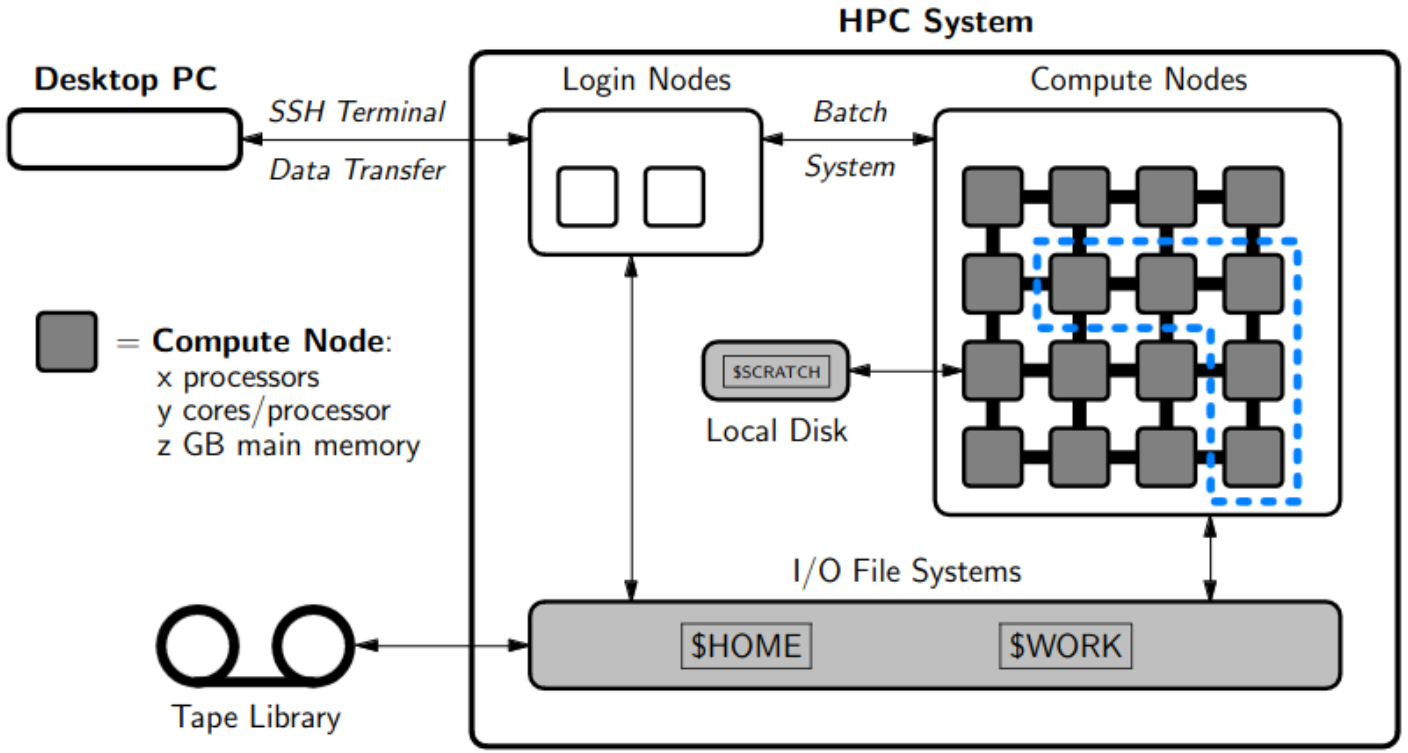
Insper

Supercomputação

Aula

- Administração de Clusters com SLURM

Um típico ambiente de HPC

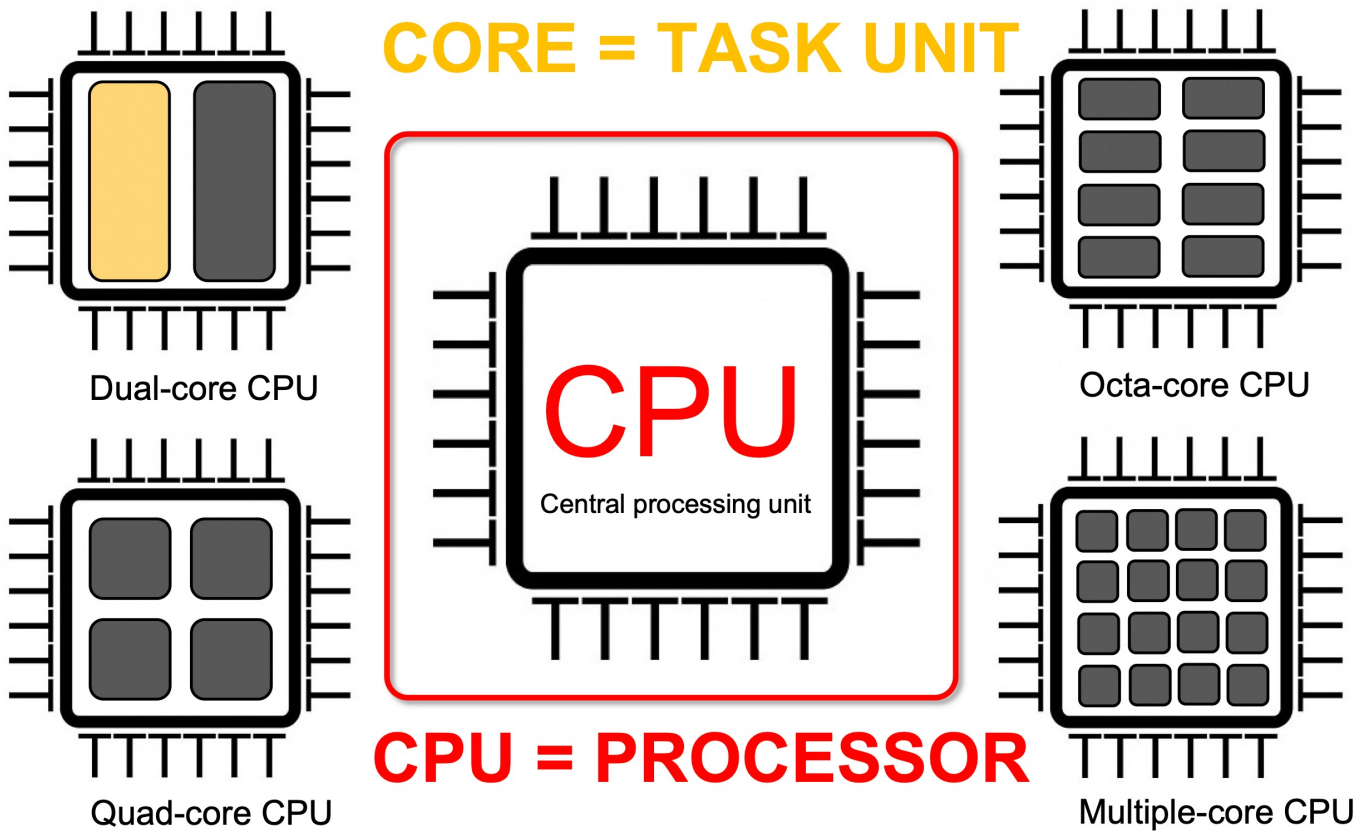


Fonte: https://www.rz.uni-kiel.de/de/angebote/hiperf/hpc-course-12feb2020

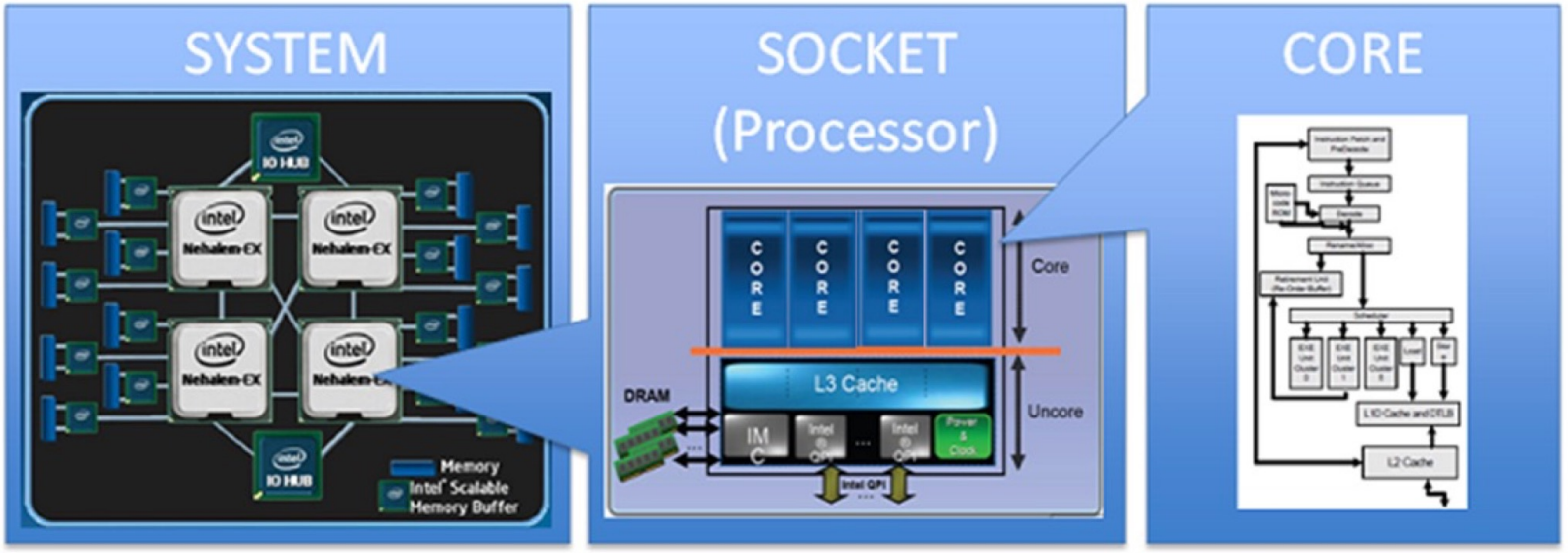
Antes de falarmos de SLURM, vamos recaptular

- Cores x CPU
- Como se avalia o desempenho de computadores (FLOPS)
- Clusters – como são

Cores x CPU


CORE = TASK UNIT
CPU
Central processing unit
Dual-core CPU
Octa-core CPU
Quad-core CPU
Multiple-core CPU
CPU = PROCESSOR

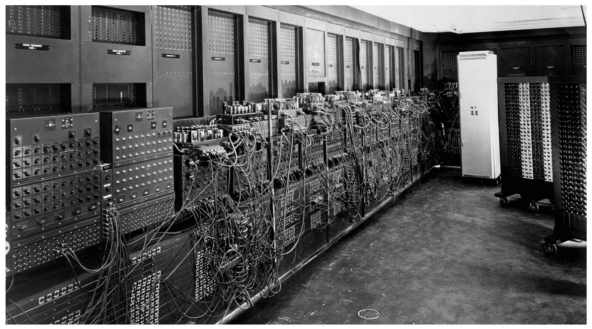
Cores x CPU



4 cores * 4 processors = 16 total cores

Medição de desempenho

- O desempenho dos ambientes de HPC é mensurado em **Floating Point Operations Per Second (FLOPS)**



ENIAC FLOPS: 500

- Por exemplo, o primeiro desktop PC a ter desempenho em teraflops (10^{12} FLOPS), foi em 2017, o Intel i97980XE

CPU clock rate: 4.4 GHz
CORE: 18 cores
FLOPs per cycle: 16

$$FLOPS = cores \times clock \times \frac{FLOPs}{cycle}$$

1267 GHz | 18 | 4.4 GHz | 16

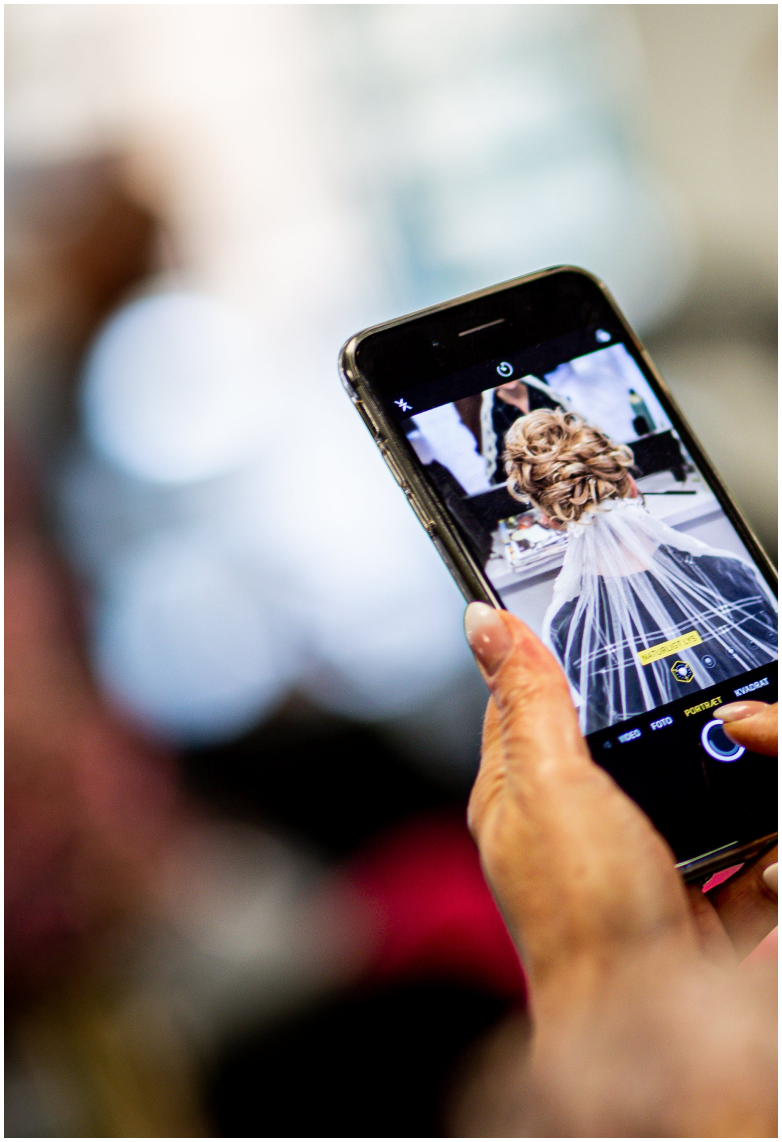
1.27 TFLOPS

Computer performance

Name	FLOPS
yottaFLOPS	10^{24}
zettaFLOPS	10^{21}
exaFLOPS	10^{18}
petaFLOPS	10^{15}
teraFLOPS	10^{12}
gigaFLOPS	10^{9}
megaFLOPS	10^{6}
kiloFLOPS	10^{3}

Medição de desempenho

- Já te falaram que você anda com um supercomputador no bolso?
- Vamos comparar um smartphone atual com um supercomputador de mais de 20 anos
    - Chip Apple A16 Bionic, usado no iPhone 14 Pro – 17 TFLOPS
    - Ano de 1996: Fujitsu 105MHz: 0.3 TFLOPS, com 167 cores
    - Anos 2000: ASCI WHITE, SP POWER3 375MHZ: 7.3 TFLOPS, com 8.192 cores



TOP 500 – Junho 2023

Na foto, Frontier, em ORNL (US), o maior supercomputador da atualidade

1.1 exaflops ~10^{18} cálculos por segundo

Insper | www.insper.edu.br

R_{max} and R_{peak} values are in PFlop/s. For more details about other fields, check the TOP500 description.

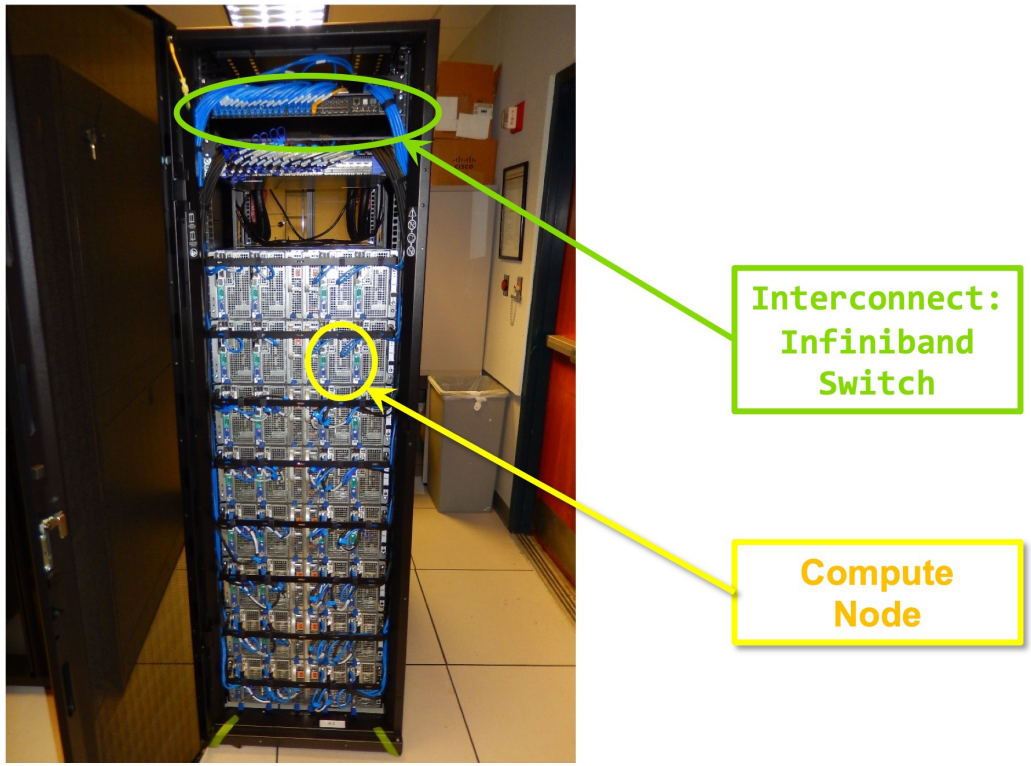
R_{peak} values are calculated using the advertised clock rate of the CPU. For the efficiency of the systems you should take into account the Turbo CPU clock rate where it applies.

Rank	System	Cores	Rmax (PFlop/s)	Rpeak (PFlop/s)	Power (kW)
1	**Frontier** - HPE Cray EX235a, AMD Optimized 3rd Generation EPYC 64C 2GHz, AMD Instinct MI250X, Slingshot-11, HPE DOE/SC/Oak Ridge National Laboratory United States	8,699,904	1,194.00	1,679.82	22,703
2	**Supercomputer Fugaku** - Supercomputer Fugaku, A64FX 48C 2.2GHz, Tofu interconnect D, Fujitsu RIKEN Center for Computational Science Japan	7,630,848	442.01	537.21	29,899
3	**LUMI** - HPE Cray EX235a, AMD Optimized 3rd Generation EPYC 64C 2GHz, AMD Instinct MI250X, Slingshot-11, HPE EuroHPC/CSC Finland	2,220,288	309.10	428.70	6,016
4	**Leonardo** - BullSequana XH2000, Xeon Platinum 8358 32C 2.6GHz, NVIDIA A100 SXM4 64 GB, Quad-rail NVIDIA HDR100 Infiniband, Atos EuroHPC/CINECA Italy	1,824,768	238.70	304.47	7,404
5	**Summit** - IBM Power System AC922, IBM POWER9 22C 3.07GHz, NVIDIA Volta GV100, Dual-rail Mellanox EDR Infiniband, IBM DOE/SC/Oak Ridge National Laboratory United States	2,414,592	148.60	200.79	10,096

Um típico cluster

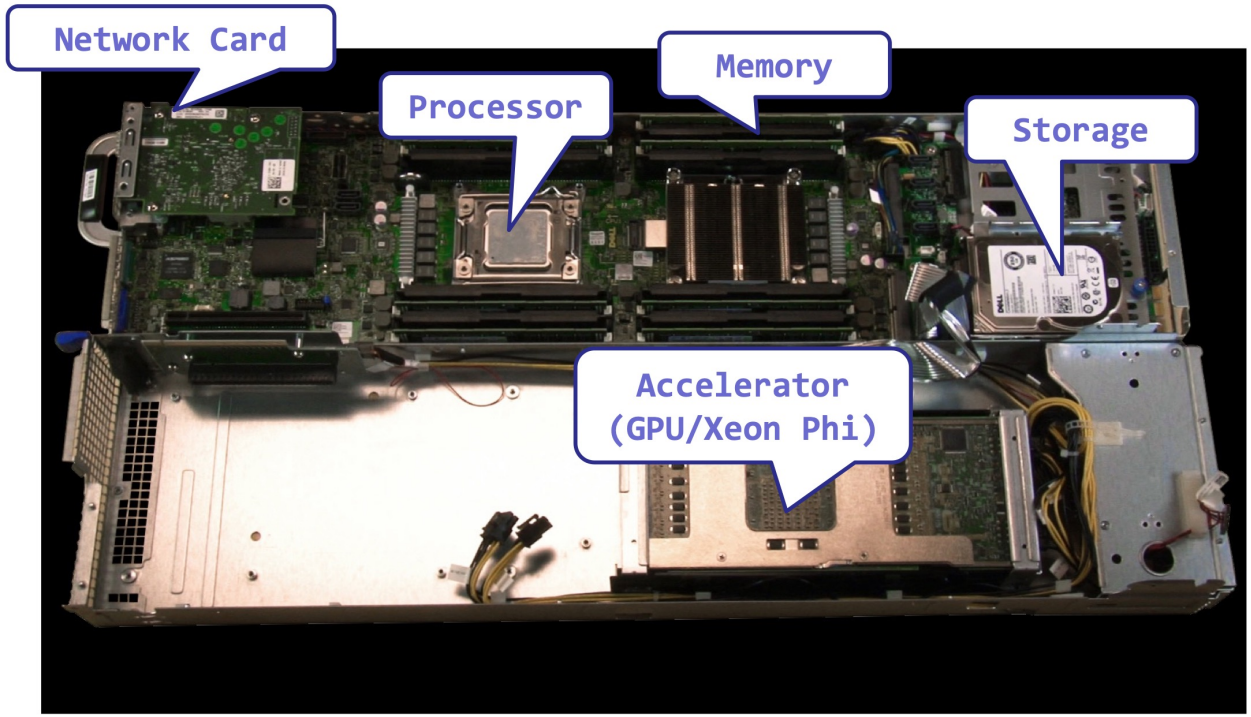
Um típico cluster

- Um rack



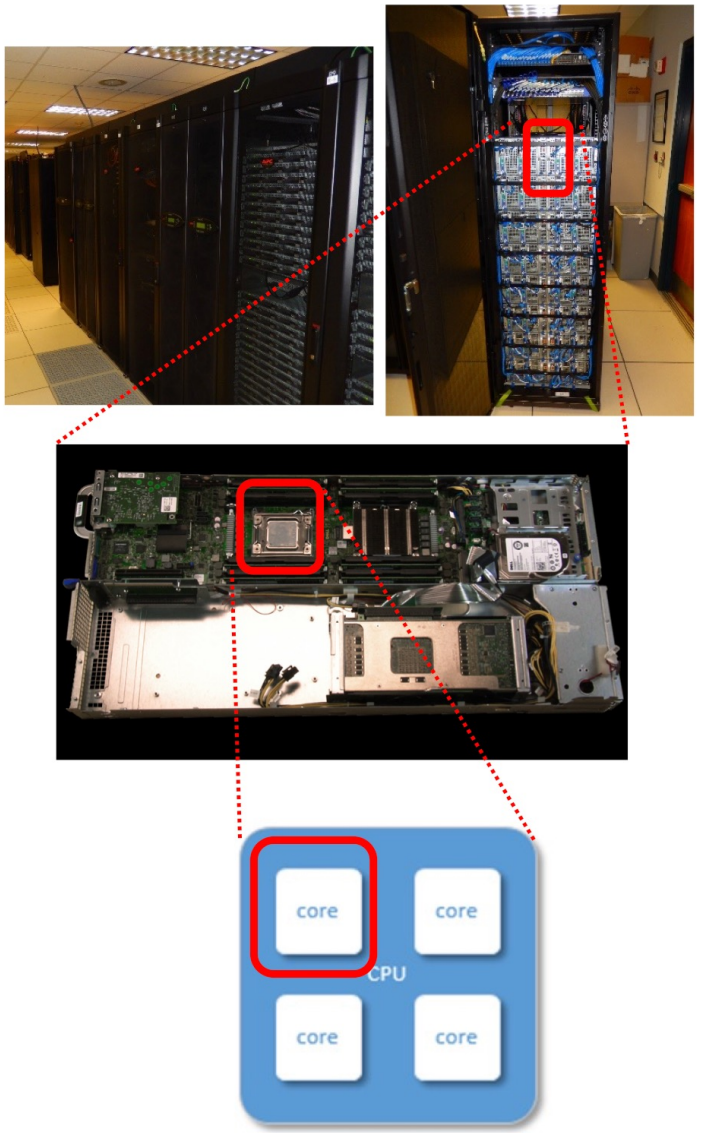
Um típico cluster

- Um node

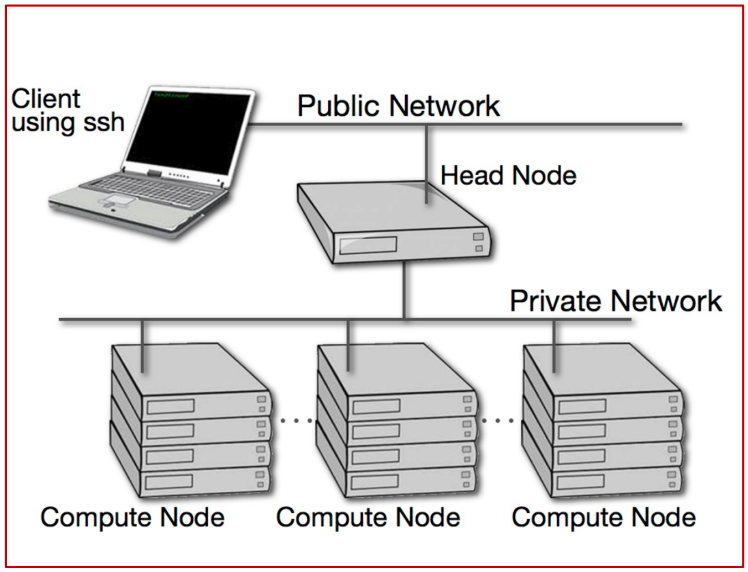


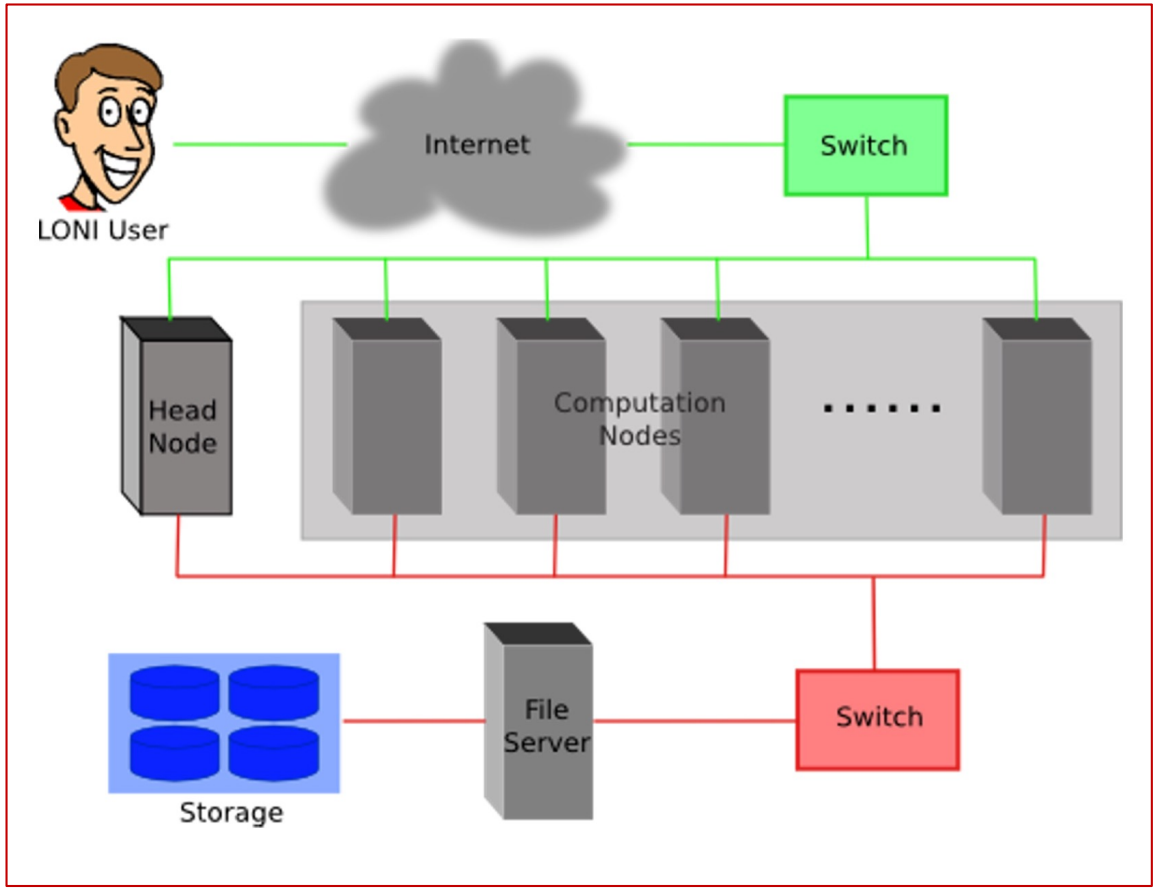
Cluster - Terminologias

Term	Definition
Cluster	A set of connected computer nodes that work together. (*E.g., QB2*)
Node	A single, named host machine in the cluster. (*E.g., qb010*)
Core	The basic computation unit in a processor. *(E.g.* , QB2 has two 10-core processors → 20 cores)
Job	A user's request to use a certain amount of resources for a certain amount of time on cluster for his/her work.



Cluster – Arquitetura convencional



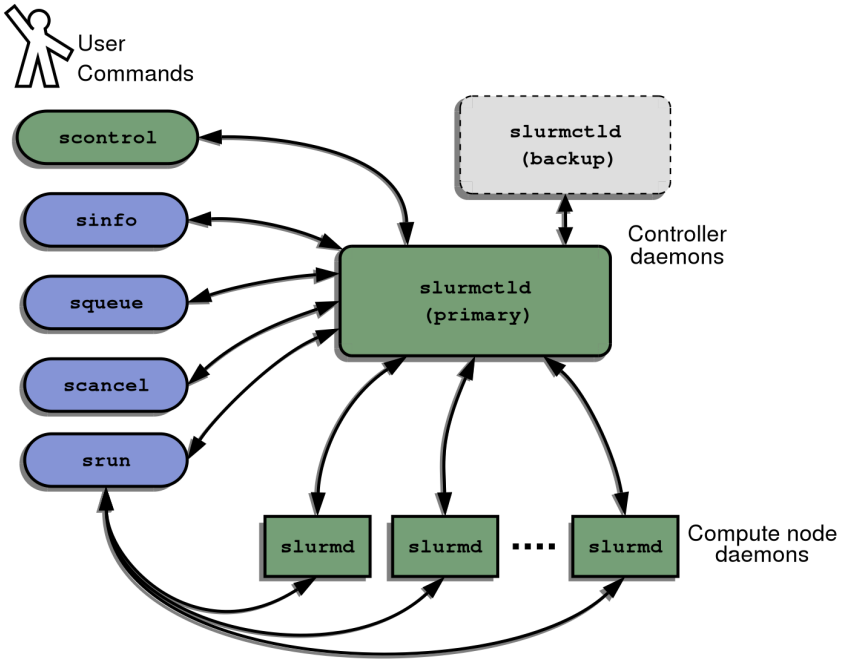


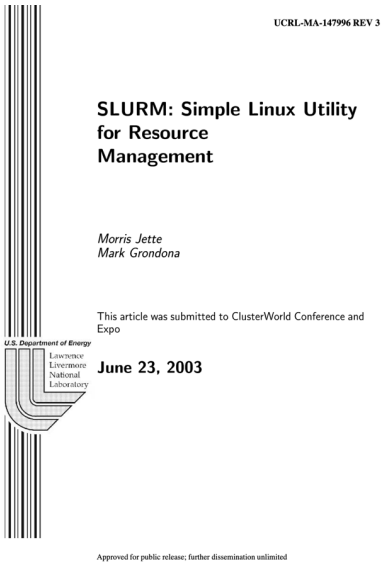
SLURM

- É um acrônimo para “Simple Linux Utility for Resource Management”
- É um sistema de gerenciamento de filas e recursos para clusters Linux
- Sua primeira versão foi em 2003
- Amplamente adotado em ambientes acadêmicos e industriais devido a sua eficiência e simplicidade
- Desenvolvimento é contínuo com contribuições da comunidade open-source
- Atualmente é mantido e atualizado pelo SchedMD
- Aproximadamente 60% dos supercomputadores da lista TOP500 usam SLURM

SLURM

- O paper de apresentação do SLURM está aqui

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SLURM: Simple Linux Utility for Resource Management

Morris Jette
Mark Grondona

This article was submitted to ClusterWorld Conference and Expo

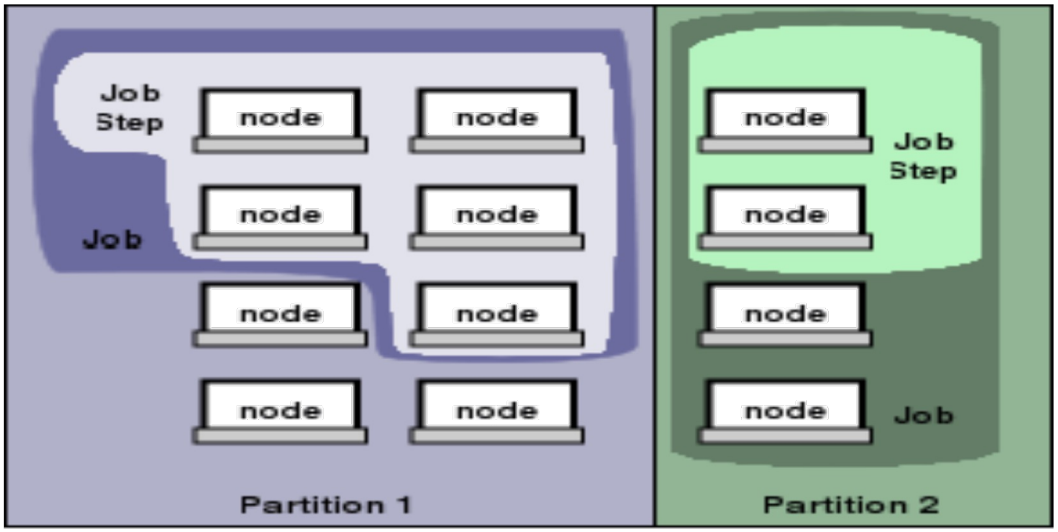
U.S. Department of Energy
Lawrence Livermore National Laboratory

June 23, 2003

Approved for public release; further dissemination unlimited

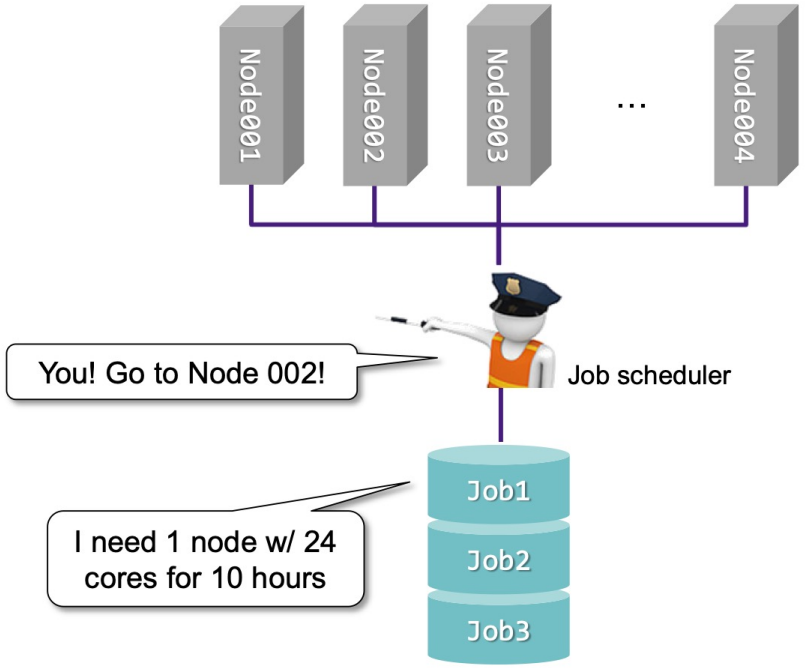
SLURM - terminologia

•**Computing node**	Computer used for the execution of programs
•**Partition**	Group of nodes into logical sets
•**Job**	allocation of resources assigned to a user for some time
•**Step**	sets of (possible parallel) tasks with a job



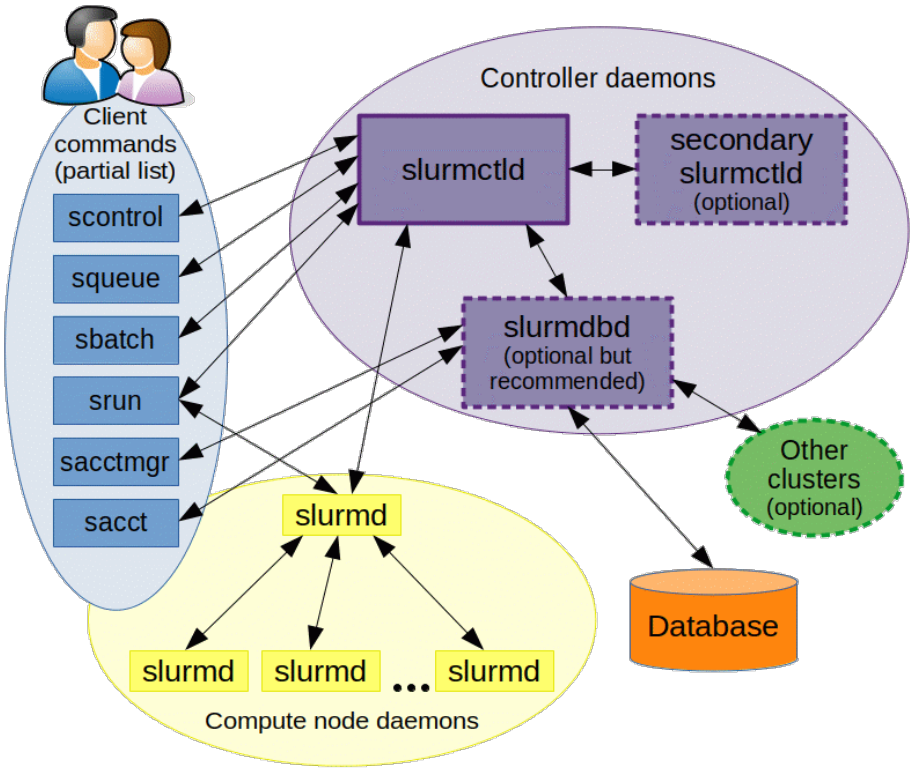
SLURM também é um Scheduler!

- E o que é isso?



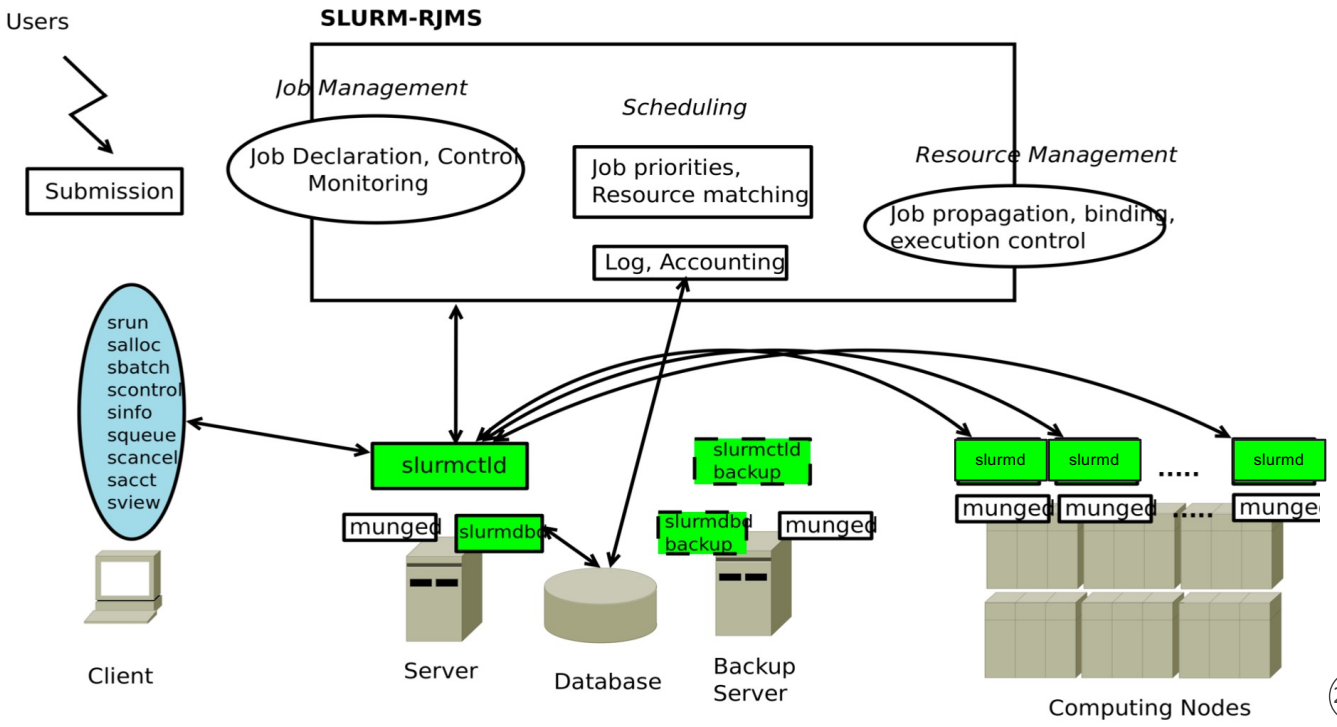
SLURM

- Componentes



SLURM – deamons

- Deamon – programa que executa como um processo em segundo plano



SLURM – Arquivos de configuração

slurm.conf
- Low level configuration
- Management policies
- Scheduling policies
- Allocation policies
- Node definition
- Partition definition

slurmdbd.conf
- Type of persistent storage (DB)
- Location of storage

topology.conf
- Switch hierarchy

gres.conf
- Generic resources details
- Device files

cgroup.conf
- Mount point
- Release agent path
- Cgroup subsystems parameters

	Controller	Compute node
Mandatory	slurm.conf slurmdbd.conf	slurm.conf
Optional	prologs epilogs topology.conf	gres.conf cgroup.conf topology.conf

SLURM – Configuração de nós e partições

- É no arquivo de configuração slurm.conf onde configuramos os nós e partições (filas) do cluster

Node definition
- **Characteristics (sockets, cores, threads, memory, features)**
- **Network addresses**

Partition definition
- **Set of nodes**
- **Sharing**
- **Priority/preemption**

```
 # Compute Nodes
NodeName=cuzco[1-10] Procs=16 Sockets=2 CoresPerSocket=8 ThreadsPerCore=1 State=UNKNOWN RealMemory=38000
NodeName=cuzco[10-20] Procs=32 Sockets=2 CoresPerSocket=8 ThreadsPerCore=2 State=UNKNOWN RealMemory=46000

 # Partitioning
PartitionName=exclusive Nodes=cuzco[1-20] MaxTime=INFINITE State=UP Priority=10 Shared=Exclusive
PartitionName=shared Nodes=berlin[1-20] Default=YES MaxTime=INFINITE State=UP Priority=30
PartitionName=procs16 Nodes=berlin[1-10] MaxTime=INFINITE State=UP Priority=30
PartitionName=procs32 Nodes=berlin[10-20] MaxTime=INFINITE State=UP Priority=30
```

Shared Option
Controls the ability of the partition to execute more than one job on a resource (node, socket, core)

EXCLUSIVE allocates entire node (overrides cons_res ability to allocate cores and sockets to multiple jobs)
NO sharing of any resource.
YES all resources can be shared, unless user specifies –exclusive on srun | salloc | sbatch

Como o SLURM prioriza?

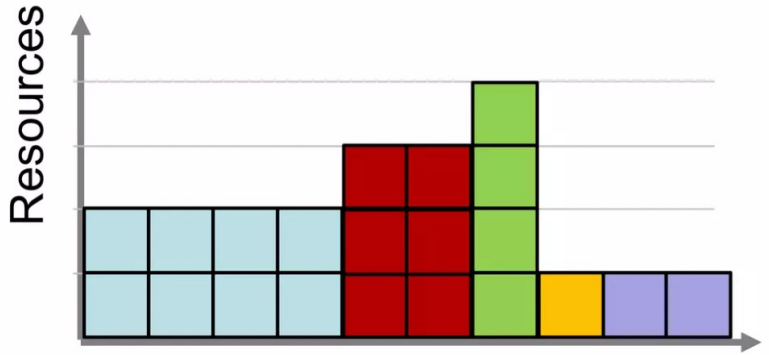
Como o SLURM prioriza?

- Por default, FIFO
- Mas há alguns outros critérios, como:

Age - the length of time a job has been waiting in the queue, eligible to be scheduled
Fairshare - the difference between the portion of the computing resource that has been promised and the amount of resources that has been consumed
Job size - the number of nodes or CPUs a job is allocated
Partition - a factor associated with each node partition
QOS - A factor associated with each Quality Of Service

Isso tem a ver com algoritmos de escalonamento

FIFO Scheduling

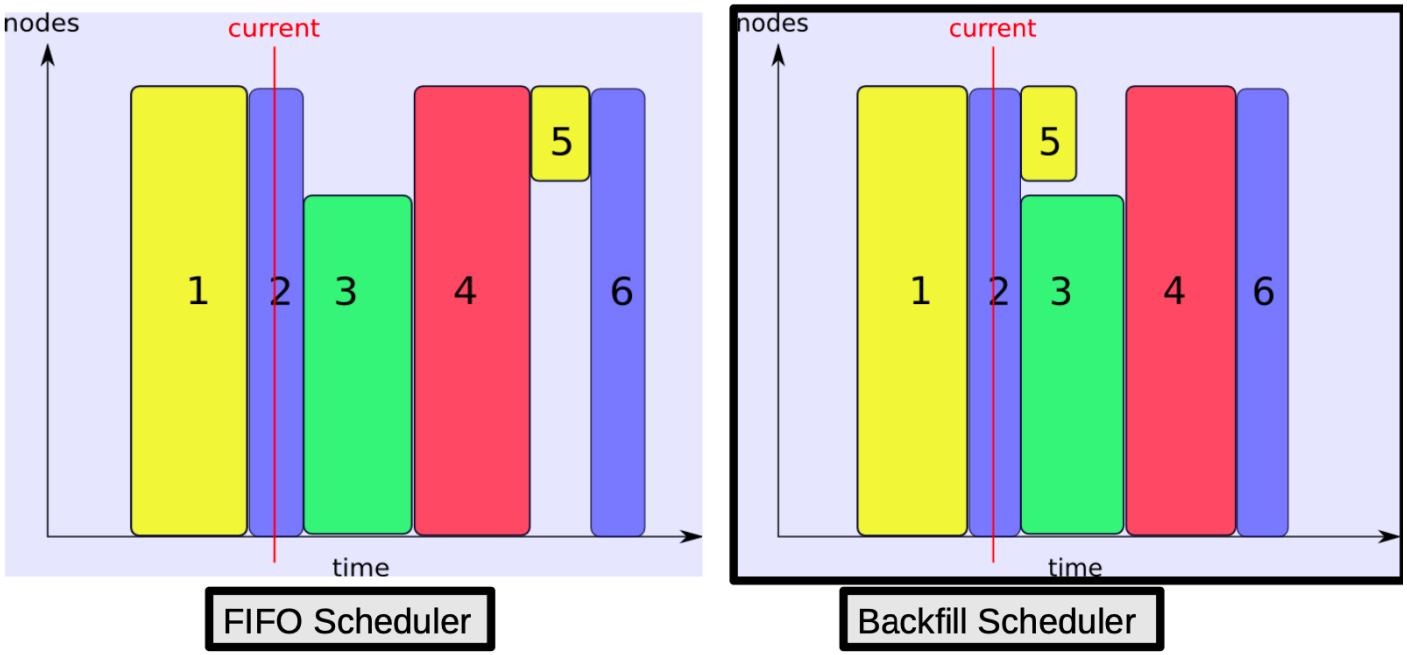


Backfill Scheduling

- Job priority
- Time limit **(Important!)**

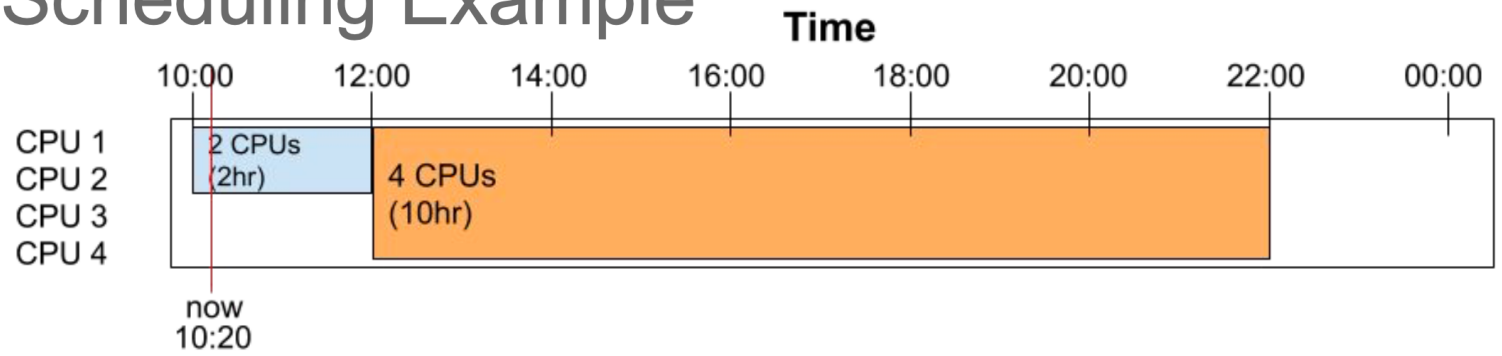
Backfill Scheduler

Holes can be filled if previous jobs order is not changed



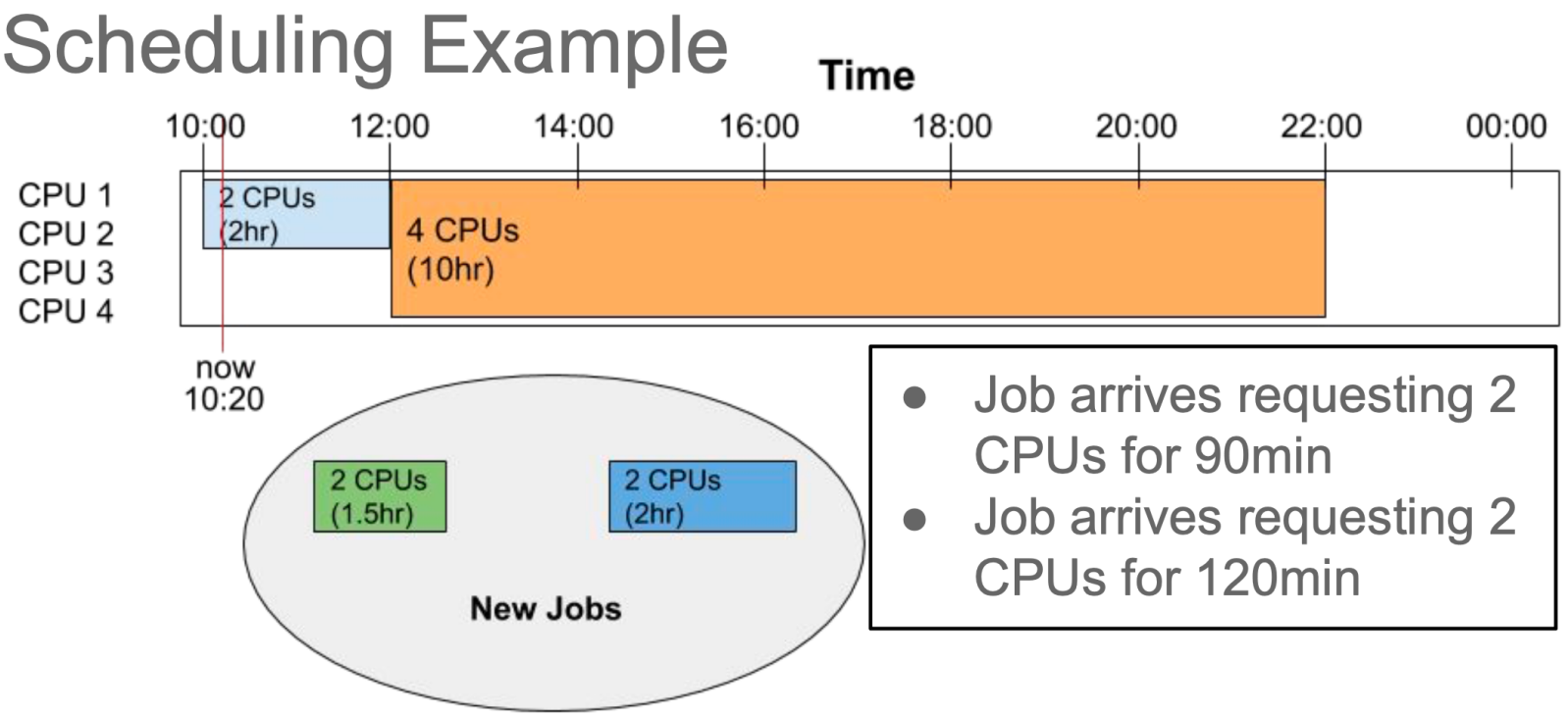
Backfill Scheduler

Scheduling Example



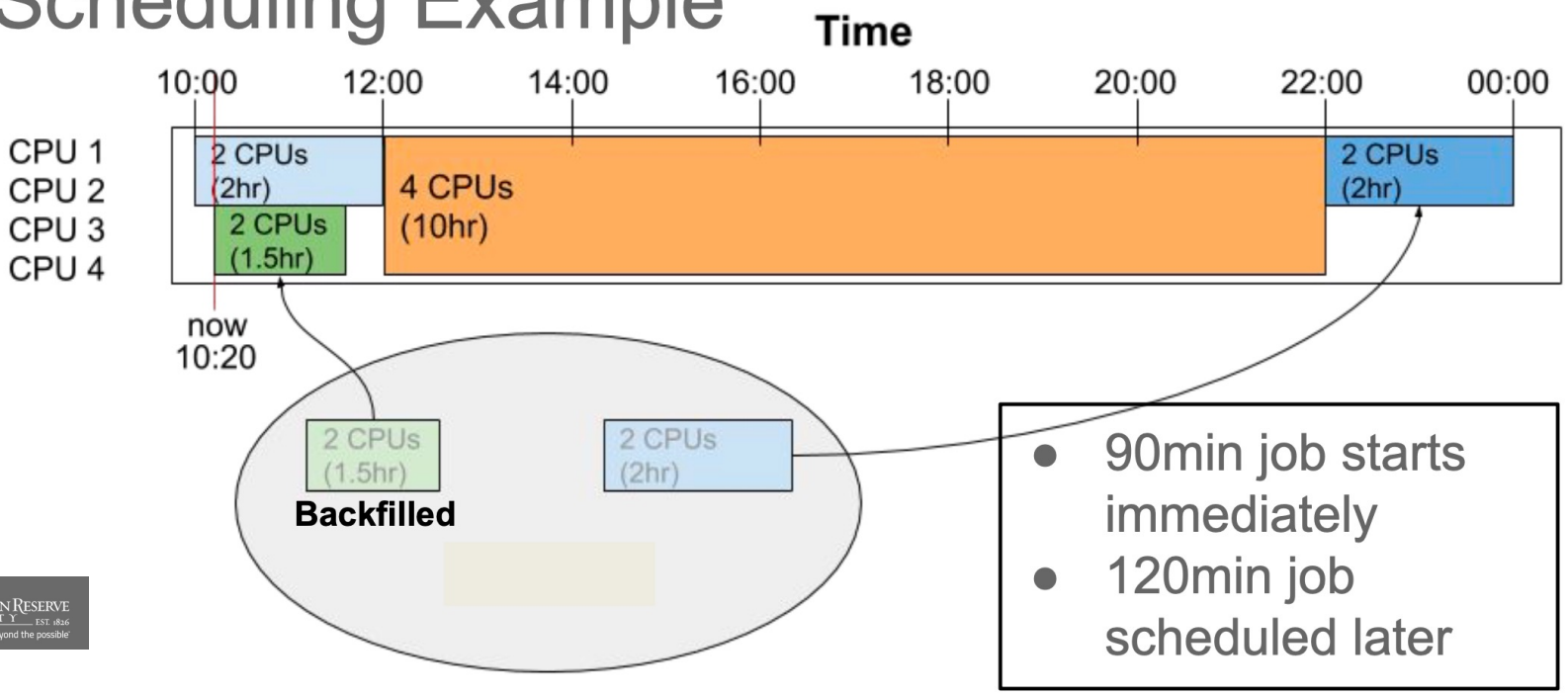
- 2 CPU job running until noon
- 4 CPU job starts at noon

Backfill Scheduler



Backfill Scheduler

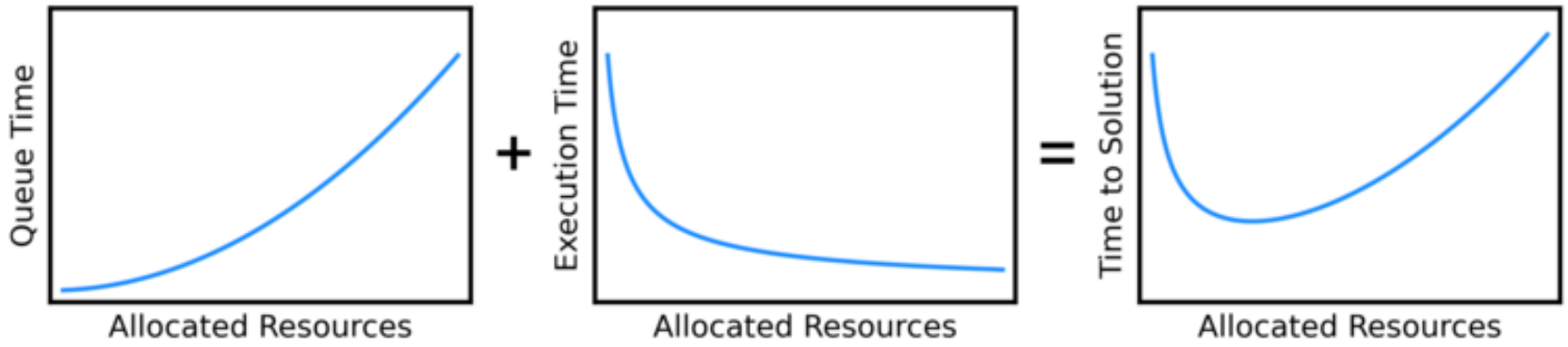
Scheduling Example



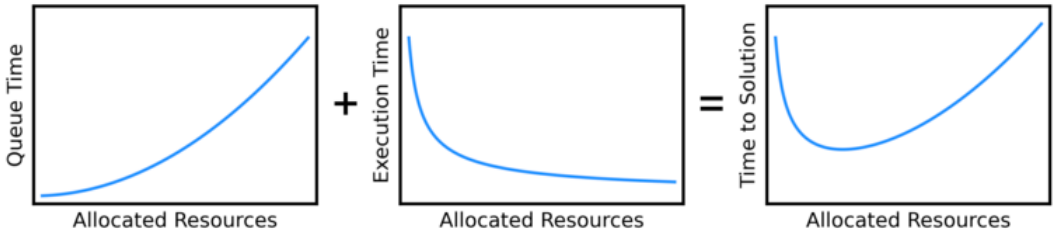
- 90min job starts immediately
- 120min job scheduled later

Quanto tempo vai demorar meu job?

- Uma regra simples é escolher o menor conjunto de recursos que proporcione uma aceleração razoável em relação ao baseline



Não é sobre pedir mais, é sobre pedir corretamente!



Ao lado temos um programa OpenMP em um cluster. Conforme aumentamos as threads (cpus-per-task) vamos melhorando o speedup. Mas veja que a partir de 16 threads, nossa eficiência diminui.

ntasks	cpus-per-task	execution time	speed-up ratio	parallel efficiency
1	1	42.0	1.0	100%
1	2	22.0	1.9	95%
1	4	16.0	2.6	66%
1	8	7.8	5.4	67%
1	16	6.5	6.5	40%
1	32	7.1	5.9	18%

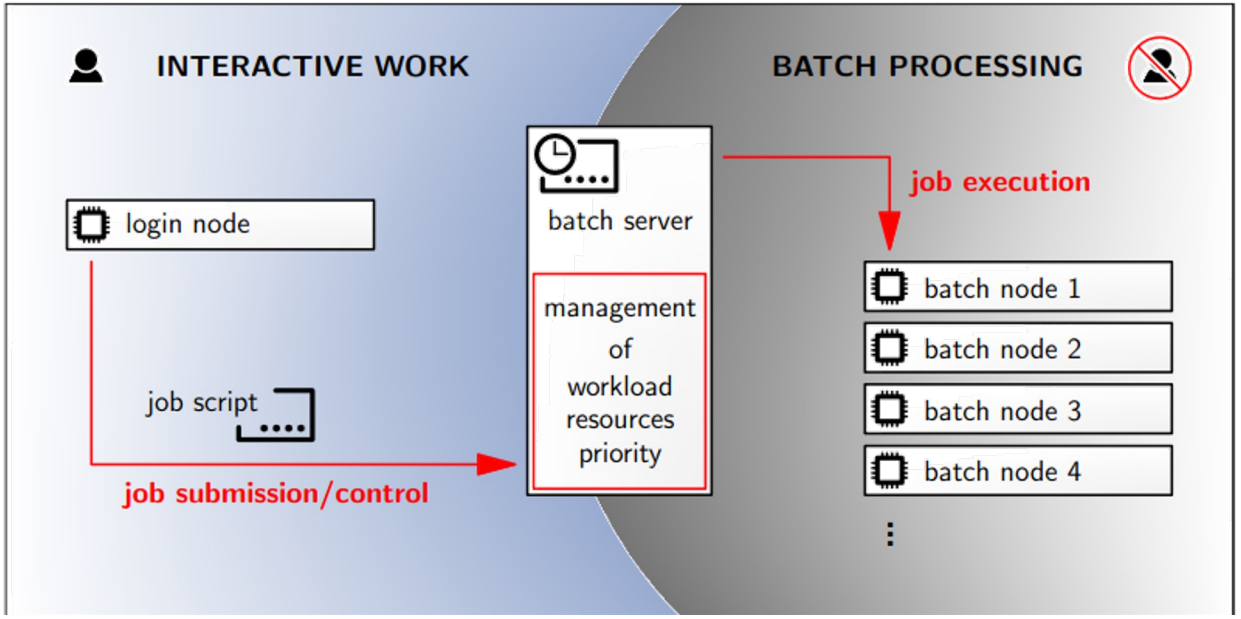
Jobs interativos e Jobs em Batch

1) Interactive job

- Runs **in terminal** (just like using a local machine)
- **Can interact** with the job while running

2) Batch job

- Submit to server and runs **by itself**, until finished or error
- **Cannot interact** with the job while running



Jobs Interativos

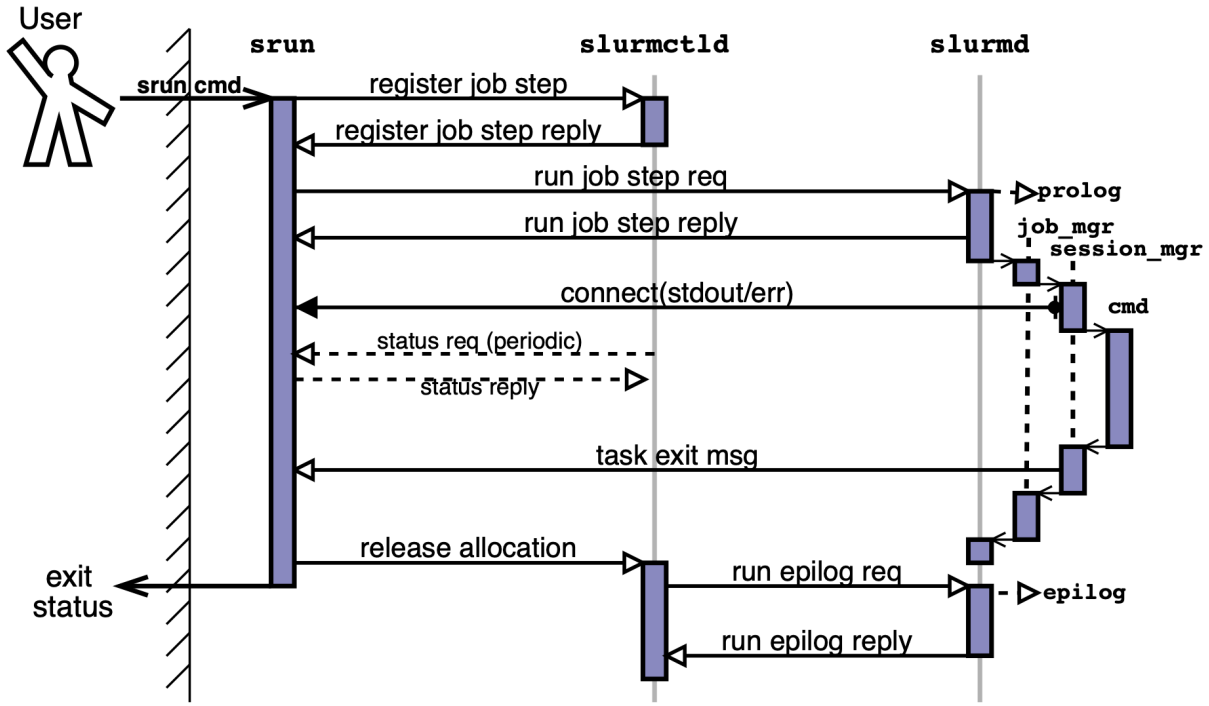
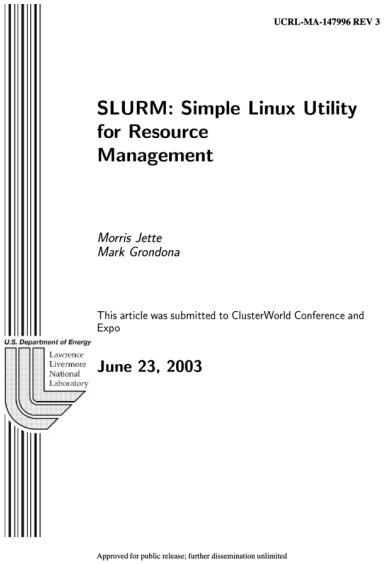


Fig. 5. Interactive job initiation. `srun` simultaneously allocates nodes and a job step from `slurmctld` then sends a run request to all `slurmd`s in job. Dashed arrows indicate a periodic request that may or may not occur during the lifetime of the job



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Jobs Batch

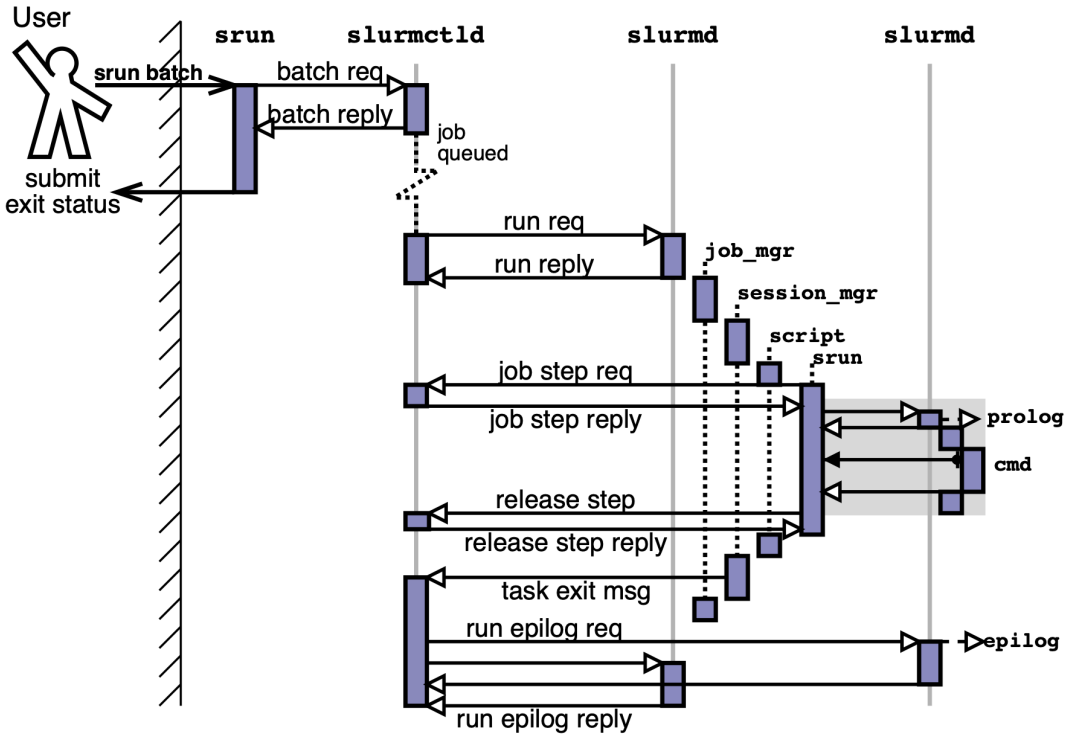
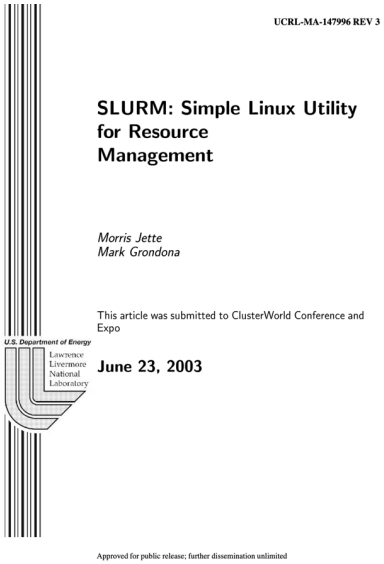


Fig. 6. Queued job initiation. `slurmctld` initiates the user's job as a batch script on one node. Batch script contains an `srun` call that initiates parallel tasks after instantiating job step with controller. The shaded region is a compressed representation and is shown in more detail in the interactive diagram (Figure 5)



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Interativo ou em Batch? R: Use os dois!

Running on HPC: Easy as 1-2-3

1. Plan ahead

- Organize project directories
- Install software, transfer data
- Think about your job requirements
  - amount of memory
  - number of i/o files
  - size of data

2. Test interactively

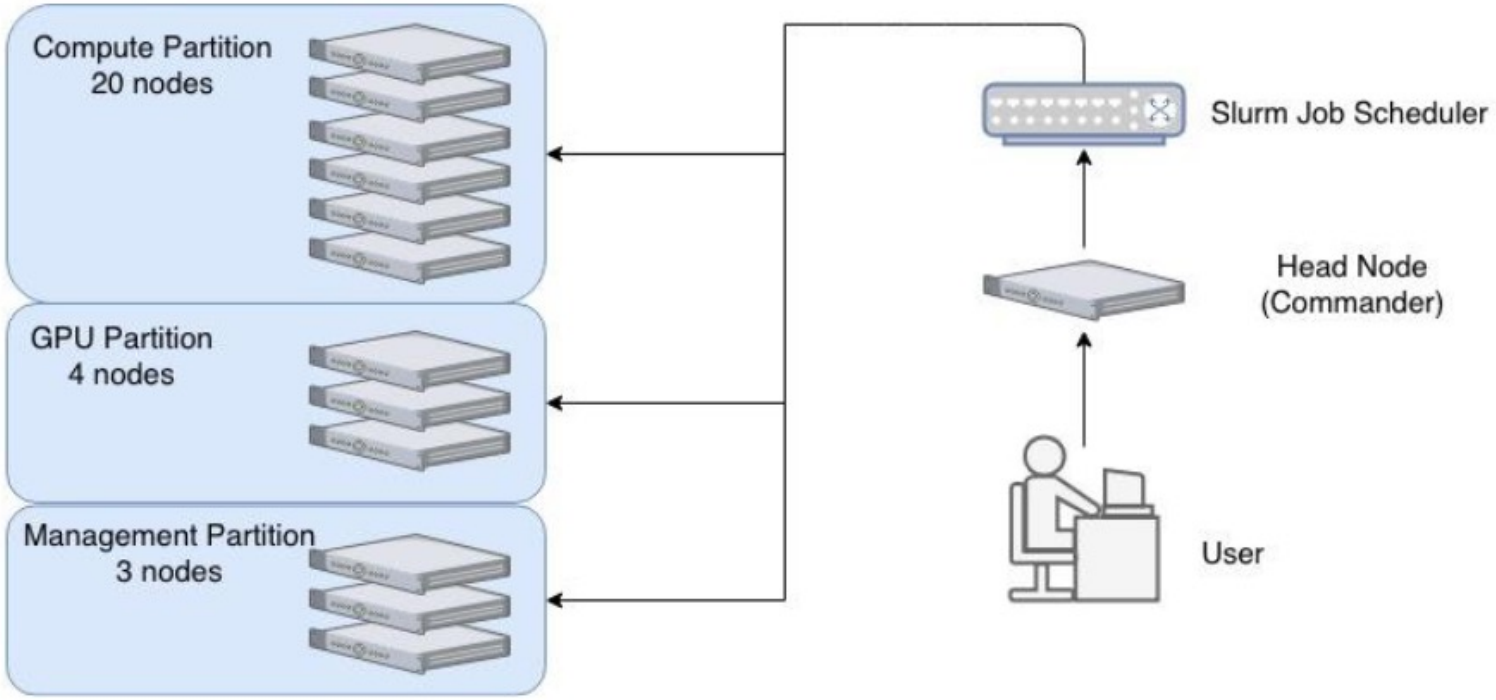
- Use salloc/srun
  - test run commands
  - check paths, results
- Experiment with resource allocation
  - number cores (cpus)
  - amount of memory
- Start small!
  - *then* scale

3. Run remotely

- Create Slurm script
  e.g., myjob.slurm
- Submit job to queue
  $sbatch myjob.slurm
- Monitor your job
  $squeue --user <uname>
- Check results
  $less slurm-<jobid>.out

https://chianglab.usc.edu/doc/Intro_to_Slurm.pdf

Partições (FILAS)



Principais comandos do SLURM - Interativo

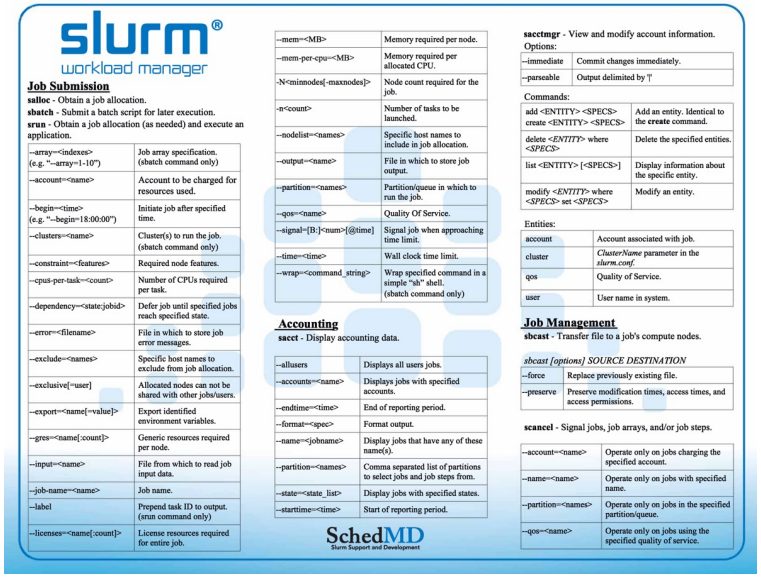
Useful SLURM Commands		
Command	**Summary**	**Example**
`srun -parameter job`	Obtain a job allocation and execute an application (see Running a Program - SRUN)	`srun -N1 -n1 example.py`
`sbatch -parameter batchscript`	Submit a batch script for later execution (see Running a Program - SBATCH)	`sbatch -o example.sh`
`sacct`	Display accounting data Use -j jobid to see status of specific job	`sacct -j 1576`
`sinfo`	View the status of the cluster's nodes and partitions	`sinfo`
`squeue`	Displays information of jobs in queue	`squeue`

Principais comandos do SLURM - Batch

Common Batch Script Directives		
Directive	**Description**	**Example**
`--job-name=name` or `-J name`	Custom job name	`--job-name=example`
`--partition=name` or `-p partition`	Partition to run on	`--partition=compute`
`--nodes=#` or `-N#`	Total number of nodes	`--nodes=1`
`--ntasks=#` or `-n#`	Number of "tasks". For use with distributed parallelism. See below.	`--ntasks=1`
`--cpus-per-task=#` or `-c#`	# of CPUs allocated to each task. For use with shared memory parallelism.	`--cpus-per-task=1`
`--ntasks-per-node=#`	Number of "tasks" per node. For use with distributed parallelism. See below.	`--ntasks-per-node=2`
`--time=[[DD-]HH:]MM:SS` or `-t [[DD-]HH:]MM:SS`	Maximum walltime of the job in Days-Hours:Minutes:Sec	`--time=10:00` 10 minutes
`--mem=#`	Memory requested per node in MB	`--mem=1G`

Resumo de comandos do SLURM

- Disponível aqui



slurm® workload manager

Job Submission

salloc - Obtain a job allocation.
sbatch - Submit a batch script for later execution.
srun - Obtain a job allocation (as needed) and execute an application.

--array=<indexes> (e.g. "--array=1-10")	Job array specification. (sbatch command only)
--account=<name>	Account to be charged for resources used.
--begin=<time> (e.g. "--begin=18:00:00")	Initiate job after specified time.
--clusters=<name>	Cluster(s) to run the job. (sbatch command only)
--constraint=<features>	Required node features.
--cpus-per-task=<count>	Number of CPUs required per task.
--dependency=<state:jobid>	Defer job until specified jobs reach specified state.
--error=<filename>	File in which to store job error messages.
--exclude=<names>	Specific host names to exclude from job allocation.
--exclusive[=user]	Allocated nodes can not be shared with other jobs/users.
--export=<name[=value]>	Export identified environment variables.
--gres=<name[:count]>	Generic resources required per node.
--input=<name>	File from which to read job input data.
--job-name=<name>	Job name.
--label	Prepend task ID to output. (srun command only)
--licenses=<name[:count]>	License resources required for entire job.
--mem=<MB>	Memory required per node.
--mem-per-cpu=<MB>	Memory required per allocated CPU.
-N<minnodes[-maxnodes]>	Node count required for the job.
-n<count>	Number of tasks to be launched.
--nodelist=<names>	Specific host names to include in job allocation.
--output=<name>	File in which to store job output.
--partition=<names>	Partition/queue in which to run the job.
--qos=<name>	Quality Of Service.
--signal=[B:]<num>[@time]	Signal job when approaching time limit.
--time=<time>	Wall clock time limit.
--wrap=<command_string>	Wrap specified command in a simple "sh" shell. (sbatch command only)

Accounting

sacct - Display accounting data.

--allusers	Displays all users jobs.
--accounts=<name>	Displays jobs with specified accounts.
--endtime=<time>	End of reporting period.
--format=<spec>	Format output.
--name=<jobname>	Display jobs that have any of these name(s).
--partition=<names>	Comma separated list of partitions to select jobs and job steps from.
--state=<state_list>	Display jobs with specified states.
--starttime=<time>	Start of reporting period.

SchedMD Slurm Support and Development

sacctmgr - View and modify account information.
Options:

--immediate	Commit changes immediately.
--parseable	Output delimited by '|'

Commands:

add <ENTITY> <SPECS> create <ENTITY> <SPECS>	Add an entity. Identical to the **create** command.
delete *<ENTITY>* where *<SPECS>*	Delete the specified entities.
list <ENTITY> [<SPECS>]	Display information about the specific entity.
modify *<ENTITY>* where *<SPECS>* set *<SPECS>*	Modify an entity.

Entities:

account	Account associated with job.
cluster	*ClusterName* parameter in the *slurm.conf*.
qos	Quality of Service.
user	User name in system.

Job Management

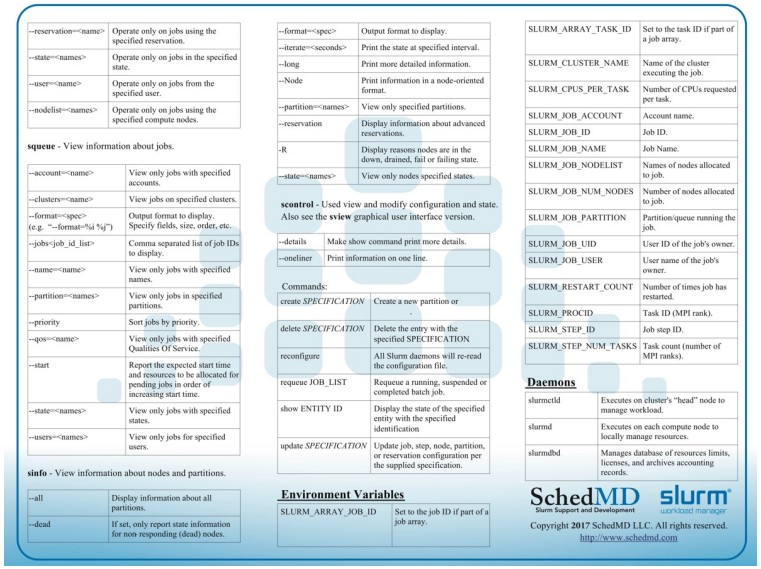
sbcast - Transfer file to a job's compute nodes.

sbcast [options] SOURCE DESTINATION

--force	Replace previously existing file.
--preserve	Preserve modification times, access times, and access permissions.

scancel - Signal jobs, job arrays, and/or job steps.

--account=<name>	Operate only on jobs charging the specified account.
--name=<name>	Operate only on jobs with specified name.
--partition=<names>	Operate only on jobs in the specified partition/queue.
--qos=<name>	Operate only on jobs using the specified quality of service.



--reservation=<name>	Operate only on jobs using the specified reservation.
--state=<names>	Operate only on jobs in the specified state.
--user=<name>	Operate only on jobs from the specified user.
--nodelist=<names>	Operate only on jobs using the specified compute nodes.

squeue - View information about jobs.

--account=<name>	View only jobs with specified accounts.
--clusters=<name>	View jobs on specified clusters.
--format=<spec> (e.g. "--format=%i %j")	Output format to display. Specify fields, size, order, etc.
--jobs<job_id_list>	Comma separated list of job IDs to display.
--name=<name>	View only jobs with specified names.
--partition=<names>	View only jobs in specified partitions.
--priority	Sort jobs by priority.
--qos=<name>	View only jobs with specified Qualities Of Service.
--start	Report the expected start time and resources to be allocated for pending jobs in order of increasing start time.
--state=<names>	View only jobs with specified states.
--users=<names>	View only jobs for specified users.

sinfo - View information about nodes and partitions.

--all	Display information about all partitions.
--dead	If set, only report state information for non responding (dead) nodes.
--format=<spec>	Output format to display.
--iterate=<seconds>	Print the state at specified interval.
--long	Print more detailed information.
--Node	Print information in a node-oriented format.
--partition=<names>	View only specified partitions.
--reservation	Display information about advanced reservations.
-R	Display reasons nodes are in the down, drained, fail or failing state.
--state=<names>	View only nodes specified states.

scontrol - Used view and modify configuration and state. Also see the **sview** graphical user interface version.

--details	Make show command print more details.
--oneliner	Print information on one line.

Commands:

create *SPECIFICATION*	Create a new partition or .
delete *SPECIFICATION*	Delete the entry with the specified SPECIFICATION
reconfigure	All Slurm daemons will re-read the configuration file.
requeue JOB_LIST	Requeue a running, suspended or completed batch job.
show ENTITY ID	Display the state of the specified entity with the specified identification
update *SPECIFICATION*	Update job, step, node, partition, or reservation configuration per the supplied specification.

Environment Variables

SLURM_ARRAY_JOB_ID	Set to the job ID if part of a job array.
SLURM_ARRAY_TASK_ID	Set to the task ID if part of a job array.
SLURM_CLUSTER_NAME	Name of the cluster executing the job.
SLURM_CPUS_PER_TASK	Number of CPUs requested per task.
SLURM_JOB_ACCOUNT	Account name.
SLURM_JOB_ID	Job ID.
SLURM_JOB_NAME	Job Name.
SLURM_JOB_NODELIST	Names of nodes allocated to job.
SLURM_JOB_NUM_NODES	Number of nodes allocated to job.
SLURM_JOB_PARTITION	Partition/queue running the job.
SLURM_JOB_UID	User ID of the job's owner.
SLURM_JOB_USER	User name of the job's owner.
SLURM_RESTART_COUNT	Number of times job has restarted.
SLURM_PROCID	Task ID (MPI rank).
SLURM_STEP_ID	Job step ID.
SLURM_STEP_NUM_TASKS	Task count (number of MPI ranks).

Daemons

slurmctld	Executes on cluster's "head" node to manage workload.
slurmd	Executes on each compute node to locally manage resources.
slurmdbd	Manages database of resources limits, licenses, and archives accounting records.

SchedMD Slurm Support and Development — slurm workload manager

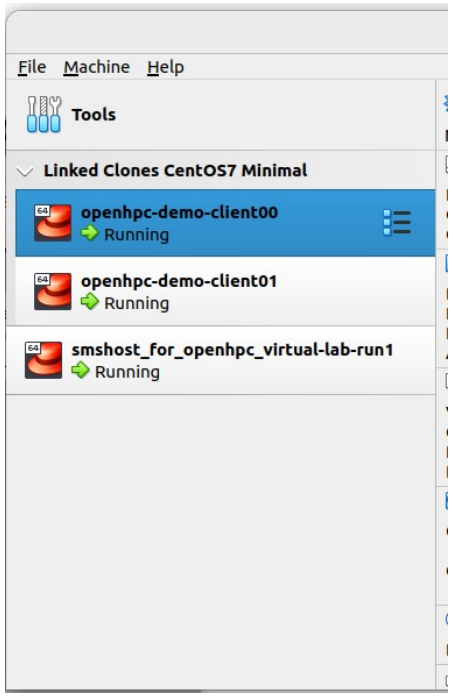
Atividade

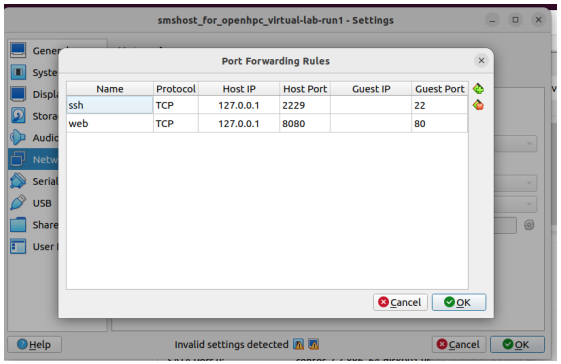
- Em nosso cluster:
  - 1 – Aprenderemos a verificar o status do cluster (sinfo, scontrol)
  - 2 – Criaremos uma nova partição (fila) para permitir que Jobs executem no máximo por 5 minutos e usando apenas 1 CPU (chamaremos essa fila de express) [modificaremos o /etc/slurm/slurm.conf no master]
  - 3 – Ampliaremos a memória disponível ao SLURM nos nós de computação
  - 4 - Submeteremos um job interativo (srun)
  - 5 – Submeteremos alguns Jobs em batch (sbatch) e monitorar a fila (squeue), além de realizar alguns comandos administrativos (scancel, shold, sactt)
  - 6 – Monitoraremos o desempenho no Ganglia

Parte prática

Inicialização

1. Inicialize as máquinas virtuais (comece pela smshost)
2. Configure o redirect da porta 8080 da sua máquina física para a 80 da sms-host
3. Vá no diretório onde há os arquivos do vagrant, e execute vagrant ssh. Com isso, você deve logar na máquina sms






```
cluster@cluster-NUC7i5DNHE:~/VagrantCluster$ vagrant ssh
Last login: Thu Nov  2 20:07:02 2023 from 10.0.2.2

This system is built by the Bento project by Chef Software
More information can be found at https://github.com/chef/bento
[vagrant@sms-host ~]$ sudo su
[root@sms-host vagrant]#
```

GIT Clone

- Alguns de nossos arquivos estão hospedados no git.
- Execute um clone na máquina master

git clone https://github.com/andrefmb/slurm_pratica.git

Verificar deamons

- Veja se o deamon slurmctld está executando

```
[root@sms-host vagrant]# systemctl status slurmctld
● slurmctld.service - Slurm controller daemon
   Loaded: loaded (/usr/lib/systemd/system/slurmctld.service; enabled; vendor preset: disabled)
   Active: active (running) since Sáb 2023-11-04 11:50:37 UTC; 11min ago
  Process: 1246 ExecStart=/usr/sbin/slurmctld $SLURMCTLD_OPTIONS (code=exited, status=0/SUCCESS)
 Main PID: 1305 (slurmctld)
   CGroup: /system.slice/slurmctld.service
           └─1305 /usr/sbin/slurmctld
```

Verificar deamons

- Veja agora, com o auxílio do pdsh, se o deamon slurmd está executando nos nós.

```
[root@sms-host vagrant]# pdsh -w compute0[0-1] systemctl status slurmd
compute01: ● slurmd.service - Slurm node daemon
compute01:    Loaded: loaded (/usr/lib/systemd/system/slurmd.service; disabled; vendor preset: disabled)
compute01:    Active: inactive (dead)
pdsh@sms-host: compute01: ssh exited with exit code 3
compute00: ● slurmd.service - Slurm node daemon
compute00:    Loaded: loaded (/usr/lib/systemd/system/slurmd.service; disabled; vendor preset: disabled)
compute00:    Active: inactive (dead)
pdsh@sms-host: compute00: ssh exited with exit code 3
[root@sms-host vagrant]#
```

- Nesse caso, não está. Então devemos executar o comando abaixo

```
[root@sms-host vagrant]# pdsh -w compute0[0-1] systemctl start slurmd
```

Verificar deamons

- Execute novamente para ver o resultado

```
[root@sms-host vagrant]# pdsh -w compute0[0-1] systemctl status slurmd
compute00: ● slurmd.service - Slurm node daemon
compute00:    Loaded: loaded (/usr/lib/systemd/system/slurmd.service; disabled; vendor preset: disabled)
compute00:    Active: active (running) since Sáb 2023-11-04 11:59:16 UTC; 3s ago
compute00:   Process: 1787 ExecStart=/usr/sbin/slurmd $SLURMD_OPTIONS (code=exited, status=0/SUCCESS)
compute00:  Main PID: 1789 (slurmd)
compute00:     Tasks: 1
compute00:    Memory: 1.0M
compute00:    CGroup: /system.slice/slurmd.service
compute00:            └─1789 /usr/sbin/slurmd
compute00:
compute00: Nov 04 11:59:16 compute00.hpcnet systemd[1]: Starting Slurm node daemon...
compute00: Nov 04 11:59:16 compute00.hpcnet systemd[1]: Started Slurm node daemon.
compute01: ● slurmd.service - Slurm node daemon
compute01:    Loaded: loaded (/usr/lib/systemd/system/slurmd.service; disabled; vendor preset: disabled)
compute01:    Active: active (running) since Sáb 2023-11-04 11:59:17 UTC; 3s ago
compute01:   Process: 1808 ExecStart=/usr/sbin/slurmd $SLURMD_OPTIONS (code=exited, status=0/SUCCESS)
compute01:  Main PID: 1810 (slurmd)
compute01:     Tasks: 1
compute01:    Memory: 1.0M
compute01:    CGroup: /system.slice/slurmd.service
compute01:            └─1810 /usr/sbin/slurmd
compute01:
compute01: Nov 04 11:59:16 compute01.hpcnet systemd[1]: Starting Slurm node daemon...
compute01: Nov 04 11:59:17 compute01.hpcnet systemd[1]: Started Slurm node daemon.
[root@sms-host vagrant]#
```

Verifique o status do cluster

- Verifique o status do cluster com sinfo

```
[root@sms-host vagrant]# sinfo
PARTITION AVAIL  TIMELIMIT  NODES  STATE NODELIST
normal*      up 1-00:00:00      2   down compute[00-01]
```

- Veja que o nó está com o STATE = DOWN. Isso provavelmente se dá porque o controlador do SLURM não atualizou o status do nó. Garanta que como root você faz ssh aos nós (compute00 e compute01). Se isso funcionar, vamos executar o comando scontrol para atualizar o status dos nós:
-

```
[root@sms-host vagrant]# scontrol update nodename=compute00 state=RESUME
[root@sms-host vagrant]# scontrol update nodename=compute01 state=RESUME
```

```
[root@sms-host vagrant]# sinfo
PARTITION AVAIL  TIMELIMIT  NODES  STATE NODELIST
normal*      up 1-00:00:00      2   idle compute[00-01]
```

Primeiro job interativo

- Vamos submeter um job interativo (srun), para executar por 1 minuto, e vamos ver qual nó o SLURM vai alocar. Vamos aguardar o SLURM finalizar nosso job pelo walltime. Aproveite para abrir uma nova aba do terminal, para monitorar a fila (squeue)

```
[root@sms-host vagrant]# su - test
Last login: Sáb Nov  4 11:53:54 UTC 2023 on pts/0
[test@sms-host ~]$ srun -N1 -t00:01:00 --pty /bin/bash
[test@compute00 ~]$
```

```
[test@sms-host ~]$ squeue
             JOBID PARTITION     NAME     USER ST       TIME  NODES NODELIST(REASON)
                39    normal     bash     test  R       0:10      1 compute00
```

Resumo de nosso job

- Vamos ver um resumo de como foi nosso job. Para isso, usamos o comando sactt <job_id>

```
[test@sms-host ~]$ sacct -j 39
       JobID    JobName  Partition    Account  AllocCPUS      State ExitCode
------------ ---------- ---------- ---------- ---------- ---------- --------
39                 bash     normal     (null)          0    TIMEOUT      0:0
```

podemos perceber que o status de nosso job é TIMEOUT, isto é, o SLURM finalizou nosso job em função do walltime.

Mudando nosso cluster

- Resgatando o sinfo, vamos ver que temos apenas uma fila normal

```
[root@sms-host vagrant]# sinfo
PARTITION AVAIL  TIMELIMIT  NODES  STATE NODELIST
normal*      up 1-00:00:00      2   idle compute[00-01]
```

- Vamos editar o arquivo /etc/slurm/slurm.conf no master, para aumentar a memória de cada nó e também criar uma nova fila

```
# OpenHPC default configuration
TaskPlugin=task/affinity
PropagateResourceLimitsExcept=MEMLOCK
AccountingStorageType=accounting_storage/filetxt
Epilog=/etc/slurm/slurm.epilog.clean
NodeName=compute0[0-1] Sockets=1 CoresPerSocket=2 RealMemory=3000 ThreadsPerCore=1 State=UNKNOWN
PartitionName=normal Nodes=compute0[0-1] Default=YES MaxMemPerNode=3000 MaxTime=24:00:00 State=UP
PartitionName=express Nodes=compute0[0-1] Default=NO MaxMemPerNode=1000 MaxTime=00:05:00  State=UP MaxNodes=1 MaxCPUsPerNode=1
ReturnToService=1
HealthCheckProgram=/usr/sbin/nhc
HealthCheckInterval=300
```

Mudando nosso cluster

- Reinicie o slurmcltd e veja se a nova fila é exibida
- Execute o comando scontrol show nodes para ver detalhes dos nós. Note as características do nó, em especial RealMemory, e veja se as duas partições (normal, express) estão alocadas para eles
-

```
[root@sms-host vagrant]# systemctl restart slurmctld
[root@sms-host vagrant]# sinfo
PARTITION AVAIL  TIMELIMIT  NODES  STATE NODELIST
normal*      up 1-00:00:00      2   idle compute[00-01]
express      up       5:00      2   idle compute[00-01]
[root@sms-host vagrant]#
```

```
[root@sms-host vagrant]# scontrol show nodes
NodeName=compute00 Arch=x86_64 CoresPerSocket=2
   CPUAlloc=0 CPUTot=2 CPULoad=0.01
   AvailableFeatures=(null)
   ActiveFeatures=(null)
   Gres=(null)
   NodeAddr=compute00 NodeHostName=compute00 Version=18.08
   OS=Linux 3.10.0-1062.el7.x86_64 #1 SMP Wed Aug 7 18:08:02 UTC 2019
   RealMemory=3000 AllocMem=0 FreeMem=1593 Sockets=1 Boards=1
   State=IDLE ThreadsPerCore=1 TmpDisk=0 Weight=1 Owner=N/A MCS_label=N/A
   Partitions=normal,express
   BootTime=2023-11-04T11:51:09 SlurmdStartTime=2023-11-04T11:59:17
   CfgTRES=cpu=2,mem=3000M,billing=2
   AllocTRES=
   CapWatts=n/a
   CurrentWatts=0 LowestJoules=0 ConsumedJoules=0
   ExtSensorsJoules=n/s ExtSensorsWatts=0 ExtSensorsTemp=n/s


NodeName=compute01 Arch=x86_64 CoresPerSocket=2
   CPUAlloc=0 CPUTot=2 CPULoad=0.01
   AvailableFeatures=(null)
   ActiveFeatures=(null)
   Gres=(null)
   NodeAddr=compute01 NodeHostName=compute01 Version=18.08
   OS=Linux 3.10.0-1062.el7.x86_64 #1 SMP Wed Aug 7 18:08:02 UTC 2019
   RealMemory=3000 AllocMem=0 FreeMem=1591 Sockets=1 Boards=1
   State=IDLE ThreadsPerCore=1 TmpDisk=0 Weight=1 Owner=N/A MCS_label=N/A
   Partitions=normal,express
   BootTime=2023-11-04T11:51:05 SlurmdStartTime=2023-11-04T11:59:17
   CfgTRES=cpu=2,mem=3000M,billing=2
   AllocTRES=
   CapWatts=n/a
   CurrentWatts=0 LowestJoules=0 ConsumedJoules=0
   ExtSensorsJoules=n/s ExtSensorsWatts=0 ExtSensorsTemp=n/s
```

Execução de programas

- Hello, World
- Vamos submete-lo interativamente:

```
[test@sms-host ~]$ srun -N1 -p express --pty ./hello_world
Hostname:compute00.hpcnet
RAM Total:3006 MB
RAM Livre:1588 MB
System uptime: 2257 segundos
```

```cpp
#include<iostream>
#include<unistd.h>
#include <sys/sysinfo.h>
using namespace std;
int main(){
        char hostname[256];
        gethostname(hostname, sizeof(hostname));
        struct sysinfo info;
        sysinfo(&info);

        cout << "Hostname:" << hostname << endl;
        cout << "RAM Total:" << info.totalram * info.mem_unit / (1024 * 1024) << " MB" << endl;
        cout << "RAM Livre:" << info.freeram * info.mem_unit / (1024 * 1024) << " MB" << endl;
        cout << "System uptime: " << info.uptime << " segundos" << endl;

        return 0;
}
```

Execução de programas

- Hello, World – agora em batch
- Vamos agora submeter em batch. Nesse caso, vamos criar um hello_world.slurm

```
[test@sms-host ~]$ squeue
             JOBID PARTITION     NAME     USER ST       TIME  NODES NODELIST(REASON)
                41   express hello_wo     test PD       0:00      1 (MaxMemPerLimit)
[test@sms-host ~]$
```

Note que nosso job está em PD (pending) e a razão é MaxMemPerLimit. Acontece que nós definimos 1000MB para um job na express e estamos pedindo 1GB. Vamos cancelar e solicitar 500MB

```
#!/bin/bash
#SBATCH --job-name=hello_world
#SBATCH --nodes=1
#SBATCH --partition=express
#SBATCH --mem=1G

echo Output do job $SLURM_JOB_ID
./hello_world
```

Execução de programas

- Para cancelar use scancel <jobid>

```
[test@sms-host ~]$ scancel 41
[test@sms-host ~]$ squeue
             JOBID PARTITION     NAME     USER ST       TIME  NODES NODELIST(REASON)
[test@sms-host ~]$ sacct -j 41
       JobID    JobName  Partition    Account  AllocCPUS      State ExitCode
------------ ---------- ---------- ---------- ---------- ---------- --------
41           hello_wor+    express     (null)          0  CANCELLED      0:0
```

- Modifique o script para 500M

```
#!/bin/bash
#SBATCH --job-name=hello_world
#SBATCH --nodes=1
#SBATCH --partition=express
#SBATCH --mem=500M

echo Output do job $SLURM_JOB_ID
./hello_world
```

```
[test@sms-host ~]$ sbatch hello_world.slurm
Submitted batch job 42
```

```
[test@sms-host ~]$ sacct -j 42
       JobID    JobName  Partition    Account  AllocCPUS      State ExitCode
------------ ---------- ---------- ---------- ---------- ---------- --------
42           hello_wor+    express     (null)          0  COMPLETED      0:0
```

```
[test@sms-host ~]$ cat slurm-42.out
Output do job 42
Hostname:compute00.hpcnet
RAM Total:3006 MB
RAM Livre:1587 MB
System uptime: 2832 segundos
```

Execução de programas

```
#!/bin/bash
#SBATCH --job-name=loop_serial
#SBATCH --nodes=1
#SBATCH --partition=express
#SBATCH --mem=500M

echo Output do job $SLURM_JOB_ID
./loop_serial
```

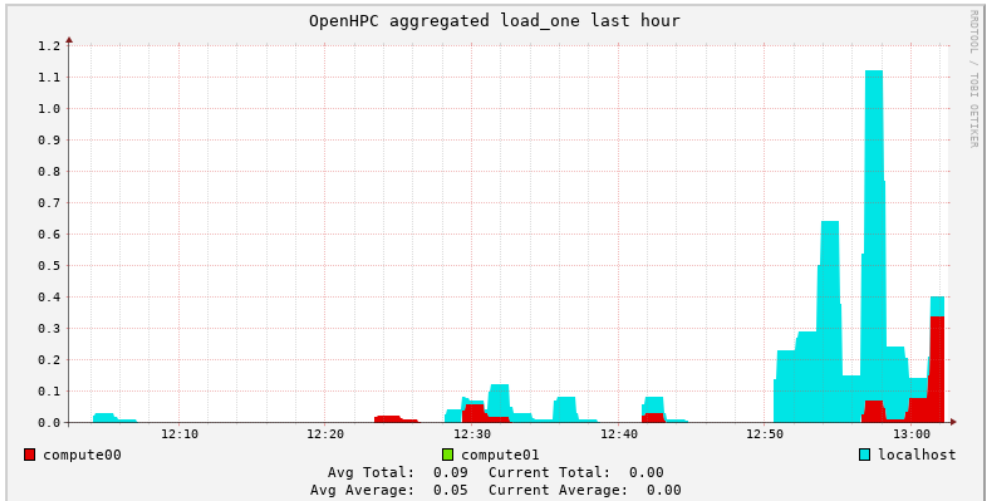
```
#include<iostream>
#include<cmath>
#include<vector>
#include<fstream>
using namespace std;

int main(){
        const int size = 50000000;
        vector<double> results(size);
        double sum = 0.0;

        for(int i = 0; i < size; ++i) {
                results[i] = sqrt(static_cast<double>(i));
                sum += results[i];

        }
        ofstream outfile("simulation_results.txt");
        for(auto &value: results){
                outfile << value << "\n";
        }
        outfile.close();
        cout << "Simulacao completa. Soma das raizes = " << sum << endl;
        return 0;
}
```

```
[test@sms-host ~]$ sbatch loop_serial.slurm
Submitted batch job 44
[test@sms-host ~]$ squeue
             JOBID PARTITION     NAME     USER ST       TIME  NODES NODELIST(REASON)
                44   express loop_ser     test  R       0:05      1 compute00
[test@sms-host ~]$
```

Execução de programas

- Não esqueça de monitorar via Ganglia

```
[test@sms-host ~]$ scontrol show job 44
JobId=44 JobName=loop_serial
   UserId=test(1001) GroupId=test(1001) MCS_label=N/A
   Priority=4294901755 Nice=0 Account=(null) QOS=(null)
   JobState=COMPLETED Reason=None Dependency=(null)
   Requeue=1 Restarts=0 BatchFlag=1 Reboot=0 ExitCode=0:0
   RunTime=00:01:05 TimeLimit=00:05:00 TimeMin=N/A
   SubmitTime=2023-11-04T12:59:22 EligibleTime=2023-11-04T12:59:22
   AccrueTime=2023-11-04T12:59:22
   StartTime=2023-11-04T12:59:22 EndTime=2023-11-04T13:00:27 Deadline=N/A
   PreemptTime=None SuspendTime=None SecsPreSuspend=0
   LastSchedEval=2023-11-04T12:59:22
   Partition=express AllocNode:Sid=sms-host:1804
   ReqNodeList=(null) ExcNodeList=(null)
   NodeList=compute00
   BatchHost=compute00
   NumNodes=1 NumCPUs=2 NumTasks=0 CPUs/Task=1 ReqB:S:C:T=0:0:*:*
   TRES=cpu=2,mem=500M,node=1,billing=2
   Socks/Node=* NtasksPerN:B:S:C=0:0:*:* CoreSpec=*
   MinCPUsNode=1 MinMemoryNode=500M MinTmpDiskNode=0
   Features=(null) DelayBoot=00:00:00
   OverSubscribe=NO Contiguous=0 Licenses=(null) Network=(null)
   Command=/home/test/loop_serial.slurm
   WorkDir=/home/test
   StdErr=/home/test/slurm-44.out
   StdIn=/dev/null
   StdOut=/home/test/slurm-44.out
   Power=
```



Execução de programas

- Loop – agora com OpenMP

```
[test@sms-host ~]$ scontrol show job 47
JobId=47 JobName=loop_serial
   UserId=test(1001) GroupId=test(1001) MCS_label=N/A
   Priority=4294901752 Nice=0 Account=(null) QOS=(null)
   JobState=COMPLETED Reason=None Dependency=(null)
   Requeue=1 Restarts=0 BatchFlag=1 Reboot=0 ExitCode=0:0
   RunTime=00:00:59 TimeLimit=00:05:00 TimeMin=N/A
   SubmitTime=2023-11-04T13:08:40 EligibleTime=2023-11-04T13:08:40
   AccrueTime=2023-11-04T13:08:40
   StartTime=2023-11-04T13:08:40 EndTime=2023-11-04T13:09:39 Deadline=N/A
   PreemptTime=None SuspendTime=None SecsPreSuspend=0
   LastSchedEval=2023-11-04T13:08:40
   Partition=express AllocNode:Sid=sms-host:1804
   ReqNodeList=(null) ExcNodeList=(null)
   NodeList=compute00
   BatchHost=compute00
   NumNodes=1 NumCPUs=2 NumTasks=1 CPUs/Task=2 ReqB:S:C:T=0:0:*:*
   TRES=cpu=2,mem=500M,node=1,billing=2
   Socks/Node=* NtasksPerN:B:S:C=0:0:*:* CoreSpec=*
   MinCPUsNode=2 MinMemoryNode=500M MinTmpDiskNode=0
   Features=(null) DelayBoot=00:00:00
   OverSubscribe=NO Contiguous=0 Licenses=(null) Network=(null)
   Command=/home/test/loop_omp.slurm
   WorkDir=/home/test
   StdErr=/home/test/slurm-47.out
   StdIn=/dev/null
   StdOut=/home/test/slurm-47.out
   Power=
```

```
#!/bin/bash
#SBATCH --job-name=loop_OMP
#SBATCH --nodes=1
#SBATCH --ntasks=1
#SBATCH --cpus-per-task=2
#SBATCH --partition=express
#SBATCH --mem=500M

echo Output do job $SLURM_JOB_ID
export OMP_NUM_THREADS=$SLURM_CPUS_PER_TASK
./loop_omp
```

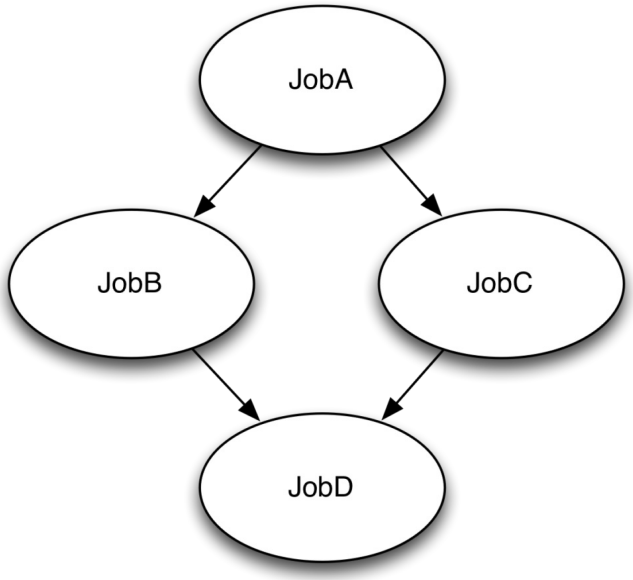
O que acontece se colocarmos –cpu-per-tasks > 2?
Lembre-se que no slurm o número de chips fisicos a serem alocados é dado por:

nro_chips = numero de nós x numero de tasks-per-node x numero de cpus-per-task

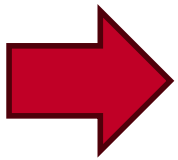
Em um job OMP, o número de nós sempre vai ser 1. Tasks-per-node deve ser 1 também e modificamos apenas o cpus-per-tasks. Mas como fazer para rodar 4 threads sem alocar 2 nós????

Dependência entre jobs

- É possível configurar dependências entre jobs e deixar com o que o SLURM determine o melhor momento de executar um job, com base no grafo de dependências.
- Vamos simular uma dependência de um novo job ao nosso loop serial



```cpp
#include<iostream>
#include<cmath>
#include<vector>
#include<fstream>
using namespace std;

int main(){
        const int size = 50000000;
        vector<double> results(size);
        double sum = 0.0;

        for(int i = 0; i < size; ++i) {
                results[i] = sqrt(static_cast<double>(i));
                sum += results[i];

        }
        ofstream outfile("simulation_results.txt");
        for(auto &value: results){
                outfile << value << "\n";
        }
        outfile.close();
        cout << "Simulacao completa. Soma das raizes = " << sum << endl;
        return 0;
}
```



```cpp
#include<iostream>
#include<fstream>
#include<vector>
#include<numeric>
#include<algorithm>
using namespace std;

int main(){
        vector<double> results;
        double value;
        ifstream infile("simulation_results.txt");
        while(infile >> value) {
                results.push_back(value);
        }
        infile.close();
        double sum = accumulate(results.begin(), results.end(), 0.0);
        double mean = sum / results.size();

        cout << "Análise completa. Média das raízes: " << mean << endl;
        return 0;

}
```

```
#!/bin/bash
#SBATCH --job-name=loop_serial
#SBATCH --nodes=1
#SBATCH --partition=express
#SBATCH --mem=500M

echo Output do job $SLURM_JOB_ID
./loop_serial


~
~
```

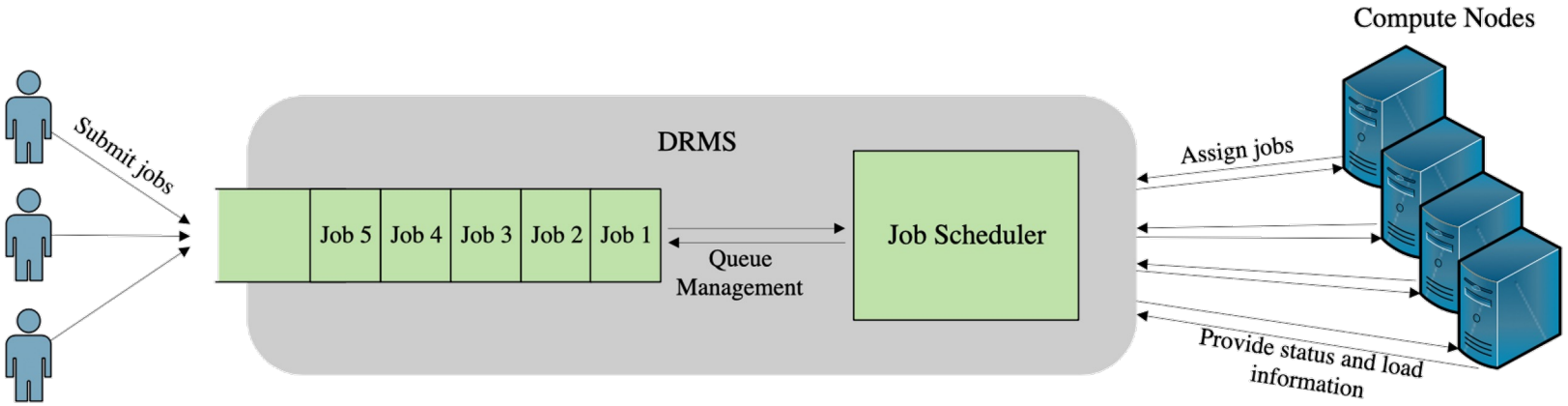
```
#!/bin/bash

#SBATCH --job-name=data_analysis
#SBATCH --partition=express
#SBATCH --output=data_analysis.out
./data_analysis
```

```
[test@sms-host ~]$ sbatch loop_serial.slurm
Submitted batch job 48
[test@sms-host ~]$ sbatch --dependency=afterok:48 data_analysis.slurm
Submitted batch job 49
[test@sms-host ~]$ squeue
             JOBID PARTITION     NAME     USER ST       TIME  NODES NODELIST(REASON)
                49   express data_ana     test PD       0:00      1 (Dependency)
                48   express loop_ser     test  R       0:19      1 compute00
[test@sms-host ~]$
```

Modificando nosso cluster – Parte II

Estamos observando que, por padrão, o SLURM aloca cada nó exclusivo a um JOB. Isto é, se temos um job que está solicitando apenas 1 core, e nosso nó possui 2 cores, ficamos com um 1 core ocioso.

Isso se dá em função do mecanismo de **scheduling** que o SLURM adota.



Modificando nosso cluster

- O que queremos mudar?

  1 – aumentar o número de cores de cada compute_node (faça isso no Virtualbox). Pare os nós, aumente para 3 cores por compute_node e inicialize as máquinas

  2 – queremos permitir que memória e cores sejam **recursos consumíveis**. Isto é, deve ser possível executar múltiplos Jobs em um nó, desde que todos os Jobs não excedam os recursos disponíveis. Para isso, vamos precisar mudar o arquivo slurm.conf, refletir esse arquivo nos nós de execução e reiniciar os deamons.

Slurm.conf (na máquina master)

```
root@sms-host:/home/vagrant
InactiveLimit=0
MinJobAge=300
KillWait=30
Waittime=0
#
# SCHEDULING
SchedulerType=sched/backfill
#SchedulerAuth=
SelectType=select/cons_res
SelectTypeParameters=CR_Core_Memory
#FastSchedule=1
#PriorityType=priority/multifactor
#PriorityDecayHalfLife=14-0
```

Aqui nós definimos que o mecanismo de alocação vai ser o de CONS_RES (recursos consumíveis) e que estes recursos são os cores da máquina e a sua memória (CR_Core_Memory)

```
Epilog=/etc/slurm/slurm.epilog.clean
NodeName=compute0[0-1] Sockets=1 CoresPerSocket=3 RealMemory=3000 ThreadsPerCore=1 State=UNKNOWN
PartitionName=normal Nodes=compute0[0-1] Default=YES MaxMemPerNode=3000 MaxTime=24:00:00 State=UP Shared=YES
PartitionName=express Nodes=compute0[0-1] Default=NO MaxMemPerNode=1000 MaxTime=00:05:00  State=UP MaxNodes=1
ReturnToService=1
```

Na linha em que definimos os nodes, garanta que CoresPerSocket seja 3.

```
Epilog=/etc/slurm/slurm.epilog.clean
NodeName=compute0[0-1] Sockets=1 CoresPerSocket=3 RealMemory=3000 ThreadsPerCore=1 State=UNKNOWN
PartitionName=normal Nodes=compute0[0-1] Default=YES MaxMemPerNode=3000 MaxTime=24:00:00 State=UP Shared=YES
PartitionName=express Nodes=compute0[0-1] Default=NO MaxMemPerNode=1000 MaxTime=00:05:00  State=UP MaxNodes=1 Shared=YES
ReturnToService=1
```

Para cada fila, garanta que temos a opção Shared=YES

Refletir as mudanças

- Desligue todos os compute nodes

- Vamos precisar copiar o slurm.conf para os nós, para que todos estejam sob a mesma configuração. Como nossos nós fazem boot por rede, você deve copiar o arquivo que está em **`/etc/slurm/slurm.conf`** para**`/install/netboot/centos7.7/x86_64/compute/rootimg/etc/slurm/`**

- Suba os nós.

Reiniciar o slurmctld

- Quando mudamos o mecanismo de scheduling do SLURM ele entra em um estado inconsistente em relação aos Jobs que já estavam executando. Dessa forma, há uma grande chance do slurmcltd não iniciar, apresentado erro.
- Esse erro é conhecido e há uma KB sobre ele, disponível aqui
- Mas na prática para resolver isso temos que fazer:
    - Iniciar o slurm com a opção –i: **`/usr/sbin/slurmctld -i`**
    - Executar o comando: **`killall slurmctld`**
    - Iniciar o slurm normalmente**`: systemctl start slurmctld`**

Vamos testar?

- Você pode submeter o job loop_serial.slurm diversas vezes. Modifique o script para ele fique da seguinte forma:

```
#!/bin/bash
#SBATCH --job-name=loop_serial
#SBATCH -c 1
#SBATCH --mem=500M

echo Output do job $SLURM_JOB_ID
./loop_serial
```

- Submeta uns 8 Jobs, e você deve ver algo parecido:

Se nosso cluster possui 6 cores, 6 Jobs devem executar simultaneamente!

```
[test@sms-host ~]$ squeue
             JOBID PARTITION     NAME     USER ST       TIME  NODES NODELIST(REASON)
                98    normal loop_ser     test PD       0:00      1 (Resources)
                99    normal loop_ser     test PD       0:00      1 (Priority)
                92    normal loop_ser     test  R       0:05      1 compute00
                93    normal loop_ser     test  R       0:04      1 compute00
                94    normal loop_ser     test  R       0:04      1 compute00
                95    normal loop_ser     test  R       0:02      1 compute01
                96    normal loop_ser     test  R       0:02      1 compute01
                97    normal loop_ser     test  R       0:02      1 compute01
[test@sms-host ~]$
```

Vamos fazer o cluster ‘trabalhar’!

Crie o arquivo ao lado, chamado long_fibo.cpp

Compile com g++ (não se esqueça que há flags omp nele!)

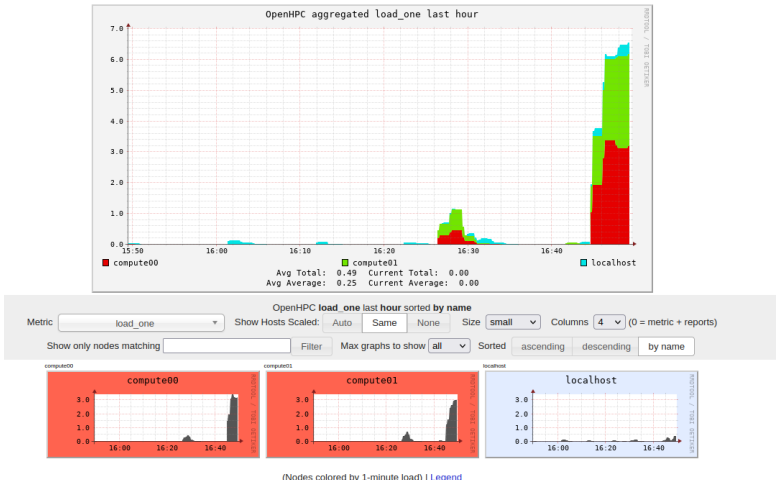
```cpp
#include<iostream>
#include<vector>
#include<omp.h>

long long fibonacci(int n){
        if (n <=1) {
                return n;
        } else {
                return fibonacci(n-1) + fibonacci(n-2);
        }
}
int main() {
        const int MAX_FIB = 100;
        #pragma omp parallel
        {
                #pragma omp for
                for(int i = 0; i < MAX_FIB; ++i){
                        long long fib_value = fibonacci(i);
                        #pragma omp critical
                        {
                                std::cout<< " Fibonacci( " << i << " ) = " << fib_value << std::endl;
                        }
                }
        }

        return 0;
}
```

Vamos fazer o cluster 'trabalhar'!

Faça um arquivo de submissão como segue:

```
#!/bin/bash
#SBATCH --job-name=long_fibo
#SBATCH --nodes=1
#SBATCH --ntasks=1
#SBATCH --cpus-per-task=1
#SBATCH --mem=200M

echo Output do job $SLURM_JOB_ID
export OMP_NUM_THREADS=$SLURM_CPUS_PER_TASK
./long_fibo
```

Submeta 6 Jobs. Acompanhe no Ganglia. Algo parecido com a imagem ao lado deve acontecer



Exercício

- Modifique o arquivo de submissão para aumentar o número de threads. Submeta Jobs de modo que se possível testar o desempenho serial, com 2 threads e com 3 threads.

- Busque controlar a fila o mais adequado possível de modo que ao menos 2 Jobs executem simultaneamente

- Coloque wall-time de 30 minutos nos Jobs. Observe nos arquivos de output até qual valor de n o Fibonacci foi calculado

- Monitore no Ganglia