

# Introduction to High Performance Computing (HPC) – Session 2

## using the "Computational Shared Facility" (CSF)

Research Platforms, Research IT, IT Services

Course materials / Slides available from:  
<https://ri.itsservices.manchester.ac.uk/course/rcsf/>

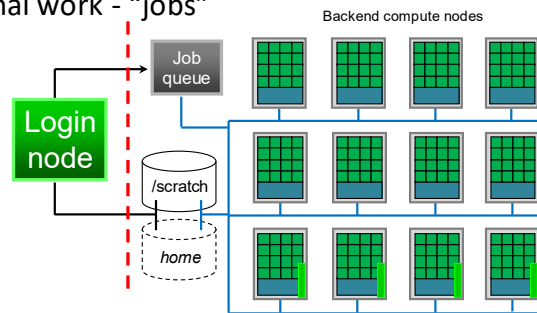
CSF online documentation  
<https://ri.itsservices.manchester.ac.uk/csf3/>

Contact Research Platforms via the Connect Portal  
<https://ri.itsservices.manchester.ac.uk/csf3/help/>

Recap slide skipped in training room

## Jobs, Jobscripts and the Batch System

- We want to do computational work - "jobs"



- You decide:
  - Which program(s) to run
  - Which resources it needs (#cores, CPU type, memory, GPU?)
  - How much time the job will need to complete its work
  - Which of your folders ("directory") to run the job in
- You'll put these requirements into a *jobscript* file
- Then submit your *jobscript* to the batch system ("Slurm")
- Slurm decides *when* the job runs and on which compute node(s). It ensures you get all of your requested resources.

## Housekeeping

- Please let me know if you're leaving
  - Morning: Session one: 10am – 12:30pm (practicals 1, 2, & 3)
  - Afternoon: Session two: 1:30pm - 4pm (practicals 4 & 5)
- 1-to-1 help is available if needed during exercises. We'll describe how this works before the first one.
- Please give feedback on this course
  - Quick form at <https://goo.gl/forms/zfZyTLw4DDaySnCF3> (choose "Introduction to HPC (Using CSF)")
  - Feedback is important to help us improve our courses
  - Records your attendance on the course

Recap slide skipped in training room

## A simple Jobscript – Serial (1 core)

**#!** on first line only (a special line)

**#SBATCH** indicates a batch system parameter to specify our job requirements. We'll use various combinations of these.

**#** lines are just comments - anything on the line after it will be ignored.

Actual Linux commands we run in our job. They will execute on a compute node.

First line indicates we use the *bash* scripting language to write our jobscript.

**-p** (**--partition=**) think of this as the queue, for serial (1-core) jobs in this case.

**-n** (**--ntasks=**) number of cores, which is 1 by default for serial jobs (**optional**).

**-t** (**--time=**) maximum "wallclock" time the job is allowed to run for. Various formats. 5 is 5 minutes. 4-0 would be 4 days (0 hours).

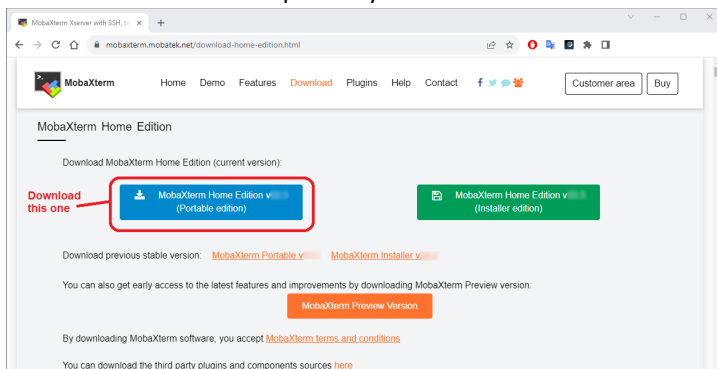
```

#!/bin/bash --login
#SBATCH -p serial
#SBATCH -n 1
#SBATCH -t 5

# Let's do some work
date
hostname
sleep 120
date
  
```

# Connect to CSF from Windows

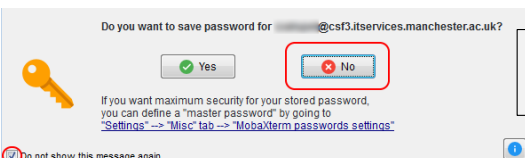
- Access the CSF from a PC / laptop using an SSH (Secure Shell) app
  - Sometimes called a "terminal".
  - There's no web-site or other fancy GUI on the CSF – use the "command-line".
- Windows users** need to install a free *terminal* app called MobaXterm
- <https://mobaxterm.mobatek.net/download-home-edition.html>  
the **Home edition** (portable edition) does *not* require Administrator rights - just *extract* the small .zip file in your P-Drive or USB stick for example.



- Download using the **blue box**.
- Once downloaded, **right-click** on the .zip file and select:  
  
"Extract all ..."  
  
This will *unpack* the .zip file to a folder.

5

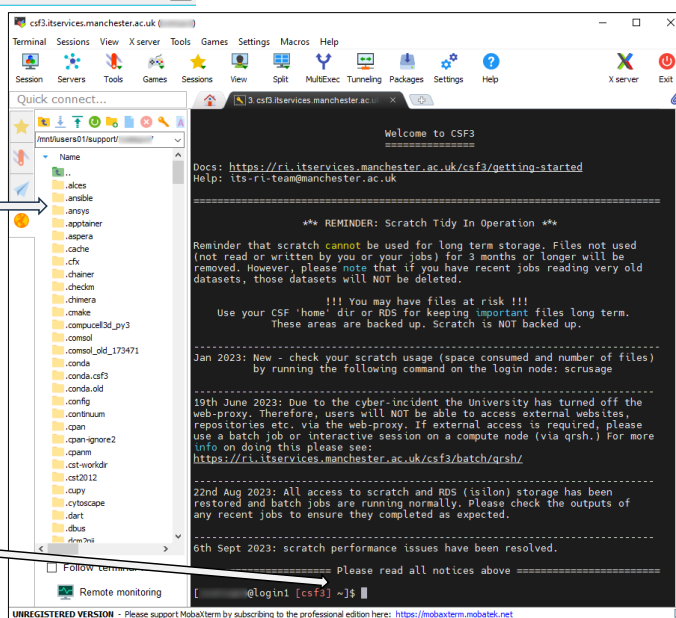
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If asked to save your password, we recommend you say "No", for security.

Drag-n-drop file browser for upload / download  
(new users won't have as many items in the list!)

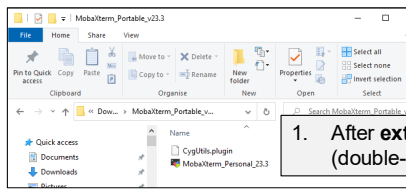
We're on (one of) the CSF login nodes. Any commands you use will be typed "at the prompt", which shows your username and current directory (folder.)



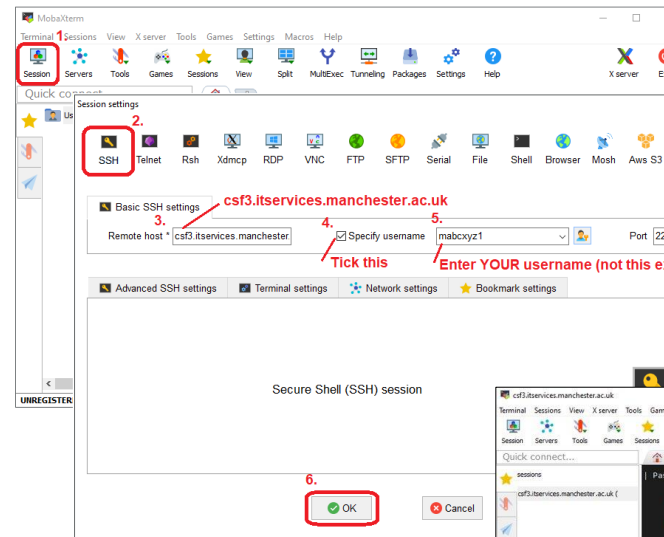
Recap slide skipped in training room

# MobaXterm "Session"

(username saved in the session setup)



- After **extracting** the .zip file, start MobaXterm\_Personal\_xy.z (double-click on the icon)



- 2 (1-6). Create a "Session" which saves the CSF's details along with *your* **username**.

This is needed to make file drag-n-drop work (see later.)

3. This will then start to log you into the CSF – it will ask for your password. Type carefully!

4. See slide about 2FA – you may be asked for DUO after your password

## Connecting from Linux / Mac

- From MacOS using a *Terminal* window (after installing [Xquartz](#))

```
ssh -Y username@csf3.itsservices.manchester.ac.uk
```

UPPERcase Y

Central IT Services username.  
Answer 'Yes' to continue *if* asked.  
Enter central IT password when asked (same as for email)

- From Linux using a Terminal window

```
ssh -X username@csf3.itsservices.manchester.ac.uk
```

UPPERcase X

Central IT Services username.  
Answer 'Yes' to continue *if* asked.  
Enter central IT password when asked (same as for email)

- Finished using CSF? Log out with: **logout** or **exit**

<https://ri.itservices.manchester.ac.uk/course/rcsf/>

<https://ri.itservices.manchester.ac.uk/csf3>

## ACCESSING APPLICATION S/W

### Modules

## Access to Application Software

- Lots of different pieces of software installed
  - Many different applications
  - Different *versions* of an application
  - Need to ensure job knows where an app is installed
    - Try `echo $PATH` to see all directories the CSF will look in
- Use "*modules*" to set up *environment* for software
  - In your jobscript, add some `module` commands
  - Sets up all necessary *environment variables*
  - Apps use these *env vars* to get various settings
  - Can also run `module` commands on the login node (e.g., to check what apps are available)

9

10

## Module Commands

- `module avail` – lists all available modules
- `module search keyword` – lists all modules with *keyword* in their name
- `module list` – lists currently loaded modules
- `module load modulename` – loads module
- `module unload modulename` – unloads module
- `module purge` – **unload all modules**
- `man module` – man pages for the module command
- **Examples:**
  - `module load apps/binapps/matlab/R2024b`
  - `module load apps/intel-19.1/amber/20-bf12-at21-bf12`
  - `module load apps/gcc/R/4.4.1`
  - `module unload apps/binapps/starccm/18.02-double`
  - `module help compilers/intel/19.1.2`
  - `module load tools/gcc/cmake/3.28.6`
- See documentation for more info
  - <https://ri.itservices.manchester.ac.uk/csf3/software/modules/>

11

## Modulefile settings

- What "settings" do modulefiles actually make?
  - Depends on the application (eg the installation instructions)
- Try the following commands on the login node:
 

```
which matlab
/usr/bin/which: no matlab in(/opt/site/sge.....

module load apps/binapps/matlab/R2024b

which matlab
/opt/apps/apps/binapps/matlab/R2024b/bin/matlab
```
- This shows that the modulefile made the matlab 2024b installation available.
- A job can do this to run that version of matlab.
- If interested, to see all of the settings that a modulefile will make:
 

```
module show apps/binapps/matlab/R2024b
```

But the idea is **you don't need to know the settings** - modulefiles take care of the details so you can concentrate on what your jobs actually *do* with the application.
- See documentation for more info
  - <https://ri.itservices.manchester.ac.uk/csf3/software/modules/>

12

# Loading modulefiles: On login nodes OR in the jobscript

Inherit from the login node (not recommended)    Only in the jobscript (recommended!)

Jobs in Slurm will inherit any modulefile settings (i.e. loaded modules) from the login node at the point when you *submit* (sbatch) the job.

```
# On the login node:
module load apps/R/4.4.1
sbatch myjob.txt
```

```
# On the login node:
sbatch myjob.txt
```

myjob.txt

```
#!/bin/bash --login
#SBATCH -p serial
#SBATCH -t 2-0

# We'll use whichever version
# of R was loaded on the login
# node. Which version of R did
# I use 6 months ago???
R CMD BATCH myscr.R
```

myjob.txt

```
#!/bin/bash --login
#SBATCH -p serial
#SBATCH -t 2-0

# Start with a clean env then
# load module inside jobscript
module purge
module load apps/R/4.4.1

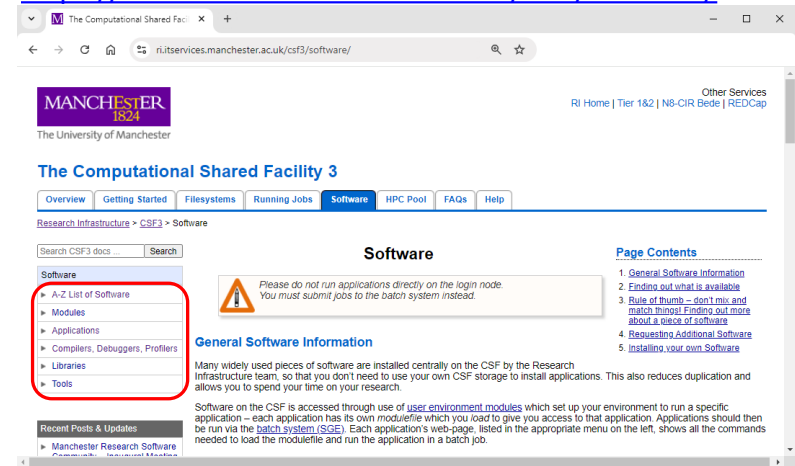
# We know the version of R!
R CMD BATCH myscr.R
```

13

## Which Modulefiles to Load

- How do I know which modulefile to load for a particular app?

– <https://ri.itsservices.manchester.ac.uk/csf3/software/>



14

## A note about our documentation

- Over the summer we change the batch system from SGE to Slurm
    - SGE uses `#$` as the jobscript *sentinel*
    - Slurm uses `#SBATCH` (as we've seen earlier)
    - Our applications documentation is being updated to convert example jobscripts from SGE to Slurm
    - If you see `#$` in our documentation, you'll need to write the equivalent Slurm jobscript (using `#SBATCH`).
    - See our SGE-to-Slurm guide, which shows how `#$` flags map to `#SBATCH` flags
- <https://ri.itsservices.manchester.ac.uk/csf3/batch-slurm/sge-to-slurm/>

15

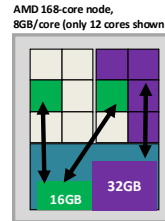
## PARALLEL COMPUTING

Background

16

# Motivations for Parallel Computing

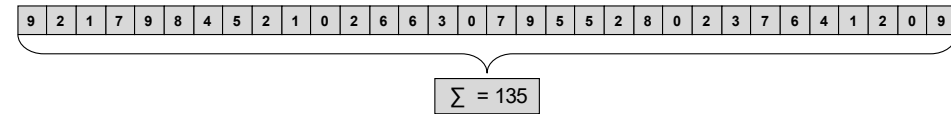
- CSF compute nodes have multiple CPU cores (32, 168)
- Many apps can use multiple cores to speed up the computation
  - Split the "work" over multiple CPU cores
    - Each core does a small(er) part of the computation, all in parallel
    - "Data parallelism" (same instructions run on each portion of "data")
  - May need to *combine* partial results together at end
  - Should get the final result quicker
    - Ideally  $N$  cores giving results  $N$  times quicker
- Also provides access to more memory
  - Each core has access to 8GB RAM (AMD nodes)
    - Ideally  $M$  cores for  $M$  times larger problem
- Both of the above!
- Another "parallel" method: High Throughput Computing
  - Multiple instances of an app with different params or data



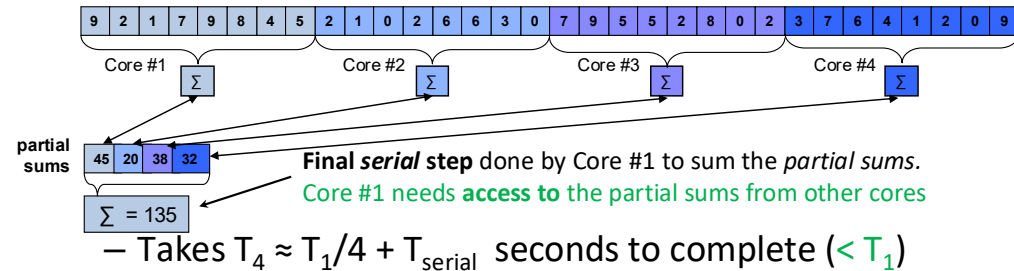
17

# Simple example: sum a list of numbers

- Could do this example manually with 4 volunteers
- 1-core:  $\text{sum} = \text{sum} + \text{number}_i$  (for  $i = 1$  to  $N$ )
  - Let's say it takes  $T_1$  seconds to complete



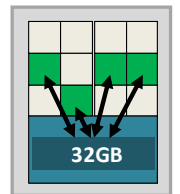
- 4-cores: Each core sums a smaller list of numbers



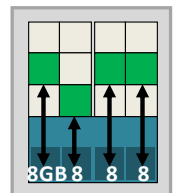
18

## Parallel Job Type #1 - single node

- A program runs on *multiple CPU cores* of **one** compute node
- Two common techniques used by apps:
  - Typically, one copy of the program runs
    - "Shared memory" (all cores see same memory)
      - Cores synchronize access to shared memory (data)
      - Look for "OpenMP" / "multi-threaded" / "Java threads" ... in an application's docs
  - Or coordinated copies of the program run, each communicating with each other
    - "Distributed memory" (each core has its own mem)
      - They communicate to share data, results
      - Look for "MPI" or "message passing" in the application's docs
- Your app must have been written to use one (or both) of the above parallel techniques!**
- We'll run this "single compute-node" type of job today



Shared Memory

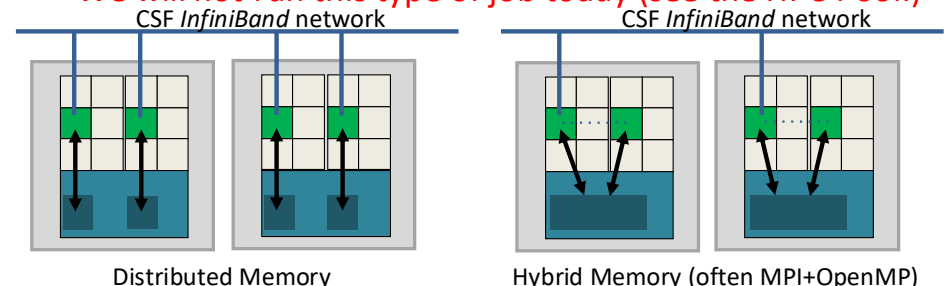


Distributed Memory

19

## Parallel Job Type #2 - multi-node

- Running a program over *several* compute nodes (and the many cores on those nodes)
  - Must be the "MPI" / "message passing" style of app (see above)
  - Uses *more* cores than available in a *single* compute node
    - On CSF we require you to use *all* of the cores in *each* compute node!
  - They communicate to share data, results etc (as before)
    - Over the fast internal *InfiniBand* network
    - Possibly via shared memory as before, if on same compute node
- Your app must have been written to support this!**
- We will not run this type of job today (see the HPC Pool.)**



Note: the diagrams only show a few cores in use for simplicity. On the CSF you must use *all* cores in *each* node.

20



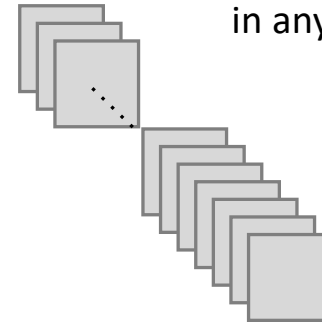
## Parallel Job Type #3 - High Throughput Computing (HTC)

- Lots of *independent* computations. EG:
  - Processing lots of data files (e.g., image files)
  - Running the same simulation many times over with different parameters ("parameter sweeps")
- Run many copies of your program
  - Programs may be serial (single core) but running lots of them at once. They **don't** communicate.
- Easy to do on CSF. See also the UoM Condor Service (formerly the EPS Condor Pool)
  - Free resource, uses UoM idle desktops over night

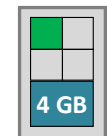
21

## Example: Image Analysis

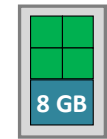
- High Throughput Computing
  - Not all s/w is "HPC" / parallel
  - But you might have *lots* of data
  - Each image takes 1hr to process (and are *independent* - process in any order)



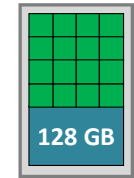
Example: 10,000 image scans to be analysed by an image processing application. Each image takes 1 hour to process.



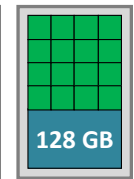
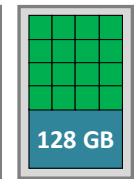
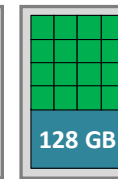
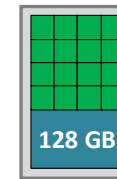
Laptop: 1 copy of software running.  
**Over 1 year to complete!!**



Desktop: 4 cores, 4 copies of software running.  
**~100 days to complete!**



Single HPC compute node: 16 copies of software running.  
**~26 days to complete**



Multiple HPC compute nodes:  
64 copies of software running.  
**~6 days to complete**

22

## Which style of parallel job to use

- Mostly determined by the capability of your app
  - Is it serial (1-core) only? Is it multi-core (single-node) only? Is it multi-node capable?
- A serial app will only ever use 1 core
  - But run as an **HTC job**, you can still process lots of data in parallel
    - Use many cores, running multiple *independent* jobs (see later)
- Parallel app using only *shared memory*
  - "OpenMP", "multithreaded", "Java threads", "shared memory"
  - Can only use 1 compute node (2--32 Intel or 2--168 AMD cores)
- Parallel app using *distributed memory*
  - "MPI" (message passing interface), "distributed memory"
  - Can use many cores across multiple compute nodes
  - But consider: the **network**
    - Communication faster *within* same compute node
    - Communication slower on network *between* nodes
    - Apps may not speed up, the more cores (and nodes) you use (see later)

## Parallel Jobscrip on CSF

- Use a jobscrip to ask the batch system to find *N* free cores
  - While matching other requirements (memory, architecture, fast networking, GPU etc).
- 1. Add extra lines in jobscrip to request:
  - **a parallel partition** (for multi-core or multi-node jobs)
  - **and number of cores** to reserve
- 2. Inform your app how many cores to use
  - Remember, the jobscrip says how many cores your *job* requires (the batch system will allocate those cores to your job.)
  - **But you** must still ensure your app uses no more!!
    - This is **not always automatic** and how you do it varies from app to app

24

## Parallel Jobscript – Multi-core (single compute-node)

myparajob.txt

#! - see serial jobscript earlier.

```
#!/bin/bash --login
#SBATCH -p multicore
#SBATCH -n 4
#SBATCH -t 3-0

# Set up to use a chemistry app
module purge
module load apps/gcc/gromacs/2023.3/double

# Inform app how many cores to use
export OMP_NUM_THREADS=4

# This job runs "gromacs"
mdrun_d
```

multicore is the partition name. This one means: app will multiple cores on a single compute node (2 to 168 AMD "Genoa" cores.)

-n (--ntasks=) 4 is the number of cores we want to reserve in the system. Each partition has a maximum number.

-t wallclock time limit for the job. This jobs is given 3 days (0 hours).

The commands we run in our job. They execute on a compute node that has the required number of cores free. mdrun\_d is Gromacs.

Key concept!

Must somehow inform the app how many cores we reserved. Must use the number (4) given on the -n line. Our app wants OMP\_NUM\_THREADS environment variable setting. Your app may use a different method!

## Parallel jobscript - Multi-core (cont...)

- That was a multicore (*single* compute node) example
- Using an app named Gromacs as an example  
<https://ri.itsservices.manchester.ac.uk/csf3/software/applications/gromacs/>
- Requested a partition (-p) and number of cores (-n)
  - Job will run the app on a single AMD "Genoa" node, allocating multiple cores on that node to the job.
- Then informed the app to use 4 cores via OMP\_NUM\_THREADS environment variable (very common).
  - Special \$SLURM\_NTASKS variable is always set to the number of cores requested on the -n (--ntasks=) line.

## Avoid a common mistake

- Can use \$SLURM\_NTASKS to get the number of cores reserved by the job

myparajob.txt

```
#!/bin/bash --login
#SBATCH -p multicore # Use the AMD "Genoa" nodes
#SBATCH -n 4         # Can be 2-168 in "multicore"
#SBATCH -t 3-0       # 3-day wallclock (max is 7-0)

# Set up to use a chemistry app
module purge
module load apps/gcc/gromacs/2023.3/double

# Inform app how many cores to use
export OMP_NUM_THREADS=$SLURM_NTASKS

# This job runs "gromacs"
mdrun_d
```

Our app wants OMP\_NUM\_THREADS environment variable to be set. Your app might use a different method!

\$SLURM\_NTASKS is automatically set to the number, 4 in this case, given on -n line. Will be 1 in "serial" partition.

## Parallel jobscript - Multi-core (cont...)

- As with the serial job, submit it to the system with  
sbatch jobscript
- Monitor with squeue
- It may take longer for *more* cores to become free in the system )
- You'll get the usual output file  
slurm-JOBID.out

## Intel nodes

- If you need Intel CPUs (Haswell or Skylake architectures), use the "multicore\_small" partition
  - Slurm will choose the architecture
  - Force it by adding "#SBATCH -C skylake", say.
  - These are older, but possibly less busy, nodes.

```
#!/bin/bash --login
#SBATCH -p multicore_small # Use the Intel CPU nodes
#SBATCH -N 4               # Can be 2-32 in multicore_small
#SBATCH -t 3-0             # 3-day wallclock limit (max 7-0)

# Set up to use "gromacs"
module purge
module load apps/gcc/gromacs/2023.3/double

# Inform app how many cores to use
export OMP_NUM_THREADS=$SLURM_NTASKS

# This job runs "gromacs"
mdrun_d
```

29

## Parallel Jobscript – multi-node

#!/ line from serial jobscript earlier.

-A gives an account code, needed for this restricted partition.

-t wallclock time limit for the job. Max in hpcpool is 4 days.

The commands we run in our job. They will execute on the compute nodes assigned to the job. pmb is the app name and is started via mpirun (very common for multi-node apps).

hpcpool is the partition name. It means: app will use multiple compute nodes (Intel 32-core nodes, all 32 cores must be used on each) and has fast InfiniBand networking between the nodes.

```
#!/bin/bash --login
#SBATCH -p hpcpool
#SBATCH -N 4 # Nodes: 4-32
#SBATCH -n 128 # Cores: 128-1024
#SBATCH -A hpc-projectcode
#SBATCH -t 4-0 # Max is 4-0 here

# Set up to use MrBayes
module purge
module load apps/gcc/mrbayes/3.2.6

# App uses MPI to run across nodes
mpirun -n $SLURM_NTASKS pmb in.nex
```

-N (--nodes=) 4 is the total number of nodes we want to reserve in the system.

-n (--ntasks=) 128 is the total number of cores for MPI processes we want to reserve in the system.

Must inform the app how many cores we reserved.

\$SLURM\_NTASKS is automatically set to number (128) given on -n line. mpirun accepts a "-n numcores" flag (which is optional – mpirun reads the -n number from Slurm if you don't supply it!!)

## Parallel jobscript - Multi-node (cont...)

- A multi-node multi-core example
- Using an app named gulp as an example
  - <https://ri.itsservices.manchester.ac.uk/csf3/software/applications/mrbayes/>
- Requested a parallel environment (pe) & 128 cores

```
#SBATCH -p hpcpool
#SBATCH -N 4
#SBATCH -n 128
#SBATCH -A hpc-projectcode
```

- Informed the app to use 4 nodes (32-core Intel Skylake nodes) with 128 cores used via "mpirun -n \$SLURM\_NTASKS appname" (very common – lots of apps use this method.)
- mpirun starts multiple copies of an MPI app on allocated nodes
- Special \$SLURM\_NTASKS variable always set to number of cores on -n line
- Can actually just use "mpirun appname" and it will use the -n number.

- Access to the "HPC Pool" requires an application form, completed by PI/Supervisors on a per-project basis
  - <https://ri.itsservices.manchester.ac.uk/csf3/hpc-pool/application-questions/>

31

## Parallel Partitions

<https://ri.itsservices.manchester.ac.uk/csf3/batch/parallel-jobs/>

Partition Name	Description
multicore	2-168 cores, single compute node. 8GB per core. Jobs will be placed on AMD EPYC "Genoa" (max 168 cores/job)
No optional flags	
Partition Name	Description
multicore_small	2-32 cores, single compute node. ~4-5GB per core. Jobs will be placed on Intel "haswell" (max 24 cores/job) or Skylake (max 32 cores/job)
-C architecture	Not recommended! (haswell or skylake)
Partition Name	Description
hpcpool	32 cores, multiple compute nodes. 5GB per core. Jobs will be placed on Intel Skylake (max 32 cores/job) CPUs. Jobs must use 4-32 compute nodes. 4-day runtime limit.
-A hpc-projectcode	You must have an approved HPC Pool project code.

- 7-day runtime limit on jobs unless otherwise indicated in table.
- Our simple jobscript did not use any of the above extra flags. Not needed in most cases.
- If you limit a job by architecture it may wait longer in the queue.

32



## Choosing the partition

- Choosing the partition is fairly simple, but:
  - Check the app's webpage for advice and examples  
<https://ri.itsservices.manchester.ac.uk/csf3/software>
  - Check the partition page for limits on number of cores  
<https://ri.itsservices.manchester.ac.uk/csf3/batch-slurm/partitions/>
  - Avoid using `#SBATCH -C architecture`
- Use Intel (**multicore\_small**) or AMD (**multicore**) nodes?
  - Most (all) apps will run on both, but AMD nodes are newer
  - The high memory nodes are all Intel CPUs (e.g., `-p himem`)
  - There are now *a lot* more AMD CPUs available than Intel CPUs
    - Submitting to **multicore** may result in shorter wait times
    - **multicore** nodes have 8GB/core (**multicore\_small** nodes have ~5-6GB/core)

33

## Parallel Software Performance

- You'll probably be running an app many times
- Worth small investigation to find optimal performance parameters (#cores & #nodes)
  - How many cores should I use?
- Do a few runs, change the number of cores
  - Plot time vs number of cores
  - Easy to do on CSF: remove "`-n numcores`" from jobscript, add it to `sbatch` command instead:

```
sbatch -n 2 myjobscript.txt
sbatch -n 4 myjobscript.txt
sbatch -n 8 myjobscript.txt
```

34

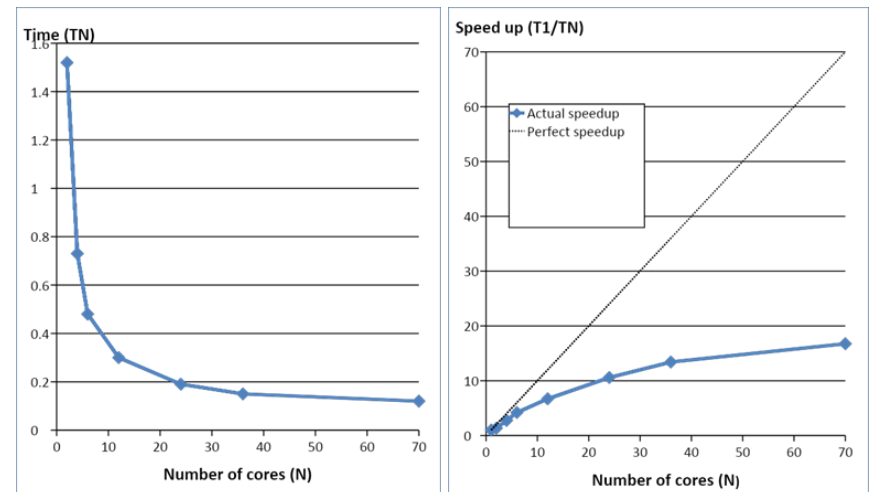
## To Assess Parallelism

- Plot the following against "Number of Cores":
  - "Speed-up" or "Parallel Efficiency"
  - Total memory usage?
- Look for the sweet-spot
- Calculate: **Speed-up** =  $T_1 / T_N$ 
  - Compare results against "ideal" scaling (where  $N$ -cores makes it go  $N$ -times faster)
- Calculate: **Parallel Efficiency** =  $T_1 / (N \times T_N)$ 
  - $N$  = number of cores,  $T_N$  = time take on  $N$  cores
- Pick a typical problem size for your work

35

## Examples of Speed-up

- Data for popular Finite Element app on CSF
  - The 'Time' graphs shows it getting faster. But...



36

## Examples of Speed-up & Efficiency

- Example showing Speed-up and Efficiency values
  - App multiplies two square matrices
    - Measured a single multiplication of two 2000x2000 matrices

No. cores	Time (Seconds)	Speed-up	Efficiency
1	45.0	1x	1.00
2	22.8	1.97x	0.99
4	11.7	3.84x	0.96
8	7.1	6.33x	0.80

- The speed-up is reasonably close to “perfect” & efficiency is reasonably close to 100% but...
  - How will this scale as we go multi-node?
  - How will this scale as the problem size increases?
  - How will this scale on other hardware?

37

## PRACTICAL SESSION 4

Parallel job and scaling

38

## Practical Session 4 - Parallel jobs

- Follow the handout ‘Practical Session 4’
  - Use `sbatch` to submit a simple parallel (2-core) job on the CSF
  - Modify the jobscript to use different numbers of cores
  - Determine whether the application "scales" with the number of cores.
- Exercise sheet (pdf) available at:  
<https://ri.itservices.manchester.ac.uk/course/rcsf/>

39

## MULTIPLE SIMILAR JOBS

High Throughput Computing and "Job arrays"

40

## Multiple Runs of an Application

- We want to run an application many times to process *many different* input files
  - For example, on a desktop PC you might run

```
myapp.exe -in mydata.1.tif -out myresult.1.tif
(wait for it to finish)
myapp.exe -in mydata.2.tif -out myresult.2.tif
(wait for it to finish)
myapp.exe -in mydata.3.tif -out myresult.3.tif
...
myapp.exe -in mydata.1000.tif -out myresult.1000.tif
```
  - If it takes 5 minutes to process one file, it will take 1000 x 5 minutes to process them all (~3.5 days)

41

## How **Not** To Do It on the CSF (1)

- Inefficient method 1: one after another in *one* job? `sbatch jobscript-all.txt`

```
jobscript-all.txt
#!/bin/bash --login
#SBATCH -p serial
#SBATCH -t 4-0      # Wallclock is 4 days for all images

myapp.exe -in mydata.1.tif -out myresult.1.tif
(wait for it to finish)
myapp.exe -in mydata.2.tif -out myresult.2.tif
(wait for it to finish)
myapp.exe -in mydata.3.tif -out myresult.3.tif
...
myapp.exe -in mydata.1000.tif -out myresult.1000.tif
```

- This is *no better* than the desktop PC method

42

## How **Not** To Do It on the CSF (2)

- Inefficient method 2: lots of individual jobscripts?

```
jobscript1.txt
#!/bin/bash --login
#SBATCH -p serial
#SBATCH -t 10      # Wallclock is 10 mins for one image

myapp.exe -in mydata.1.tif -out myresult.1.tif

sbatch jobscript1.txt
sbatch jobscript2.txt
sbatch jobscript3.txt
...
sbatch jobscript1000.txt
```

Make 1000 copies of this jobscript, edit each one to process a different file (mydata.2.tif, ...)

Then submit each job

- **Strains the batch system queue manager**
- But, you will get many jobs running in parallel
  - EG: approx 100-200 jobs running at same time

43

## How To Do It - a "Job Array" Jobscript

**1-1000** (start-end) says how many tasks to run and how they should be numbered. Note: Can start at 0. Can use **start-end:increment** to increase the ID by more than 1.

**-t** wallclock. Each individual array task has a wallclock of 10 minutes. There is no overall time limit for the job.

**-a** an array job. Runs multiple copies of the job a specified number of times. These are called **array tasks**. Each is numbered uniquely 1, 2, 3 ..., 1000.

The commands we run in our job. They will execute on backend nodes (different cores and nodes for different tasks).

```
arrayjob.txt
#!/bin/bash --login
#SBATCH -p serial      # Each task gets 1 core
#SBATCH -t 10          # 10 minutes per task
#SBATCH -a 1-1000      # 1000 tasks

echo "I am task ${SLURM_ARRAY_TASK_ID}"
myapp.exe \
-in mydata.${SLURM_ARRAY_TASK_ID}.tif \
-out myresult.${SLURM_ARRAY_TASK_ID}.tif
```

**\${SLURM\_ARRAY\_TASK\_ID}** is automatically set by the batch system and tells us which array task we are (1,2,...). We can use this to do something different in array task.

44

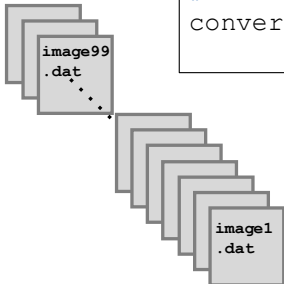
# "Job Array" Jobscript

- Our app is a serial (1-core) app
  - But you *could* use the multicore partition if your app is multi-core capable.
- The total number of tasks can be 100s, 1000s, 10000s (max 25,000 on CSF)
- The system will run *many* of the tasks concurrently
  - Usually 100s - "High-throughput Computing"
  - You get lots of work done sooner
  - It will eventually churn through *all* of them
  - They are started in numerical order but no guarantee they'll finish in that order!
- The extra jobscript `#SBATCH -a` line is easy. Using the `$_SLURM_ARRAY_TASK_ID` number *creatively* is the key to job arrays.
- **Note:** Do not confuse Slurm's `-n/--ntasks` (number of cores) flag with `-a/--array` (start-end for array tasks) flag. The names can be confusing :-)

45

## The \$\_SLURM\_ARRAY\_TASK\_ID variable (1)

- Want to do something different in each task. EG:
  - Read a different data file to process
  - Pass a different parameter to an application
- You can get this different "thing" in many ways:
  - EG: Use the `$_SLURM_ARRAY_TASK_ID` in filenames:



```
#SBATCH -a 1-1000
convert -i image_${SLURM_ARRAY_TASK_ID}.jpg \
        -o image_${SLURM_ARRAY_TASK_ID}.png
```

Task 1 reads image\_1.jpg writes image\_1.png  
 Task 2 reads image\_2.jpg writes image\_2.png  
 ...  
 Task 1000 reads image\_1000.jpg writes image\_1000.png

46

## The \$\_SLURM\_ARRAY\_TASK\_ID variable (2)

- Or have a "master" list (a text file) of names etc
- The N<sup>th</sup> task reads the N<sup>th</sup> line from that text file:

```
#SBATCH -a 1-4000
# Read the Nth line of filenamelist.txt and save in variable MYFILENAME
MYFILENAME=$(awk "NR==${SLURM_ARRAY_TASK_ID}" filenamelist.txt)

# Now use whatever the value of variable is in the next command
myapp.exe -input ${MYFILENAME} -output ${MYFILENAME}.out
```

### filenamelist.txt

```
ptn1511.dat
ptn7235.dat
ptn7AFF.dat
ptn6E14.dat
ptn330D.dat
...
```

Task 1 reads ptn1511.dat writes ptn1511.dat.out  
 Task 2 reads ptn7235.dat writes ptn7235.dat.out  
 ...

- Number of lines in master file **must** match number of tasks
- To get number of lines in master file use:  
`wc -l filenamelist.txt`
- bash: `VAR=$(command arg1 arg2)` captures output from *command* and assigns to variable *VAR* for use later.

<https://ri.itservices.manchester.ac.uk/csf3/batch/job-arrays/> 47

## The \$\_SLURM\_ARRAY\_TASK\_ID variable (3)

- Another way to use the "master" list method
- The N<sup>th</sup> task reads the N<sup>th</sup> line from that text file:

```
#SBATCH -a 1-50
# Read the Nth line of foldername list.txt and save as $FOLDER
FOLDER=$(awk "NR==${SLURM_ARRAY_TASK_ID}" foldername list.txt)

# Now use whatever the value of variable is in the next command
cd ~/scratch/experiments/${FOLDER}
mdrun_d
```

### foldername list.txt

```
znc24/100p/a1
znc24/200p/b2
ag80/100p/b1
ag81/100q/c1
ptn2/50a/a1
ptn3/50b/c1
...
```

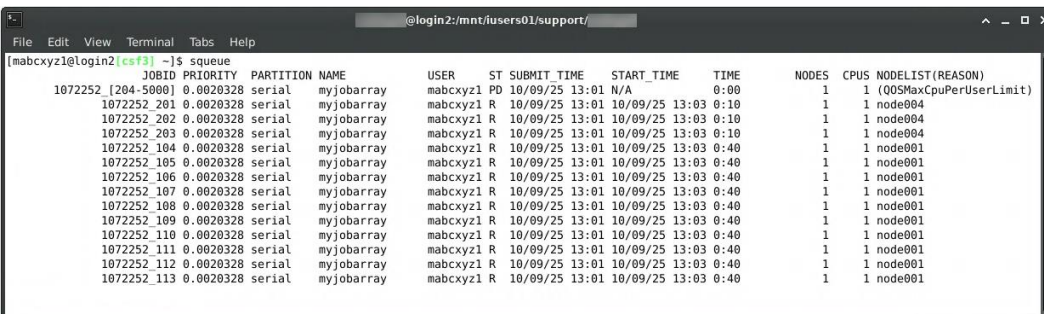
Task 1 reads znc24/100p/a1 as folder name  
 Task 2 reads znc24/200p/b2 as folder name  
 ...

- Number of lines in master file **must** match number of tasks
- To get number of lines in master file use:  
`wc -l foldername list.txt`
- bash: `VAR=$(command arg1 arg2)` captures output from *command* and assigns to variable *VAR* for use later.

<https://ri.itservices.manchester.ac.uk/csf3/batch/job-arrays/> 48

# Jobarrays – queue and scancel

- `squeue` shows pending and running tasks
  - `QOSMaxCpuPerUserLimit` means the limit of number of CPUs in use at any one time (for this user) has been reached.
  - Hence some array tasks must wait until earlier ones have finished.



```
@login2:/mnt/users01/support/
[mabckxyz1@login2[csf]] ~]$ squeue
JOBID PRIORITY PARTITION NAME USER ST SUBMIT TIME START TIME TIME NODES CPUS NODELIST(REASON)
1072252 [204-5000] 0.0020328 serial myjobarray mabckxyz1 PD 10/09/25 13:01 N/A 0:00 1 1 (QOSMaxCpuPerUserLimit)
1072252_201 0.0020328 serial myjobarray mabckxyz1 R 10/09/25 13:01 10/09/25 13:03 0:10 1 1 node004
1072252_202 0.0020328 serial myjobarray mabckxyz1 R 10/09/25 13:01 10/09/25 13:03 0:10 1 1 node004
1072252_203 0.0020328 serial myjobarray mabckxyz1 R 10/09/25 13:01 10/09/25 13:03 0:10 1 1 node004
1072252_104 0.0020328 serial myjobarray mabckxyz1 R 10/09/25 13:01 10/09/25 13:03 0:40 1 1 node001
1072252_105 0.0020328 serial myjobarray mabckxyz1 R 10/09/25 13:01 10/09/25 13:03 0:40 1 1 node001
1072252_106 0.0020328 serial myjobarray mabckxyz1 R 10/09/25 13:01 10/09/25 13:03 0:40 1 1 node001
1072252_107 0.0020328 serial myjobarray mabckxyz1 R 10/09/25 13:01 10/09/25 13:03 0:40 1 1 node001
1072252_108 0.0020328 serial myjobarray mabckxyz1 R 10/09/25 13:01 10/09/25 13:03 0:40 1 1 node001
1072252_109 0.0020328 serial myjobarray mabckxyz1 R 10/09/25 13:01 10/09/25 13:03 0:40 1 1 node001
1072252_110 0.0020328 serial myjobarray mabckxyz1 R 10/09/25 13:01 10/09/25 13:03 0:40 1 1 node001
1072252_111 0.0020328 serial myjobarray mabckxyz1 R 10/09/25 13:01 10/09/25 13:03 0:40 1 1 node001
1072252_112 0.0020328 serial myjobarray mabckxyz1 R 10/09/25 13:01 10/09/25 13:03 0:40 1 1 node001
1072252_113 0.0020328 serial myjobarray mabckxyz1 R 10/09/25 13:01 10/09/25 13:03 0:40 1 1 node001
```

- `scancel` can remove all tasks or just some

```
scancel 1072252          Remove all running and waiting tasks
scancel 1072252_300      Remove task 300 (a bit strange)
scancel 1072252_[4000-5000] Remove last 1000 tasks
```

49

# Jobarray Output Files

- You'll get the usual Slurm output file but
  - One per task
  - Potentially a lot of files!

- Look for  
`slurm-JOBID_TASKID.out`

EG: `slurm-1046732_1.out`  
`slurm-1046732_2.out`  
...  
`slurm-1046732_1000.out`

- You should delete empty / unwanted files soon and often

50

## PRACTICAL SESSION 5

Job array examples

## Practical Session 5 – Job arrays

- Follow the handout 'Practical Session 5'
  - Modify, and run, a simple job-array jobscript to run an app with different input values.
  - Write a new job-array jobscript to do some python image processing on a set of Hubble Ultra Deep Field images.
- Exercise sheet (pdf) available at:  
<https://ri.itservices.manchester.ac.uk/course/rcsf/>

51

52

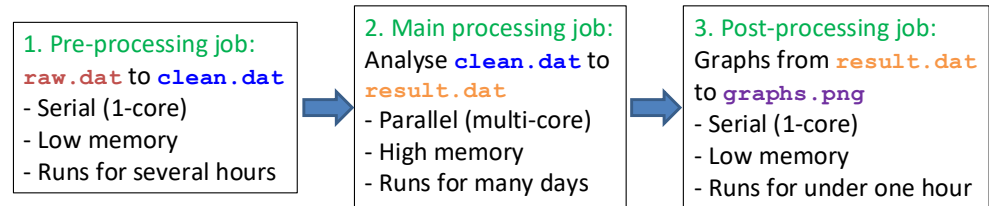


# A Job Pipeline (aka workflow)

- Suppose you have several apps that:
  - Need to run in a specific order - a "pipeline"
    - There is a *dependency* between apps
  - Each might have different CPU-core and memory requirements
  - Each might take different amounts of time to run

## JOB PIPELINES

Ordering jobs



53

54

## How **not** to do it on the CSF (1)

- Put all steps in one job?
  - Wastes resources (some cores and memory)
  - May go over 7-day runtime limit

```

mypipeline_bad.txt
#!/bin/bash --login
#SBATCH -p himem      # Uses a high-memory node
#SBATCH --mem 2000G   # ... with 2TB of RAM
#SBATCH -n 16         # ... and 16 cores
#SBATCH -t 7-0        # ... for 7 days
module purge
module load apps/.....

# First app (1-core, low memory usage)
preproc -i raw.dat -out clean.dat
# Second app (multiple cores, high memory usage)
mapper -p $SLURM_NTASKS -in clean.dat -out result.dat
# Third app (1-core, low memory usage)
drawGraphs -in result.dat -out graphs.png
    
```

Only one  
command uses  
all of the cores

55

## Better but still not perfect

- Split into multiple jobs, notice when jobs finish, submit next...?
  - Log in to CSF, check if previous job has finished.... wastes time!

A serial job (no wasted cores)	<pre> #!/bin/bash --login #SBATCH -p serial      # 1-core job #SBATCH -t 0-2         # 2 hour wallclock module load apps/..... # First 'job' (1-core, low memory usage) preproc -i raw.dat -o clean.dat                     </pre>	firstjob.txt
A parallel, high-mem job	<pre> #!/bin/bash --login #SBATCH -p himem      # Uses a high-memory node #SBATCH --mem 2000G   # ... with 2TB RAM #SBATCH -n 16         # ... and 16 cores #SBATCH -t 7-0        # ... 7 day wallclock module load apps/..... # Second 'job' (multiple cores, high memory usage) mapper -p \$SLURM_NTASKS -i clean.dat -o result.dat                     </pre>	secondjob.txt
A serial job (no wasted cores)	<pre> #!/bin/bash --login #SBATCH -p serial      # 1-core job #SBATCH -t 30          # 30 minute wallclock module load apps/..... # Third 'job' (1-core, low memory usage) drawGraphs -i result.dat -o graphs.png                     </pre>	thirdjob.txt

sbatch firstjob.txt  
 (now you need to wait until this job has finished before submitting the next one!)  
 sbatch secondjob.txt  
 (now you need to wait until this job has finished before submitting the next one!)  
 sbatch thirdjob.txt

56

## How to do it - Job Dependencies

- Using the previous individual jobscripts
  - Add a `-d/--dependency=` flag when submitting them
  - Use the JOBID of the previous job to make the current job wait for it

```

sbatch firstjob.txt
Submitted batch job 1074214
      ↓
sbatch -d afterok:1074214 secondjob.txt
Submitted batch job 1074217
      ↓
sbatch -d afterok:1074217 thirdjob.txt
Submitted batch job 1074232
    
```

- The **afterok** flag means do not run this job until the earlier dependency job has finished successfully.
- Note, you cannot use jobscript names. You must use the JOBID of an earlier job.
- There are lots of dependency parameters (e.g, afterany, afternotok, and multiple dependencies can be setup.)

57

## Job Dependencies

- You *must* submit the jobs in the correct order
  - EG: If `secondjob.txt` is submitted first, it runs immediately (no dependency job exists to wait for)
- `squeue` shows (Dependency) for jobs on hold

JOBID	PRIORITY	PARTITION	NAME	USER	ST	SUBMIT_TIME	START_TIME	TIME	NODES	CPUS	NODELIST(REASON)
1074232	0.0020341	serial	thirdjob.txt	mabcxyz1	PD	10/09/25 16:35	N/A	0:00	1	1	(Dependency)
1074217	0.0020341	serial	secondjob.txt	mabcxyz1	PD	10/09/25 16:34	N/A	0:00	1	1	(Dependency)
1074214	0.0020341	serial	firstjob.txt	mabcxyz1	R	10/09/25 16:34	10/09/25 16:34	0:44	1	1	node001

- Later jobs may still *wait* to be scheduled
  - They don't always run *immediately* after earlier jobs finish

58

## Job Dependencies

- Can submit the jobs in a more programmatic manner:

- Use `--parsable` flag to get *just* the JOBID of the submitted job (instead of 'long' message):

```

• sbatch myjobscript
Submitted batch job 1074233

• sbatch --parsable myjobscript
1074233
    
```

- Capture output of command into shell variable

```

JOBID=$(sbatch --parsable firstjob.txt)
JOBID=$(sbatch --parsable -d afterok:$JOBID secondjob.txt)
JOBID=$(sbatch --parsable -d afterok:$JOBID thirdjob.txt)
    
```

59

## Job-Array Dependencies (1)

- An ordinary job can wait for a *job array* to finish
  - All tasks in the job array must have finished

```

#!/bin/bash --login
#SBATCH -p serial          # 1-core job
#SBATCH -t 30              # 30 minute wallclock
#SBATCH -a 1-1000         # Job array with 1000 tasks
convert img.${SLURM_ARRAY_TASK_ID}.tif img.${SLURM_ARRAY_TASK_ID}.pdf
    
```

arrayjob.txt

```

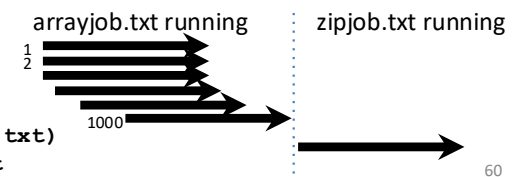
#!/bin/bash --login
#SBATCH -p serial          # 1-core job
#SBATCH -t 5               # 5 minute wallclock
zip conference.zip img.*.pdf
    
```

zipjob.txt

Add a job dependency so that second job waits until entire job-array has finished.

```

JID=$(sbatch --parsable arrayjob.txt)
sbatch -d afterok:$JID zipjob.txt
    
```



60

## Job-Array Dependencies (2)

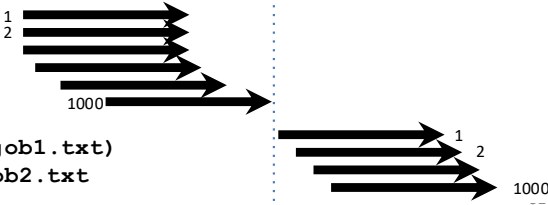
- A *job array* can wait for a *job array* to finish
  - All tasks in the *first* job array must have finished

#!/bin/bash --login #SBATCH -p serial #SBATCH -t 30 #SBATCH -a 1-1000 someapp data.\${SLURM_ARRAY_TASK_ID}.xyz data.\${SLURM_ARRAY_TASK_ID}.dat	arrayjob1.txt
#!/bin/bash --login #SBATCH -p multicore #SBATCH -n 4 #SBATCH -t 60 #SBATCH -a 1-1000 otherapp data.\${SLURM_ARRAY_TASK_ID}.dat result.\${SLURM_ARRAY_TASK_ID}.dat	arrayjob2.txt

arrayjob1.txt running      arrayjob2.txt running

Add a job dependency so that second job array waits until entire first job-array has finished.

```
JID=$(sbatch --parsable arrayjob1.txt)
sbatch -d afterok:$JID arrayjob2.txt
```



## Job-Array Dependencies (3)

- A *job array* can wait for a *job array* to finish
  - Each task in *second* job array waits for *corresponding* task in *first* job array to finish

#!/bin/bash --login #SBATCH -p serial #SBATCH -t 30 #SBATCH -a 1-1000 someapp data.\${SLURM_ARRAY_TASK_ID}.xyz data.\${SLURM_ARRAY_TASK_ID}.dat	arrayjob1.txt
#!/bin/bash --login #SBATCH -p multicore #SBATCH -n 4 #SBATCH -t 60 #SBATCH -a 1-1000 otherapp data.\${SLURM_ARRAY_TASK_ID}.dat result.\${SLURM_ARRAY_TASK_ID}.dat	arrayjob2.txt

arrayjob1.txt tasks running then arrayjob2.txt tasks

Add a job dependency so that second job array tasks wait for *corresponding* tasks in first job-array to finish.

```
JID=$(sbatch --parsable arrayjob1.txt)
sbatch -d aftercorr:$JID arrayjob2.txt
```



## INTERACTIVE JOBS

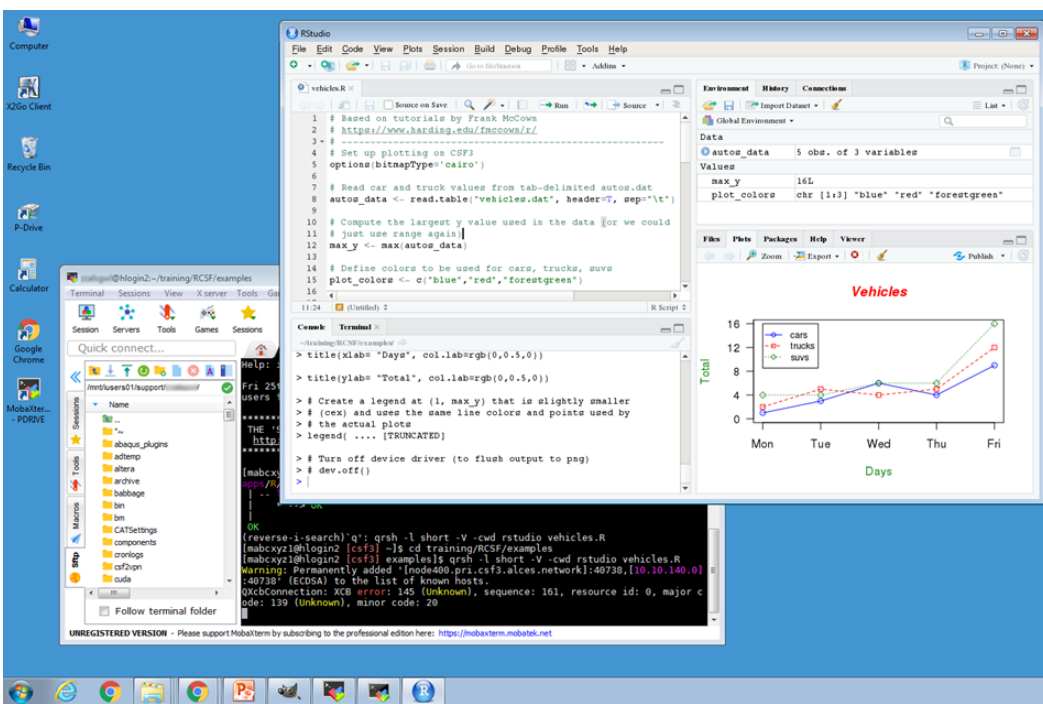
Compute apps with GUIs

## Interactive work

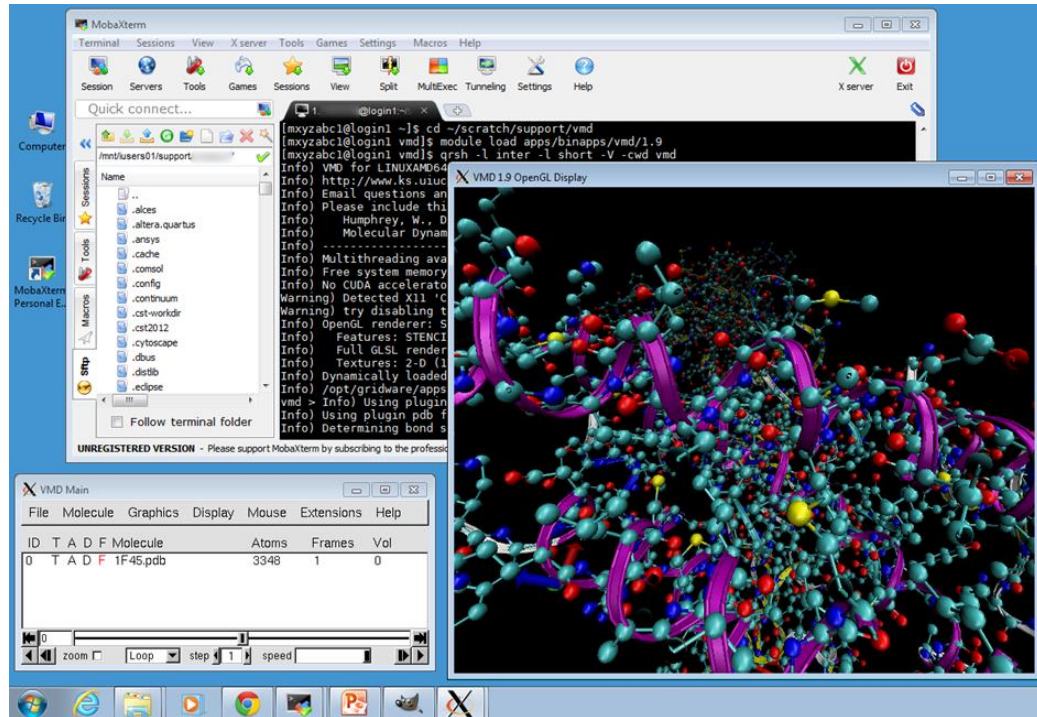
- Some apps (eg Rstudio, VMD, molder, paraview) may have a GUI but should not be run on the login node.
  - The GUI itself might be quite a light-weight program, but if you then load a huge dataset in, or set off some long-running multi-process computation, via the GUI, you'll "hammer" the login node.
- Use the `srun` command to get an *interactive session* on a *compute node*

```
# We are on the login node here
module purge
module load apps/gcc/R/4.5.0
module load apps/binapps/rstudio/2025.05.0-any-r
srun -p interactive -t 60 -n 1 rstudio vehicles.R
```

- No dedicated resource, priority to batch jobs.
- Runs on an AMD 168-core node, hence 8GB per core.
- Max 60 minutes wallclock limit.
- Remember - a GUI app, as with `gedit`, needs an X-server running on your PC (as provided by MobaXTerm, or X-Quartz, or a Linux desktop)
- Remember to exit your GUI app when you have finished so the resource is made available for others.



65



66

## GPU Jobs

Accessing the GPUs

## Nvidia GPUs

- CSF3 has 168 x Nvidia GPUs
  - A100(80GB), L40S are available to all users. The A100(40GB) GPUs are for a specific research group.

**84 x Ampere A100 GPUs** in total – 4 GPUs/node  
 80GB(76x) or 40GB(8x) GPU mem, Mem b/w 2TB/s  
 6912 CUDA cores (108 Multiprocessors, 64 cores/MP)  
 432 Tensor cores  
 Peak FP64 9.7 TFLOPS  
 48-core AMD Epyc "Milan"  
 512GB RAM host node  
 40GB A100 nodes restricted to one research group

**84 x Ada Lovelace L40S GPUs** in total – 4 GPUs/node  
 48GB GPU memory, Mem bandwidth 864GB/s  
 18176 CUDA cores (142 Multiprocessors, 128 cores/MP)  
 142 RT cores  
 568 Tensor cores  
 Peak SP 91.6 TFLOPS  
 48-core Intel Xeon Gold "Sapphire Rapids"  
 512GB RAM host node

67

68

# GPU Jobscript

**gpuA**, **gpuL**, or **gpuA40GB** is the **partition** name. It means: app will use a GPU compute node containing the indicated type of GPU - A100, L40S or gpuA40GB (this one has restricted access.)

**-t** wallclock time limit for the job. Max in **gpuX** is 4 days.

```
#!/bin/bash --login
#SBATCH -p gpuX      # Partition (A,L)
#SBATCH -G 2          # GPUs: 1-4
#SBATCH -n 8          # Cores: 1-8,12
#SBATCH -t 4-0        # Max is 4-0 here
# Set up to use the CUDA toolkit
module purge
module load libs/cuda/12.4.1

# Run a GPU app. Slurm will ensure no
# other jobs can use your GPUs.
deviceQuery
```

**-G (--gpus=) 2** is the total number of GPUs we want to reserve in the system.

**-n (--ntasks=) 8** is the total number of host CPU cores we want to reserve in the system.

Slurm will set some environment variables for use in your jobscript:

**\$CUDA\_VISIBLE\_DEVICES** gives the device IDs (0 or 0,1 or 0,1,2 or 0,1,2,3) depending number of GPUs.

**\$SLURM\_GPUS** gives the number of GPUs you request on the -G line.

**\$SLURM\_NTASKS** as previous jobs, the number on the -n (host CPU cores).

69

# GPU Limits

- Most users get access to **up to two GPUs** from the gpuA or gpuL partitions, in use at any one time with a max of 4 overall (e.g., 2xA100 and 2xL40S.)
  - This is "free at point of use access", funded by the Research Lifecycle Programme, managed by Research IT.
  - Users from some contributing groups who have funded GPUs may get access to more GPUs.
  - All GPU nodes contain 4 GPUs. Multi-node (>4 GPU jobs) are NOT possible.
- CPU host cores are limited by number of GPUs in job and by node-type
  - Note that unless the jobscript contains the **-n** flag, jobs will only have one host CPU core.
  - Many GPU apps can still make use of multiple host CPU cores for some of their processing.

GPU Partition (GPU type)	Host CPU type	Max host CPU cores per GPU	Host RAM per CPU core (GB)	Max host RAM per GPU (GB)
gpuA (A100 80GB)	48-core AMD EPYC "Milan"	12	10.4	125
gpuL (L40S)	48-core Intel Xeon "Sapphire Rapids"	12	10.4	125
gpuA40GB (A100 40GB)	48-core AMD EPYC "Milan"	12	10.4	125

70

## Other GPU Notes

- GPUs are run in **DEFAULT** compute mode (not **EXCLUSIVE\_PROCESS**.)
  - You can run multiple processes / apps on the same GPU – e.g., several small chemistry simulations.
- You can monitor your GPU jobs by accessing the compute node and GPU once your job as started.
  - Use the **srun** command on the login node to "login" to the compute node and resource container where your job is running:
 

```
srun --jobid=JOBID --pty bash
```

 (wait until you are logged into the compute node where you job is running. You'll see the same GPUs.)
 

```
nvidia-smi
```

 or, for example:
 

```
module load libs/cuda/12.4.1
ncu-ui or nvvp (or other Nvidia tool)
```
- A quick exercise 6:
  - If you are logged-in to the CSF, try editing the `~/training/RCSF/examples/dq_gpu.sbatch` jobscript (change the **-p** line to request one of the **gpuV**, **gpuA** or **gpuL** partitions.) Then **submit** the job.
  - It runs the Nvidia **deviceQuery** utility to return some stats about the GPU assigned to your job.

71

## High Memory Jobs

Accessing the high memory nodes

72



## High Memory Jobs

- So far, our serial and parallel jobs have access to a fixed amount of memory
  - The partitions provide a specific amount of memory per core.
    - e.g. the multicore partition provides 8GB/core
  - If you want more memory, you need to request more cores.
  - Max in **multicore** is ~ 1.5 TB if all 168 cores used.
  - Can be very wasteful of CPU resources
- The **himem** and **vhimem** partitions provide access to more memory (up to 2TB and 4TB.)
  - Memory is a "consumable" - the amount of memory can be requested independently of the number of cores.

73

## Do you need more memory?

- If a job fails and reports an "OOM" error in the `slurm-JOBID.out` file, you should request more memory.
- You can also check a previous job to see how much memory it used with "`seff`"

```
[mabcxyz1@login1[csf3] ~]$ seff 12345
Job ID: 12345
Cluster: csf3.man.alces.network
User/Group: username/xy01
State: COMPLETED (exit code 0)
Nodes: 1
Cores per node: 2
CPU Utilized: 00:04:13
CPU Efficiency: 49.41% of 00:08:32 core-walltime
Job Wall-clock time: 00:04:16
Memory Utilized: 21.45 GB           # Peak memory usage
Memory Efficiency: 33.5% of 64.00 GB # A low memory efficiency means this job did NOT need
                                         # to use the himem partition. You should check this.
```

74

## High-memory Compute Nodes

- The 2TB (**himem**) partition contains various Intel compute nodes.
  - Slurm will place your job on any of the node-types that have enough resources (memory, cores) as requested by your job.
- The 4TB (**vhimem**) partition is restricted
  - Please request access via the Connect Portal
  - We will need evidence from previous jobs that you need >2TB of RAM.

Partition (required)	Default job mem-per-core if memory not requested (GB)	Max job size (cores)	Max job memory (GB)	Arch Flag (optional, but will activate specific limits shown in the next columns)	Max job size (cores)	Max job memory (GB)	Has SSD storage	Old SGE flag (DO NOT USE)
himem	31	32	2000	-C haswell	16	496	No	mem512
				-C cascadelake	32	1472	No	mem1500
				-C icelake (also ssd)	32	2000	Yes	mem2000
				-C icelake (also ssd)	32	4000	Yes	mem4000
vhimem	125	32	4000	-C icelake (also ssd)	32	4000	Yes	mem4000

## High Memory Jobscripts

```
#!/bin/bash --login
#SBATCH -p himem           # Partition
#SBATCH -n 2               # Cores: Can be 1-32
#SBATCH --mem=1200G        # Total memory for the job
#SBATCH -t 4-0             # Wallclock (max is 7-0 here)

# Set up to use your app
module purge
module load apps/gcc/something/1.2.3

# Run a GPU app. Slurm will ensure no
someApp -in hugh_dataset.dat -out results.dat
```

```
#!/bin/bash --login
#SBATCH -p himem           # Partition
#SBATCH -n 2               # Cores: Can be 1-32
#SBATCH --mem-per-cpu=600G # OR specify the Memory per Core
                           # (note: name of flag uses 'cpu')
#SBATCH -t 4-0             # Wallclock (max is 7-0 here)
```

76

## HPC Pool

- Dedicated pool for HPC jobs
    - 4096 cores of Infiniband connected Skylake
    - Minimum 128-core job size, maximum 1024
    - Frontend shared with CSF3
      - You just submit HPC jobs like any other CSF job (with a different "partition" name and an account code.)
    - Lightweight application process – must be made by PI
    - Currently free
- <https://ri.itservices.manchester.ac.uk/csf3/hpc-pool>

77

78

## OTHER PARALLEL HARDWARE

What else is available?

## N8 Bede (NICE)

- 32 IBM Power 9 dual-CPU nodes
  - Each node comprises 4 NVIDIA V100 GPUs and high performance interconnect.
- 5 Nvidia GH200 Grace Hopper nodes
  - Each node comprises 1x NVIDIA H100 96GB with 900 GB/s NVLink-C2C and 1x NVIDIA Grace aarch64 CPU @ 3.483 GHz (72 Arm Neoverse V2 cores)
- Same architecture as the US government's SUMMIT and SIERRA supercomputers which occupied the top two places in a recently published list of the world's fastest supercomputers.
- Contact Research IT for advice
- <https://n8cir.org.uk/supporting-research/facilities/bede/docs/>

79

## ARCHER2

- National supercomputer funded by UK Research Councils
  - Archer2 has replaced Archer which was 118,080 cores
  - Now 5,848 compute nodes, each with dual AMD EPYC Zen2 (Rome) 64 core CPUs at 2.2GHz, giving 748,544 cores in total.
  - Estimated peak performance of 28 PFLOP/s
- Mostly open source / free HPC software
- See <https://www.archer2.ac.uk/>
  - Info for how to apply for access
    - Applications assessed for suitability
- IT Services can help you apply for access

80

## FINAL POINTS

Further info

- MOTD when you log into the CSF - please read it
- Problems e.g. system down, can't log in, minor changes to the service (and other services - e.g storage):  
<https://ri.itservices.manchester.ac.uk/services-news/>
- Prolonged problems or major changes emailed to all users

81

<https://ri.itservices.manchester.ac.uk/csf3/help/>

82

- CSF Slurm documentation  
<https://ri.itservices.manchester.ac.uk/csf3/batch-slurm/>
- Job Arrays - multiple similar jobs from a single submission script  
<https://ri.itservices.manchester.ac.uk/csf3/batch-slurm/job-arrays-slurm/>
- SSHFS - another means of file transfer  
<https://ri.itservices.manchester.ac.uk/userdocs/file-transfer/>
- Virtual Desktop Service – another means of connecting and running GUIs and logging in from off campus  
<https://ri.itservices.manchester.ac.uk/virtual-desktop-service/>
- Please give feedback: Quick form at  
<https://goo.gl/forms/zfZyTLw4DDaySnCF3>  
(choose "*Introduction to HPC (Using CSF)*")

## Thank you!

83