HPC File Systems

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Overview

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File Systems

Lustre

Best Practices

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File I/O

HPC Environment

The typical HPC system has multiple file systems intended for different uses.

- **Home**
  Individual user home directories. Backed-up with quotas.
- **Scratch**
  Fast temporary access, not backed-up.
  - *Shared* file system across all nodes.
  - *Local* each node has it's own.
    (A lot of clusters do not put disks in the nodes)
- **Mass Storage**
  Long term storage, typically a tape system.

File Systems

- NFS – Network File System
- CXFS – Clustered XFS
- PanFS – Panasas ActiveScale File System
- GPFS – General Parallel File System
- PVFS – Parallel Virtual File System
- Lustre

Why?

- Spinning disks are slow.
- Serial I/O is even slower.

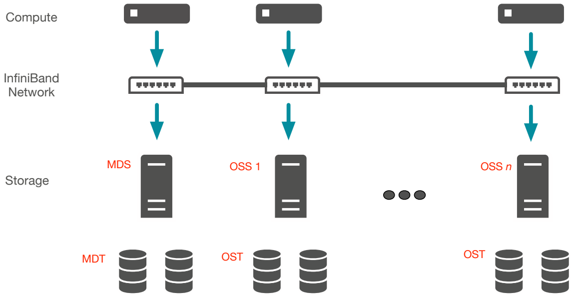
Key Features

- Scalability.
  Can scale out to tens of thousands of nodes and petabytes of storage.
- Performance.
  Throughput of a single stream ~GB/s and parallel I/O ~TB/s.
- High availability.
- POSIX compliance.
- Supports ROMIO

Lustre

Approximately 50% of top 100 HPC's use Lustre.
It consists of four components:

MDS	Metadata Server
MDT	Metadata Target
OSS	Object Storage Server
OST	Object Storage Target



Metadata Server and Target

The MDS is a single service node that assigns and tracks all of the storage locations associated with each file in order to direct file I/O requests to the correct set of OSTs and corresponding OSSs.

The MDT stores the metadata, filenames, directories, permissions and file layout.

Object Storage Servers and Targets

An OSS managers a small set of OSTs by controlling I/O access and handling network requests to them.

An OST is a block storage device. Often several disks in a RAID configuration.

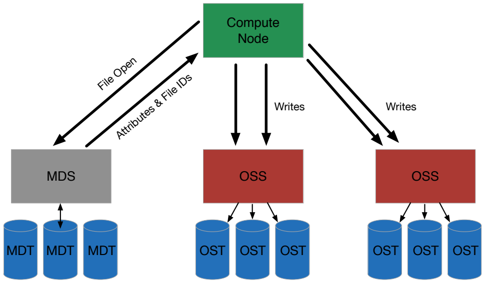
Typical Setup

- All nodes (login, compute, compile, ...) have the lustre file-system mounted at `/lustre/`.
- The number of servers and targets.
  - 2 MDSs (active, standby)
  - 10's OSSs
  - 100's OSTs
- Often giving a total of ~1PB of usable disk space.

File Operations

- When a compute node needs to create or access a file, it requests the associated storage locations from the MDS and the associated MDT.

- I/O operations then occur directly with the OSSs and OSTs associated with the file bypassing the MDS.
- For read operations, file data flows from the OSTs to the compute node.



User Commands

Lutre provides a utility to query and set access to the file system. They are all sub commands to the program `lfs`.

- For a complete list of available options.

  ```
  login01 $ lfs help
  ```

- To get more information on a specific option.

  ```
  login01 $ lfs help option
  ```

Checking Diskspace

The `lfs df` command displays the file system disk space usage. Additional parameters can be specified to display inode usage of each MDT/OST or a subset of OSTs. The usage for the `lfs df` command is:

```
login01 $ lfs help df
Usage: df [-i] [-h] [--lazy|-l] [--pool|-p <fsname>[.<pool>] [path]
```

Example, get a summary of the disk usage:

```
login01 $ lfs df -h /lustre/tbrown/ | \
          grep -v ^scratch
UUID                  bytes  Used   Available Use% Mounted on
filesystem summary: 852.8T 607.5T 236.8T    72% /lustre/
```

Finding Files

The `lfs find` command is more efficient the GNU `find`. Example, finding fortran source files accessed within the last day.

```
login01 $ lfs find . -atime -1 -name '*.f90'
```

Other `lfs` Commands

- `lfs cp` – to copy files.
- `lfs ls` – to list directories and files.

These commands are often quicker as they reduce the number of `stat` and `rpc` calls needed.

Avoid Wild Cards

- `tar` and `rm` are inefficient when operating on a large class of files on lustre.
- The reason lies in the time it takes to expand the wild card.
- `rm -rf *` on millions of files could take days, and impact all other users.
- Generate a list of files to be removed or tar-ed, and to act them one at a time, or in small sets.

```
login01 $ lfs find old/ -t f -print0 | xargs -0 rm
```

Avoid Colons

MPI-IO will split a path and file name on a colon to obtain a file system hint.

- If the colon is used in the time format specification, the interpretation of the hint will cause an error.

  `/lustre/tbrown/wrfout_2015_06_23_00:00:00.nc`

- Provide a hint that the underlying file system is lustre.

  `lustre:/lustre/tbrown/wrfout_2015_06_23_00_00_00.nc`

Limit Files Per Directory

- It is best to limit the number of files per directory.
- Writing thousands of files to a single directory produces a massive load on the MDSs, this often takes the file system offline.
- If you need to create a large number of files. Use a directory structure.
- A suggested approach is a two-level directory structure with $\sqrt{N}$ directories each containing $\sqrt{N}$ files, where N is the number of tasks.

Read Only Access

- If a file is only going to be read, open it as `O_RDONLY`.
- If you don't care about the access time, open it as `O_RDONLY|O_NOATIME`.
- If you need access time information and your doing parallel IO, let the master open it as `O_RDONLY` and all other ranks as `O_RDONLY|O_NOATIME`.

Broadcast Stat

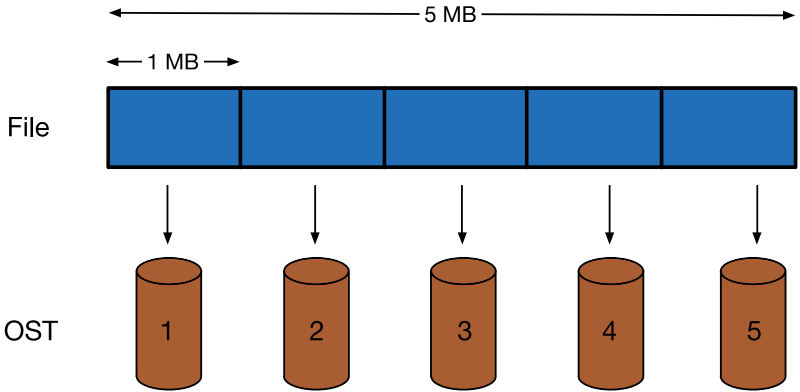
- If many processes need the information from `stat()`.
- Have the master process perform the `stat()` call.
- Then broadcast it to all processes.

```c
#include <stdio.h>
#include <stdlib.h>
#include <sys/stat.h>
#include <err.h>
#include <mpi.h>
int
main(int argc, char **argv)
{
        int rank = 0;
        int len  = 0;
        struct stat sbuf = {0};

        MPI_Init(&argc, &argv);
        MPI_Comm_rank(MPI_COMM_WORLD, &rank);
        if (rank == 0) {
                if (stat(argv[0], &sbuf)) {
                        warn("Unable to stat %s", argv[0]);
                }
        }
        len = sizeof(sbuf);
        MPI_Bcast(&sbuf, len, MPI_BYTE, 0, MPI_COMM_WORLD);
        MPI_Finalize();
        return(EXIT_SUCCESS);
}
```

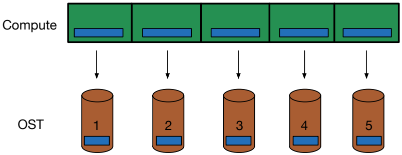
File Striping

- A file is split into segments and consecutive segments are stored on different physical storage devices (OSTs).

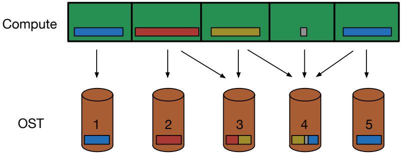


Aligned vs Unaligned Stripes

- Aligned stripes is where each segment fits fully onto a single OST. Processes accessing the file do so at corresponding stripe boundaries.



- Unaligned stripes means some file segments are split across OSTs.



Stripe Sizes

- You can get/set the stripe size, number of OSTs and which OST to start at.
- The stripe size must be a multiple of the maximum page size (64 KB).
- The typical default is
  - stripe count: 1
  - stripe size: 1048576 (1 MB)
  - stripe offset: -1 (MDS selects)

```
login01 $ lfs getstripe .
login01 $ lfs setstripe -s 32m -c 4 .
```

Large File Stripe Sizes

- Set the stripe count of the directory to a large value.
- This spreads the reads/writes across more OSTs, therefore balancing the load and data.

```
login01 $ lfs setstripe -c 30 \
          /lustre/tbrown/large_files/
```

Small File Stripe Sizes

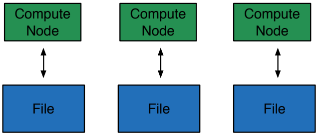
- Place small files on a single OST.
- This causes the small files not to be spread out/fragmented across OSTs.

```
login01 $ lfs setstripe -s 1m -c 1 \
          /lustre/tbrown/small_files/
```

File I/O

Three cases of file I/O:

- Single stream.



File I/O

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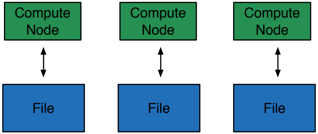
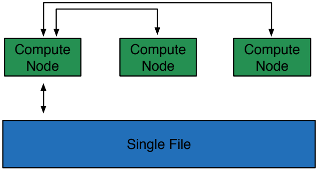


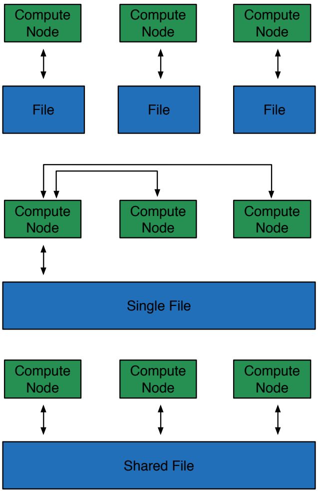
- Single stream through a master.



File I/O

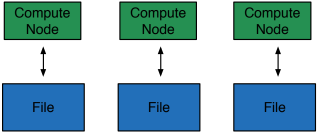
Three cases of file I/O:

- Single stream.
- Single stream through a master.
- Parallel.



Single Stream IO

- Set the stripe count to 1 on a directory.
- Write all files in this directory.

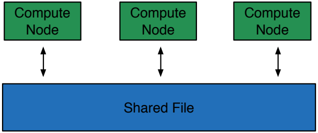


- Otherwise set the stripe count to 1 for the file.

```
login01 $ lfs setstripe -s 1m -c 1 \
          /lustre/tbrown/serial/
```

Parallel IO Stripe Count I

- Single shared files should have a stripe count equal to the number of processes which access the file.



- If the number of processes is >160, set the count to -1, this will stripe across all OSTs (lustre has a max of 160).
- The stripe size should be set to allow as much stripe alignment as possible.
- Try to keep each process accessing as few OSTs as possible.

```
login01 $ lfs setstripe -s 32m -c 24 \
          /lustre/tbrown/parallel/
```

Parallel IO Stripe Count II

You can specify the stripe count and size programmatically, by creating an MPI info object.

```
use mpi
use hdf5
implicit none
integer              :: info                  ! MPI IO Info
integer              :: ierr                  ! Error status
integer(kind=hid_t)  :: p_id, f_id            ! Property and file id
character(len=256)   :: filename,lcount,lsize ! Filename

! Init the HDF5 library
call h5open_f(ierr)
! Create an MPI object setting the strip size and count
call mpi_info_create(info, ierr)
write(lcount, '(I4)') 4
write(lsize,  '(I8)') 4 * 1024 * 1024
call mpi_info_set(info, "striping_factor", trim(lcount), ierr)
call mpi_info_set(info, "striping_unit",   trim(lsize),  ierr)
! Set up the access properties
call h5pcreate_f(H5P_FILE_ACCESS_F, p_id, ierr)
call h5pset_fapl_mpio_f(p_id, MPI_COMM_2D, info, ierr)

! Open the file
call h5fcreate_f(filename, H5F_ACC_TRUNC_F, f_id, ierr, &
                 access_prp = p_id)
```

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