfs_spin_metadata	replicated	cephfs	128 active+clean	3		repl_ssd	0%		
kub_metadata	replicated	cephfs	8 active+clean	3		repl_nvme	0%		
kub_data	replicated	cephfs	32 active+clean	3		repl_ssd	1%		
os-images	replicated	rbd	64 active+clean	3		repl_ssd	0%		
os-volumes-ssd	replicated	rbd	1024 active+clean	3		repl_ssd	0%		
os-vms	replicated	rbd	32 active+clean	3		repl_ssd	0%		
os-backups	replicated	rbd	32 active+clean	3		repl_ssd	0%		

0 selected / 17 total

‹ « 1 2 » ›

fast

large

ORFEO /fast and /large from CEPH

- /large
  - 90 disks (12TB each) –> 90 OSDs
  - Erasure code: 4+2 (1:1.666 ratio)
  - 1080 raw capacity →648 useful size
- /fast
  - 80 disks (4TB each) → 80 OSDs
  - Replication: 3 copies each object
  - 320TB raw capacity → 320/3 =~ 100TB useful size

ORFEO CEPH file system

- 3 different file-system

Filesystems

fast

Name	Created	Enabled
cephfs	2020-01-25 15:06:37.434728	true
cephfs_spin	2020-04-06 15:24:22.897778	true
kubefs	2020-05-12 16:34:13.390075	true

large

1 selected / 3 total

Details | Clients: 19 | Performance Details

Ranks

Rank	State	Daemon	Activity	Dentries	Inodes
0	active	ct1ps-ceph003	Reqs: 5.2 /s	1.7 M	1.5 M

1 total

Standby daemons	ct1ps-ceph004

Pools

Pool	Type	Size	Usage
cephfs_spin_data	data	652.8 TiB	23%
cephfs_spin_metadata	metadata	81.5 TiB	0%

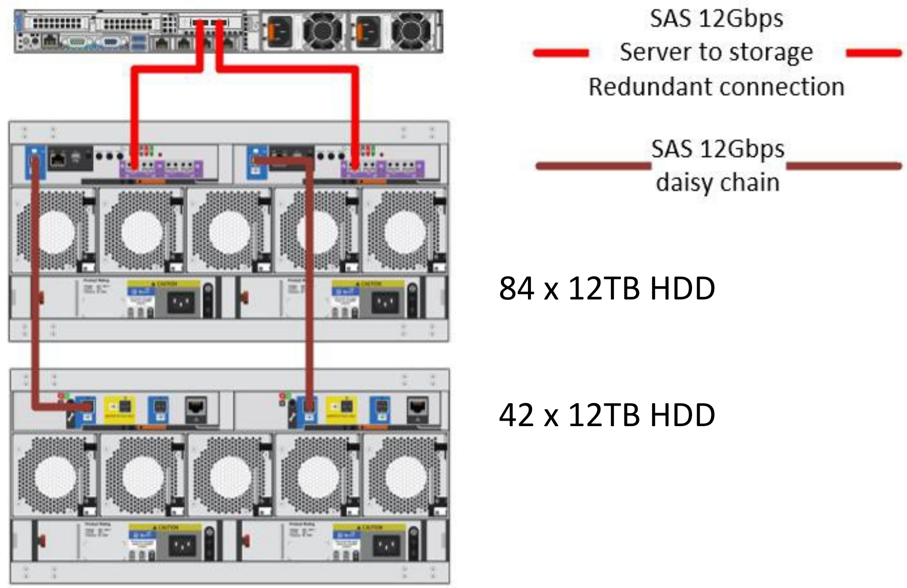
2 total

ORFEO: long term storage

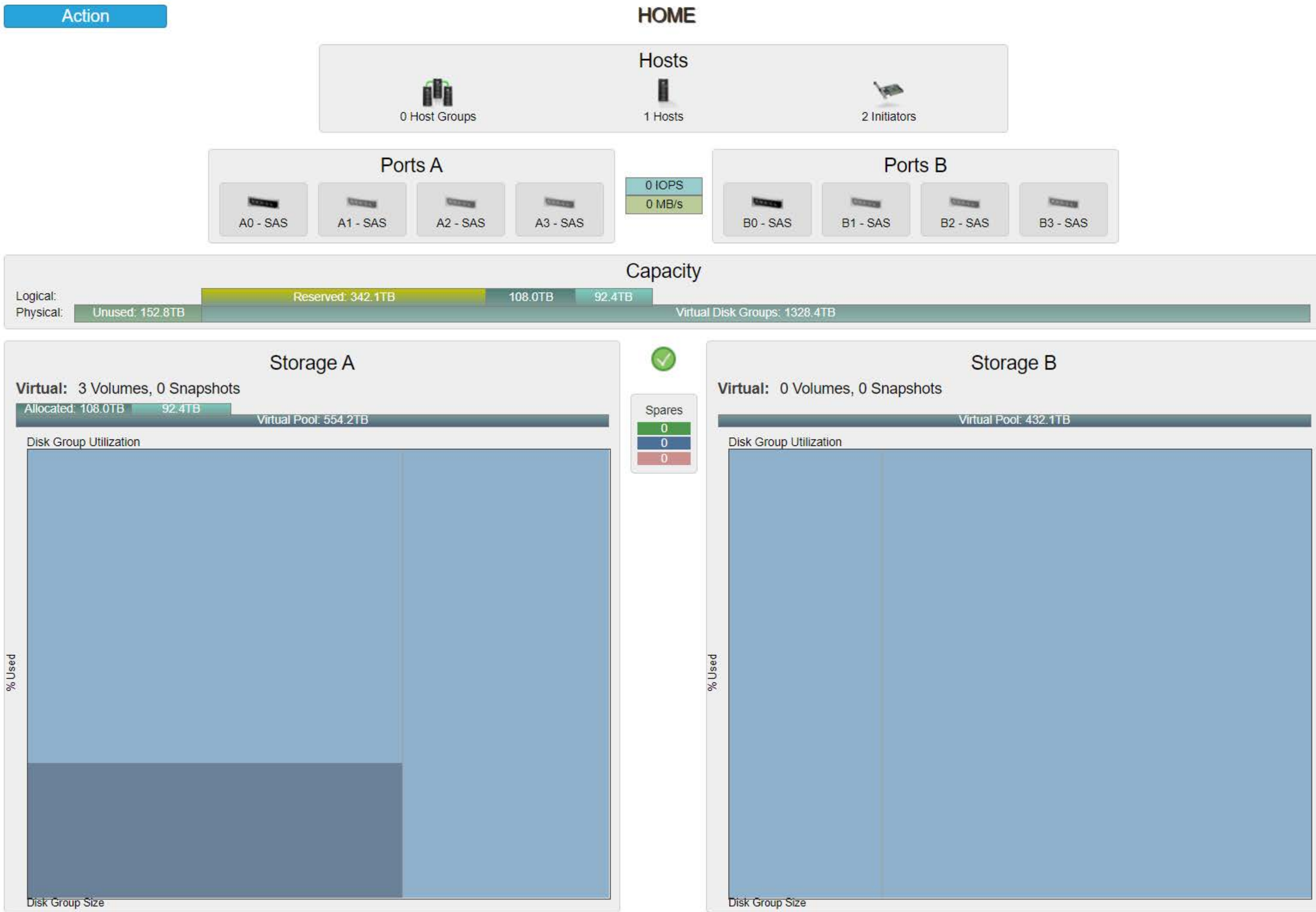
- A NAS for ORFEO Cluster
- Internally:
  - An entry level SAN

ORFEO: long term storage

- Dell EMC PowerEdge R640
- Dell EMC PowerVault ME4084
- + Dell EMC PowerVault ME4084



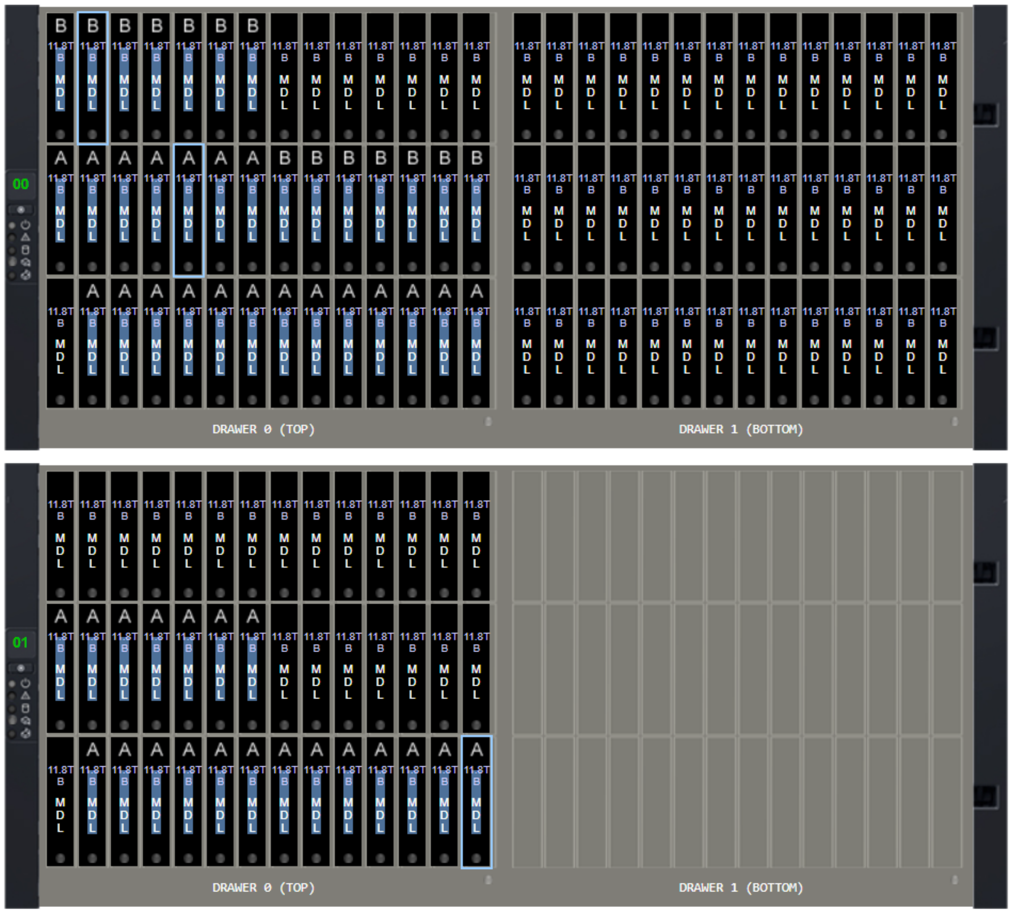

```
>df -h
10.128.2.231:/storage          37T   18T   20T  48% /storage
10.128.2.231:/illumina_run     46T   42T  4.2T  92% /illumina_run
```


Action
HOME
Hosts
0 Host Groups
1 Hosts
2 Initiators
Ports A
A0 - SAS
A1 - SAS
A2 - SAS
A3 - SAS
0 IOPS
0 MB/s
Ports B
B0 - SAS
B1 - SAS
B2 - SAS
B3 - SAS
Capacity
Logical:
Reserved: 342.1TB
108.0TB
92.4TB
Physical:
Unused: 152.8TB
Virtual Disk Groups: 1328.4TB
Storage A
Virtual: 3 Volumes, 0 Snapshots
Allocated: 108.0TB
92.4TB
Virtual Pool: 554.2TB
Disk Group Utilization
% Used
Disk Group Size
Spares
0
0
0
Storage B
Virtual: 0 Volumes, 0 Snapshots
Virtual Pool: 432.1TB
Disk Group Utilization
% Used
Disk Group Size

SYSTEM

Front Rear Table

Turn On LEDs Turn Off LEDS



POOLS

Clear Filters | Export to CSV | Show All | Showing 1 to 2 of 2 entries(1 selected)

Name	Health	Size	Class	Avail	Volumes	Disk Groups
A	OK	356.9TB	Virtual	248.9TB	3	1
B	OK	112.7TB	Virtual	112.7TB	0	1

Related Disk Groups

Clear Filters | Export to CSV | Show All | Showing 1 to 1 of 1 entries(1 selected)

Name	Health	Pool	RAID	Class	Disk Description	Size	Free	Current Job	Status	Disks
dgB01	OK	B	ADAPT	Virtual	SAS MDL	112.7TB	112.7TB	VRSC (58%)	FTOL	14

Related Disks

Clear Filters | Export to CSV | Show All | Showing 1 to 14 of 14 entries

Location	Health	Description	Size	Usage	Disk Group	Status
0.21	OK	SAS MDL	11.7TB	VIRTUAL POOL	dgB01	Up
0.22	OK	SAS MDL	11.7TB	VIRTUAL POOL	dgB01	Up
0.23	OK	SAS MDL	11.7TB	VIRTUAL POOL	dgB01	Up
0.24	OK	SAS MDL	11.7TB	VIRTUAL POOL	dgB01	Up
0.25	OK	SAS MDL	11.7TB	VIRTUAL POOL	dgB01	Up
0.26	OK	SAS MDL	11.7TB	VIRTUAL POOL	dgB01	Up
0.27	OK	SAS MDL	11.7TB	VIRTUAL POOL	dgB01	Up
0.28	OK	SAS MDL	11.7TB	VIRTUAL POOL	dgB01	Up
0.29	OK	SAS MDL	11.7TB	VIRTUAL POOL	dgB01	Up
0.30	OK	SAS MDL	11.7TB	VIRTUAL POOL	dgB01	Up
0.31	OK	SAS MDL	11.7TB	VIRTUAL POOL	dgB01	Up
0.32	OK	SAS MDL	11.7TB	VIRTUAL POOL	dgB01	Up
0.33	OK	SAS MDL	11.7TB	VIRTUAL POOL	dgB01	Up
0.34	OK	SAS MDL	11.7TB	VIRTUAL POOL	dgB01	Up

Action

VOLUMES

Clear Filters | Export to CSV | Show 10 | Showing 1 to 3 of 3 entries(1 selected)

Group	Name	Pool	Type	Size	Allocated
-	illumina_run	A	base	50.4TB	45.9TB
-	long_term_storage	A	base	109.9TB	40.5TB
-	storage	A	base	39.9TB	21.5TB

Snapshots | Maps | Replication Sets | Schedules

Clear Filters | Export to CSV | Show 10 | Showing 1 to 1 of 1 entries

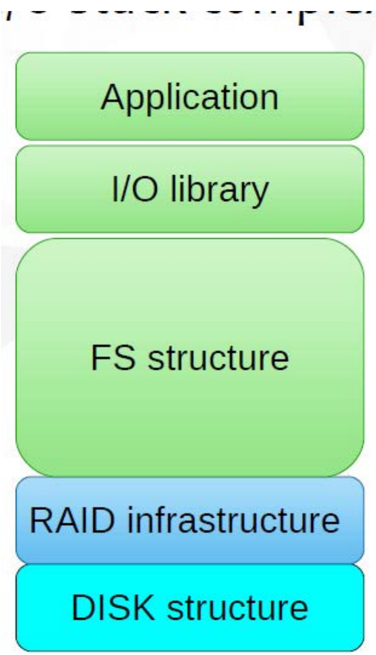
Group.Host.Nickname	Volume	Access	LUN	Ports
ceph9.*	storage	read-write	2	0,1,2,3

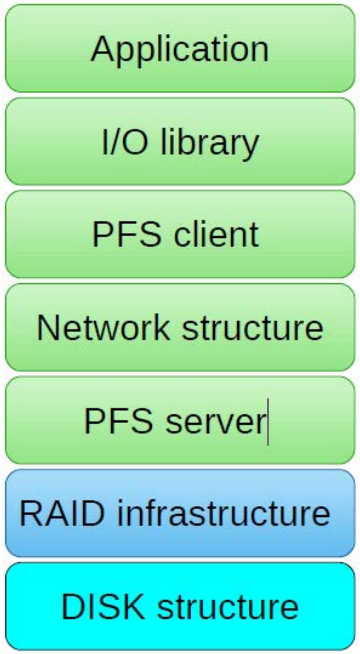
```
[root@login bin]# df -h | grep storage
10.128.2.231:/storage                37T   18T   20T  48% /storage
```

Benchmarking I/O on ORFEO

I/O benchmarking…

- It is becoming more and more important
- I/O performance tends to be trickier than CPU/memory ones





How to test a complex I/O infrastructure ?

- Benchmark all the single component of the infrastructure
- Compare simple component Peak performance with measured numbers
- Combine all numbers together to get a performance model and some expected value
- Perform the high level benchmark and compare against what you evaluated.

I/O microbenchmarks to play..

- Measures one fundamental operation in isolation
  - Read throughput, write throughput, creates/sec, etc.
- Good for:
  - Tuning a specific operation
  - Post-install system validation
  - Publishing a big number in a press release
- Not as good for:
  - Modeling & predicting real application performance
  - Measuring broad system performance characteristics
- Example to play
  - IOR: https://github.com/hpc/ior
  - iozone (www.iozone.org)
  - Mdtest (included in the IOR)

Estimate I/O performance of ORFEO storage..

- Peak performance estimate:
  - Network:
    - Infiniband Network from server toward clients: 12GB/sec
  - Disks:
    - HDD: 150 MB/sec (estimate)
    - SDD: 600 MB/sec (estimate)

→

/fast: 80x600=32 GB/sec without replicas

/scratch: 90x150= 13GB/sec without erasure code

Measure performance of ORFEO storage..

- Acceptance tests:

  /fast without replica with 56 disks:

  - ~ 20 GB/seconds

Iozone

- Compilation trivial: see tutorial.
- Things to try:
- Test to run:
  - Iozone -a (basic testing)
  - Large file (large than memory to avoid caching effects)

  ```
  iozone -i 1 -i 0 -s 32g -r 1M -f ./32gzero2
  ```
- Short introduction of basic flags:

  http://www.thegeekstuff.com/2011/05/iozone-examples/

IOR: the de-facto I/O benchmark for HPC

HPC IO Benchmark Repository build error

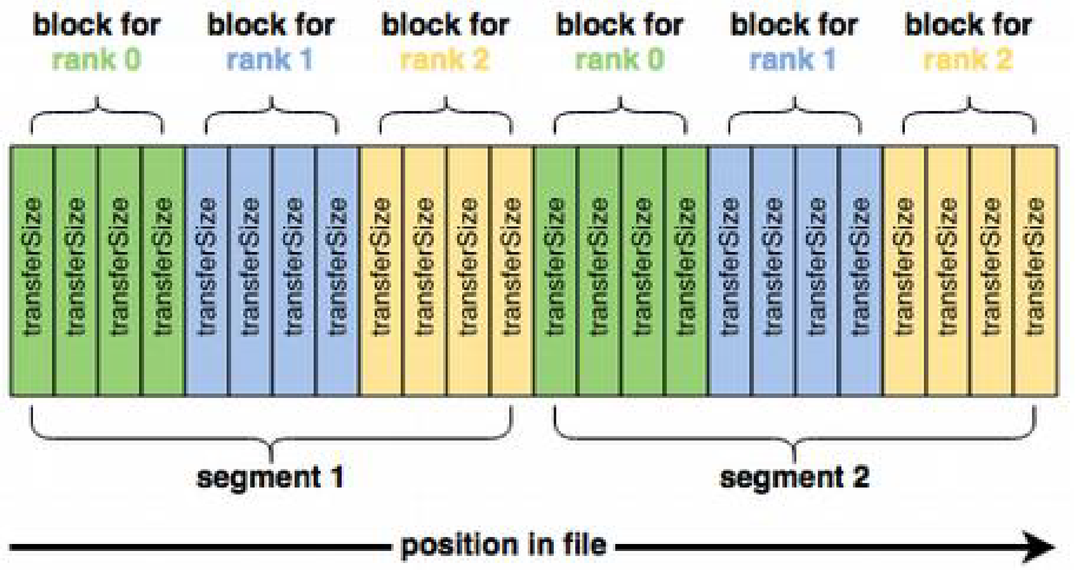
This repository contains the IOR and mdtest parallel I/O benchmarks. The official IOR/mdtest documention can be found in the `docs/` subdirectory or on Read the Docs.

Building

1. If `configure` is missing from the top level directory, you probably retrieved this code directly from the repository. Run `./bootstrap` to generate the configure script. Alternatively, download an official IOR release which includes the configure script.
2. Run `./configure`. For a full list of configuration options, use `./configure --help`.
3. Run `make`
4. Optionally, run `make install`. The installation prefix can be changed via `./configure --prefix=...`.

IOR basic usage:

- IOR writes data sequentially with the following parameters:
  - blockSize (-b)
  - transferSize (-t)
  - segmentCount (-s)
  - numTasks (-n)



IOR number to collect..

- Compare performance of HDF5 vs MPIIO vs POSIX..
- Possible experiments:
  - mpirun -np 32 IOR -a [POSIX|MPIIO] -i 3 -d 32 -k -r -E -o yourfile_name -s 1 -b 60G -t 1m
  - mpirun -np 32 IOR -a [POSIX|MPIIO] -i 3 -d 32 -k -r -E -o yourfile_name -s 1 -b 16G -t 1m
  - mpirun -np 32 IOR -a [POSIX|MPIIO] -i 3-d 32 -k -r -E -o yourfile_name -s 1 -b 4G -t 1m

MD test

- How much does it cost metadata operations ?
- Example to run:

```
mdtest -n 10 -i 200 -y -N 10 -t -u –d $test_directory
```

  - -n: every process will creat/stat/remove # directories and files
  - -i: number of iterations the test will run
  - -y: sync file after writing
  - -N: stride # between neighbour tasks for file/dir stat (local=0)
  - -t: time unique working directory overhead
  - -u: unique working directory for each task
  - -d: the directory in which the tests will run

The end