Advanced Message-Passing Programming

Parallel Filesystems and Lustre

Reusing this material

Overview

- Lecture will cover
  - Parallel Filesystems
  - Lustre Filesystem
  - benchio
  - Speeds and feeds
    - maximum
    - achieved

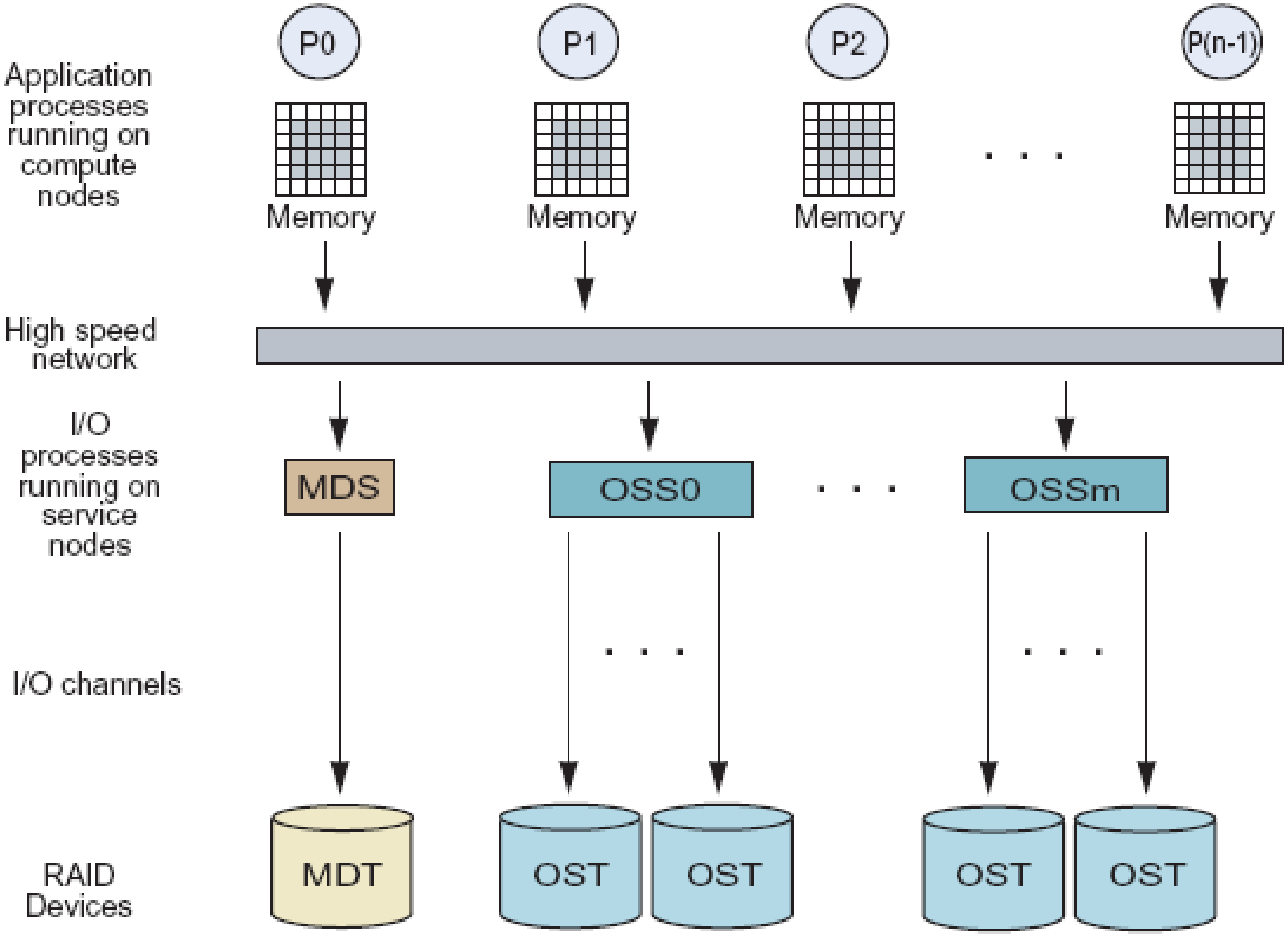
Parallel File Systems

- Parallel computer
  - constructed of many standard processors, each not particularly fast
  - performance comes from using many processors at once
  - requires manual distribution of data and calculation across processors

- Parallel file systems
  - constructed from many standard disks, each not particularly fast
  - performance comes from reading / writing to many disks at once
  - requires many *clients* to read / write to different disks
    - each HPC *node* appears as a separate IO client
  - data from a single file can be *striped* across many disks

- Must appear as a single file system to user
  - typically have a single *MetaData* Server (MDS)

Parallel File Systems: Lustre



ARCHER's (**not** ARCHER2) Cray Sonexion Storage

SSU: ***Scalable Storage Unit***

Multiple OSS's each with multiple OSTs

Multiple SSUs are combined to form storage racks

Terminology

- Lustre has many different levels and virtualisations
  - e.g. one Object Storage Server has multiple Object Storage Targets
  - a single OST has many physical disks in a RAID array
- I will refer to the following parts of Lustre
  - Meta Data Server (MDS)
    - the database that contains information on, e.g., where a file is stored
  - Object Storage Target
    - the physical device that stores your data
    - I may also call this a “disk” (although it contains multiple hard drives)
- The MDS and the OSTs are what a user interacts with

ARCHER2 hardware

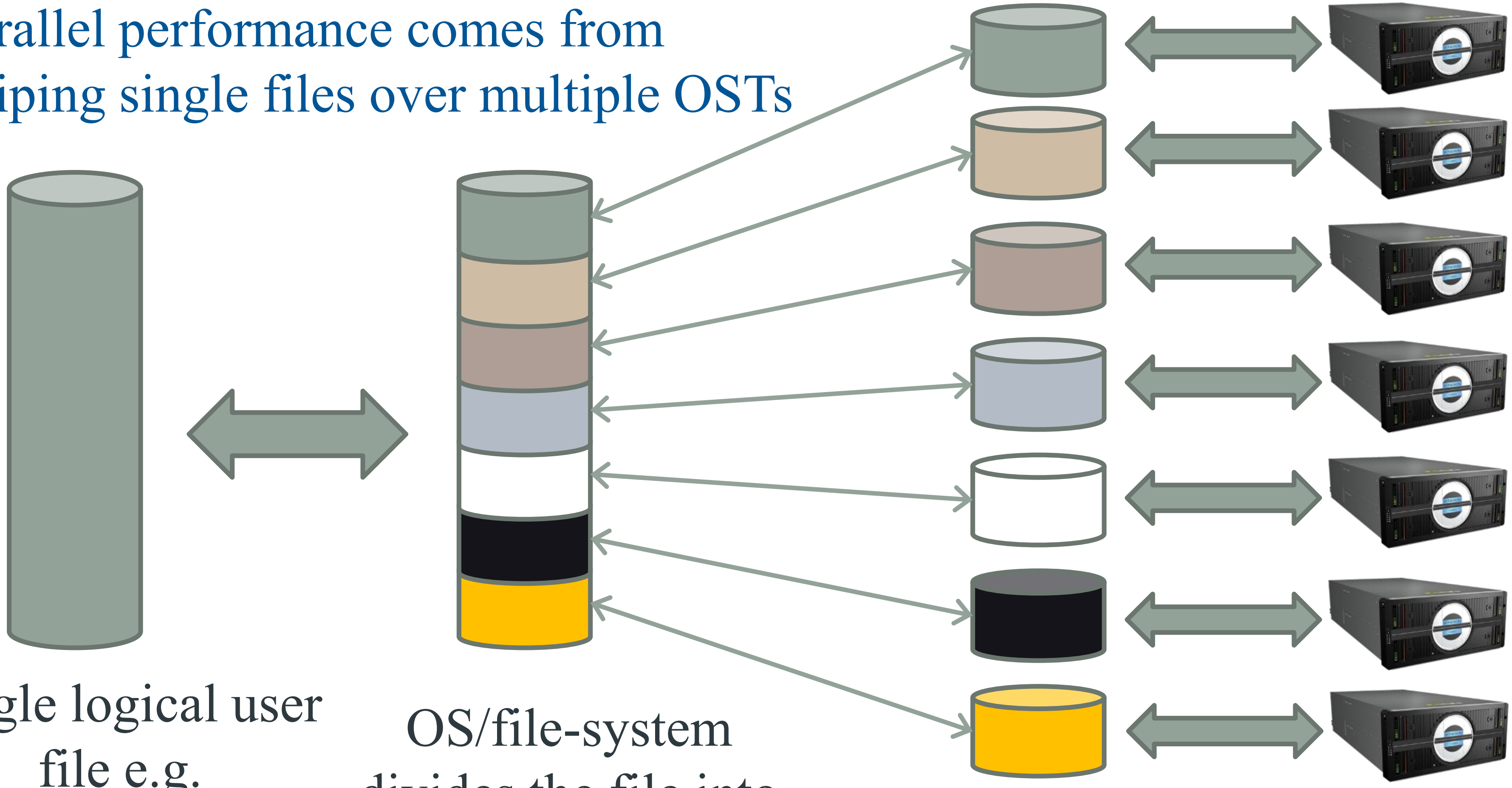
- Four /work filesystems (work1, work2, work3 & work4)
  - each has 12 OSTs and one MDS
  - consortia assigned to different partitions to share the load
  - multiple filesystems means the MDS is less likely to be overloaded
- One filesystem with Solid State storage, not spinning disks
  - NVMe – non-volatile memory – and we have access for this course
  - expect better latency, e.g. good for small I/O transactions
    - may also yield better bandwidth
    - possibly more reproducible in terms of performance due to fewer users
- Each disk system has around 3.3 PiB of storage
  - total of 13.2 PiB (which is 14.5 PB !)

Default Configuration

- By default, each file is stored on a single OST
  - assigned when the file is created
  - automatically distributed across available OSTs to balance the load
    - each OST is actually a separate Linux filesystem
- This is called an “unstriped” file
- Reading and writing multiple files from multiple nodes can benefit from multiple OSTs
- Access to a single file will not benefit from the parallel nature of the filesystem (for a single user)

Lustre data striping

Parallel performance comes from striping single files over multiple OSTs



Single logical user file e.g. `/work/q01/q01/user/bigfile.dat`

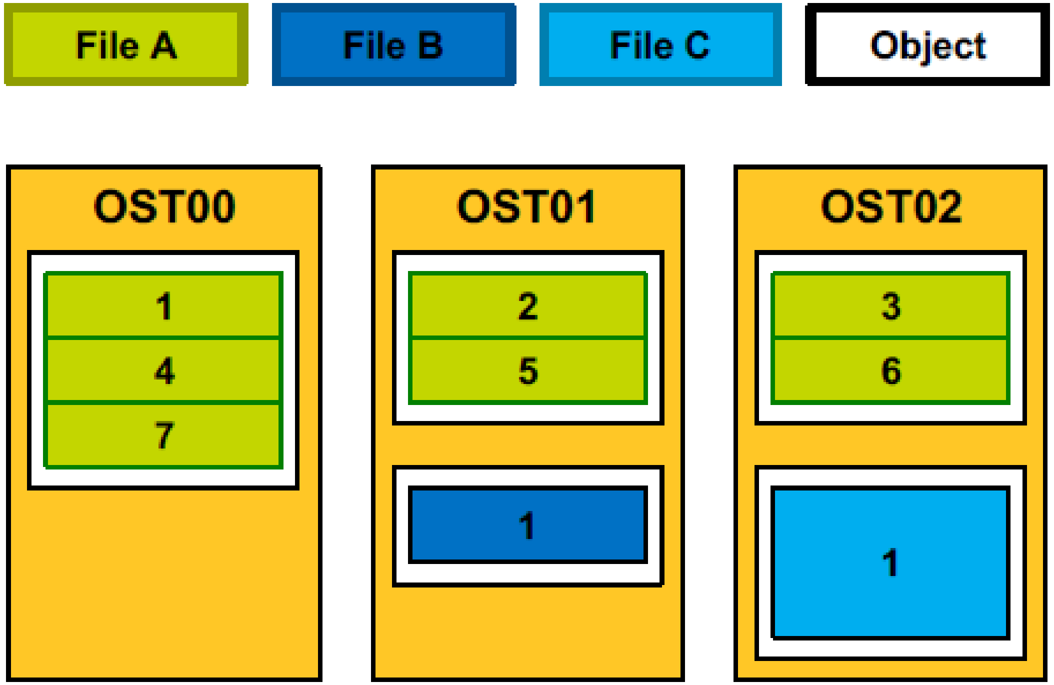
OS/file-system divides the file into stripes *if requested by the user*

Stripes read/written to/from their assigned OST

Striping

- Allow multiple IO processes to access same file
  - increases bandwidth as you are accessing multiple OSTs
- Typically optimised for bandwidth, not for latency
  - e.g. reading/writing small amounts of data is very inefficient
- This is called striping
  - striping of a file is fixed when it is created, under control of the user
  - fundamental parameters are the number of stripes and stripe size
- For example, if a file is created with a stripe count of 4
  - Lustre assigns four OSTs: OST1, OST2, OST3, OST4
  - first MiB is stored on OST1, second on OST2, third on OST3, fourth on OST4, fifth on OST1, sixth on OST2, ...
  - i.e. round-robin with default stripe size of 1MiB

Lustre usage



From https://wiki.lustre.org/images/6/64/LustreArchitecture-v4.pdf

Lustre commands

- To set the striping on a directory or file

```
lfs setstripe –c nstripe <dir/file>
```

  - nstripe = -1 is full striping (12 on ARCHER2’s three disk filesystems)
  - Stripe size: `lfs setstripe –S 4m <dir/file>`

- Does **not** alter striping for existing files: that requires a copy
- I always use setstripe on directories
  - all files subsequently created in directory will have the same striping

- To enquire: `lfs getstripe <dir/file>`

Parallel IO to a striped file

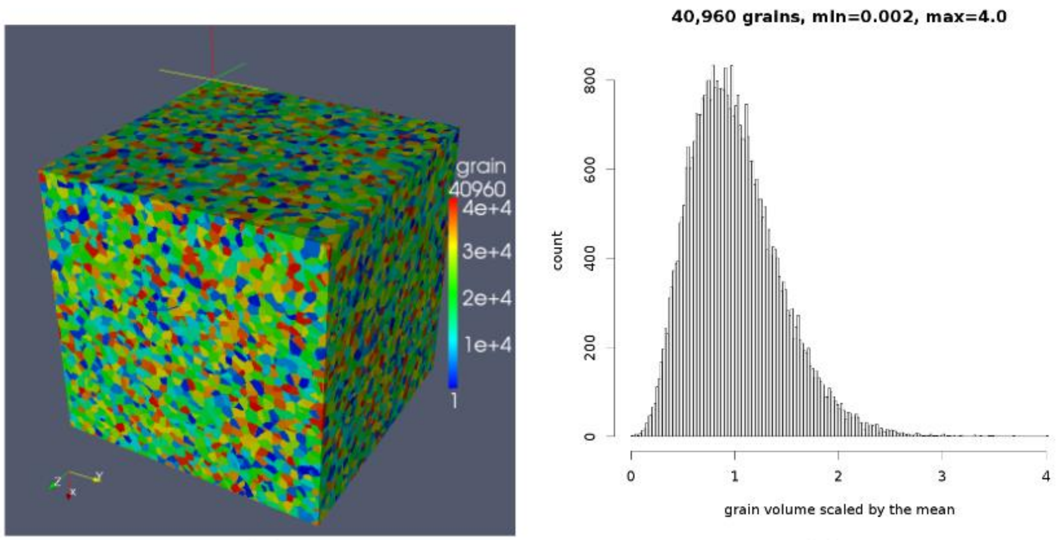
- Very complicated in practice!
  - where in the file does the local data need to be written?
  - which OSTs are the stripes located on?
  - are there write conflicts coming from different processes?

- Need to use a parallel IO library

Benchio benchmark

- Obvious questions:
  - does the MDS become overloaded for large numbers of files?
  - what is the maximum performance of a single OST?
  - can one process saturate an OST? can a node saturate an OST?
    - or is the network the limiting factor?
  - how well do different IO libraries work with Lustre?
  - what are the best stripe count (and size) settings?
  - ....
- I wrote a simple benchmark to help investigate Lustre performance characteristics and bottlenecks
  - we will use benchio for the practical examples
  - writes a large distributed 3D array of double precision numbers
  - https:/github.com/davidhenty/benchio/.

Cellular Automaton Model



(a) (b)

Figure 1: A 4.1 × 10^9 cell, 40,960 grain equiaxed microstructure model, showing (a) grain arrangement with colour denoting orientation; (b) grain size size (volume) histogram.

- *Fortran coarray library for 3D cellular automata microstructure simulation*, Anton Shterenlikht, proceedings of 7th International Conference on PGAS Programming Models, 3-4 October 2013, Edinburgh, UK.

ARCHER2 speeds and feeds

- From the HPE data sheets

FS	GiB/s OST	GiB/s total
/work	11	132
NVMe	55	1100

- What can we get in practice?

- Note that serial IO is slow
  - “fopen(); fwrite(); fclose();” gets less than 1GiB/s from a single process

Node bandwidth

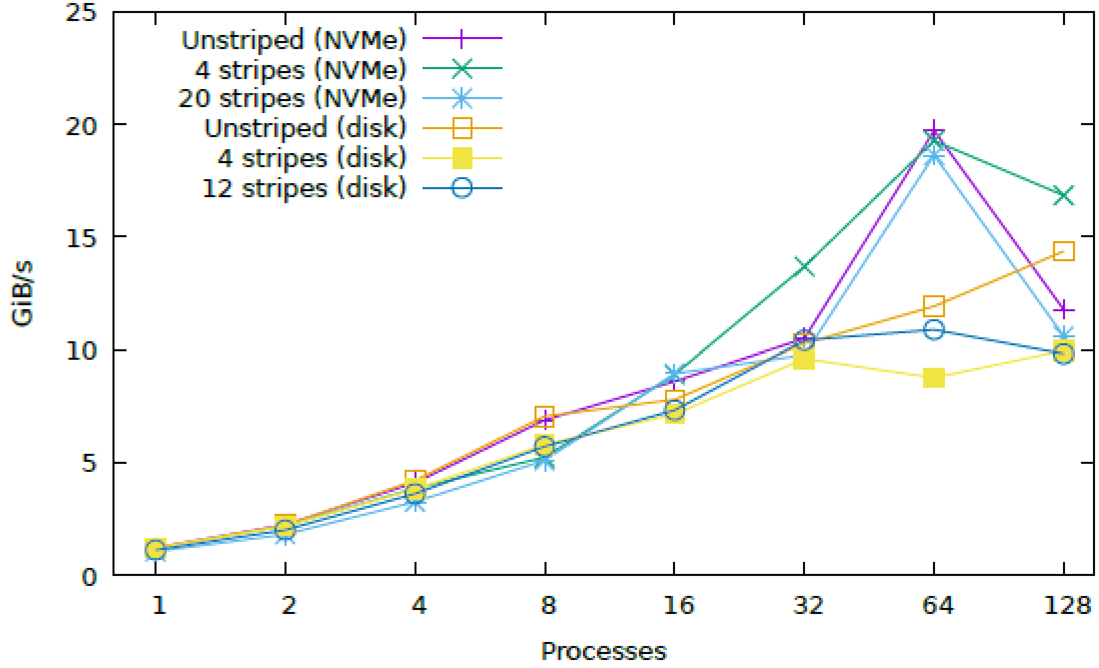


Fig. 3. File-per-process bandwidth from a single node with 16 GiB of data.

From “Performance of Parallel IO on the 5860-node HPE Cray EX System ARCHER2”, CUG2022

OST bandwidth

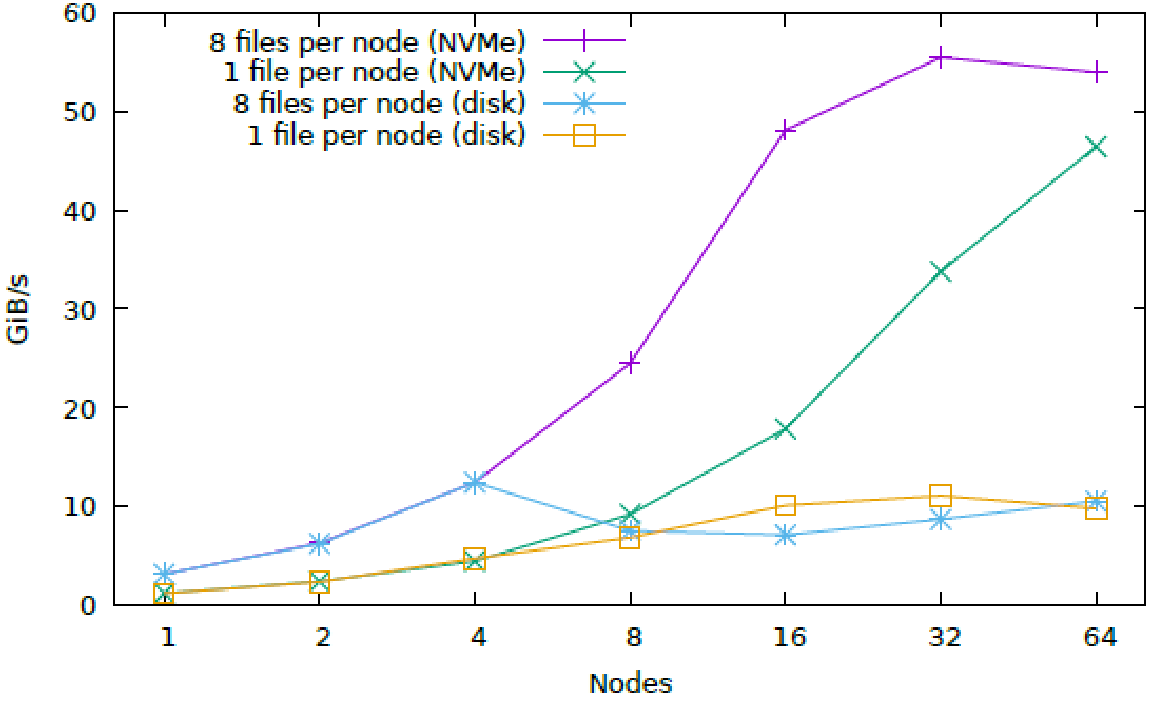


Fig. 2. File-per-process bandwidth to 1 OST with 1 GiB of data per node.

From “Performance of Parallel IO on the 5860-node HPE Cray EX System ARCHER2”, CUG2022

Sample results

- Ballpark maximum measured figures

single process:	0.8 GiB/s
single node	15 GiB/s max
single OST:	10 GiB/s /work, 50 GiB/s NVMe

- To be able to saturate the whole filesystem
  - around 10 nodes for /work
  - around 80 nodes for NVMe

- However
  - single process bandwidth is severely limiting
  - need around 20 IO processes/node to saturate nodal bandwidth