Using Lustre

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May 2024

File systems on LUMI

- HPC since the second half of the 1980s has mostly been about trying to build a fast system from relatively cheap hardware and cleverly written software.
  - The Lustre parallel file system fits in that way of thinking:
    - Link several regular servers
    - with a good network to the compute resources
    - to build a single system with a lot of storage capacity and a lot of bandwidth
    - (though unfortunately not all IOPS – number of I/O operations – scaled as nicely).
  - And it is the main file system on large HPE Cray systems.
- HPE Cray EX systems go one step further:
  - Lustre is the only network file system on the compute nodes,
  - other external file systems come via DVS – Data Virtualisation Service
  - as part of the measures taken to minimise OS jitter and reduce node memory use.

Lustre building blocks

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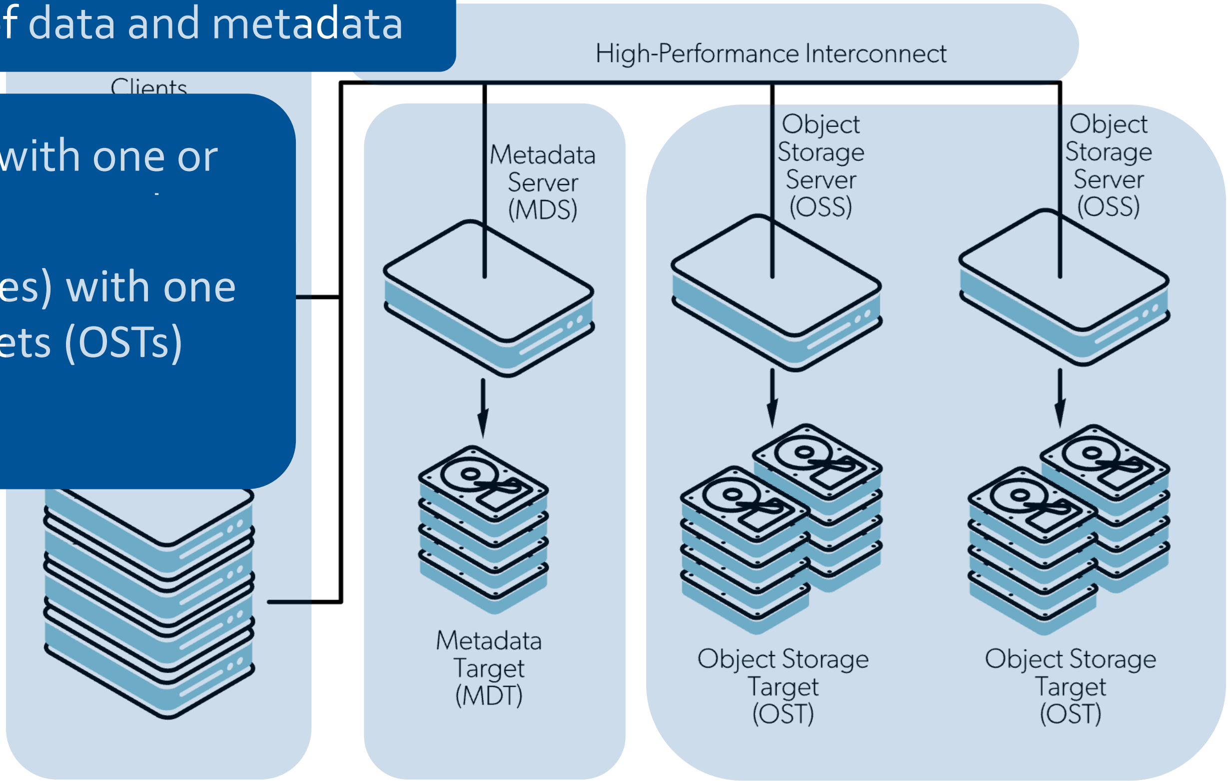
Key element: Separation of data and metadata

- Metadata servers (MDSes) with one or
- Object storage servers (OSSes) with one ... rgets (OSTs)
- Lustre clients that
- High-performance interconnect between all pieces of the storage system



Lustre building blocks (2)

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- Lustre separates data and metadata as both are used differently
- Metadata servers (MDSes) with one or more metadata targets (MDTs) each store namespace metadata (filename, access permissions, ...) and file layout.
- Object storage servers (OSSes) with one or more object storage targets (OSTs) each store the actual data.
  - Capacity of Lustre is the sum of the capacity of the OSTs
- Lustre clients that access and use the data and makes the whole Lustre setup look like a single large file system
  - Transparent in functionality: You can use it as any regular Linux file system
  - But not transparent in performance: How you use Lustre can have a huge impact on performance
- All linked together through the high performance interconnect.

Striping: Large files spread across OSTs

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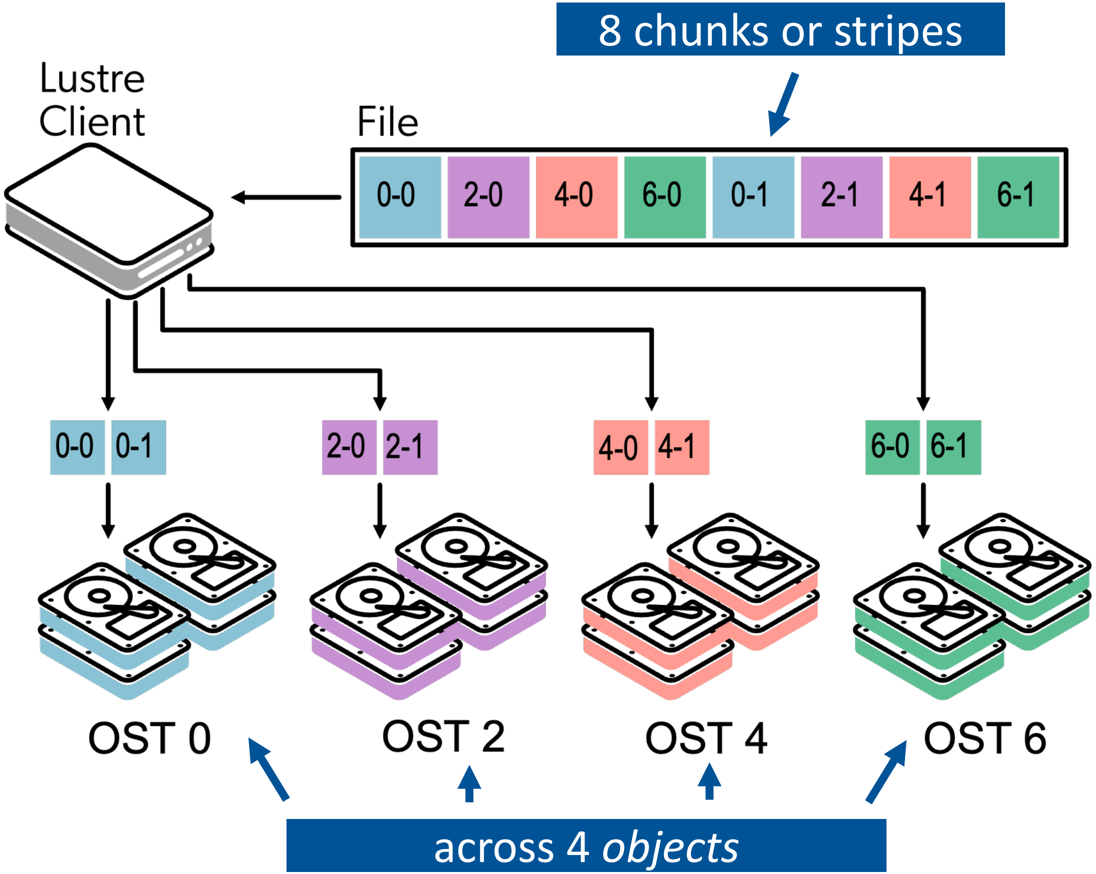
- Files broken in chunks/stripes, distributed cyclically across a number of chunk files/objects, each on a separate OST
- Transparent to the user with respect to correctness
- But large impact on performance
- 2 parameters:
  - Size of the stripes
  - Number of OSTs
- Default on LUMI is to use only one OST



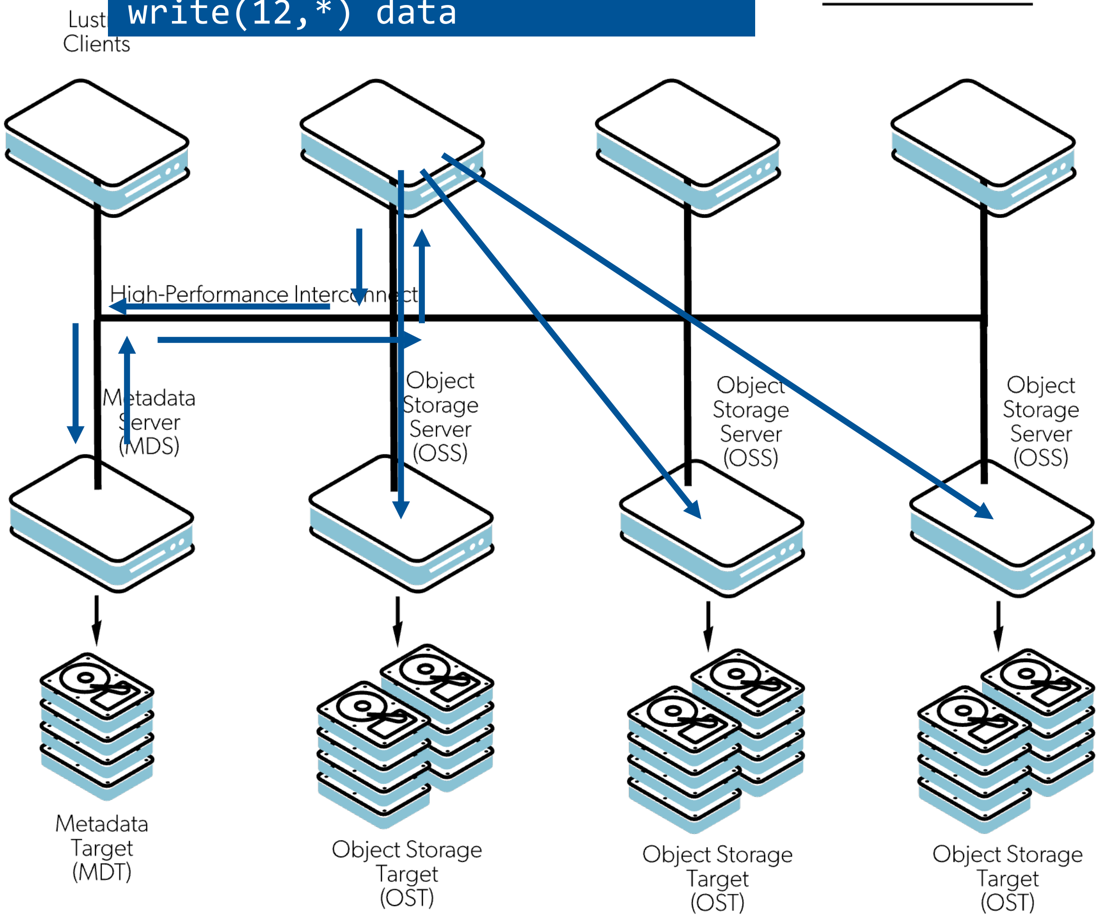
Accessing a file

```
open(unit=12, file="out.dat")
write(12,*) data
```

Client queries MDS

MDS returns layout/location

Subsequent read or write calls can talk directly to all OSSes involved



Parallelism is key!

- MDS access can be problematic
  - Difficult to spread across multiple MDSes
  - Small accesses, so each MDS doesn't really exploit parallelism in RAID either
- But up to four levels of parallelism in reads and writes
  - Engage multiple OSSes
  - Which can each engage multiple OSTs
  - That typically engage multiple disks in a RAID setup for reliability
  - For an SSD file system: Modern SSDs are also highly parallel
- So large I/O operations needed
  - Very small I/O operations won't even benefit from RAID acceleration
  - Relatively large stripe size for more efficient I/O at the OST level (especially for hard drives)
  - And even larger I/O operations needed to engage enough OSTs (but that access can come from multiple nodes in the process)

Parallelism is key! (2)

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- 😀 HPC file formats such as HDF5 and netCDF
  - When used properly, very good bandwidth possible
  - Old codes can be very good. But their authors have known floppy drives…
- 😭 Codes that open one or more files per MPI rank
  - Won't scale to large numbers of ranks
  - Disaster for MDS as files will be opened more or less simultaneously
  - Potential disaster for ODS also as each ODS will serve many files with writes or reads coming in simultaneously
  - Also in old codes that were never meant to scale to 1000s or cores
- 😭 😭 Abuse the file system as an unstructured database by dumping data in thousands or millions of small files with each one data element
  - Local SSD not really a solution as you "own" a node only shortly
  - A Python or conda software installation by itself is already an example

How to determine the striping value?

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- Small files accessed sequentially: 😭 😭 😭
- Try to use all OSTs without overloading them.
  - #files ≥ #OSTs: stripe count 1 is best
  - #files = 1: Set the stripe count to #OSTs, or a smaller number if the performance plateaus (benchmarking needed!). The latter will happen if not enough Lustre clients are used simultaneously to access the file.
  - #files < #OSTs: Chose such that stripe count * #files = #OSTs.
    E.g.: 32 OSTs and 8 files: Use a stripe count of 4.
- Let the system choose the OSTs, don’t try to impose them.
- An ideal stripe size will usually be 1 MB or more.
  Maximum value is 4 GB but that is only useful for very large files.

Managing the striping parameters (1)

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- The basic command line tool to manage striping in lustre is the `lfs` command.
- Use `lfs df -h` to get information about the file systems

```
UUID                       bytes        Used   Available Use% Mounted on
lustref1-MDT0000_UUID       11.8T       16.8G       11.6T   1% /pfs/lustref1[MDT:0]
lustref1-MDT0001_UUID       11.8T        4.1G       11.6T   1% /pfs/lustref1[MDT:1]
lustref1-MDT0002_UUID       11.8T        2.8G       11.7T   1% /pfs/lustref1[MDT:2]
lustref1-MDT0003_UUID       11.8T        2.7G       11.7T   1% /pfs/lustref1[MDT:3]
lustref1-OST0000_UUID      121.3T       21.7T       98.3T  19% /pfs/lustref1[OST:0]
lustref1-OST0001_UUID      121.3T       21.8T       98.2T  19% /pfs/lustref1[OST:1]
lustref1-OST0002_UUID      121.3T       21.7T       98.4T  19% /pfs/lustref1[OST:2]
```

  - A way to find the number of OSTs

Managing the striping parameters (2)

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- Use `lfs getstripe` to check striping information at the directory or file level

```
$ lfs getstripe -d /appl/lumi/SW
stripe_count:  1 stripe_size:   1048576 pattern:       0 stripe_offset: -1

$ lf                           l/lumi/SW
stri                            0 pattern:       0 stripe_offset: -1

$ lfs getstripe /appl/lumi/LUMI-SoftwareStack/etc/motd.txt
/appl/
lmm_st
lmm_stripe_size:    1048576
lmm_pattern:        raid0
lmm_layout_gen:     0
lmm_stripe_offset:  2
        obdid           objid               objid               group
            2       292319061          0x116c6f55                   0
```

Only show directory itself

Let the MDS chose

Actually the defaults for the file system

OSTs for the file

Managing the striping parameters (3)

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- Use `lfs setstripe` to set the striping information

```
$ module use /appl/local/training/modules/2day-20240502
$ module load lumi-training-tools
$ mkdir testdir
$ lfs setstripe -S 2m -c 4 testdir
$ cd testdir
$ mkfile 2g testfile1
$ lfs getstripe testfile1
testfile1
lmm_stripe_count:  4
lmm_stripe_size:   2097152
lmm_pattern:       raid0
lmm_layout_gen:    0
lmm_stripe_offset: 28
        obdidx           objid          objid           group
            28        66250987      0x3f2e8eb               0
            30        66282908      0x3f3659c               0
             1        71789920      0x4476d60               0
             5        71781120      0x4474b00               0
```

Default striping for this directory

Tool to create a new file of given size (2G here)

And we get the values that we set for the directory

The 4 OSTs

Managing the striping parameters (4)

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- Use `lfs setstripe` to set the striping information

```
$ lfs setstripe -S 16m -c 2 testfile2
$ ls -lh
total 0
-rw-rw---- 1 XXXXXXXX project_462000000 2.0G Jan 15 16:17 testfile1
-rw-rw---- 1 XXXXXXXX project_462000000    0 Jan 15 16:23 testfile2
$ lfs getstripe testfile2
testfile2
lmm_stripe_count:  2
lmm_stripe_size:   16777216
lmm_pattern:       raid0
lmm_layout_gen:    0
lmm_stripe_offset: 10
        obdidx           objid           objid           group
            10        71752411       0x446dadb               0
            14        71812909       0x447c72d               0
```

Create an empty file with given striping

The metadata servers (1)

- Finite and shared resource
- Involved in many file system operations:
  - Create/open/close
  - Get attributes
  - Managing file locking
- Slow or variable filesystem performance when overstressed
  - Less than 200k operations per second, depending on operation type also!

The metadata servers (2)

- Important to be careful with what you do
  - E.g., `ls -l` is rather costly on Lustre
  - Access to many small files from many processes is not a good idea (think Python): Run from a container or move to /tmp (which will eat from your RAM). Use file formats as HDF5, ADIOS, ...
  - The filesystem is not a communication device for shuffling data between nodes
  - Avoid very large directories
  - Use `lfs find` instead of find
  - And many more tips for programmers...

Lustre on LUMI

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- LUMI-P:
  - 4 disk based storage systems
  - 18 PB capacity each
  - 240 GB/s aggregated bandwidth each
  - 2 MDTs (1 per MDS), 32 OSTs (2 per OSS)
  - Serves /users, /project and /scratch
- LUMI-F
  - Solid State Drive based storage system
  - 8.5 PB capacity
  - >2 TB/s aggregated bandwidth
  - 4 MDTs (1 per MDS) and 72 OSTs (1 per OSS)
  - Serves /flash

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Questions?