Advanced Message-Passing Programming

Parallel Filesystems and Lustre

Reusing this material

Overview

- Lecture will cover
  - Parallel Filesystems
  - Lustre Filesystem
  - Striping
  - Simple Lustre commands
  - Bottlenecks

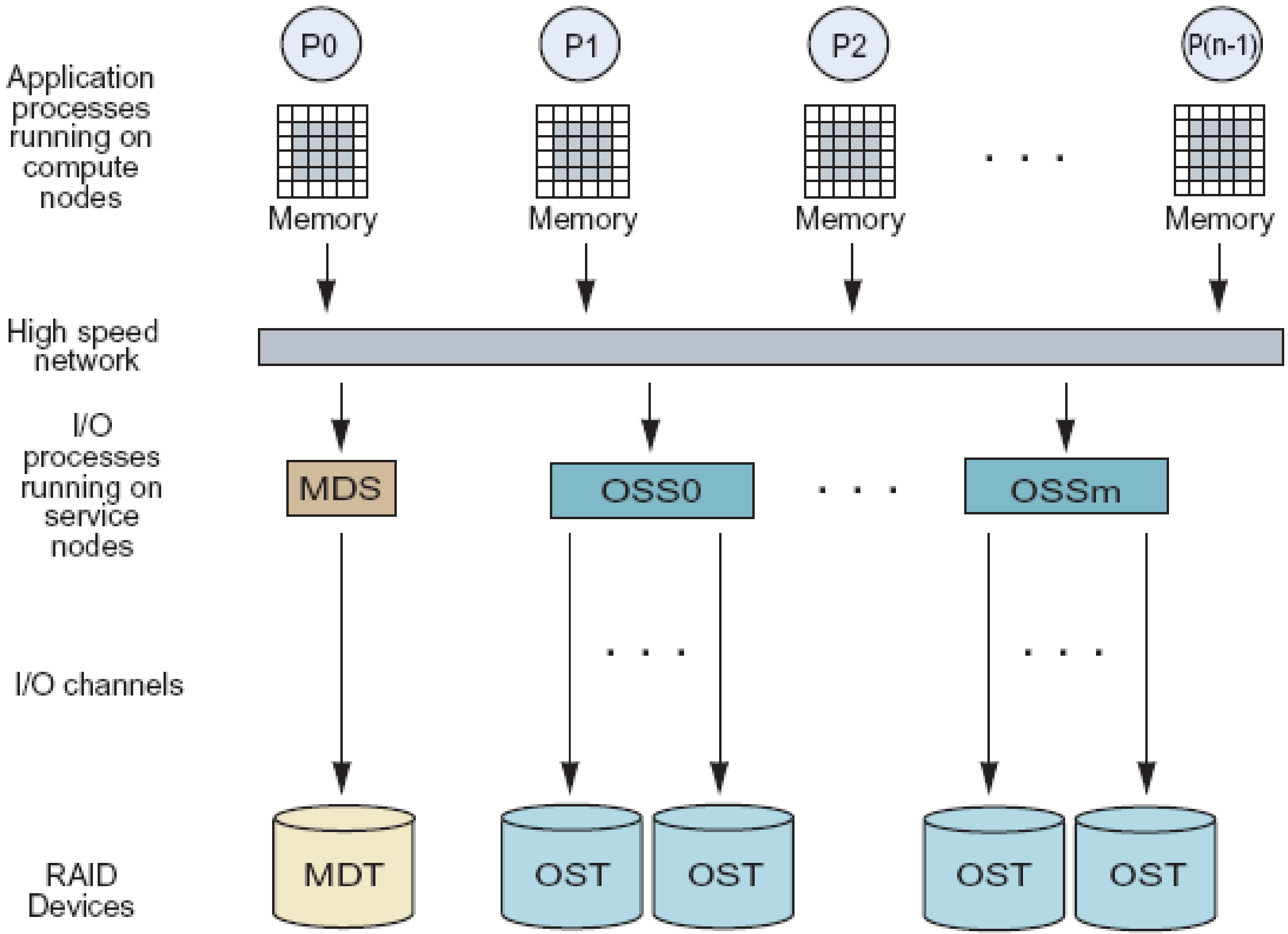
Parallel File Systems

- 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

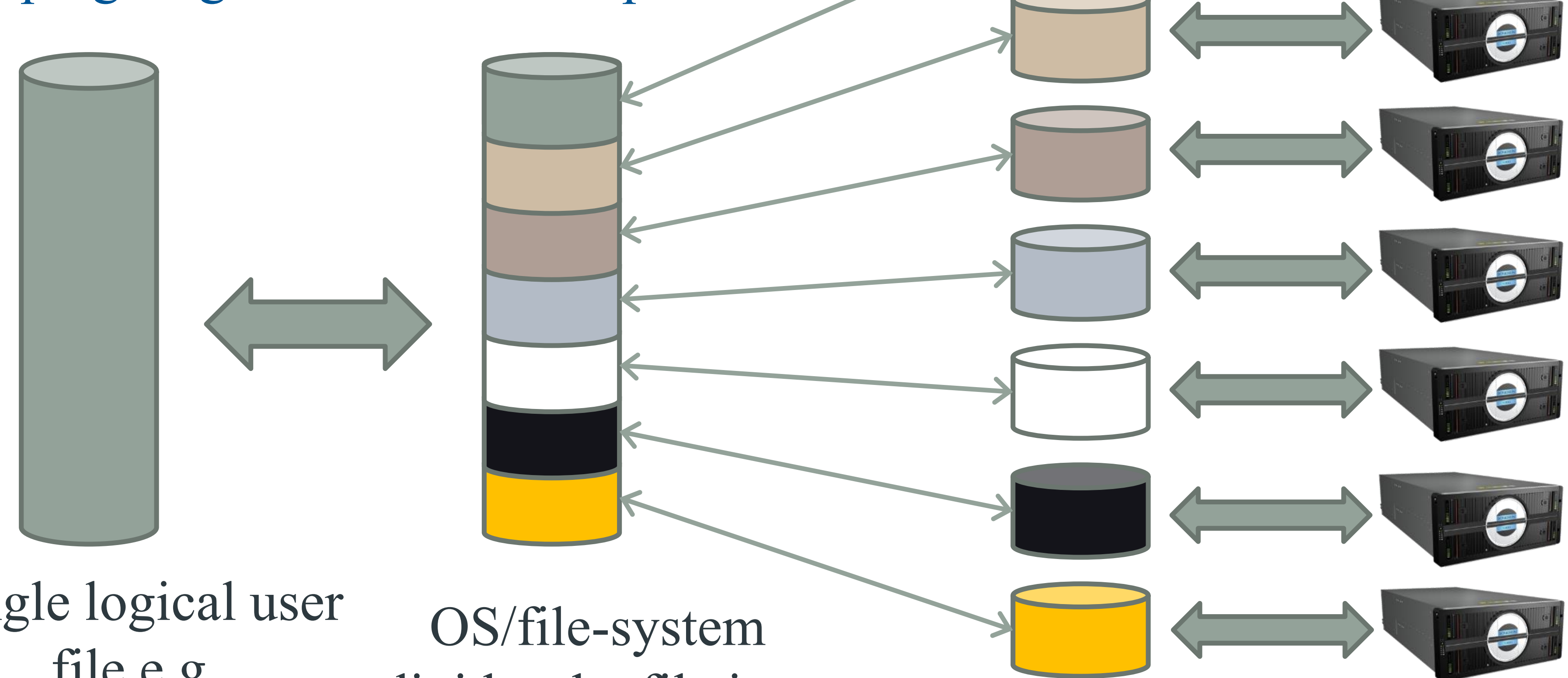
- Three separate /work filesystems (work1, work2 & work3)
  - each has 12 OSTs and one MDS
  - consortia assigned to different partitions to share the load
  - multiple filesystems means the MDS is less likely to be overloaded
- One filesystem with Solid State storage, not spinning disks
  - NVMe – non-volatile 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 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

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 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>`**

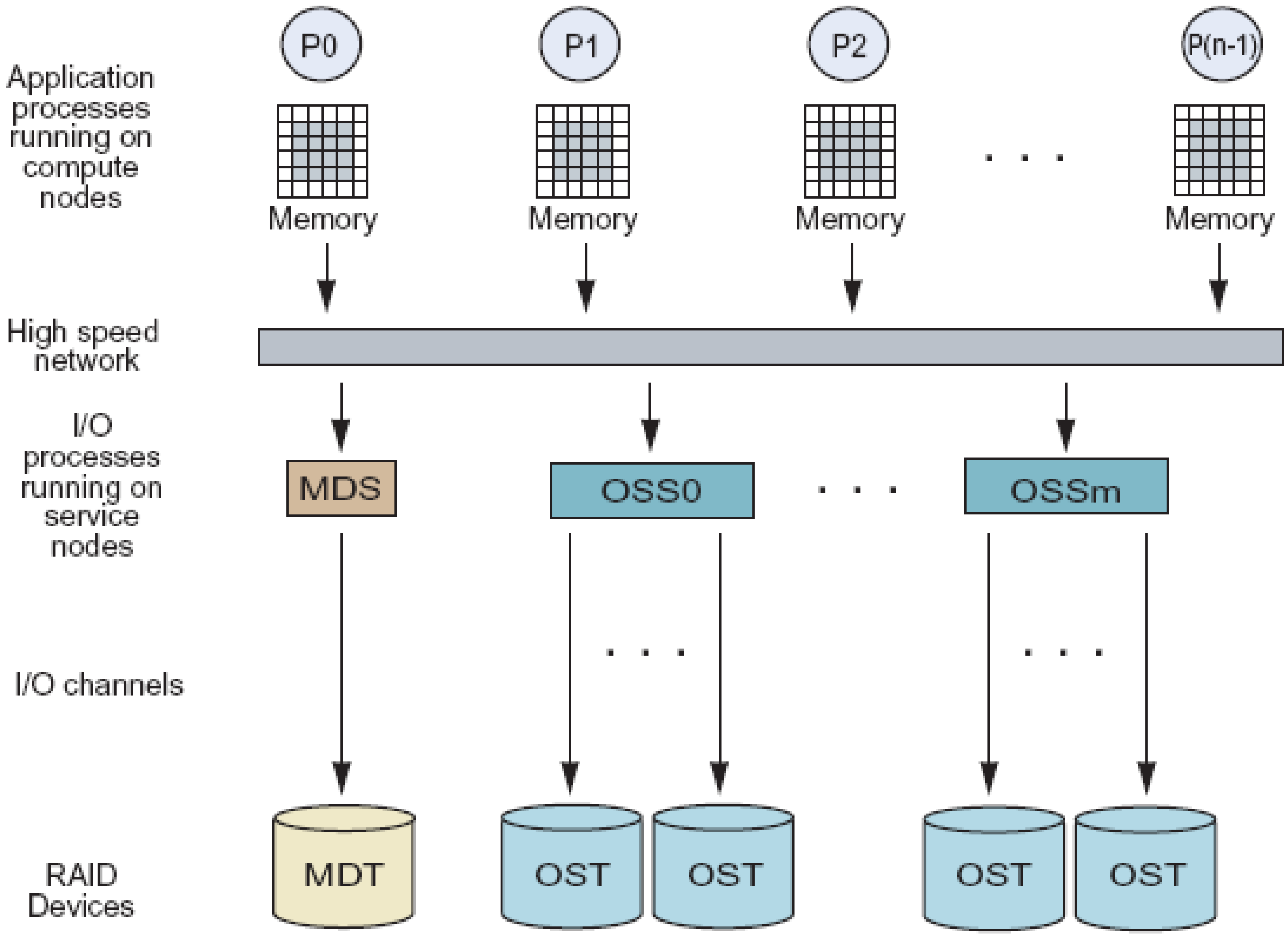
- Does **not** alter striping for existing files: that requires a copy
- I always use setstripe on directories
  - all files subsequently created in directory will have the same striping
- To enquire: **`lfs getstripe <dir/file>`**

Parallel IO to a striped file

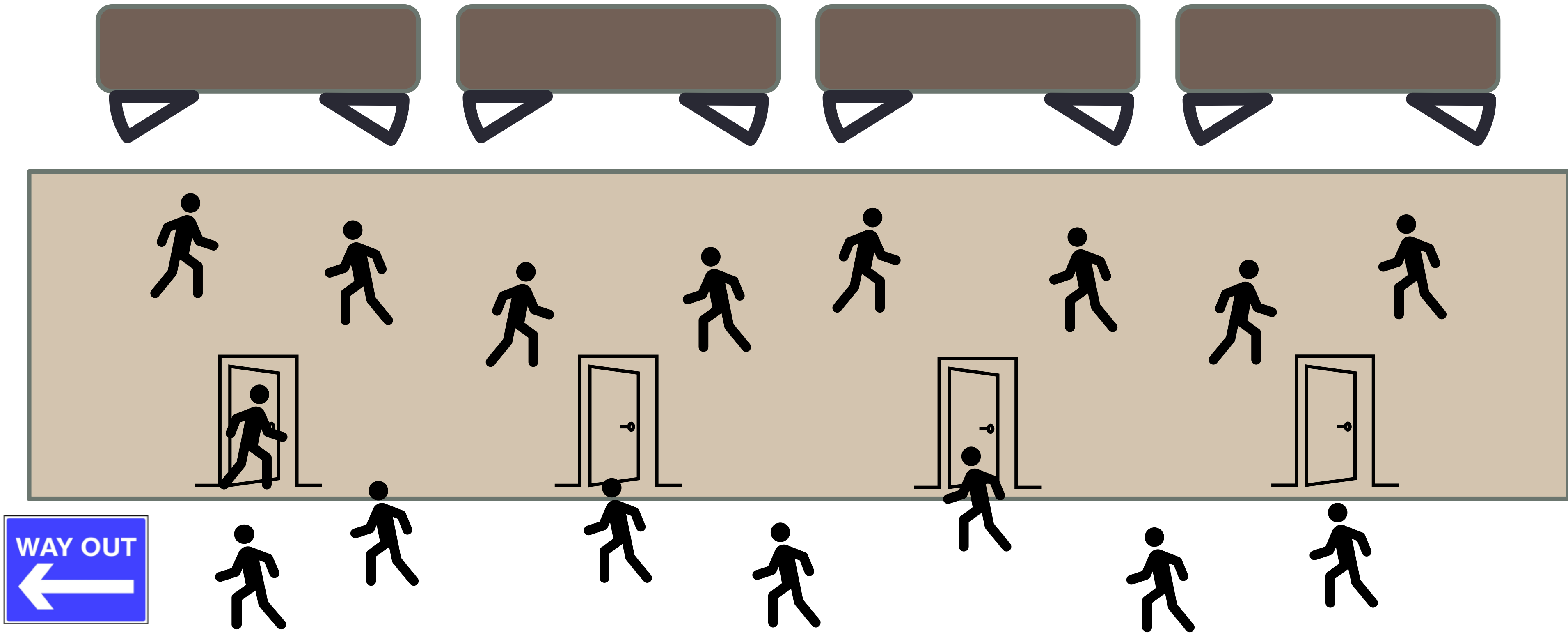
- Very complicated in practice!
  - where in the file does the local data need to be written?
  - which OSTs are the stripes located on?
  - are there write conflicts coming from different processes?

- Need to use a parallel IO library

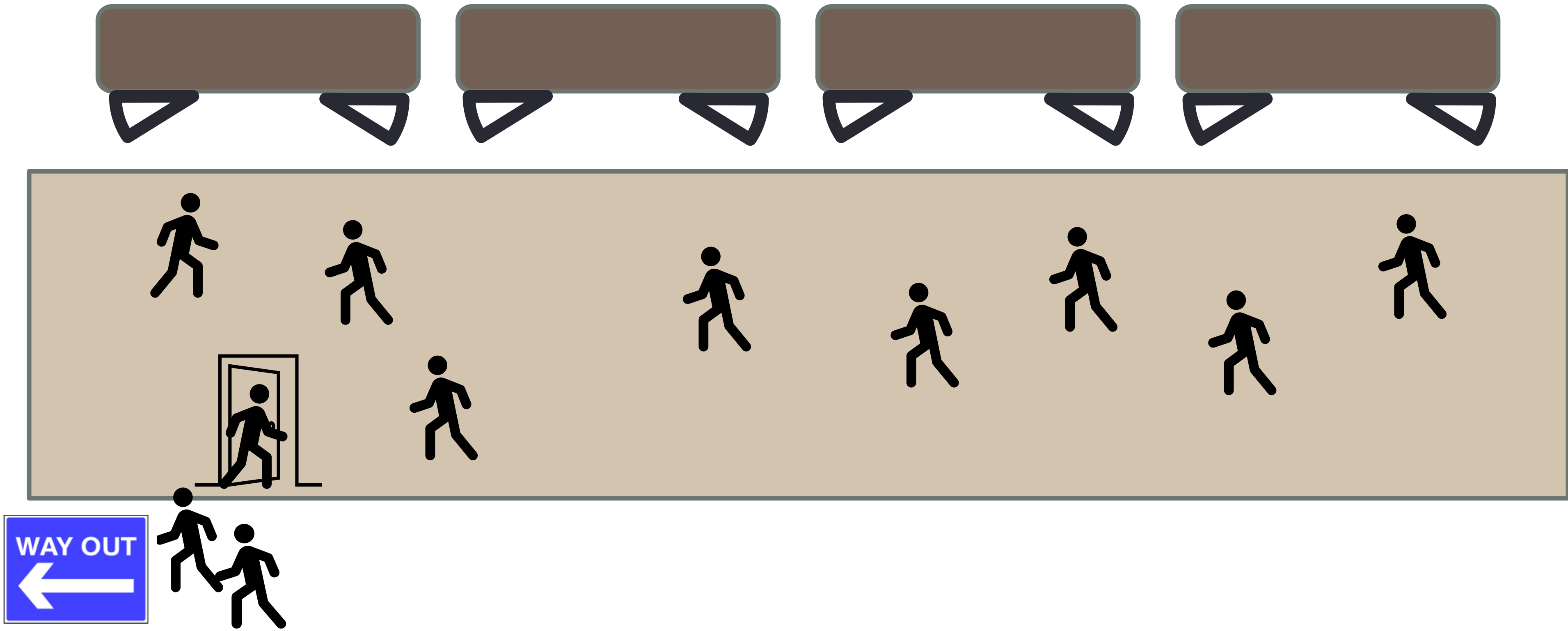
Lustre: where are the bottlenecks?



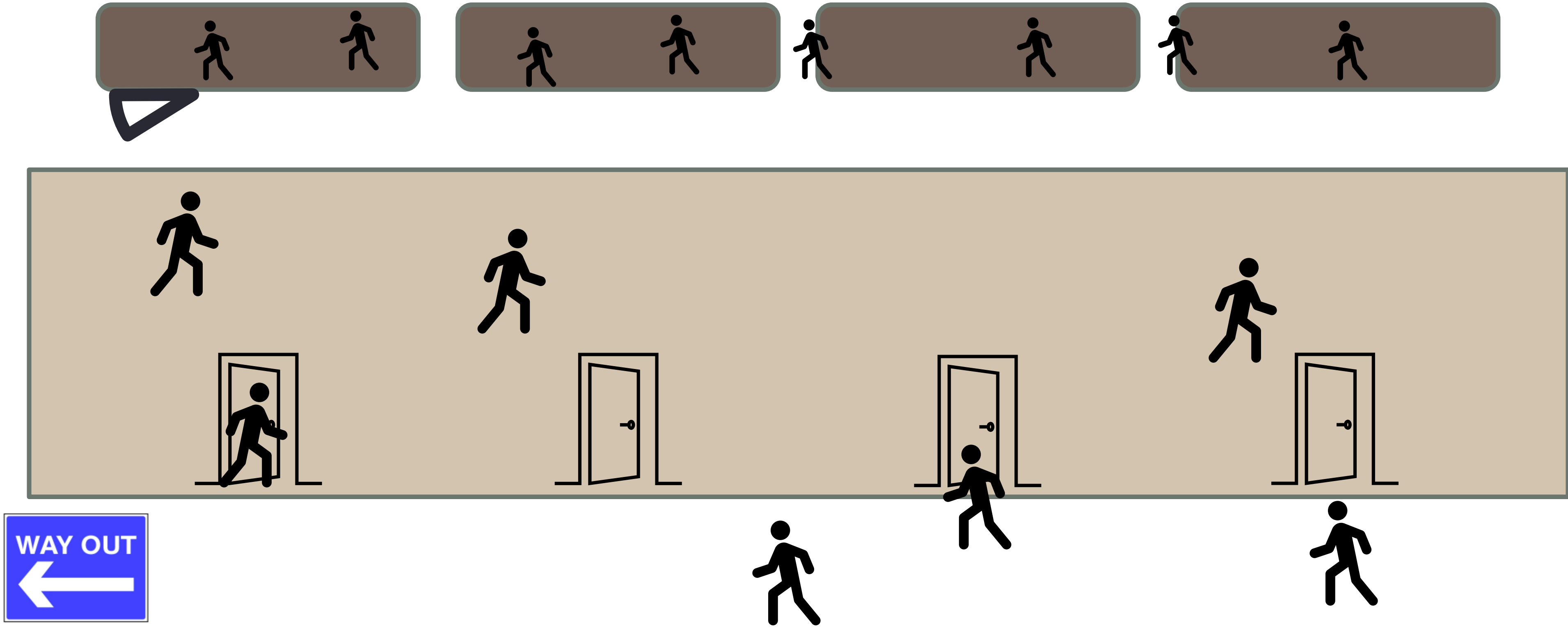
Train Analogy



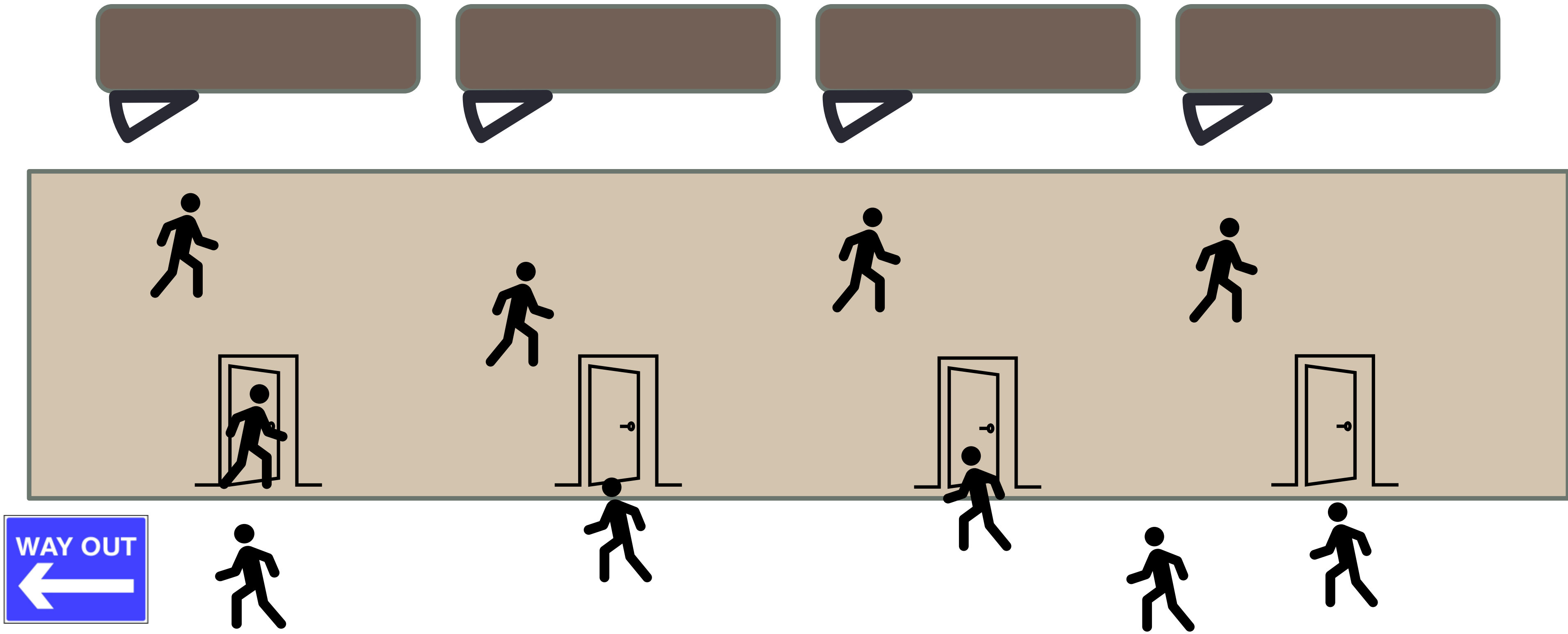
Serial Exit Door



Serial Train Door



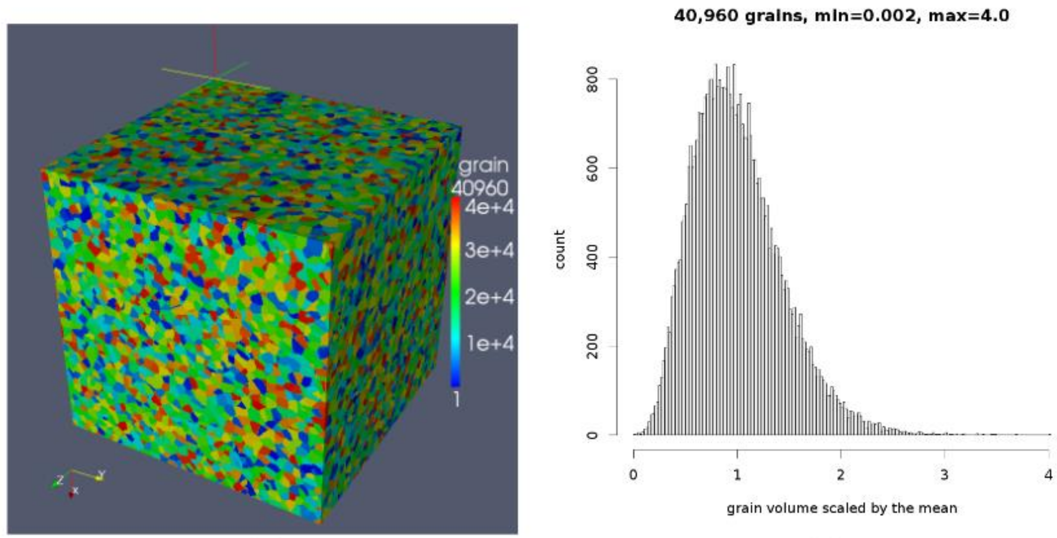
Reduced Train Doors



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.

Performance variability

- Share HPC resources with all users on the machine
  - network bandwidth

- Share IO resources with all users on same filesystem
  - access to OSTs
  - access to MDS

- Any of these can suffer from contention
  - IO can sometimes be very slow due to congestion

Summary

- A Lustre filesystem has multiple OSTs
  - I think of these as being multiple disks
- By default on ARCHER2, each file stored on a single OST
  - i.e. an unstriped file with a stripe count of 1
  - increased performance for multiple files
    - a single user writing many files
    - multiple users each writing a single file
- Improving performance for a single file requires striping
  - fully under control of the user
  - expect parallel IO libraries to take advantage of striping