# SLURM 101

or How I Learned to Stop Worrying and Love the Scheduler

**Josh Sonstroem**
Sr. Infrastructure Engineer
jsonstro@ucsc.edu

UC SANTA CRUZ

## What is SLURM

https://slurm.schedmd.com/

SLURM is an open source, fault-tolerant, highly scalable cluster management and job scheduling system for *NIX clusters.

**SLURM has 3 distinct features**

1. Allocates access to compute node resources for some period of time
2. Offers a framework for starting, executing and monitoring (often parallel) jobs on those allocated resources
3. Arbitrates contention for those resources by utilizing a queueing system to manage pending work

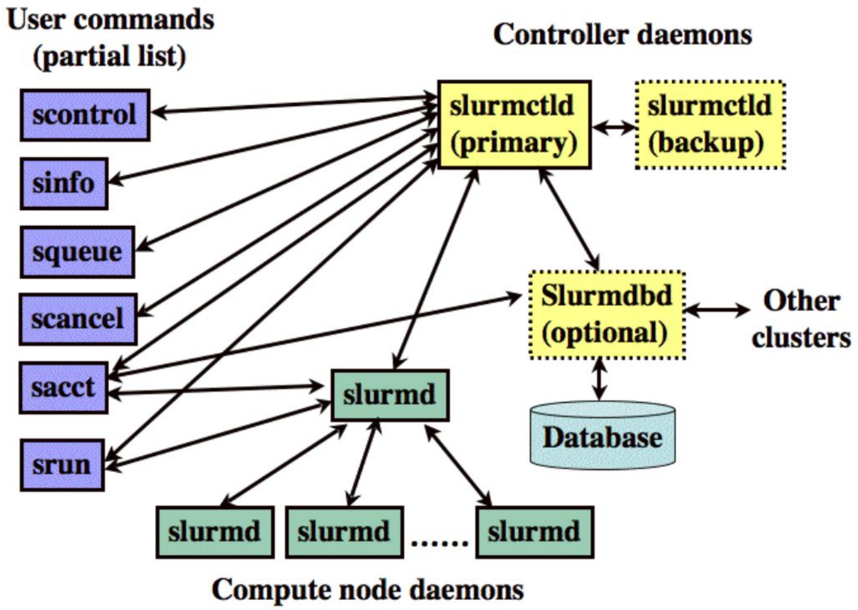
**What's in the name? S**imple **L**inux **U**tility for **R**esource **M**anagement (**SLURM**)

# SLURM Architecture

SLURM's architecture supports a distributed management model with hierarchical design and high-availability failover capabilities

It also provides a general-purpose plugin mechanism available to easily support various infrastructures

One or more physical and/or logical clusters can be managed by a single controller



## SLURM Components

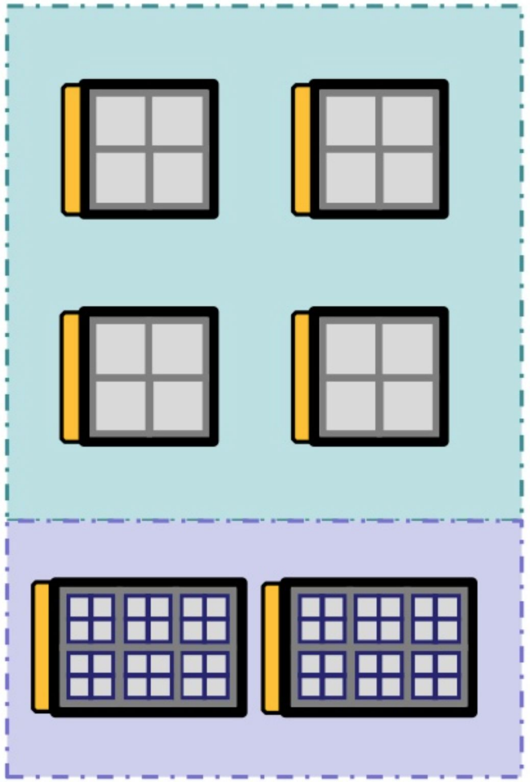
**The 4 elements of SLURM’s distributed architecture:**

1. A *centralized manager*, **slurmctld**, to monitor resources and work
2. A *backup manager* in HA configurations
3. Each *compute server (node)* has a **slurmd** daemon, which can be compared to a remote shell awaiting work, executing it and returning
4. An optional **slurmdbd** (SLURM *DataBase Daemon*) which can be used to record accounting information

***HB*** uses the backfill scheduler calculation to fit properly sized and time-limited jobs into the queues

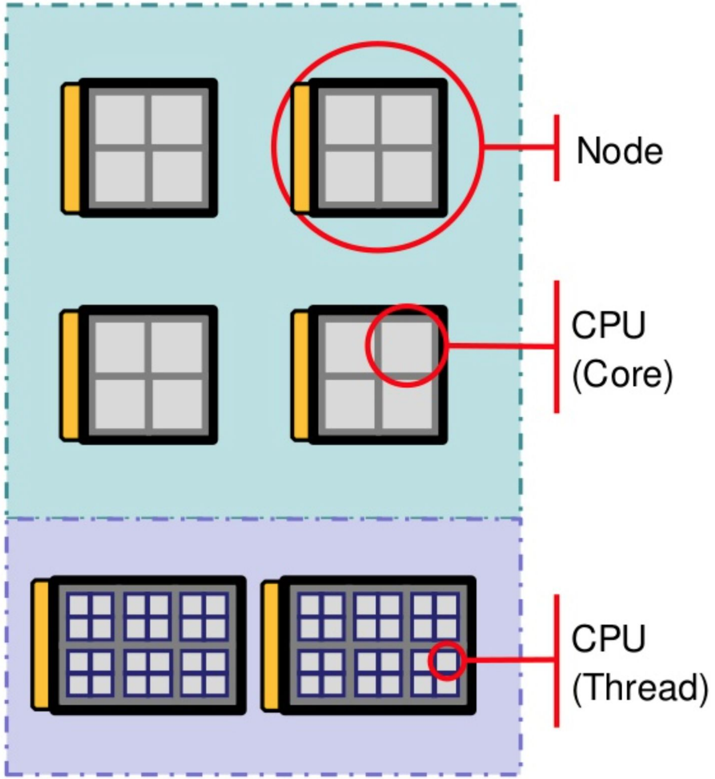
## SLURM Vocab:

- Nodes
- Partitions
- Jobs
- Job Steps



# SLURM Vocab:

- **Nodes**
- Partitions
- Jobs
- Job Steps

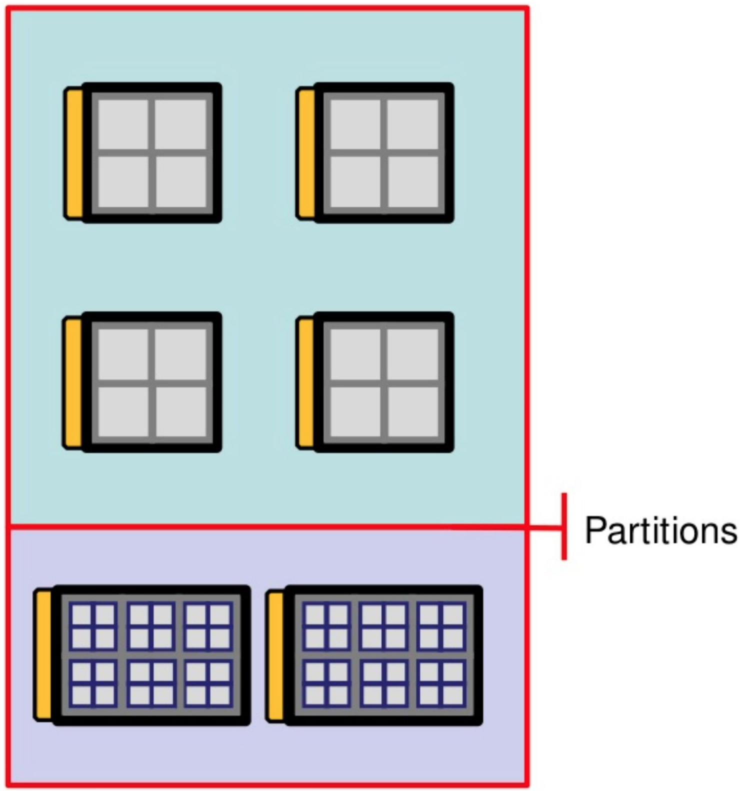


**Nodes:**

- Baseboards, Sockets, Cores, Threads
- CPUs (Core or thread)
- Memory size
- Generic resources
- Features
- State
  - Idle
  - Mix
  - Alloc
  - Completing
  - Drain / ing
  - Down

# SLURM Vocab:

- Nodes
- **Partitions**
- Jobs
- Job Steps

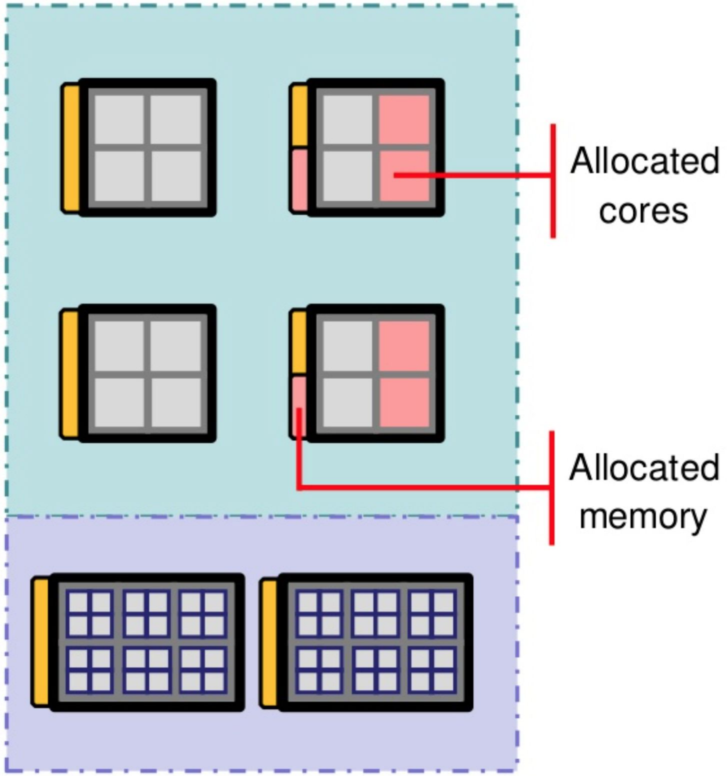


**Partitions:**

- Associated with specific set of nodes
- Nodes can be in more than one partition
- Job size and time limits
- Access control list
- State information
  - Up
  - Drain
  - Down

## SLURM Vocab:

- Nodes
- Partitions
- **Jobs**
- Job Steps

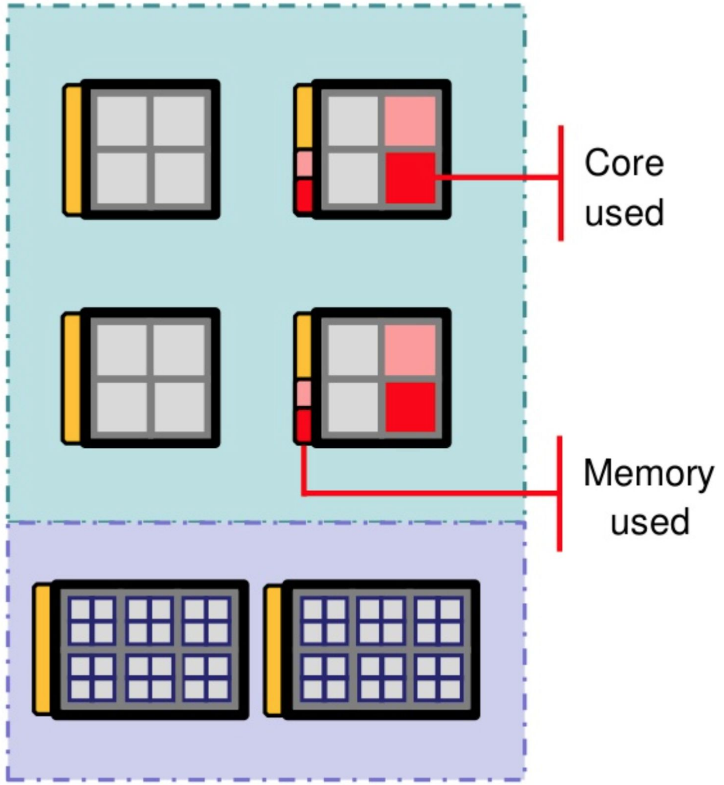


**Jobs:**

- ID (a number)
- Name
- Time limit
- Size specification
- Node features required
- Other Jobs Dependency
- Quality Of Service (QoS)
- State (Pending, Running, Suspended, Canceled, Failed, etc.)

## SLURM Vocab:

- Nodes
- Partitions
- Jobs
- **Job Steps**



**Jobs Step:**

- ID (a number)
- Name
- Time limit (maximum)
- Size specification
- Node features required in allocation

,

# SLURM Userland Tools

**On *Hummingbird* the SLURM command line (CLI) tools are loaded by default upon user login**

**These include, but are not limited to:**

1. **srun** and **sbatch** to initiate different types of compute jobs
2. **scancel** to terminate queued or running jobs
3. **sinfo** to report system status
4. **squeue** to report the status of jobs
5. **sacct** to get information about jobs and job steps that are running or have completed

## SLURM Administrative Tools

In addition to the userland tools every user has access to some administrative information via the SLURM CLI admin tools

1. **scontrol** is the tool available to monitor and/or modify configuration and state information on the cluster such as partitions (queues) and other settings as well as detailed job information and accounting
2. **sacctmgr** is tool used to manage quality of service settings as well as the bank accounting and user database

## Partitions (aka Queues) and Accounts

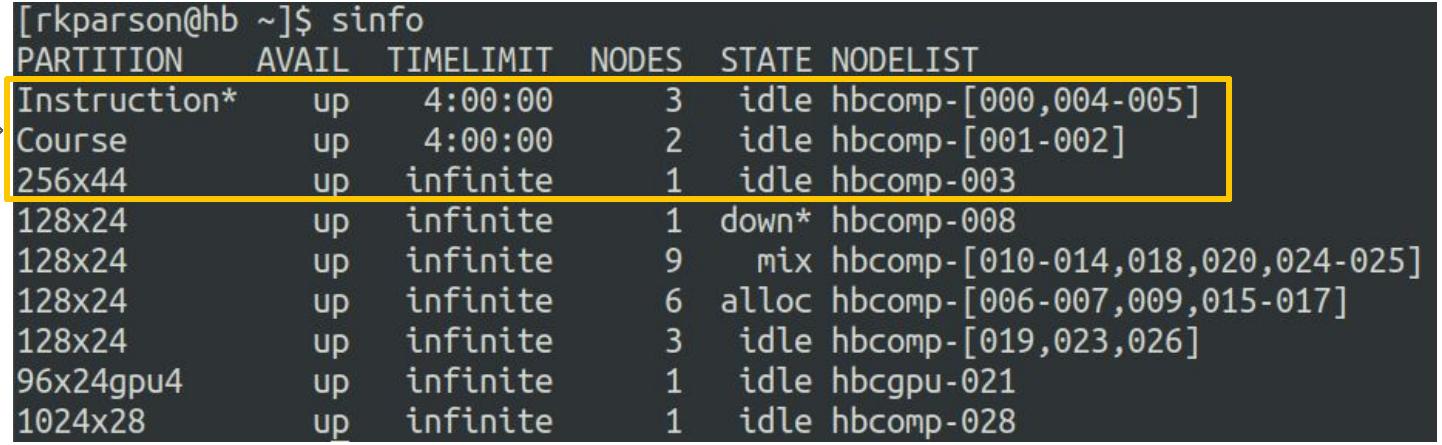
On *Hummingbird* the SLURM command line tools are loaded by default upon login

- Accounts are access groups allowing use of resources on the cluster
- Partitions are a logical unit which break up the cluster into different usable units based on the qualities or traits of different nodes or users/groups

<u>When examining the system:</u>

- To look at the partition definitions use **scontrol**
- To look at the available partitions use **sinfo**
- To look at the current and scheduled jobs use **squeue**
- To stop or cancel a current job use **scancel**
- To modify a current job use **scontrol**

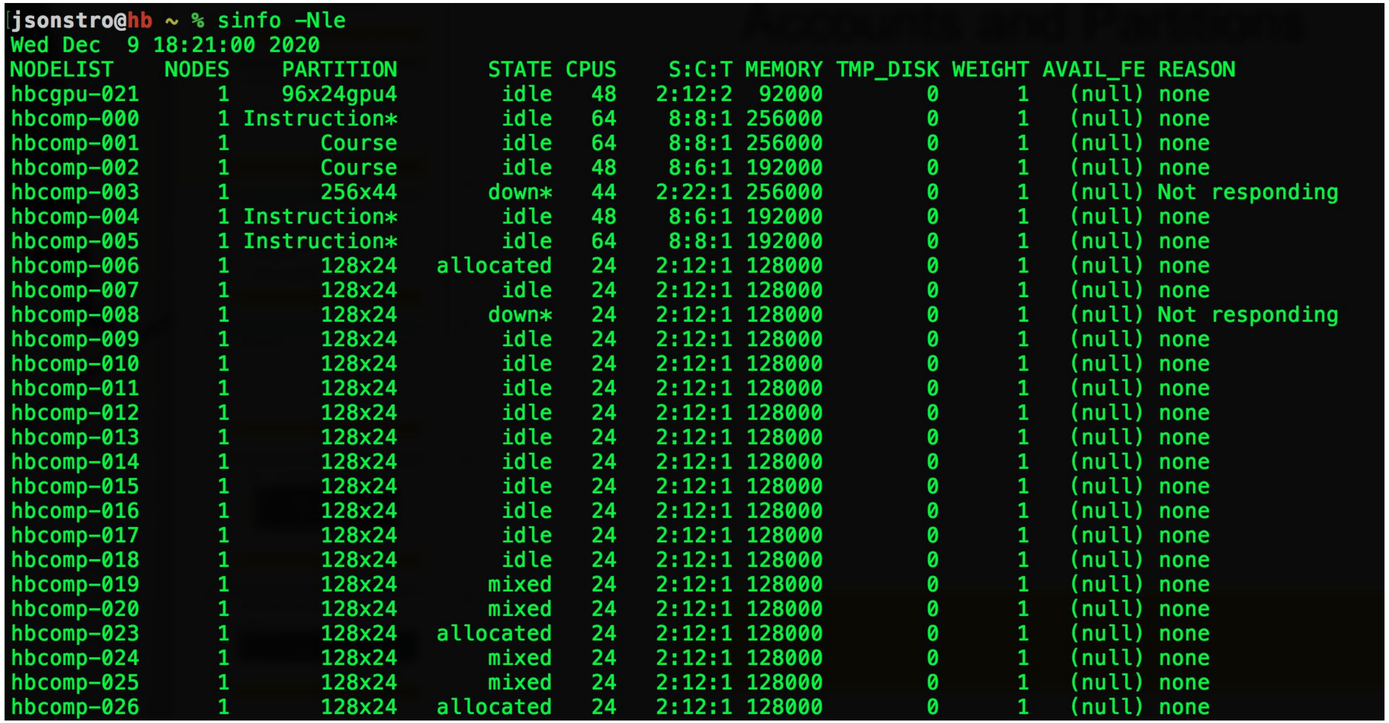
## `sinfo` - A quick way to check the cluster



```
[rkparson@hb ~]$ sinfo
PARTITION     AVAIL  TIMELIMIT  NODES  STATE NODELIST
Instruction*     up    4:00:00      3   idle hbcomp-[000,004-005]
Course           up    4:00:00      2   idle hbcomp-[001-002]
256x44           up   infinite      1   idle hbcomp-003
128x24           up   infinite      1  down* hbcomp-008
128x24           up   infinite      9    mix hbcomp-[010-014,018,020,024-025]
128x24           up   infinite      6  alloc hbcomp-[006-007,009,015-017]
128x24           up   infinite      3   idle hbcomp-[019,023,026]
96x24gpu4        up   infinite      1   idle hbcgpu-021
1024x28          up   infinite      1   idle hbcomp-028
```

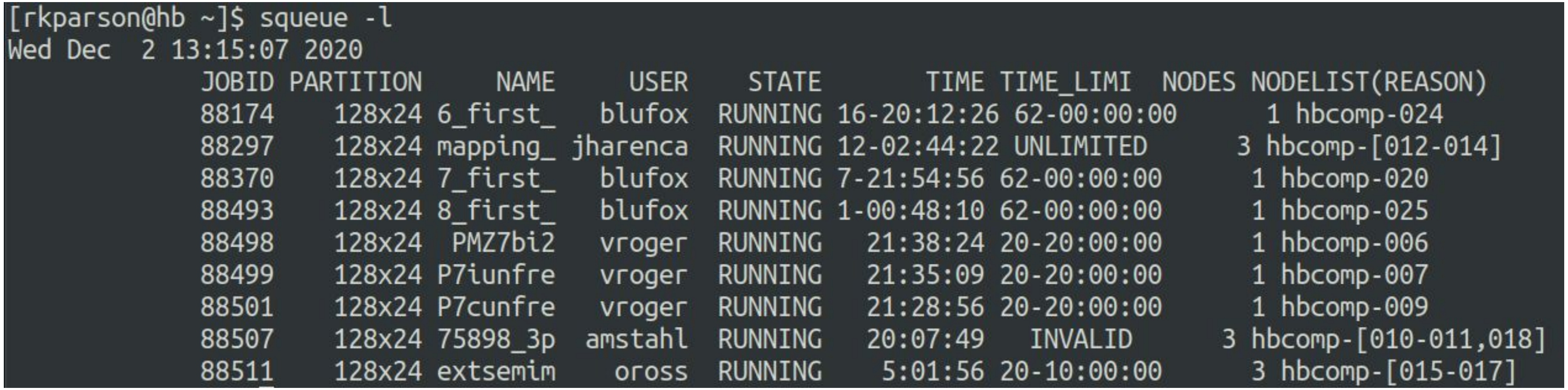
Some queues are restricted and are not for general use

## `sinfo` - Use command line options to customize



```
[jsonstro@hb ~ % sinfo -Nle
Wed Dec  9 18:21:00 2020
NODELIST    NODES   PARTITION       STATE CPUS    S:C:T MEMORY TMP_DISK WEIGHT AVAIL_FE REASON
hbcgpu-021      1    96x24gpu4       idle   48   2:12:2  92000        0      1   (null) none
hbcomp-000      1 Instruction*       idle   64    8:8:1 256000        0      1   (null) none
hbcomp-001      1       Course       idle   64    8:8:1 256000        0      1   (null) none
hbcomp-002      1       Course       idle   48    8:6:1 192000        0      1   (null) none
hbcomp-003      1       256x44      down*   44   2:22:1 256000        0      1   (null) Not responding
hbcomp-004      1 Instruction*       idle   48    8:6:1 192000        0      1   (null) none
hbcomp-005      1 Instruction*       idle   64    8:8:1 192000        0      1   (null) none
hbcomp-006      1       128x24  allocated   24   2:12:1 128000        0      1   (null) none
hbcomp-007      1       128x24       idle   24   2:12:1 128000        0      1   (null) none
hbcomp-008      1       128x24      down*   24   2:12:1 128000        0      1   (null) Not responding
hbcomp-009      1       128x24       idle   24   2:12:1 128000        0      1   (null) none
hbcomp-010      1       128x24       idle   24   2:12:1 128000        0      1   (null) none
hbcomp-011      1       128x24       idle   24   2:12:1 128000        0      1   (null) none
hbcomp-012      1       128x24       idle   24   2:12:1 128000        0      1   (null) none
hbcomp-013      1       128x24       idle   24   2:12:1 128000        0      1   (null) none
hbcomp-014      1       128x24       idle   24   2:12:1 128000        0      1   (null) none
hbcomp-015      1       128x24       idle   24   2:12:1 128000        0      1   (null) none
hbcomp-016      1       128x24       idle   24   2:12:1 128000        0      1   (null) none
hbcomp-017      1       128x24       idle   24   2:12:1 128000        0      1   (null) none
hbcomp-018      1       128x24       idle   24   2:12:1 128000        0      1   (null) none
hbcomp-019      1       128x24      mixed   24   2:12:1 128000        0      1   (null) none
hbcomp-020      1       128x24      mixed   24   2:12:1 128000        0      1   (null) none
hbcomp-023      1       128x24  allocated   24   2:12:1 128000        0      1   (null) none
hbcomp-024      1       128x24      mixed   24   2:12:1 128000        0      1   (null) none
hbcomp-025      1       128x24      mixed   24   2:12:1 128000        0      1   (null) none
hbcomp-026      1       128x24  allocated   24   2:12:1 128000        0      1   (null) none
```

## `squeue` - A view into what's running

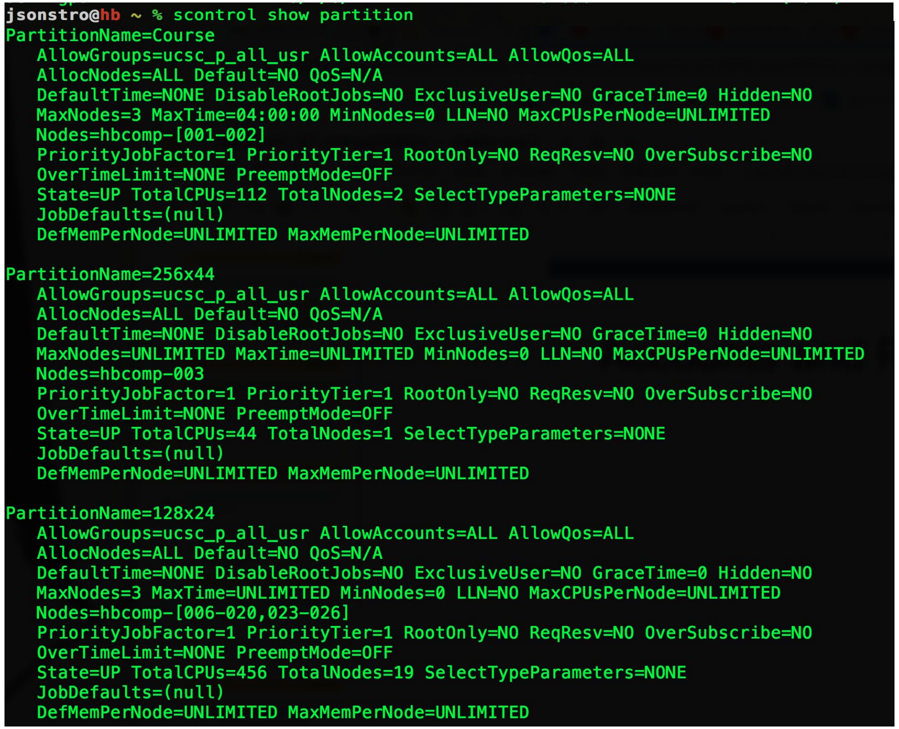


```
[rkparson@hb ~]$ squeue -l
Wed Dec  2 13:15:07 2020
             JOBID PARTITION     NAME     USER    STATE       TIME TIME_LIMI  NODES NODELIST(REASON)
             88174    128x24 6_first_   blufox  RUNNING 16-20:12:26 62-00:00:00      1 hbcomp-024
             88297    128x24 mapping_ jharenca  RUNNING 12-02:44:22 UNLIMITED      3 hbcomp-[012-014]
             88370    128x24 7_first_   blufox  RUNNING 7-21:54:56 62-00:00:00      1 hbcomp-020
             88493    128x24 8_first_   blufox  RUNNING 1-00:48:10 62-00:00:00      1 hbcomp-025
             88498    128x24  PMZ7bi2   vroger  RUNNING   21:38:24 20-20:00:00      1 hbcomp-006
             88499    128x24 P7iunfre   vroger  RUNNING   21:35:09 20-20:00:00      1 hbcomp-007
             88501    128x24 P7cunfre   vroger  RUNNING   21:28:56 20-20:00:00      1 hbcomp-009
             88507    128x24 75898_3p  amstahl  RUNNING   20:07:49   INVALID      3 hbcomp-[010-011,018]
             88511    128x24 extsemim    oross  RUNNING    5:01:56 20-10:00:00      3 hbcomp-[015-017]
```

Much easier to parse!

UC SANTA CRUZ

# `scontrol` - Understanding Partition Limits/Size



```
jsonstro@hb ~ % scontrol show partition
PartitionName=Course
   AllowGroups=ucsc_p_all_usr AllowAccounts=ALL AllowQos=ALL
   AllocNodes=ALL Default=NO QoS=N/A
   DefaultTime=NONE DisableRootJobs=NO ExclusiveUser=NO GraceTime=0 Hidden=NO
   MaxNodes=3 MaxTime=04:00:00 MinNodes=0 LLN=NO MaxCPUsPerNode=UNLIMITED
   Nodes=hbcomp-[001-002]
   PriorityJobFactor=1 PriorityTier=1 RootOnly=NO ReqResv=NO OverSubscribe=NO
   OverTimeLimit=NONE PreemptMode=OFF
   State=UP TotalCPUs=112 TotalNodes=2 SelectTypeParameters=NONE
   JobDefaults=(null)
   DefMemPerNode=UNLIMITED MaxMemPerNode=UNLIMITED

PartitionName=256x44
   AllowGroups=ucsc_p_all_usr AllowAccounts=ALL AllowQos=ALL
   AllocNodes=ALL Default=NO QoS=N/A
   DefaultTime=NONE DisableRootJobs=NO ExclusiveUser=NO GraceTime=0 Hidden=NO
   MaxNodes=UNLIMITED MaxTime=UNLIMITED MinNodes=0 LLN=NO MaxCPUsPerNode=UNLIMITED
   Nodes=hbcomp-003
   PriorityJobFactor=1 PriorityTier=1 RootOnly=NO ReqResv=NO OverSubscribe=NO
   OverTimeLimit=NONE PreemptMode=OFF
   State=UP TotalCPUs=44 TotalNodes=1 SelectTypeParameters=NONE
   JobDefaults=(null)
   DefMemPerNode=UNLIMITED MaxMemPerNode=UNLIMITED

PartitionName=128x24
   AllowGroups=ucsc_p_all_usr AllowAccounts=ALL AllowQos=ALL
   AllocNodes=ALL Default=NO QoS=N/A
   DefaultTime=NONE DisableRootJobs=NO ExclusiveUser=NO GraceTime=0 Hidden=NO
   MaxNodes=3 MaxTime=UNLIMITED MinNodes=0 LLN=NO MaxCPUsPerNode=UNLIMITED
   Nodes=hbcomp-[006-020,023-026]
   PriorityJobFactor=1 PriorityTier=1 RootOnly=NO ReqResv=NO OverSubscribe=NO
   OverTimeLimit=NONE PreemptMode=OFF
   State=UP TotalCPUs=456 TotalNodes=19 SelectTypeParameters=NONE
   JobDefaults=(null)
   DefMemPerNode=UNLIMITED MaxMemPerNode=UNLIMITED
```

**Important fields to note:**

- MaxNodes
- TotalNodes
- TotalCPUs
- Max wall clock time
- AllowGroups
- State

UC SANTA CRUZ

## Before submitting ask yourself...

- How many jobs will you need to run?
- How large will those jobs be?
  - How many cores will each job require (-n)
  - How much memory will each job require total or per cpu
  - How many nodes to accommodate these memory/core/size requirements? (-N)
- How long will each job take? (Wall time)
- What kind of execution is required -- serial or parallel?
- What is a reasonable max time to allocate to contain runaway or failure potentials?

**Accordingly, what job type best fits my workflow:** single-run, interactive, batch *or* array

- Is the software I need already available as a module?
- Are there sufficient compute resources currently available?
- Do I need access to any additional Generic RESouces (GRES) such as a GPU?

**Finally, choose your partition based on these requirements and current availability**

# Interlude - Laying out a scientific work space

HB is a shared research system and as such has some limitations and some baseline expectations for how users will behave and manage both their custom software and research data on the cluster

***HB*** IS **NOT INTENDED** AS A LONG TERM or REDUNDANT STORAGE SYSTEM FOR DATA OR CODE -- it is YOUR responsibility to backup and maintain additional copies of important bits

There are 4 primary types of data we deal with in High Performance Computing (HPC):

1. Initial data: Often sync'd from external sources (no preservation, easily replicated)
2. Intermediate data: intermediary data generated by your work (no preservation, able to be replicated)
3. Custom code/documentation: preserved/versioned in a Source Control system like *git* or *svn*)
4. Results: Final results of one's own work (long term preservation, MULTIPLE offsite backups)

Each of these types of data require different data protection, backup and long-term storage strategies and it is important to layout your workspace in a way that administrators, collaborators and "future yous" can quickly and succinctly differentiate between the types

## Interlude - Example directory structure for HPC data

## Types of Jobs - Single-Run

Single use or interactive jobs use **srun**

This can be helpful when trying to debug a batch script or problematic job step

To request an “interactive” job, if needed for debugging, use the --pty argument like so:

```
% srun -N 1 -n 1 -p 128x24 --pty bash
```

Then you will be able to ssh directly to the node and access your allocation

However, **DO NOT run your software from here manually** or your job will be killed since the management of the resources are not under SLURMs control

## Types of Jobs - Batch

Batch use or array jobs use **sbatch**

**Sbatch** can take its arguments either from command line flags or from special comments in the batch submit script or mix & match (command line args take priority)

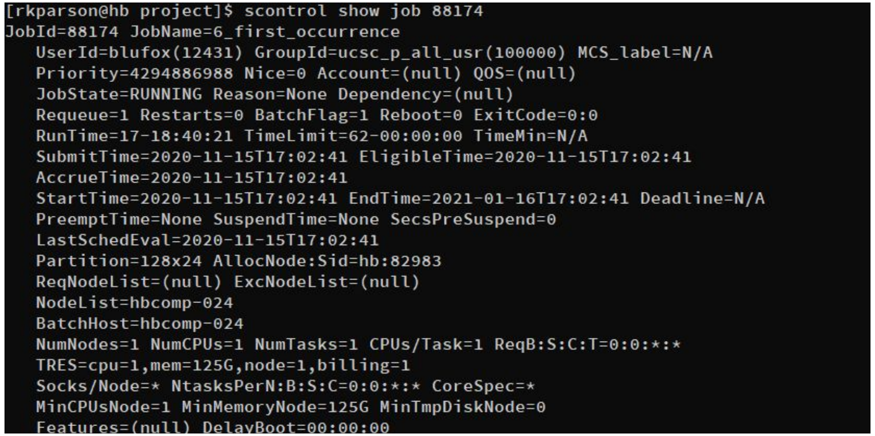
You should use a batch job anytime you have parallel work that needs doing or have an actual HPC workload that is heavy duty

## Submitting your job

```
sbatch your_job_script.slurm
```

## Verifying your job's settings

```
scontrol show job <jobid>
```



```
[rkparson@hb project]$ scontrol show job 88174
JobId=88174 JobName=6_first_occurrence
   UserId=blufox(12431) GroupId=ucsc_p_all_usr(100000) MCS_label=N/A
   Priority=4294886988 Nice=0 Account=(null) QOS=(null)
   JobState=RUNNING Reason=None Dependency=(null)
   Requeue=1 Restarts=0 BatchFlag=1 Reboot=0 ExitCode=0:0
   RunTime=17-18:40:21 TimeLimit=62-00:00:00 TimeMin=N/A
   SubmitTime=2020-11-15T17:02:41 EligibleTime=2020-11-15T17:02:41
   AccrueTime=2020-11-15T17:02:41
   StartTime=2020-11-15T17:02:41 EndTime=2021-01-16T17:02:41 Deadline=N/A
   PreemptTime=None SuspendTime=None SecsPreSuspend=0
   LastSchedEval=2020-11-15T17:02:41
   Partition=128x24 AllocNode:Sid=hb:82983
   ReqNodeList=(null) ExcNodeList=(null)
   NodeList=hbcomp-024
   BatchHost=hbcomp-024
   NumNodes=1 NumCPUs=1 NumTasks=1 CPUs/Task=1 ReqB:S:C:T=0:0:*:*
   TRES=cpu=1,mem=125G,node=1,billing=1
   Socks/Node=* NtasksPerN:B:S:C=0:0:*:* CoreSpec=*
   MinCPUsNode=1 MinMemoryNode=125G MinTmpDiskNode=0
   Features=(null) DelayBoot=00:00:00
```

That's a lot of details!

# Types of Jobs - Array

- Array jobs are a special type of batch job allowing for simultaneous execution
- A job array is a collection of jobs that differ from each other by only a single index parameter
- Job arrays provide an easy way to group related jobs together
- To specify that only a certain number of sub-jobs in the array can run at a time, use the percent sign (%) delimiter
- To submit a specific set of array sub-jobs, use the comma delimiter in the array index list
- You can specify a step size using a colon (:) in the array range for how many jobs to step

```
# Submit a job array with index values between 0 and 31
$ sbatch --array=0-31    -N1 tmp

# Submit a job array with index values of 1, 3, 5 and 7
$ sbatch --array=1,3,5,7 -N1 tmp

# Submit a job array with index values between 1 and 7
# with a step size of 2 (i.e. 1, 3, 5 and 7)
$ sbatch --array=1-7:2   -N1 tmp
```

UC SANTA CRUZ

## Array job example

We have a file with a list of paths to different files that you wish perform the same action on

You could submit a job that loops through the file on 1 node and does said action, or you could submit an **array job with an index range** with however many lines the file contains

For this example, our file contains 1000 lines:

```
#!/bin/bash
#
#SBATCH --ntasks=1
#SBATCH --partition sixhour
#SBATCH --time=6:00:00
#SBATCH --array=1-1000

LINE=$(sed -n "$SLURM_ARRAY_TASK_ID"p File.txt)
echo $LINE

call-program-name-here $LINE
```

## What are Job Steps?

- All SLURM jobs can be broken down into steps.
- Job steps are sets of (possibly parallel) tasks within a job

To limit the number of simultaneous tasks in an array use the % delimiter

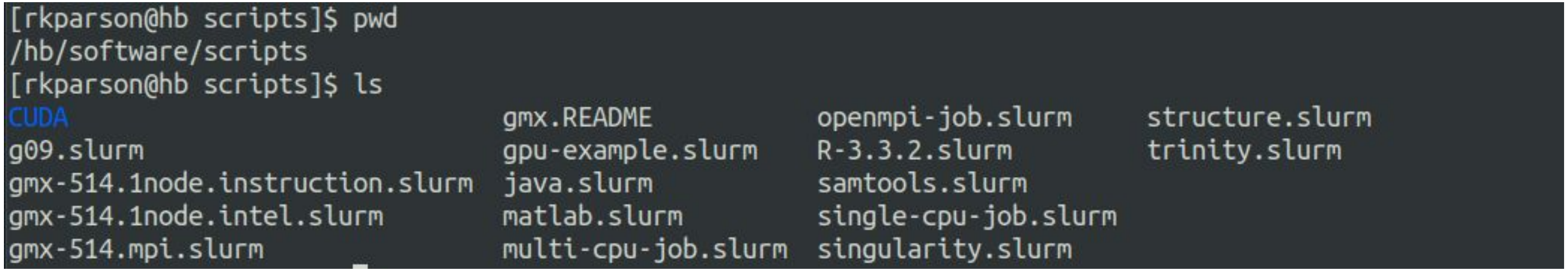
- For example "--array=0-15%4" will limit the number of simultaneously running tasks from the example job array to 4

```
$ sbatch --array [1-1000]%5 testarray.sh
```

```
516540_1
516540_2
516540_3
516540_4
516540_5
```

## *HB* Template SLURM scripts

Premade templates for your convenience. Just make a copy to your working directory and edit to meet your needs



```
[rkparson@hb scripts]$ pwd
/hb/software/scripts
[rkparson@hb scripts]$ ls
CUDA                             gmx.README            openmpi-job.slurm     structure.slurm
g09.slurm                        gpu-example.slurm     R-3.3.2.slurm         trinity.slurm
gmx-514.1node.instruction.slurm  java.slurm            samtools.slurm
gmx-514.1node.intel.slurm        matlab.slurm          single-cpu-job.slurm
gmx-514.mpi.slurm                multi-cpu-job.slurm   singularity.slurm
```

If you have a template that is useful to more than just yourself, let us know and we can include it here.

# Anatomy of a basic **sbatch** Script (Preamble)

Name of Partition to use

Name to give your run

Name for output/error logs
(use for troubleshooting)

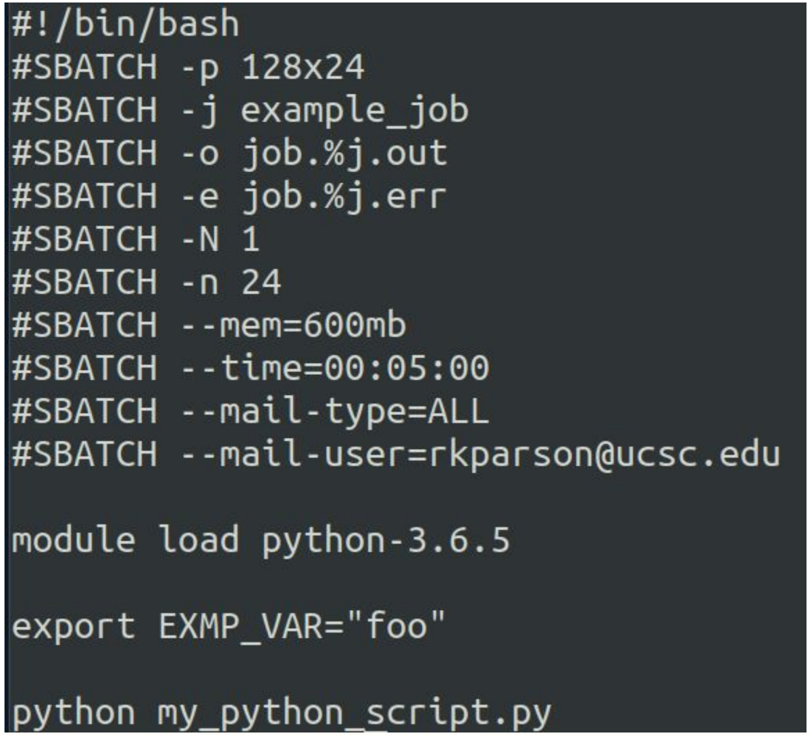
Number of nodes to request

Number of tasks your
program will require

Amount of RAM requested
for your program

Time limit for the run (!!!)

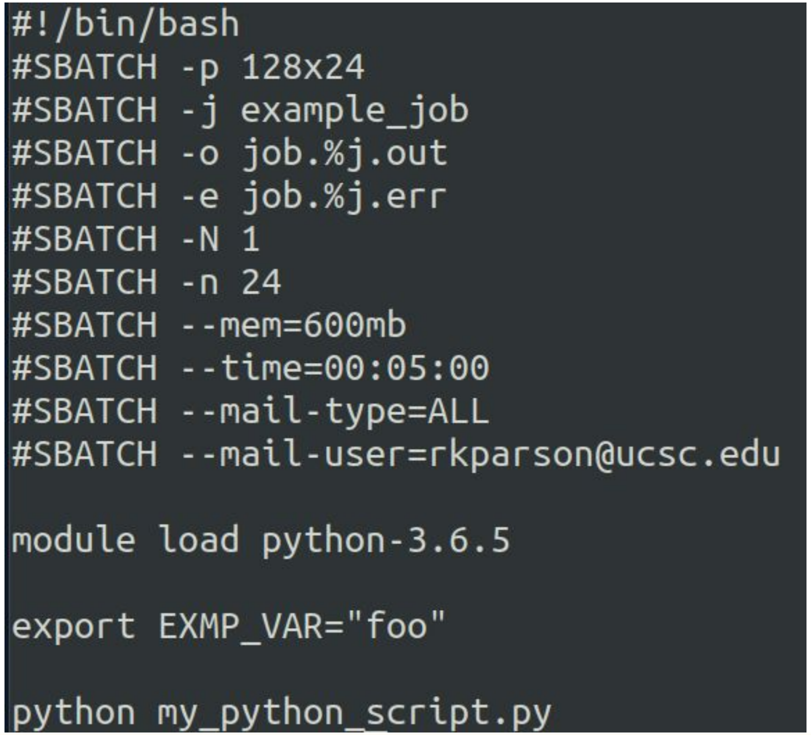
Get status emails about your job



```
#!/bin/bash
#SBATCH -p 128x24
#SBATCH -j example_job
#SBATCH -o job.%j.out
#SBATCH -e job.%j.err
#SBATCH -N 1
#SBATCH -n 24
#SBATCH --mem=600mb
#SBATCH --time=00:05:00
#SBATCH --mail-type=ALL
#SBATCH --mail-user=rkparson@ucsc.edu

module load python-3.6.5

export EXMP_VAR="foo"

python my_python_script.py
```

UC SANTA CRUZ

## Anatomy of a basic **sbatch** Script



```
#!/bin/bash
#SBATCH -p 128x24
#SBATCH -j example_job
#SBATCH -o job.%j.out
#SBATCH -e job.%j.err
#SBATCH -N 1
#SBATCH -n 24
#SBATCH --mem=600mb
#SBATCH --time=00:05:00
#SBATCH --mail-type=ALL
#SBATCH --mail-user=rkparson@ucsc.edu

module load python-3.6.5

export EXMP_VAR="foo"

python my_python_script.py
```

Any modules your program requires in order to run

Any system variables your program might require

The program to run

UC SANTA CRUZ

## Some helpful detailed sinfo/squeue aliases

**BASH version**

```
# User specific aliases and functions
alias si="sinfo -o \"%20P %5D %14F %8z %10m %10d %11l %32f %N\""
alias si2="sinfo -o \"%20P %5D %6t %8z %10m %10d %11l %32f %N\""
alias sq="squeue -o \"%8i %12j %4t %10u %20q %20a %10g %20P %10Q %5D %11l %11L %R\""
alias sq2="squeue --long -o \"%.8i %.12P %.12a %.12q %.8j %.8u %.8T %.10M %.12l %.6D %.10Q %.20R\""
```

**TCSH version**

```
alias si 'sinfo -o "%20P %5D %14F %8z %10m %11l %32f %N"'
alias si2 'sinfo -o "%20P %5D %6t %8z %10m %10d %11l %32f %N"'
alias sq 'squeue -o "%8i %12j %4t %10u %20q %20a %10g %20P %10Q %5D %11l %11L %R"'
alias sq2 'squeue --long -o "%.8i %.12P %.12a %.12q %.8j %.8u %.8T %.10M %.12l %.6D %.10Q %.20R"'
```

## SLURM with MPI, threaded, or OpenMP (shared memory) Jobs

SLURM supports multiple frameworks for parallel execution including the industry standard OpenMPI (message passing interface) and OpenMP for threaded or shared memory workloads. There are a number of options available to optimize these types of workloads (and the details get complex quick):

OpenMPI jobs can use multiple processors that may, or may not, be on multiple compute nodes:

- The SLURM --ntasks flag specifies the number of MPI tasks created for your job, which can end up on different nodes
- For more control over how SLURM lays out your job, you can add the --nodes and --ntasks-per-node flags
    - --nodes specifies how many nodes to allocate to your job and SLURM will allocate your requested number of cores to a minimal number of nodes on the cluster

For OpenMP Shared memory applications they can only run on a single node:

- You must set --ntasks=1, and then set --cpus-per-task to the number of threads you wish to use
- You must make the application aware of how many processors to use which depends on the application:
    - For some applications, set OMP_NUM_THREADS to a value less than or equal to the # of --cpus-per-task you set
    - For some applications, use a command line option when calling that application

## Knowing your Hummingbird variants

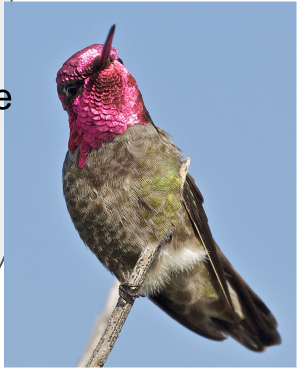
### hb.ucsc.edu

- Cluster login node
- Used for:
  - Compiling your code
  - Submitting jobs
  - Checking the status on your submitted jobs

### hbfeeder.ucsc.edu

- Cluster storage node and data transfer node (DTN)
- Used for:
  - Accessing your data when you don't need the cluster
  - Transferring your data to or from the cluster

"Violet-tailed Sylph resting on a branch in northwestern Ecuador"
https://en.wikipedia.org/wiki/File:Violet-tailed_Sylph_2_JCB.jpg


Male Anna's Hummingbird
https://en.wikipedia.org/wiki/File:AnnasHummingbirdPaloAltoNorvig.jpg

UC SANTA CRUZ

## Thank you!!! Questions, Comments???

## DO Set time limits on your jobs

In the event of a run-away job, this keeps it contained and keeps us admins happy

## DON'T Overprovision

Request only the resources you need

This is especially true for the GPU node! There are four GPUs, but if you're only using one, you need to declare it so that the other three are available to others!

## DON'T Leave data in Scratch

You are encouraged to use the scratch space when compiling your code or post-processing your results
Note however, that the scratch storage is NOT GUARANTEED
We regularly purge the contents of scratch based on age - if your stuff is languishing in there being unused, it will be deleted

UC SANTA CRUZ