# INTRODUCTION TO SUPERCOMPUTING

## SLURM Workload Manager

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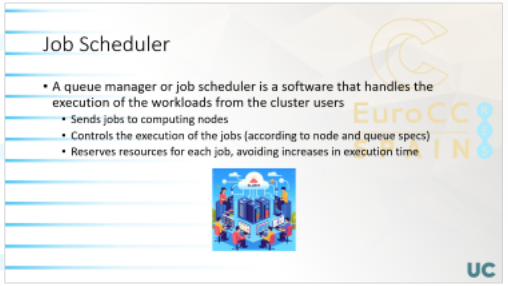
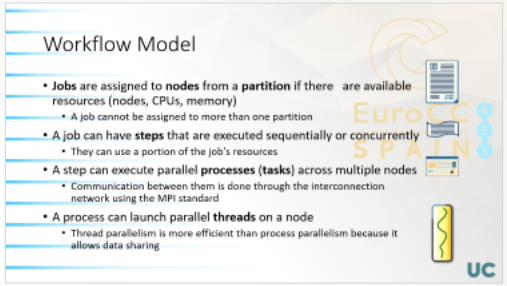
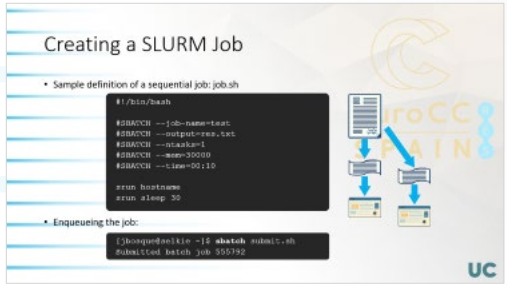
# SLURM workload manager





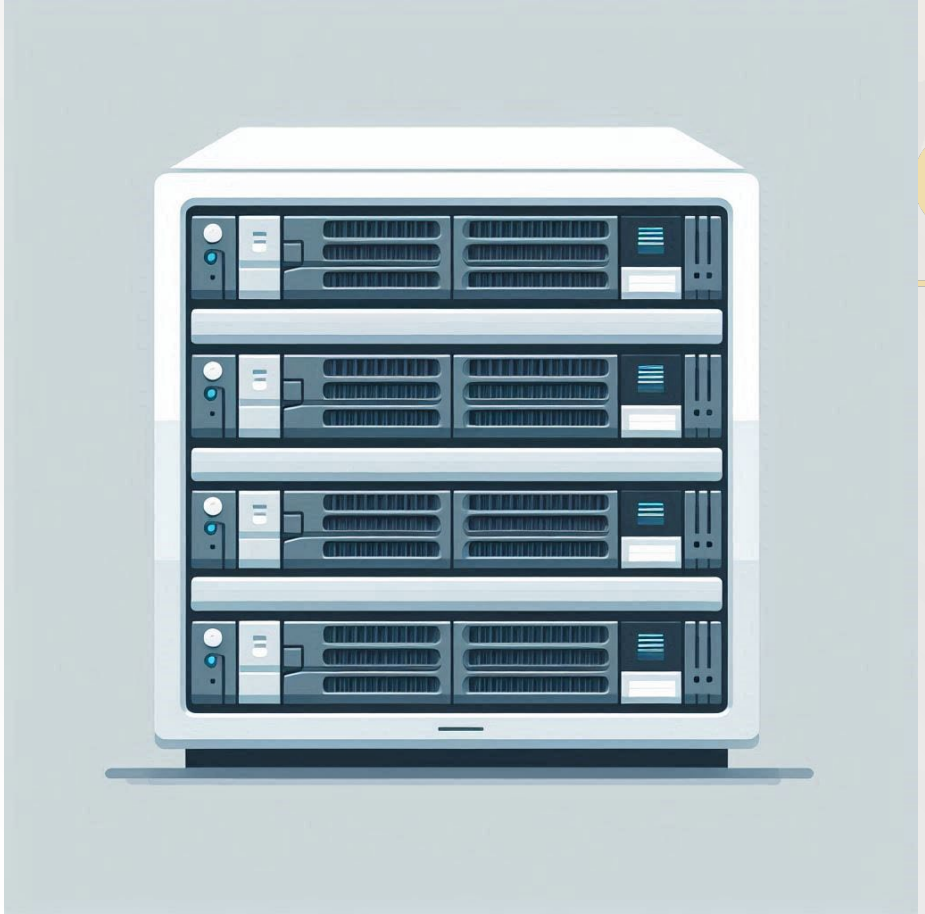



# Job Scheduler

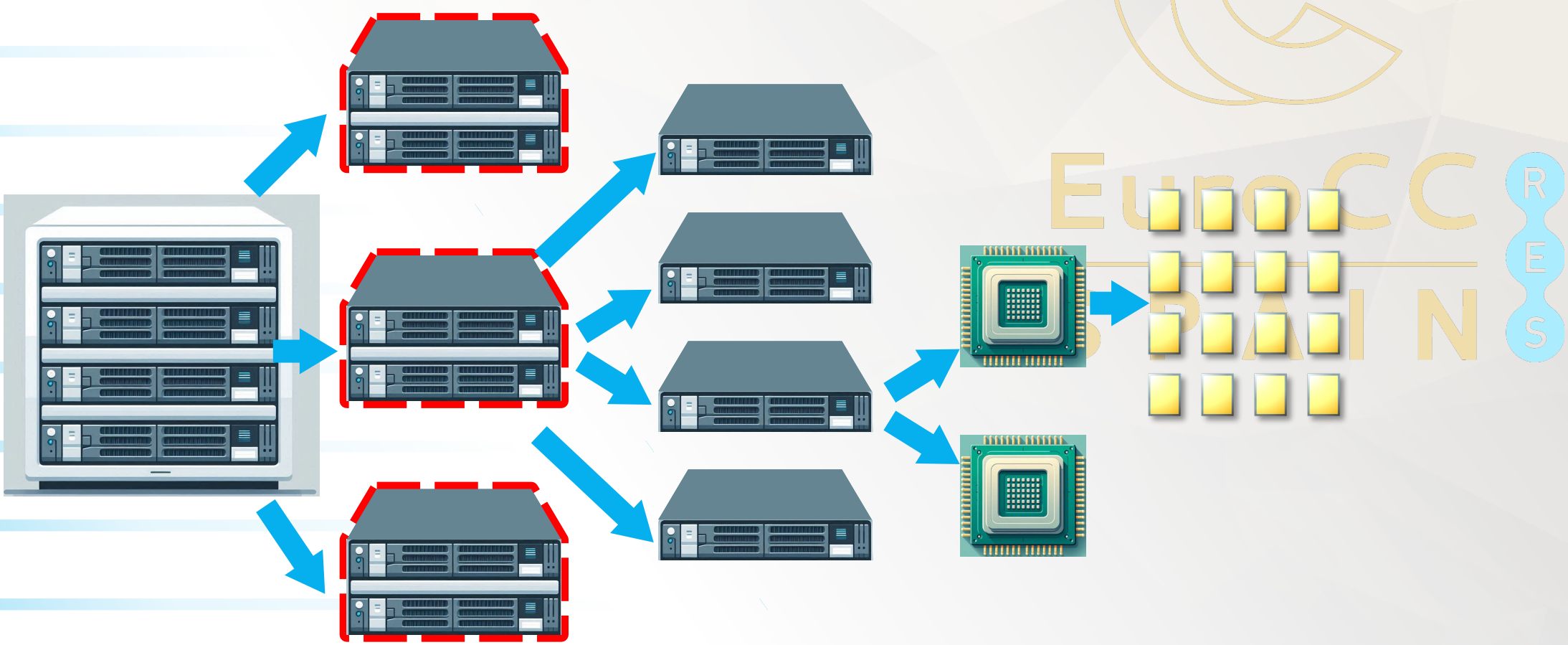
- A queue manager or job scheduler is a software that handles the execution of the workloads from the cluster users
  - Sends jobs to computing nodes
  - Controls the execution of the jobs (according to node and queue specs)
  - Reserves resources for each job, avoiding increases in execution time

# Job Scheduler

- Partition: group nodes into sets
  - They do not have to be disjoint
  - They have an associated job queue
  - They can be restricted to users, requested time, etc.
- Node: container of computing resources
  - A task is assigned to a set of nodes
  - The assignment gives users rights over the nodes
- CPU: computing resource
  - They carry out the computation defined in the tasks
  - Their capacity can be assigned, but not the CPUs themselves



# Job Scheduler



Cluster Partition Node Processor Core

# Workflow Model

- **Jobs** are assigned to **nodes** from a **partition** if there are available resources (nodes, CPUs, memory)
  - A job cannot be assigned to more than one partition
- A job can have **steps** that are executed sequentially or concurrently
  - They can use a portion of the job's resources
- A step can execute parallel **processes** (**tasks**) across multiple nodes
  - Communication between them is done through the interconnection network using the MPI standard
- A process can launch parallel **threads** on a node
  - Thread parallelism is more efficient than process parallelism because it allows data sharing

# SLURM

- Job scheduler for Linux clusters
  - https://slurm.schedmd.com/
- Developed in Livermore Computing Center
  - Open-Source, supported by the original developers
  - Fault-tolerance
  - Highly scalable (TOP500)
- It has three main functions:
  - Temporary allocation of resources (nodes) to users
  - Allowing process management (startup, monitoring…)
  - Arbitrating the shared use of resources

# SLURM Basic Commands

- **`sinfo`**: reports the status of the partitions and the compute nodes managed by Slurm
  - Wide variety of filtering, sorting, and formatting options

```
[jbosque@selkie ~]$ sinfo
PARTITION AVAIL  TIMELIMIT  NODES  STATE NODELIST
latc*        up   1-00:00:00     24   down* n16-[21-44]
lsci         up   1-00:00:00     42   down* n232-[21-62]
lscii        up   1-00:00:00     25   down* n232-[71-95]
lsciii       up   1-00:00:00     17   down* n232-[121-137]
lsciv        up   1-00:00:00     31   down* n232-[171-201]
lscv         up   1-00:00:00     16   down* n132-[21-36]
all          up   1-00:00:00    155   down* n16-[21-44],n132-
[21-36],n232-[21-62,71-95]
```

# SLURM Basic Commands

- **`squeue`**: reports the status of running and pending jobs.
  - It has a wide variety of filtering, sorting, and formatting options: `–user`, `–partition`, or `–state`
  - By default, it reports running jobs in order of priority and then pending jobs in order of priority

```
[jbosque@selkie ~]$ squeue
JOBID PARTITION NAME USER ST TIME NODES NODELIST
548449 normal smart_32x32 enrique R 0-21:09:15 1 comp005
548992 normal smart_32x32 enrique R 0-21:09:15 1 comp005
548214 normal fsin esteban R 0-07:09:15 1 comp005
548933 normal smart_32x32 enrique R 0-12:10:34 1 comp004
548445 normal fsin esteban R 0-09:10:34 1 comp004
548877 normal MultiRingRL enrique R 0-00:26:34 2 comp00[1,2]
```

# SLURM Basic Commands

- **`sbatch`**: submits a job script for later execution
  - The script will typically contain one or more `srun` commands to launch parallel tasks
- **`scancel`**: cancels a pending or running job or job step
- **`sstat`**: obtains information about the resources used by a running job or job step

```
[jbosque@selkie ~]$ sstat -j 548449
JobID    MaxVMSize AveCPU   NTasks AveCPUFreq ConsumedEnergy
-----    --------- ------   ------ ---------- --------------
555793.1 203540K   00:00.000 1            800M            642
```

# Creating a SLURM Job

- The definition of a job is divided into two parts:
  - Resource request
    - Number of CPUs
    - Estimated runtime
    - Amount of memory
  - Job definition
    - Description of steps
    - Definition of variables
    - Which programs are executed

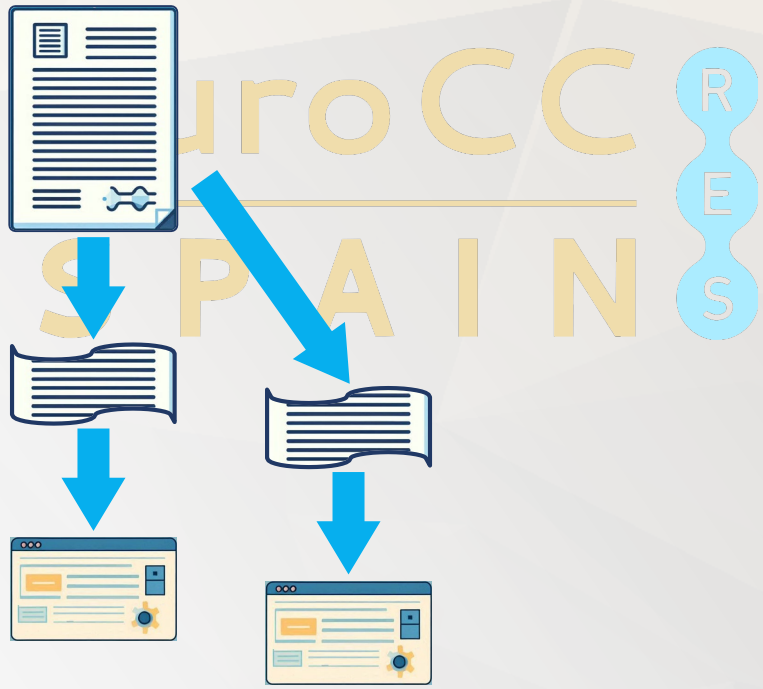
# Creating a SLURM Job

- Sample definition of a sequential job: job.sh

```
#!/bin/bash

#SBATCH --job-name=test
#SBATCH --output=res.txt
#SBATCH --ntasks=1
#SBATCH --mem=30000
#SBATCH --time=00:10

srun hostname
srun sleep 30
```



- Enqueueing the job:

```
[jbosque@selkie ~]$ sbatch submit.sh
Submitted batch job 555792
```

# Most Frequent SLURM Directives

| Option | Description |
|---|---|
| `--job-name=name` | Job name – It facilitates job identification |
| `--nodes=\#` | Number of nodes to use |
| `--ntasks=\#` | Number of tasks to execute (distributed parallelism) |
| `--ntasks-per-node=\#` | Number of tasks assigned to each physical node |
| `--time=[[DD-]HH:]MM:SS` | Maximum job runtime |
| `--mem-per-cpu=\#` | RAM required per CPU (MB) |
| `--mem=\#` | RAM required per node (MB) |
| `--output=out-\%j.log` | File to store standard output from the job |
| `error=err-\%j.log` | File to store error output from the job |
| `--chdir=[dirname]` | Working folder |

# SLURM Job States

- Once a job is sent to the queue, it goes through different states:
  - **PENDING**: the job is waiting for resources to execute
  - **RUNNING**: when resources are available and the priority allows it, the job starts executing
  - **COMPLETED**: when the execution finishes successfully
  - **FAILED**: when the execution ends abnormally

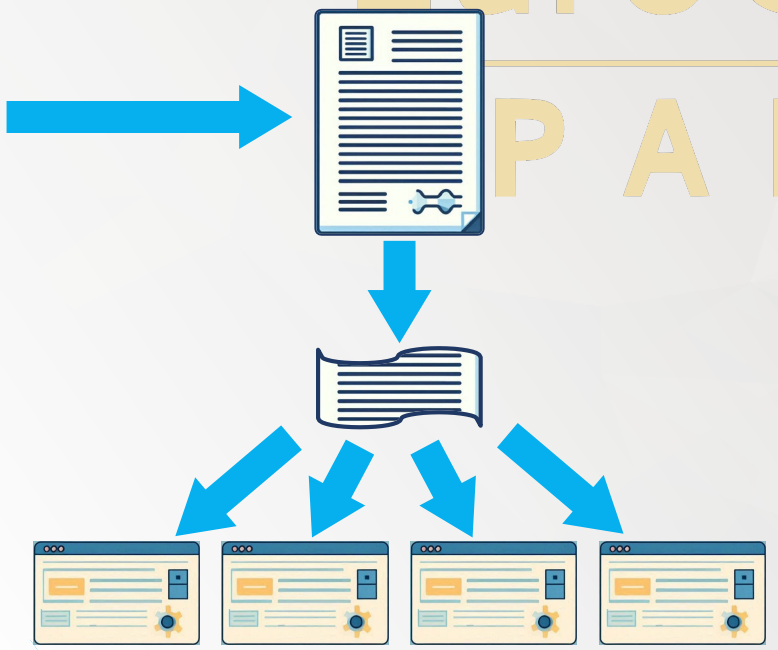
# MPI Jobs

- We start with a simple MPI program: *Hello World*
- The code is saved in the file **`hello_mpi.c`**

```
#!/bin/bash

#SBATCH --job-name=test_mpi
#SBATCH --output=res_mpi.txt
#SBATCH --ntasks=4
#SBATCH --nodes=2
#SBATCH --time=00:10
#SBATCH --mem-per-cpu=200

prun ./hello_mpi
```



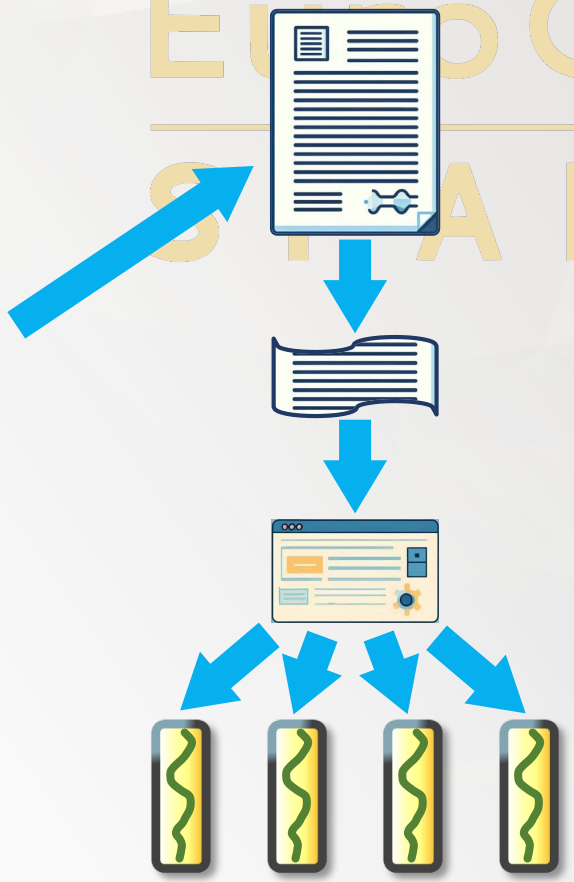
# OpenMP Jobs

- We try with an equivalent OpenMP program: *Hello World*
- The code is saved in the file **`hello_omp.c`**
- To compile the code, we use the command:
  - `gcc -fopenmp -o hello_omp hello_omp.c`

```
#!/bin/bash

#SBATCH --job-name=test_omp
#SBATCH --output=res_omp.txt
#SBATCH --ntasks=1
#SBATCH --cpus-per-task=4
#SBATCH --mem-per-cpu=200
#SBATCH --time=00:10

export OMP_NUM_THREADS=$SLURM_CPUS_PER_TASK
srun ./hello_omp
```



# SLURM environment variables

- Variables are defined in the job environment when the script is executed through the job scheduler
  - They can be used in the script for different purposes
- Most interesting variables:
  - **`$SLURM_JOB_ID`**: job identifier
  - **`$SLURM_JOB_NAME:`** job name
  - **`$SLURM_SUBMIT_DIR`**: submit directory
  - **`$SLURM_JOB_NUM_NODES`**: number of nodes assigned to the job
  - **`$SLURM_CPUS_ON_NODE`**: number of cores per node
  - **`$SLURM_NTASKS`**: total number of cores per job
  - **`$SLURM_NODEID`**: index of the executing node in relation to the nodes assigned to the job
  - **`$SLURM_PROCID`**: index of the task in relation to the job

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