Advanced Parallel Programming

Overview of Parallel IO

ARCHER Training Courses

Sponsors

Reusing this material

Overview

- Lecture will cover
  - Why is IO difficult
  - Why is parallel IO even worse
  - Straightforward solutions in parallel
  - What is parallel IO trying to achieve?
  - Files as arrays
  - MPI-IO and derived data types

Why is IO hard?

- Breaks out of the nice process/memory model
  - data in memory has to physically appear on an external device
- Files are very restrictive
  - linear access probably implies remapping of program data
  - just a string of bytes with no memory of their meaning

- Many, many system-specific options to IO calls
- Different formats
  - text, binary, big/little endian, Fortran unformatted, ...
- Disk systems are very complicated
  - RAID disks, many layers of caching on disk, in memory, ...
- IO is the HPC equivalent of printing!

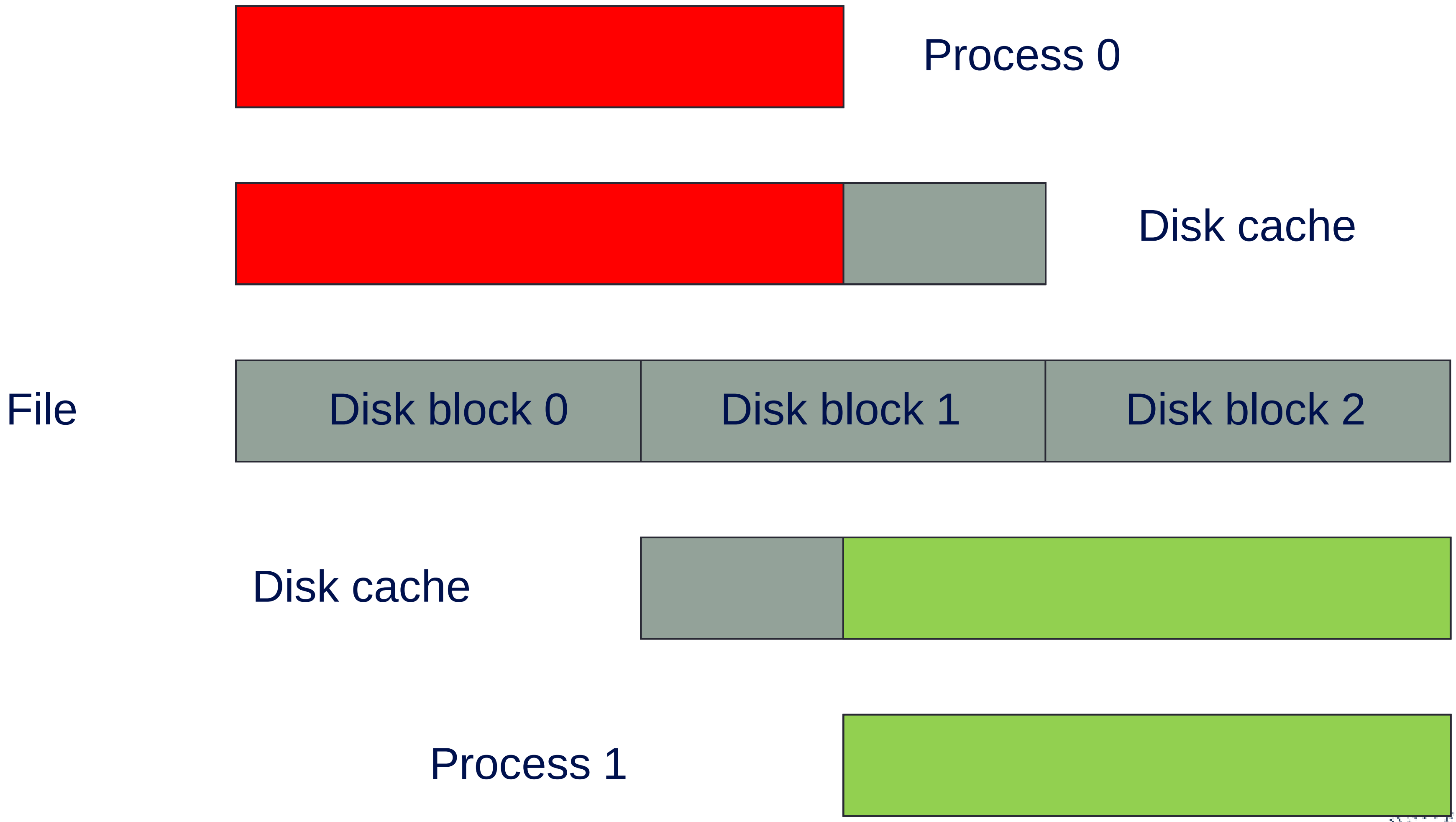
Why is Parallel IO Harder?

- Cannot have multiple processes writing a single file
  - Unix generally cannot cope with this
  - data cached in units of disk blocks (eg 4K) and is *not coherent*
  - not even sufficient to have processes writing to distinct parts of file

- Even reading can be difficult
  - 1024 processes opening a file can overload the filesystem (fs)

- Data is distributed across different processes
  - processes do not in general own contiguous chunks of the file
  - cannot easily do linear writes
  - local data may have halos to be stripped off

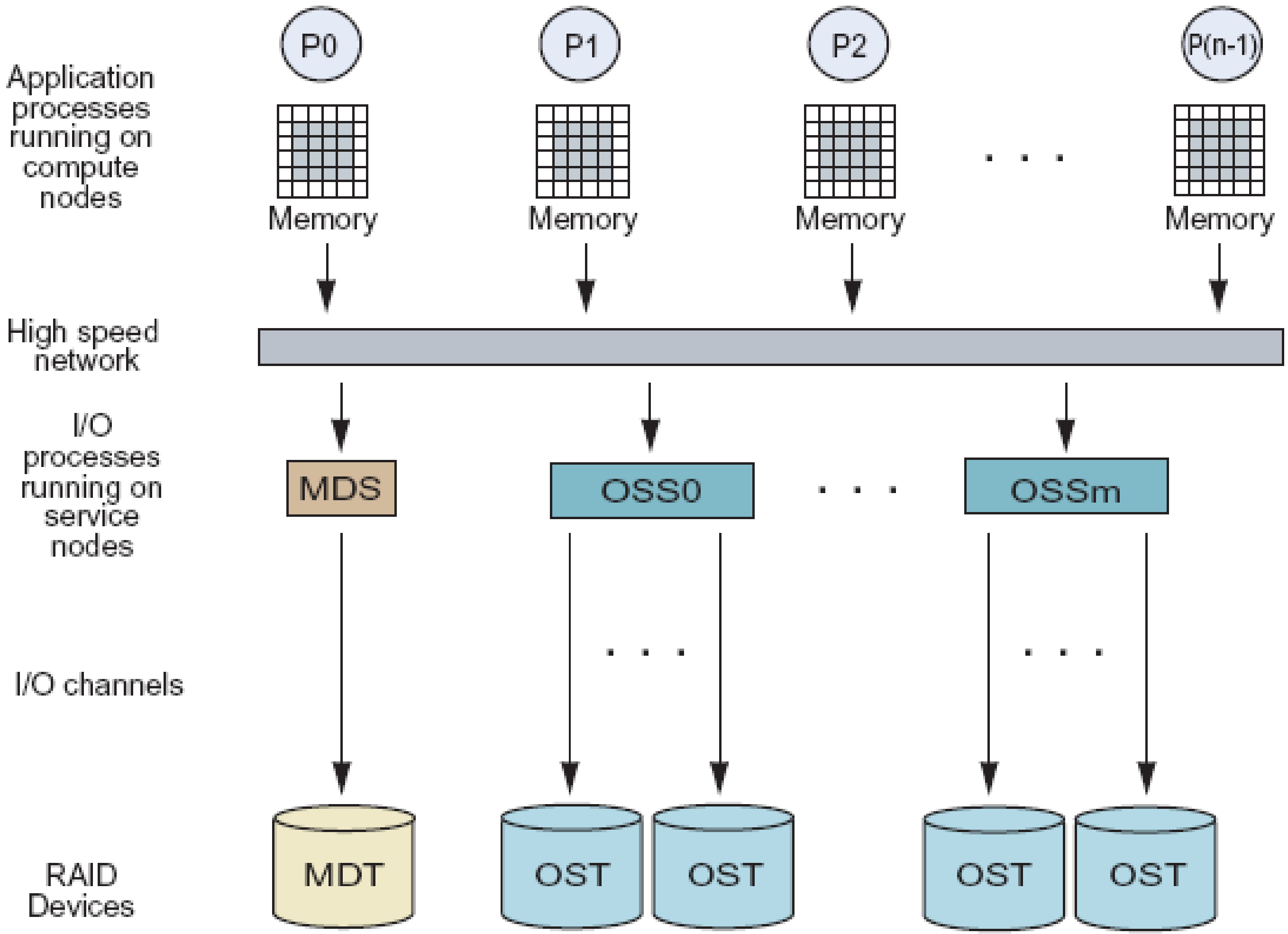
Simultaneous Access to Files



Parallel File Systems

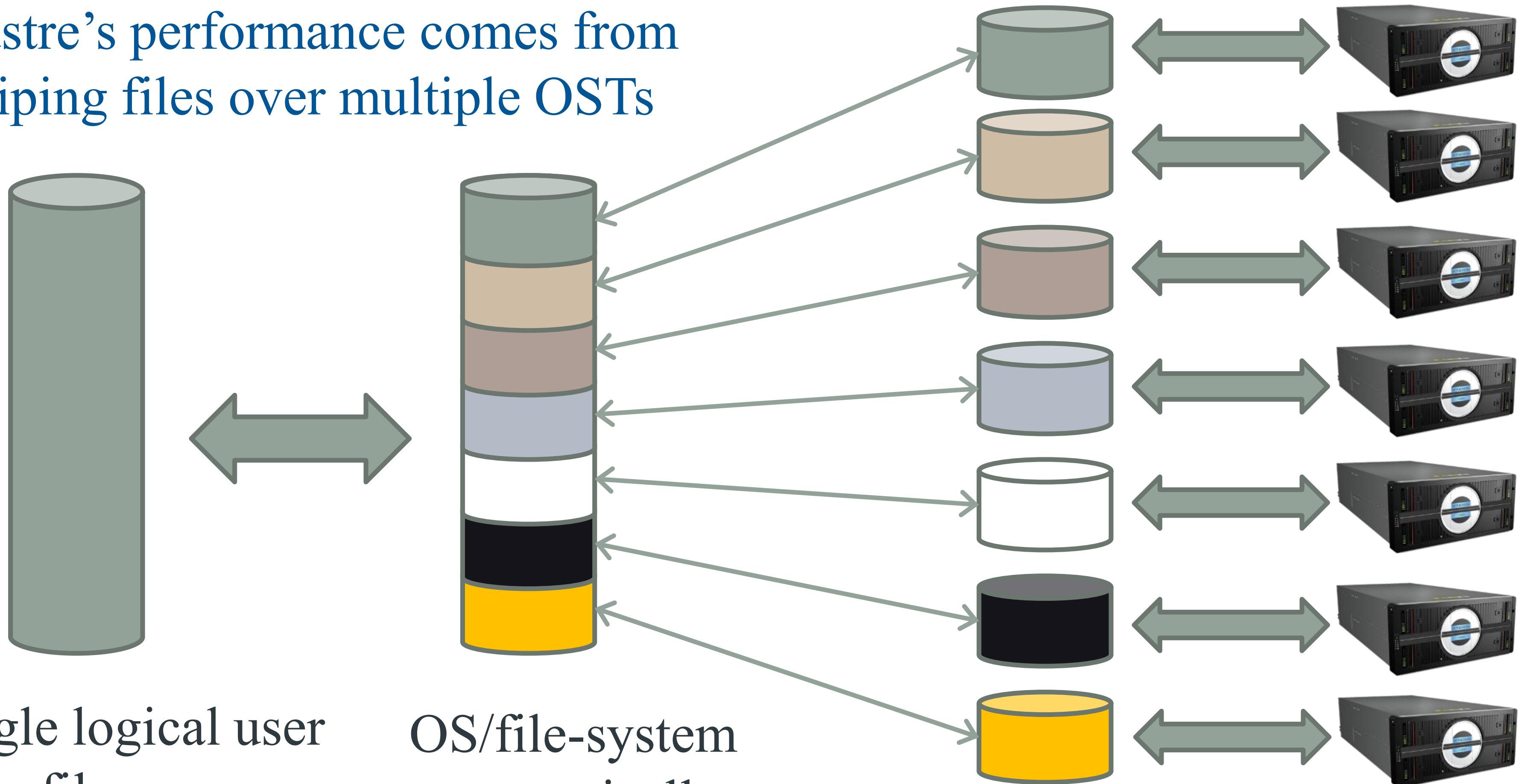
- Parallel computer
  - constructed of many processors
  - each processor not particularly fast
  - performance comes from using many processors at once
  - requires distribution of data and calculation across processors
- Parallel file systems
  - constructed from many standard disk
  - performance comes from reading / writing to many disks
  - requires many *clients* to read / write to different disks at once
  - data from a single file must be *striped* across many disks
- Must appear as a single file system to user
  - typically have a single *MedaData* Server (MDS)
  - can become a bottleneck for performance

Parallel File Systems: Lustre



Lustre data striping

Lustre's performance comes from striping files over multiple OSTs



Single logical user file e.g. `/work/y02/y02/ted`

OS/file-system automatically divides the file into stripes

Stripes read/written to/from their assigned OST

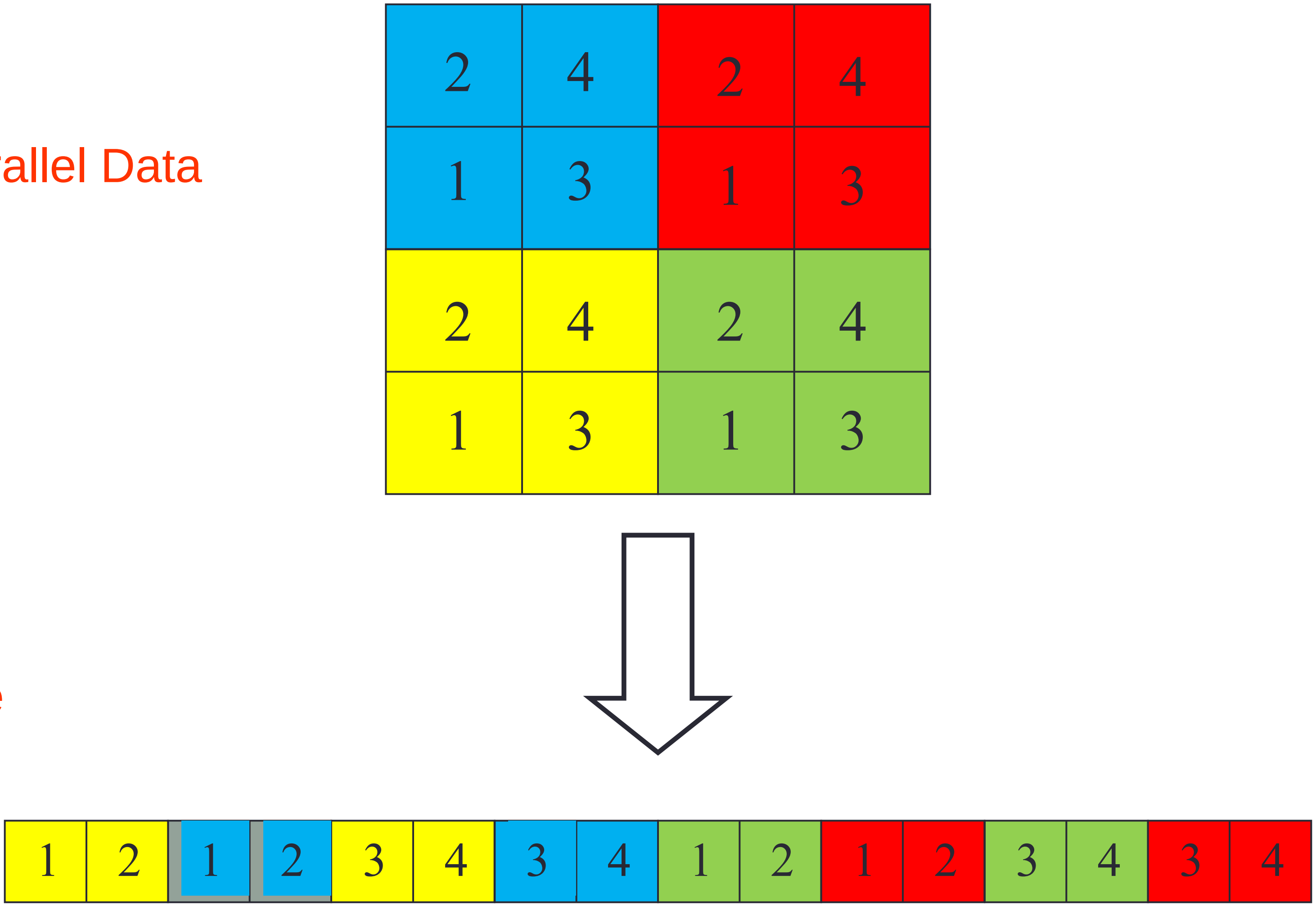
Parallel File Systems

- Allow multiple IO processes to access same file
  - increases bandwidth
- Typically optimised for bandwidth
  - not for latency
  - e.g. reading/writing small amounts of data is very inefficient
- Very difficult for general user to configure and use
  - need some kind of higher level abstraction
  - allow user to focus on data layout across user processes
  - don't want to worry about how file is split across IO servers

4x4 array on 2x2 Process Grid

Parallel Data

File



Shared Memory

- Easy to solve in shared memory
  - imagine a shared array called **x**

```
begin serial region
      open the file
      write x to the file
      close the file
end serial region
```

- Simple as every thread can access shared data
  - may not be efficient but it works
- But what about message-passing?

Message Passing: Naive Solutions

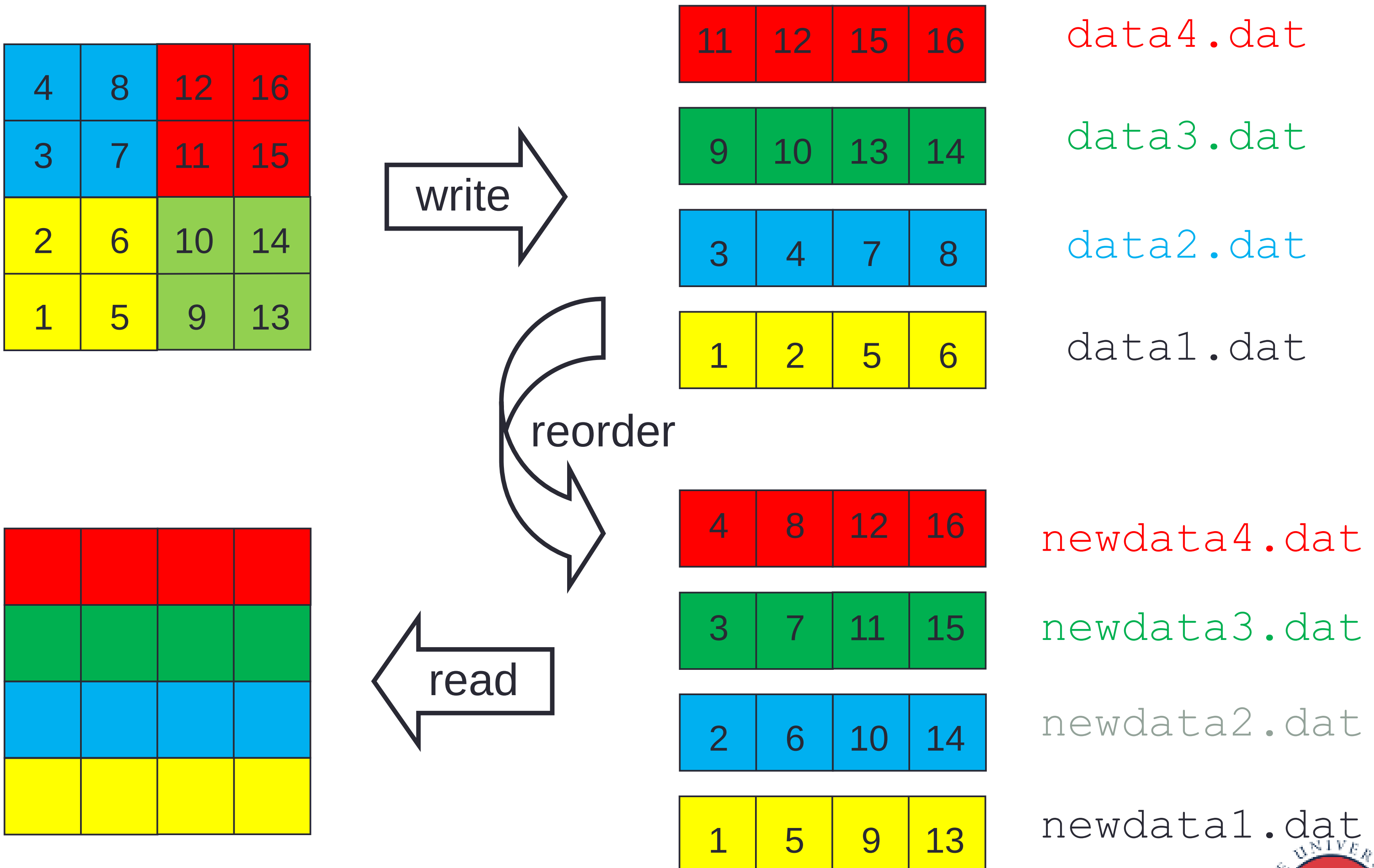
- Master IO
  - send all data to/from master and write/read a single file
  - quickly run out of memory on the master
    - or have to write in many small chunks
  - does not benefit from a parallel fs that supports multiple write streams

- Separate files
  - each process writes to a local fs and user copies back to home
  - or each process opens a unique file (dataXXX.dat) on shared fs

- Major problem with separate files is reassembling data
  - file contents dependent on number of CPUs and decomposition
  - pre / post-processing steps needed to change number of processes
  - but at least this approach means that reads and writes are in parallel

- But may overload filesystem for many processes
  - e.g. MDS cannot keep up with requests

2x2 to 1x4 Redistribution



What do we Need?

- A way to do parallel IO properly
  - where the IO system deals with all the system specifics
- Want a single file format
  - We already have one: the serial format

- All files should have same format as a serial file
  - entries stored according to position in global array
    - not dependent on which process owns them
  - order should always be 1, 2, 3, 4, ..., 15, 16

Information on Machine

- What does the IO system need to know about the parallel machine?
  - all the system-specific fs details
  - block sizes, number of IO servers, etc.

- All this detail should be hidden from the user
  - but the user may still wish to pass system-specific options …

ARCHER's Cray Sonexion Storage

1

MMU: *Metadata Management Unit*

Lustre MetaData Server

- Contains server hardware and storage

2

SSU: *Scalable Storage Unit*

2 x OSSs and 8 x OSTs (Object Storage Targets)

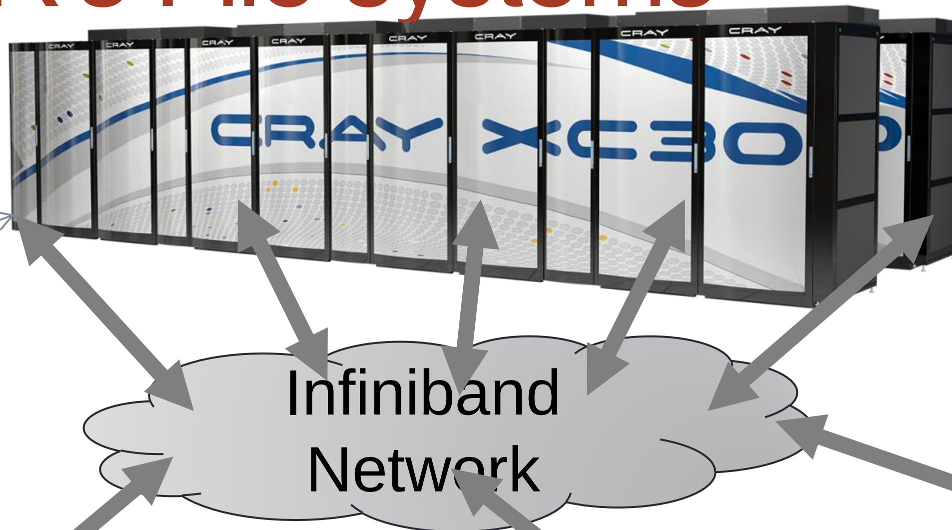
- Contains Storage controller, Lustre server, disk controller and RAID engine
- Each unit is 2 OSSs each with 4 OSTs of 10 (8+2) disks in a RAID6 array

3

Multiple SSUs are combined to form storage racks

ARCHER's File systems

Connected to the Cray XC30 via LNET router service nodes.



/fs2
6 SSUs
12 OSSs
48 OSTs
480 HDDs
4TB per HDD
1.4 PB Total

/fs3
6 SSUs
12 OSSs
48 OSTs
480 HDDs
4TB per HDD
1.4 PB Total

/fs4
7 SSUs
14 OSSs
56 OSTs
560 HDDs
4TB per HDD
1.6 PB Total

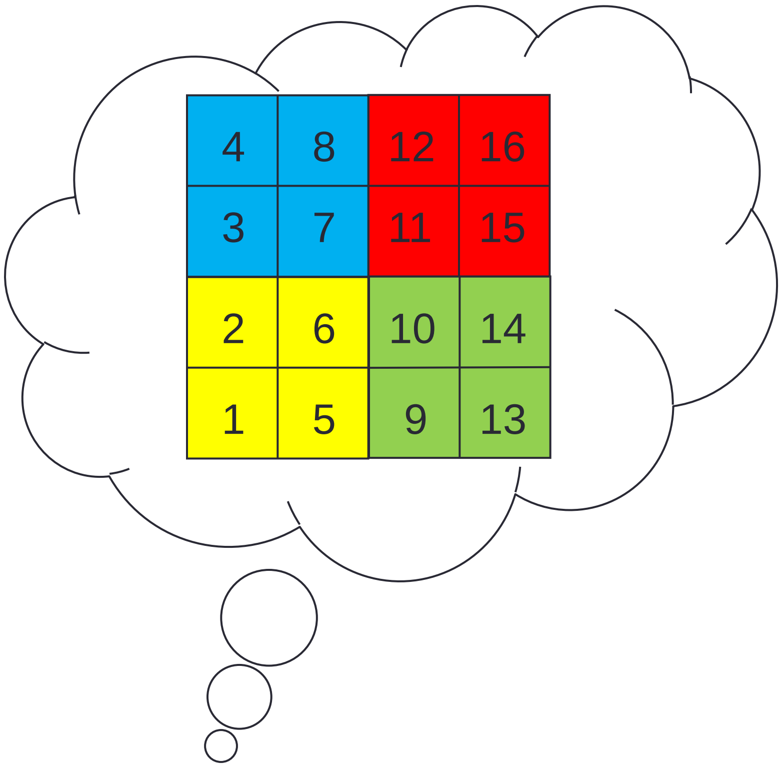
Information on Data Layout

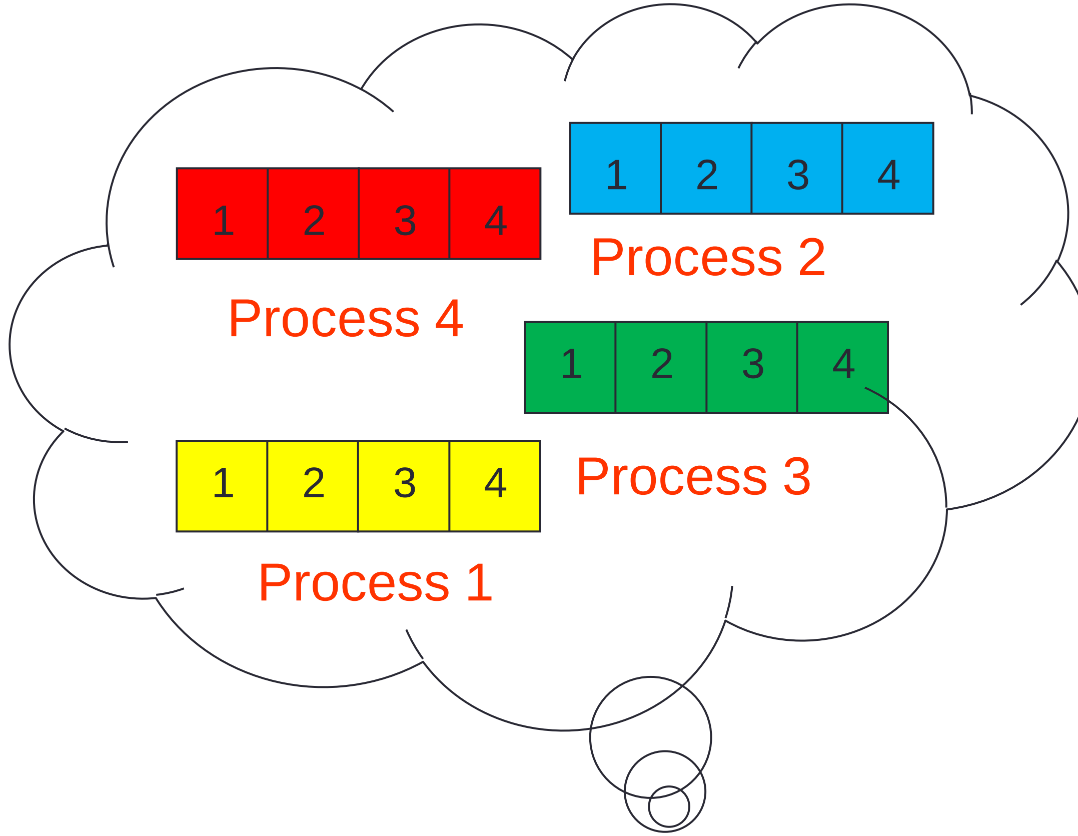
- What does the IO system need to know about the data?
  - how the local arrays should be stitched together to form the file

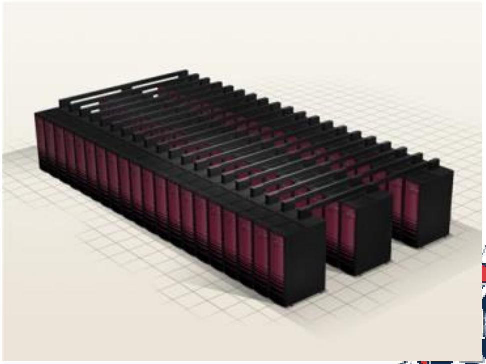
- But ...
  - mapping from local data to the global file is only in the mind of the programmer!
  - the program does not know that we imagine the processes to be arranged in a 2D grid

- How do we describe data layout to the IO system
  - without introducing a whole new concept to MPI?
  - cartesian topologies are not sufficient
    - do not distinguish between block and block-cyclic decompositions

Programmer View vs Machine View







Files vs Arrays

- Think of the file as a large array
  - forget that IO actually goes to disk
  - imagine we are recreating a single large array on a master process

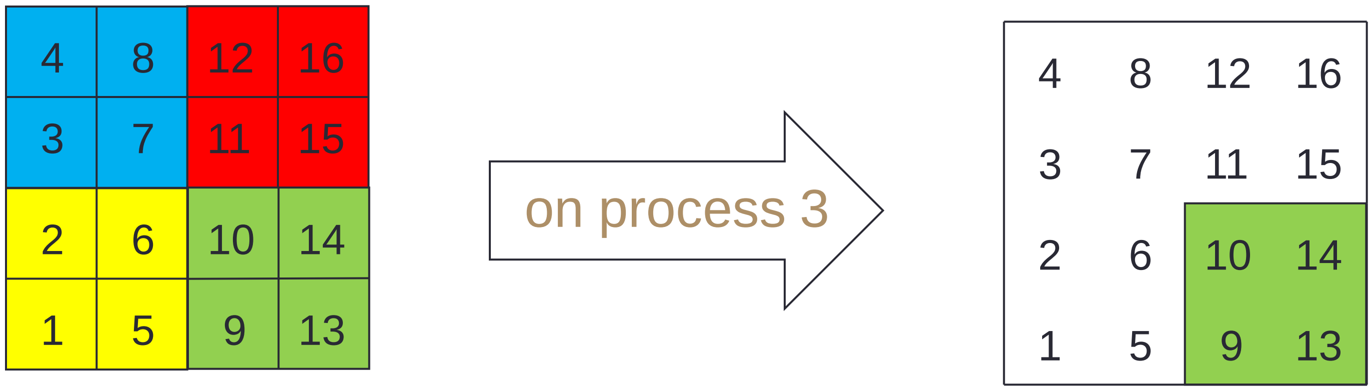
- The IO system must create this array and save to disk
  - without running out of memory
    - never actually creating the entire array
    - ie without doing naive master IO
  - and by doing a small number of large IO operations
    - merge data to write large contiguous sections at a time
  - utilising any parallel features
    - doing multiple simultaneous writes if there are multiple IO nodes
    - managing any coherency issues re file blocks

MPI-IO Approach

- MPI-IO is part of the MPI standard
  - http://www.mpi-forum.org/docs/docs.html

- Each process needs to describe what subsection of the global array it holds
  - it is entirely up to the programmer to ensure that these do not overlap for write operations!
- Programmer needs to be able to pass system-specific information
  - pass an **`info`** object to all calls

Data Sections



- Describe 2x2 subsection of 4x4 array
- Using standard MPI derived datatypes
- A number of different ways to do this
  - we will cover three methods in the course

Summary

- Parallel IO is difficult
  - in theory and in practice
- MPI-IO provides a higher-level abstraction
  - user describes global data layout using derived datatypes
  - MPI-IO hides all the system specific fs details …
  - … but (hopefully) takes advantage of them for performance
- More flexible formats like NetCDF and HDF5 exist
  - they gain performance by layering on top of MPI-IO
- User requires a good understanding of derived datatypes
  - see next lecture