Slurm Priority, Fairshare and Fair Tree

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Agenda

- Job Prioritization
- Fairshare
- Fair Tree

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- Fairshare
- Fair Tree

Why Prioritize?

- Because **NOT** all clusters have 200,000 nodes

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- **NOT** on the Top 500 list


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Slurm Job Prioritization Discussion

- FIFO by default
- Priority Plugins define Slurm's behavior:
  - Priority/basic - Provides rudimentary FIFO scheduling (default)
  - Priority/multifactor - Sets priority based on:

- Job Age
- Fairshare
- Job Size
- Queue/Partition
- QOS
- TRES
- Nice
- Assoc (19.05)
- Site (19.05)

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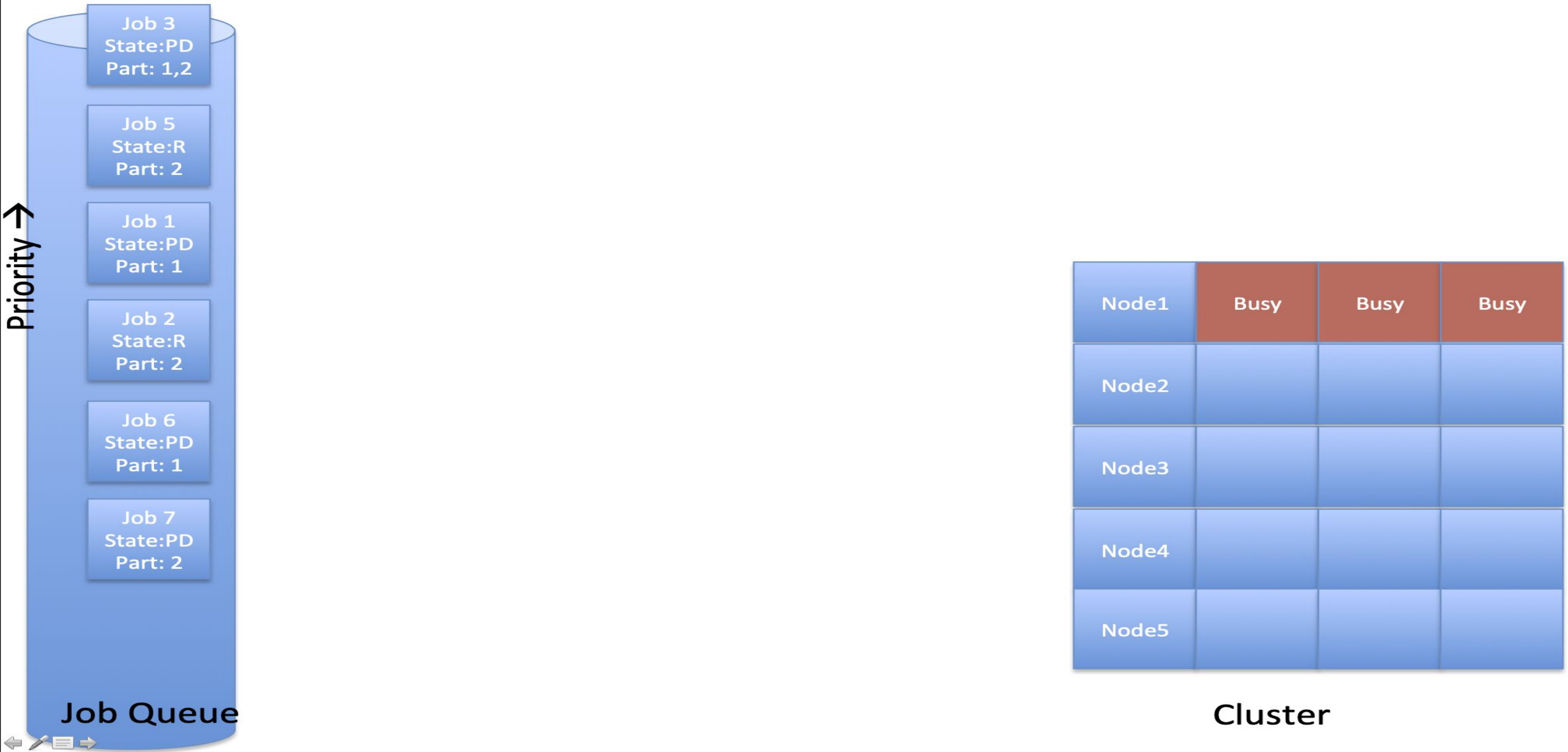
- Nice
- Assoc (19.05)
- Site (19.05)

Job Prioritization Discussion

- Define the plugin in slurm.conf:

```
PriorityType=priority/basic # Default
or
PriorityType=priority/multifactor
```

Slurm Quick Scheduling Iteration



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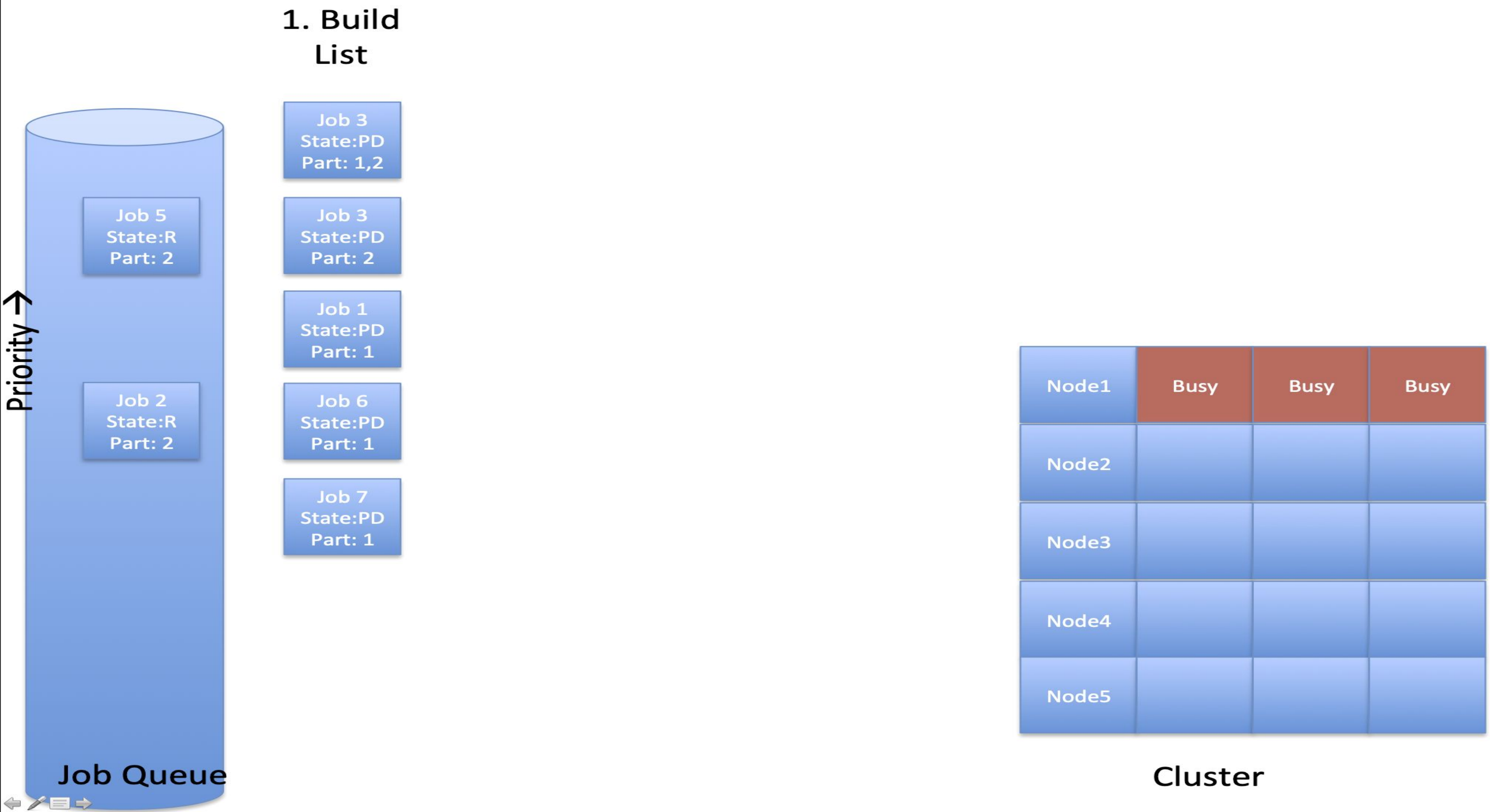

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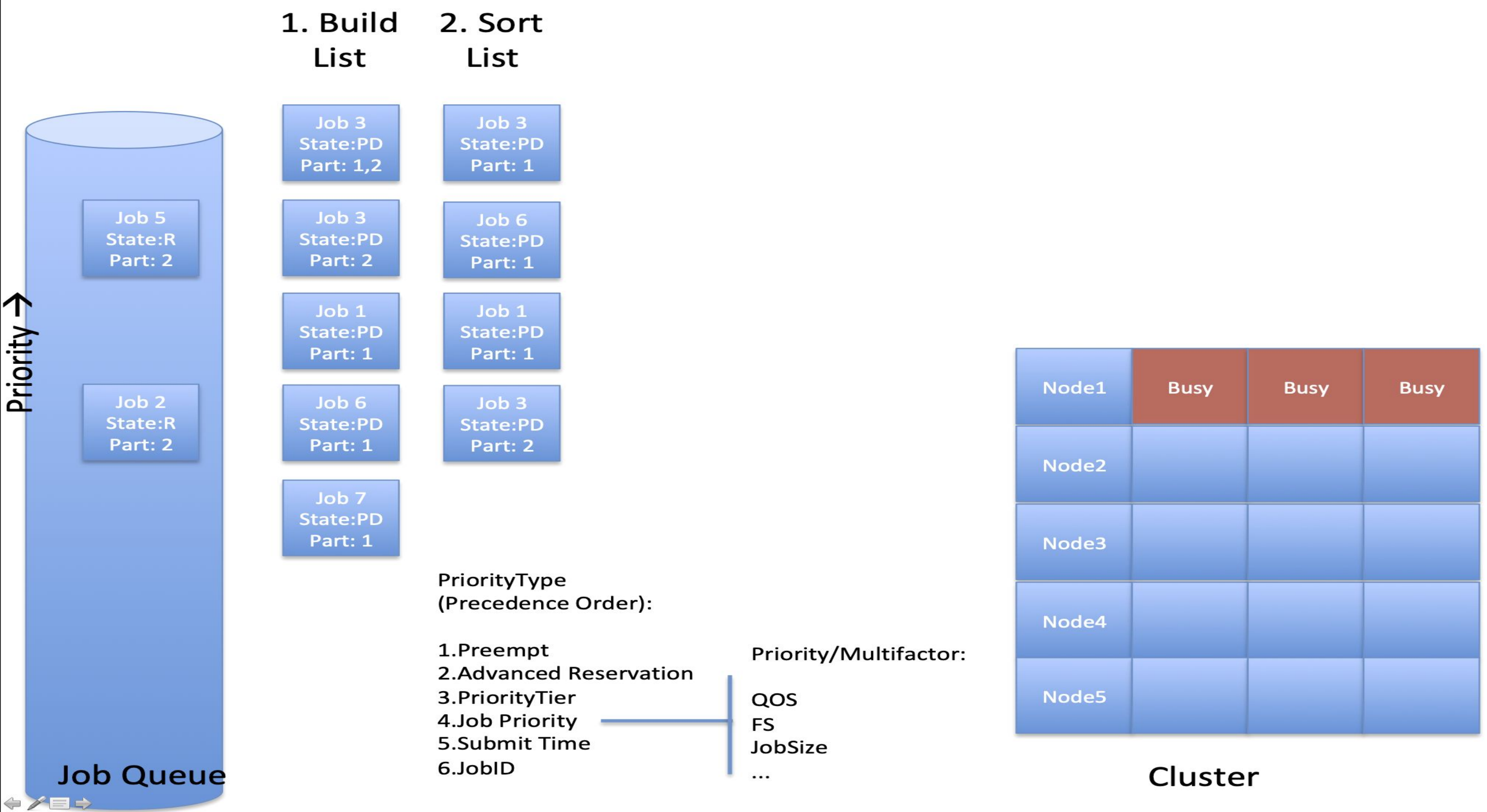
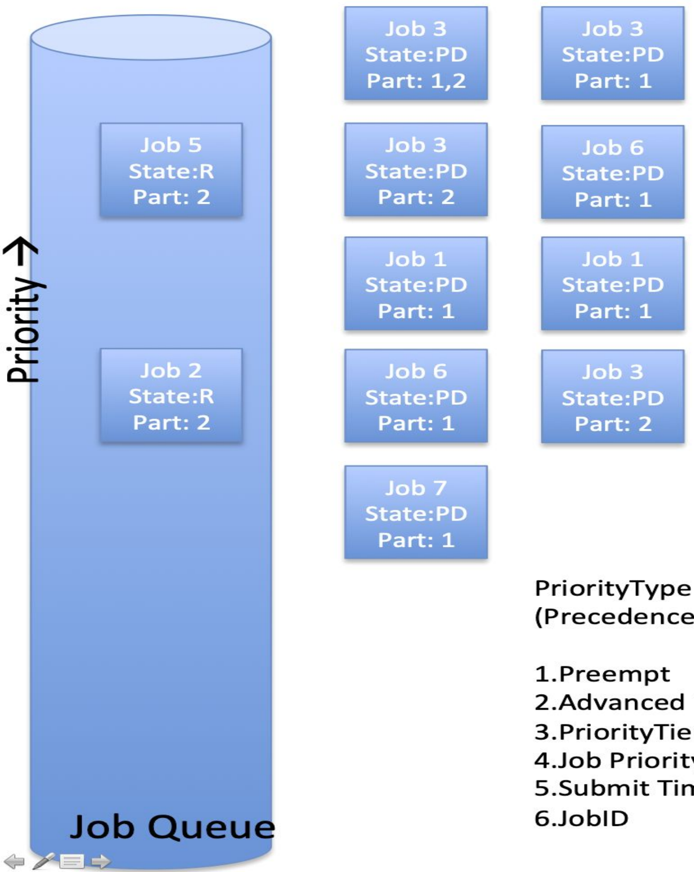


Slurm Quick Scheduling Iteration

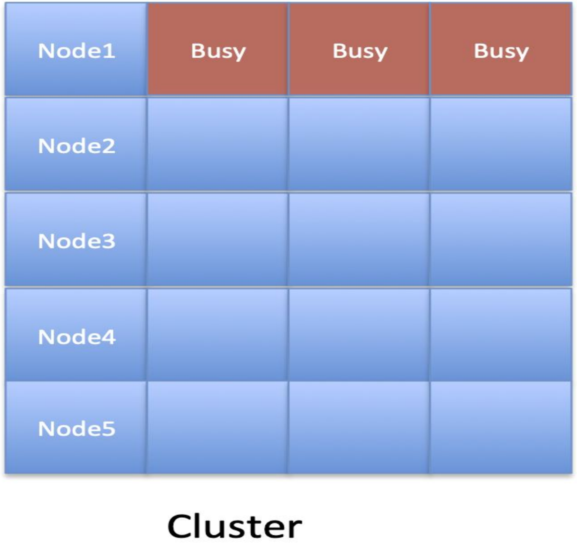
1. Build List   2. Sort List



3. Schedule

SchedulerParameters=default_queue_depth=4

```
until(DefaultQueueDepth) {
  pop 1 job from list
  try to schedule...
    call select plugin
}
```



PriorityType
(Precedence Order):

1. Preempt
2. Advanced Reservation
3. PriorityTier
4. Job Priority
5. Submit Time
6. JobID

Priority/Multifactor:

QOS
FS
JobSize
...

Slurm Quick Scheduling Iteration

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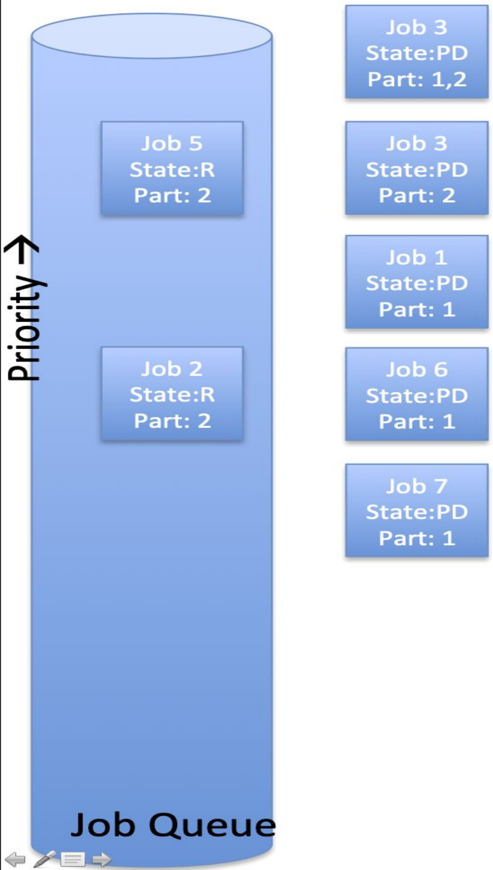


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FS
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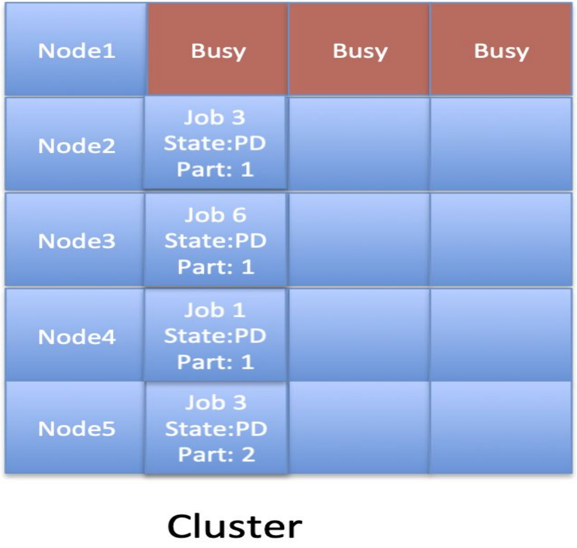
...



Job Prioritization Factors

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

Job Prioritization Factors - Cont’d

TRES - Each TRES Type has it's own factor for a job which represents the number of requested/allocated TRES Type in a given partition
Nice - Users can adjust the priority of their own jobs by setting the nice value on their jobs
Association - Each association can be assigned an integer priority
Site - Can be set either using scontrol, through a job_submit or site_factor plugin

Job Prioritization Value Calculation

```
Job_priority =
    (PriorityWeightAge) * (age_factor) +
    (PriorityWeightFairshare) * (fair-share_factor) +
    (PriorityWeightJobSize) * (job_size_factor) +
    (PriorityWeightPartition) * (partition_factor) +
    (PriorityWeightQOS) * (QOS_factor) +
    SUM(TRES_weight_cpu * TRES_factor_cpu,
        TRES_weight_<type> * TRES_factor_<type>,
        ...)
```

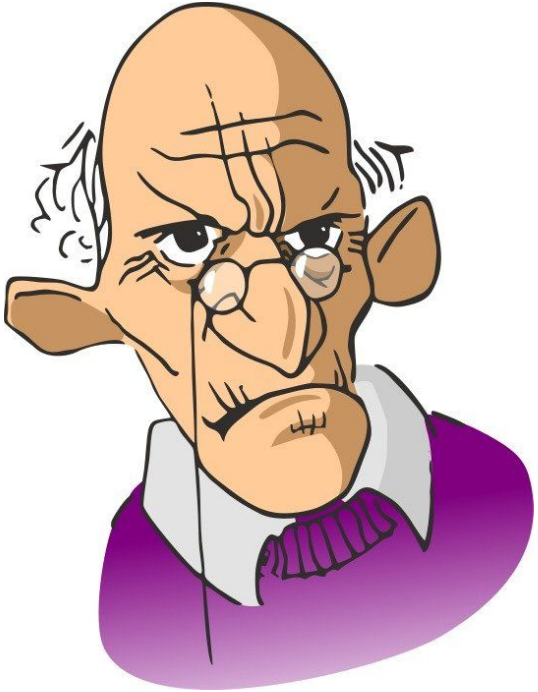
Notes on Prioritization

- All **factors** in the formula are floating point numbers 0.0-1.0
- **Weights** are unsigned 32-bit integers
- Slurm priority is **normalized***

*Can be turned off for some priority calculations in 19.05.x code

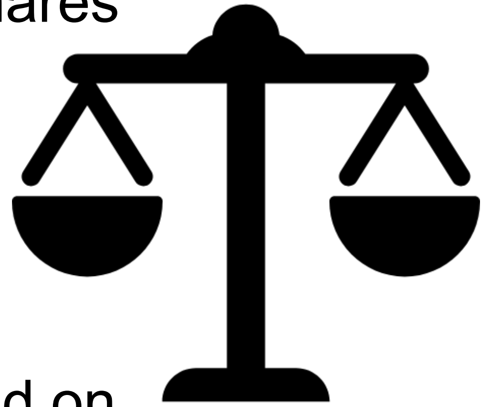
Age Factor

- Length of time a job has been sitting in the queue, eligible to run
- Age factor for dependencies does not change while it waits on the depended job to complete
- At PriorityMaxAge, the age factor max's out at 1.0. The default is 7 days, meaning after 7 days, all jobs get the same age-based priority



Fairshare Factor

- Fairshare calculation in Slurm requires the Slurm Accounting Database to provide the assigned shares and the consumed computing resources
- Takes into consideration computing resources allocated and computing resources already consumed
- The fairshare factor prioritizes queued jobs based on under/over utilization



Fairshare Factor (Cont'd)

- Fairshare factor is a floating point number between 0.0 and 1.0
- You can configure TRESBillingWeights on a partition to account for consumed resources other than just CPUs
- For example, the following jobs on a partition configured with TRESBillingWeights=CPU=1.0,Mem=0.25G and 16CPU, 64GB nodes would be billed as:

```
         CPUs         Mem GB
Job1: (1 *1.0) + (60*0.25) = (1 + 15) = 16
Job2: (16*1.0) + (1 *0.25) = (16+.25) = 16.25
Job3: (16*1.0) + (60*0.25) = (16+ 15) = 31
```

Job Size Factor

- Correlates to the number of nodes or CPUs requested
- Can favor either larger or smaller jobs, depending on PriorityFavorSmall=yes/no
- A job that requests all the nodes gets a job size factor of 1.0
- If PriorityFavorSmall=yes, a single node job will get a job size factor of 1.0

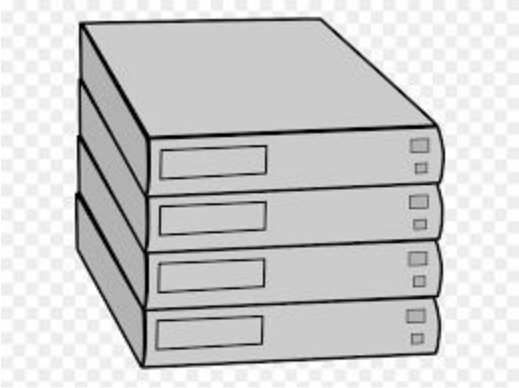
Job Size Factor - Cont'd

- Can alter scheduler job size factor behavior by setting: PriorityFlags=SMALL_RELATIVE_TO_TIME :

$$\frac{\left(\dfrac{\texttt{job size in CPUs}}{\texttt{time limit in minutes}}\right)}{\texttt{total cpus in cluster}} = \texttt{Job Size Factor}$$

- A full-system job with a time limit of 1 will receive a job size factor of 1.0, while a tiny job with a large time limit will receive a job size factor closer to 0.0

Partition Factor (priority job factor on a partition)



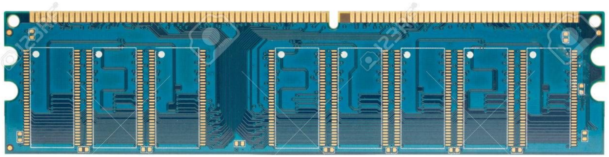
- Each partition (queue) can be assigned an integer priority
- The larger the number, the greater the job priority will be for jobs that request to run in this partition
- The priority is then **normalized** to the highest priority of all the partitions to become the partition factor

Quality of Service (QOS) Factor

- Each QOS can be assigned an integer priority
- The larger the number, the greater the job priority will be for jobs requesting that QOS
- The priority is then **normalized** to the highest priority of all the QOSs to become the QOS factor

TRES Factors

- Each TRES Type has its own priority factor which represents the amount of TRES Type requested/allocated in a given partition
- For globals, like Licenses, the factor represents the number of TRES Type requested/allocated in the whole system
- The more TRES Type is requested/allocated on a job, the greater the job priority will be for that job



Nice Factor

- Users can adjust the priority of their own jobs by setting the nice value on their jobs
- Like the system nice, positive values negatively impact a job's priority and positive values increase a job's priority
- Only privileged users can specify a negative value
- The adjustment range is +/-2147483645.

Association Factor

- Each association can be assigned an integer priority
- The larger the number, the greater the job priority will be for jobs that request this association
- This priority value is normalized to the highest priority of all the association to become the association factor

Site Factor

- The site factor is a factor that can be set either using scontrol, through a job_submit or site_factor plugin
- An example use case, might be a job_submit plugin that sets a specific priority based on how many resources are requested

QOS Priority Calculation Example

```
PriorityType=priority/multifactor
PriorityWeightQOS=1000
```

```
$>sprio -w
          JOBID PARTITION   PRIORITY       SITE        QOS
        Weights                               1       1000
```

QOS Priority Calculation Example-Cont'd

```
$>sacctmgr -i add qos high set priority=1000
$>sacctmgr -i add qos medium set priority=500
$>sacctmgr -i add qos low set priority=100
$>sacctmgr -i modify account bedrock set qos=low
$>sacctmgr -i modify account bedrock set defaultqos=low
```

```
$>sacctmgr show qos format=name,priority
      Name   Priority
---------- ----------
    normal          0
      high       1000
    medium        500
       low        100
```

QOS Priority Calculation Example-Cont’d

```
$>sacctmgr -i modify user fred,barney set qos=high,medium,low
$>sacctmgr -i modify user wilma,betty set qos=medium,low
```

```
$>sacctmgr list assoc user=fred,barney,wilma,betty,bambam,pebbles
format=Cluster,Account,User,QOS,defaultqos
   Cluster    Account       User                  QOS   Def QOS
---------- ---------- ---------- -------------------- ---------
   cluster    bedrock     bambam                  low       low
   cluster    bedrock     barney      high,low,medium       low
   cluster    bedrock      betty           low,medium       low
   cluster    bedrock       fred      high,low,medium       low
   cluster    bedrock    pebbles                  low       low
   cluster    bedrock      wilma           low,medium       low
```

QOS Priority Calculation Example-Cont'd

```
$>sprio -o "%.15i %9r %.8u %.10Y"

          JOBID PARTITION     USER   PRIORITY
              2 debug         fred    1000000
              3 debug       barney    1000000
              4 debug        wilma     500000
              5 debug        betty     500000
              6 debug       bambam     100000
              7 debug       pebbles    100000
```

QOS Priority Calculation Example-Cont'd

- The Math:

```
Job_priority =
    ...(PriorityWeightQOS) * (QOS_factor) + ...)
       1000                    1000/1000 = 1.0 (for fred)
                                        Or, 100% of PriorityWeightQOS
      From slurm.conf          priority/highest QOS Prio

       1000                    500/1000 = .50 (for wilma)
                                        Or, 50% of PriorityWeightQOS
      From slurm.com           priority/highest QOS Prio

       1000                    100/1000 = .10 (for bambam)
                                        Or, .10% of PriorityWeightQOS
      From slurm.conf           priority/highest QOS Prio
```

Priority Change in 19.05

- PriorityFlags = NO_NORMAL_ALL
  - NO_NORMAL_ALL If set, all NO_NORMAL_* flags are set.
  - NO_NORMAL_ASSOC If set, the association factor is **not** normalized against the highest association priority.
  - NO_NORMAL_PART If set, the partition factor is **not** normalized against the highest partition PriorityTier.
  - NO_NORMAL_QOS If set, the QOS factor is **not** normalized against the highest qos priority.
  - NO_NORMAL_TRES If set, the QOS factor is **not** normalized against the job's partition TRES counts.

QOS Priority Calculation Example-Cont’d

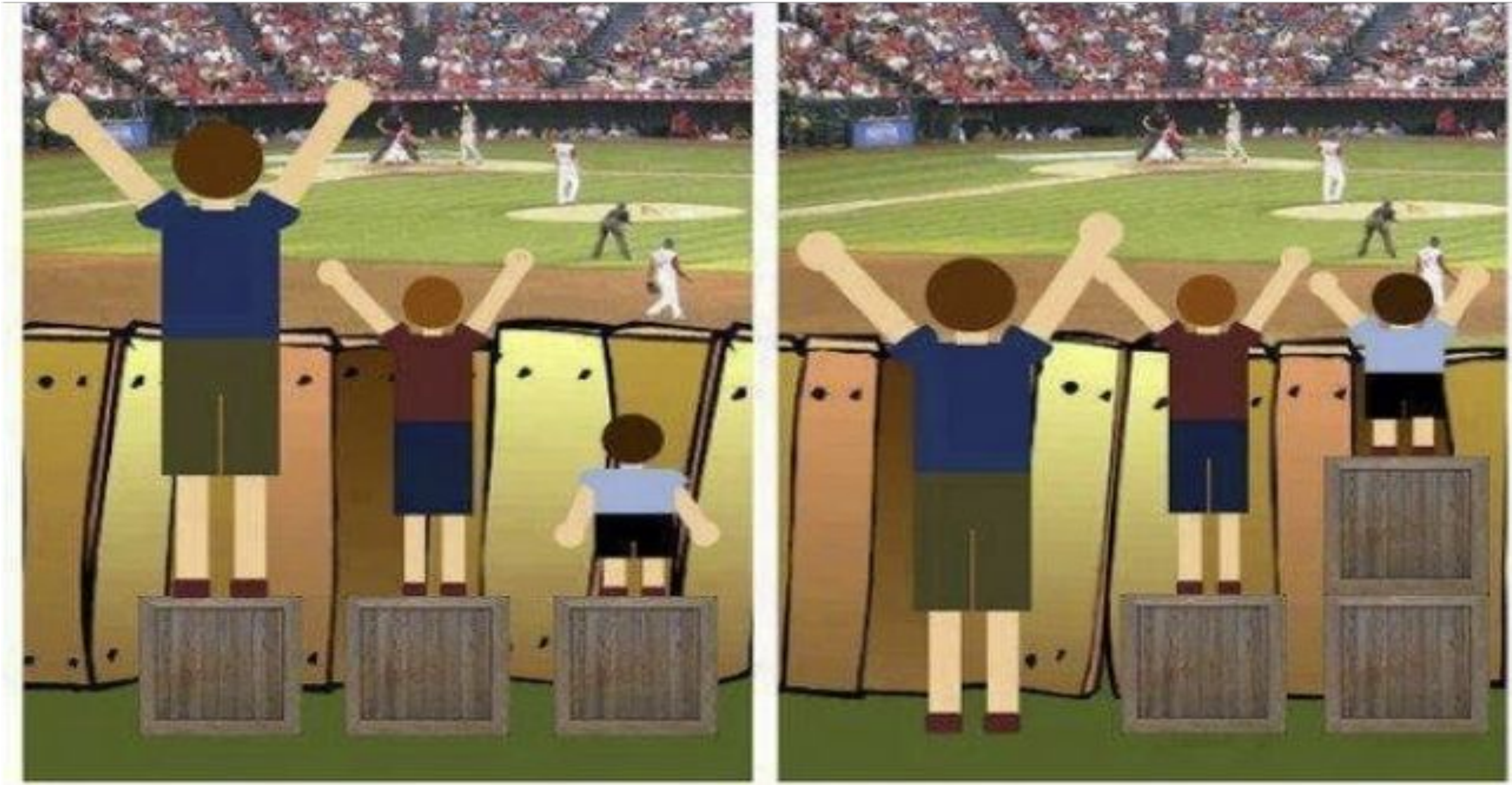
- Non-Normalized Math (using PriorityFlags = NO_NORMAL_ALL):

```
Job_priority =
    ...(PriorityWeightQOS) * (QOS_factor) + ...)
       1                   * 1000 = 1000 (1*1000 for fred)
       From slurm.conf

       1                   * 500  = 500 (1*500 for wilma)
       From slurm.com

       1                   * 100  = 100 (1*100 for bambam)
       From slurm.conf
```

Agenda

- Job Prioritization
- Fairshare
- Fair Tree

Fairshare-Fair vs Equal



Fairshare

- In Slurm, Fairshare **shares** are normalized
- The fair-share hierarchy represents the portions of the computing resources that have been allocated to multiple projects
- These allocations are assigned to an account
- There can be multiple levels of allocations made as allocations of a given account are further divided to sub-accounts

Fairshare-Usage Factor

- In Slurm, Fairshare **usage** is normalized
  - The processor*seconds allocated to every job are tracked in real-time. If one only considered usage over a fixed time period, then calculating a user's normalized usage would be a simple quotient

$U_N = U_{user} / U_{total}$

Where:

U_N is normalized usage, between zero and one

U_{user} is the processor*seconds consumed by all of a user's jobs in a given account for over a fixed time period

U_{total} is the total number of processor*seconds utilized across the cluster during that same time period

Fairshare-Decay Factor

- Most workload spans multiple time periods. Slurm’s fairshare priority calculation places more importance on the most recent resource usage and less importance on usage from way back
- The metric used is based on a half-life formula that favors most recent usage statistics, based on a **decay** factor (D):

$$U_H = U_{current\_period} + (D * U_{last\_period}) + (D * D * U_{period-2}) + \ldots$$

Where:

U_H is the historical usage subject to the half-life decay
$U_{current\_period}$ is the usage charged over the current measurement period
U_{last_period} is the usage charged over the last measurement period
$U_{period-2}$ is the usage charged over the second last measurement period
D is a decay factor between zero and one that delivers the half-life decay based off the PriorityDecayHalfLife setting in the slurm.conf file

Fairshare-Simplified Formula

- The simplified formula for calculating the fair-share factor for usage that spans multiple time periods and subject to a half-life decay is:

```
F = 2**(-U/S/d)

Where:
F         is the fair-share factor
S         is the normalized shares
U         is the normalized usage factoring in half-life decay
d         is the FairShareDampeningFactor (a configuration parameter, default value
          of 1)
```

Fairshare-Calculating the Values

- The fair-share factor ranges from zero to one
    - One represents the highest priority for a job
    - A fair-share factor of 0.5 indicates that the user's jobs have used/not used exactly the portion of the machine that they have been allocated
    - A fair-share factor of above 0.5 indicates that the user's jobs have consumed less than their allocated share while a fair-share factor below 0.5 indicates that the user's jobs have consumed more than their allocated share of the computing resources

Fairshare Factor Under Account Hierarchy

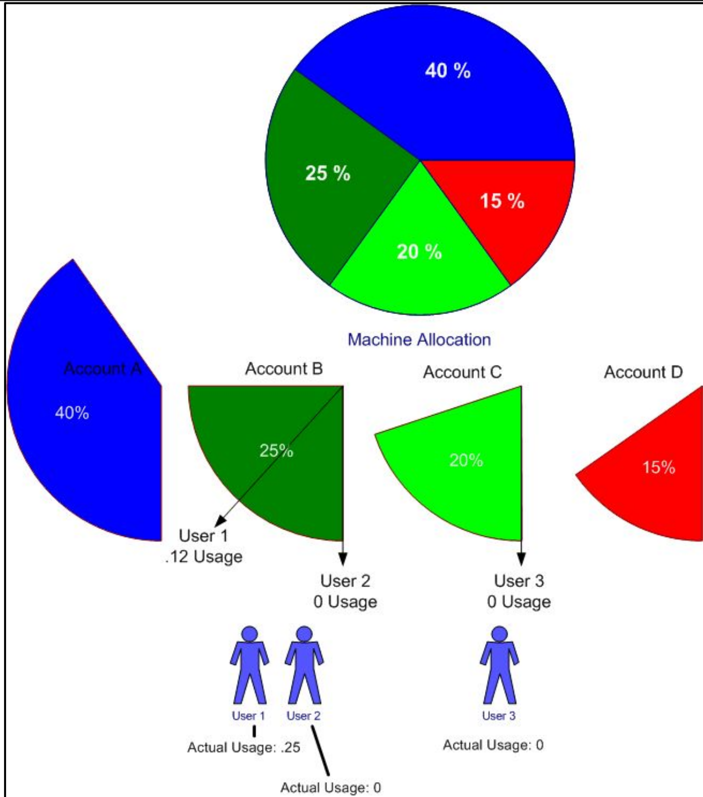
- The method described above presents a system whereby the priority of a user's job is calculated based on the portion of the machine allocated to the user and the historical usage of all the jobs run by that user under a specific account.
- Another layer of "fairness" is necessary however, one that factors in the usage of other users drawing from the same account. This allows a job's fair-share factor to be influenced by the computing resources delivered to jobs of other users drawing from the same account.

Fairshare Factor Under Account Hierarchy

- If there are two members of a given account, and if one of those users has run many jobs under that account, the job priority of a job submitted by the user who has **not** run any jobs will be negatively affected. This ensures that the combined usage charged to an account matches the portion of the machine that is allocated to that account

Fairshare Factor Under Account Hierarchy

In this example, when user 3 submits their first job using account C, they will want their job's priority to reflect all the resources delivered to account B. They do not care that user 1 has been using up a significant portion of the cycles allocated to account B and user 2 has yet to run a job out of account B. If user 2 submits a job using account B and user 3 submits a job using account C, user 3 expects their job to be scheduled before the job from user 2



The Slurm Fairshare Formula

- The Slurm Fairshare formula has been designed to provide fair scheduling to users based on the allocation and usage of **every** account. Now, the usage term is **effective** usage:

$F = 2^{**}(-U_E/S)$ (Effective Usage Formula)

$U_E = U_{Achild} + ((U_{Eparent} - U_{Achild}) * S_{child}/S_{all\_siblings})$

Where:

U_E is the effective usage of the child user or child account

U_{Achild} is the actual usage of the child user or child account

UE_{parent} is the effective usage of the parent account

S_{child} is the shares allocated to the child user or child account

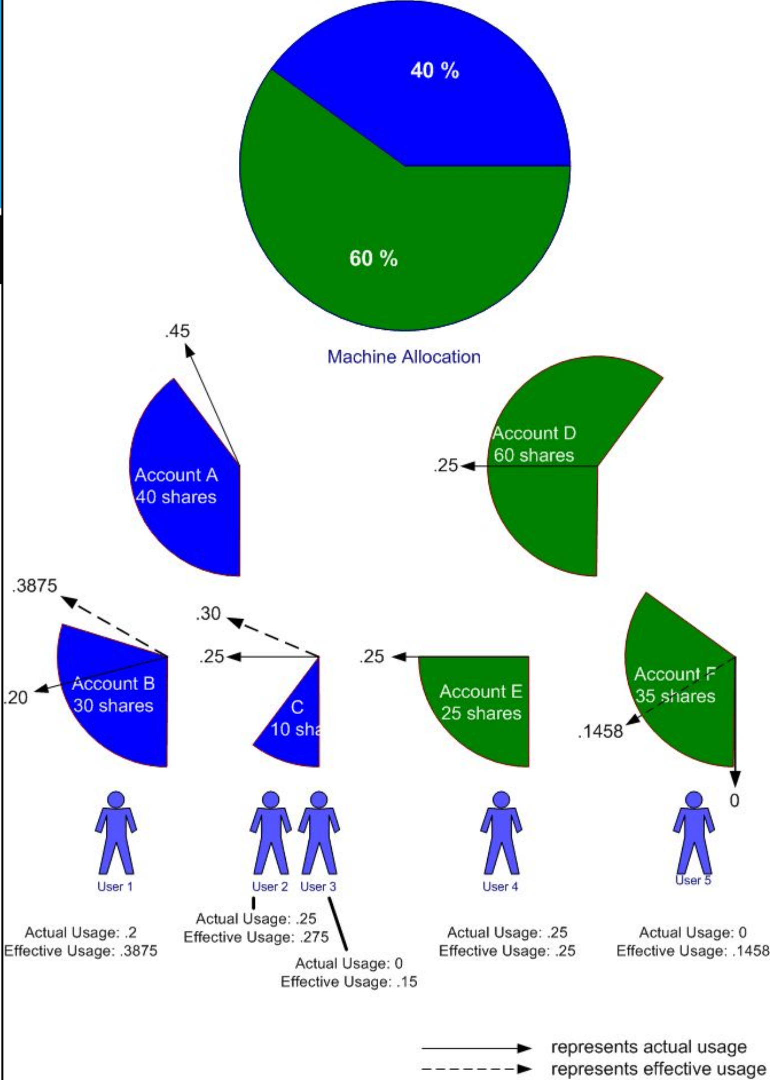
$S_{all\_siblings}$ is the shares allocated to all the children of the parent account

The Slurm Fairshare Formula

- Because the formula for effective usage includes a term of the effective usage of the parent, the calculation for each account in the tree must start at the <u>second tier</u> of accounts and proceed downward: to the children accounts, then grandchildren, etc. The effective usage of the users will be the last to be calculated.
- Plugging in the effective usage into the fair-share formula above yields a fair-share factor that reflects the **aggregated usage** charged to each of the accounts in the fair-share hierarchy.

Slurm Fairshare Example

The machine's computing resources are allocated to accounts A and D with 40 and 60 shares respectively. Account A is further divided into two children accounts, B with 30 shares and C with 10 shares. Account D is further divided into two children accounts, E with 25 shares and F with 35 shares



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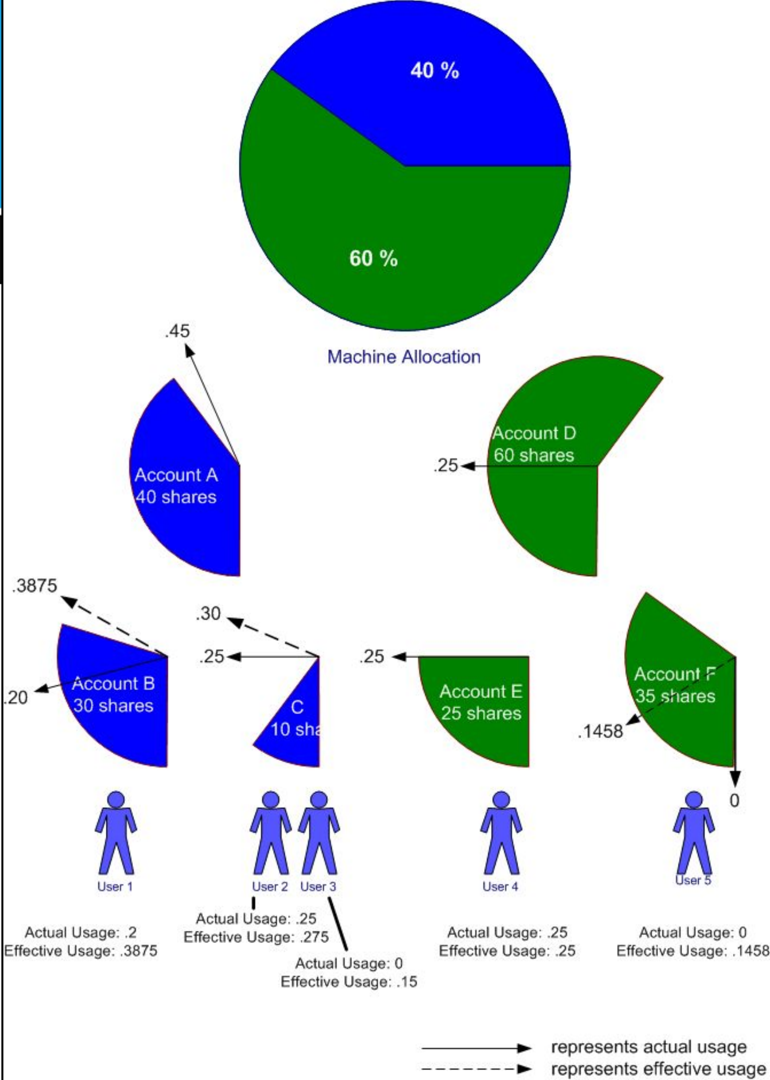
Slurm Fairshare Example

Note: the shares at any given tier in the Account hierarchy do not need to total up to 100 shares. This example shows them totaling up to 100 to make the arithmetic easier to follow in your head



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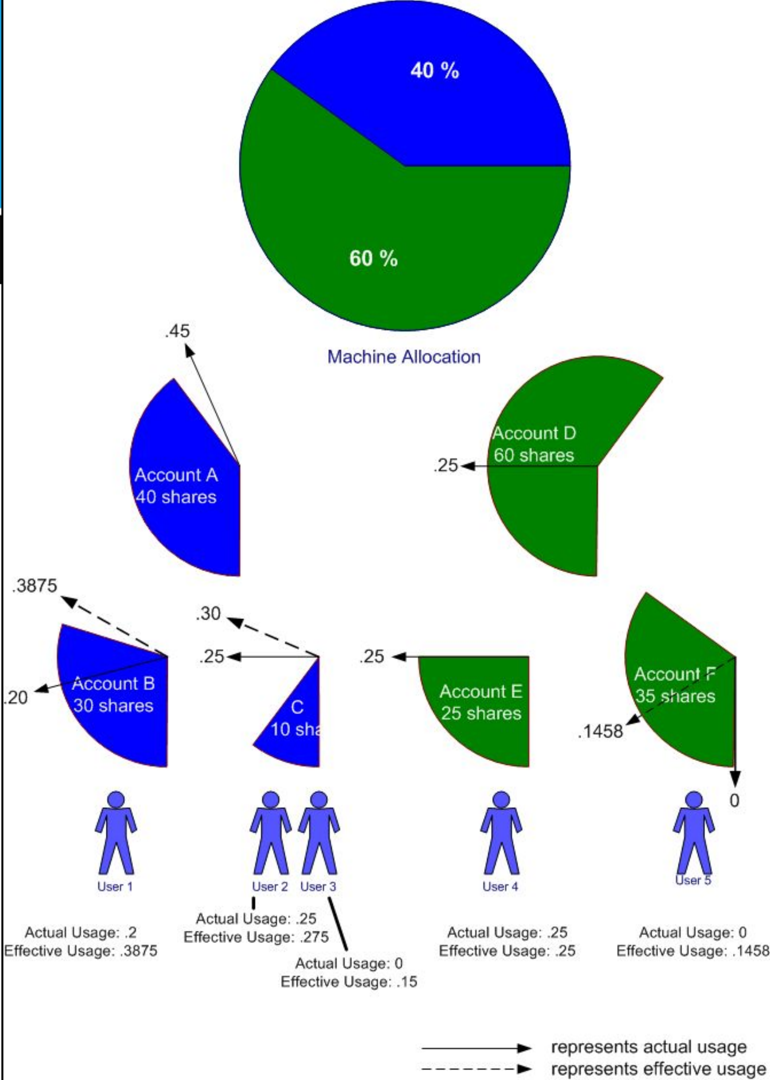
Slurm Fairshare Example

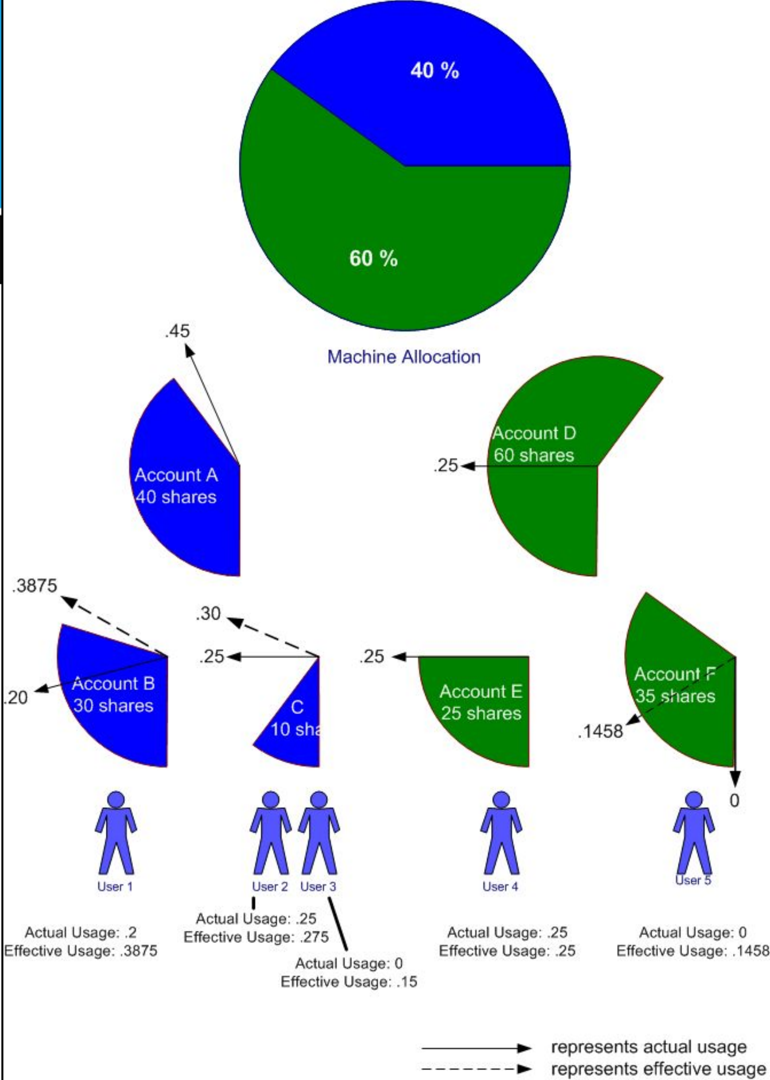
User 1 is granted permission to submit jobs against the B account. Users 2 and 3 are granted one share each in the C account. User 4 is the sole member of the E account and User 5 is the sole member of the F account.

Note: accounts A and D do not have any user members in this example, though users could have been assigned.



Slurm Fairshare Example

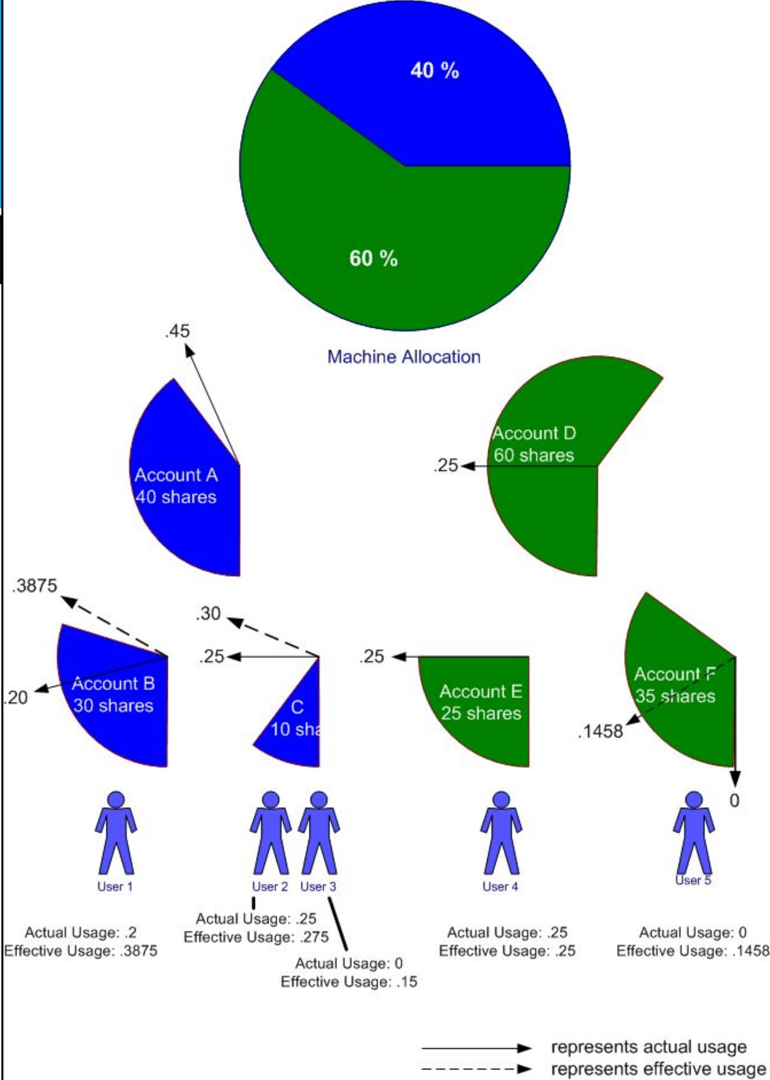
The shares assigned to each account make it easy to determine normalized shares of the machine's complete resources. Account A has .4 normalized shares, B has .3 normalized shares, etc. Users who are sole members of an account have the same number of normalized shares as the account. (E.g., User 1 has .3 normalized shares). Users who share accounts have a portion of the normalized shares based on their shares. For example, if user 2 had been allocated 4 shares instead of 1, user 2 would have had .08 normalized shares. With users 2 and 3 each holding 1 share, they each have a normalized share of 0.05



Slurm Fairshare Example

Users 1, 2, and 4 have run jobs that have consumed the machine's computing resources. User 1's actual usage is 0.2 of the machine; user 2 is 0.25, and user 4 is 0.25

The actual usage charged to each account is represented by the solid arrows. The actual usage charged to each account is summed as one goes up the tree. Account C's usage is the sum of the usage of Users 2 and 3; account A's actual usage is the sum of its children, accounts B and C



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Slurm Fairshare Example

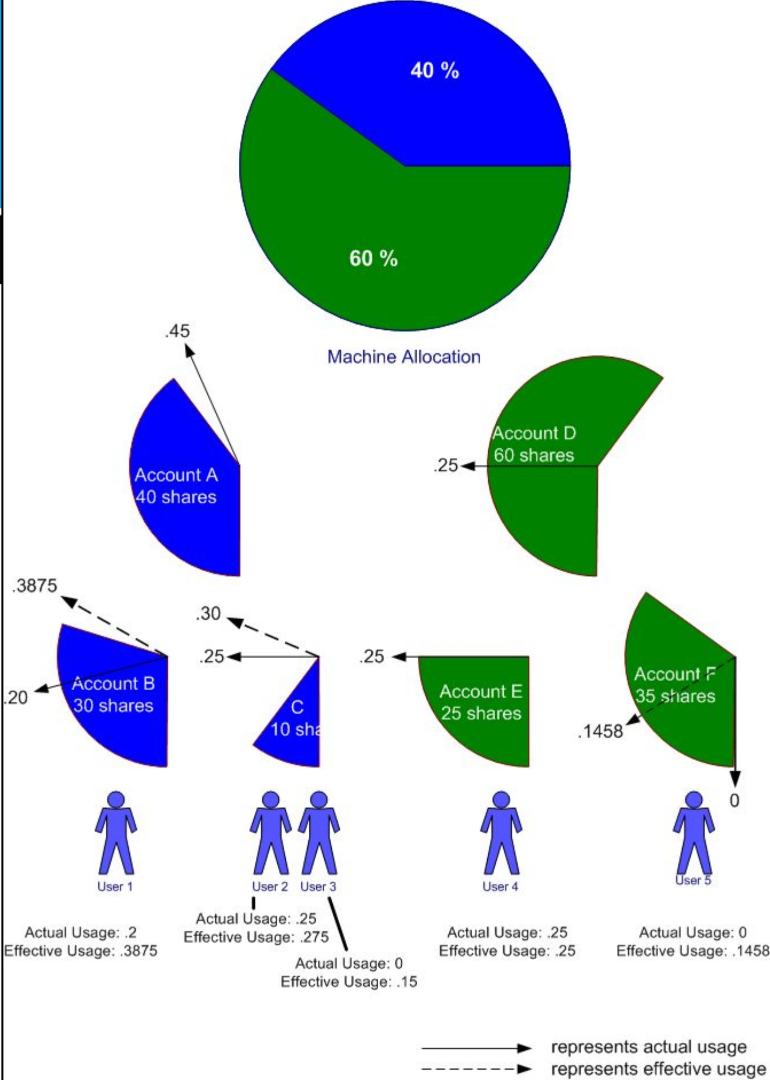
User 1 normalized share: 0.3

User 2 normalized share: 0.05

User 3 normalized share: 0.05

User 4 normalized share: 0.25

User 5 normalized share: 0.35



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Slurm Fairshare Example

The effective usage for **all accounts** at the first tier under the root allocation is always equal to the actual usage:

$F = 2^{**}(-U_E/S)$ (Effective Usage Formula)

$U_E = U_{Achild} + ((U_{Eparent} - U_{Achild}) * S_{child}/S_{all\_siblings})$

Account A's effective usage is therefore equal to .45. Account D's effective usage is equal to .25.

Account B effective usage: 0.2 + ((0.45 - 0.2) * 30 / 40) = 0.3875

Account C effective usage: 0.25 + ((0.45 - 0.25) * 10 / 40) = 0.3

Account E effective usage: 0.25 + ((0.25 - 0.25) * 25 / 60) = 0.25

Account F effective usage: 0.0 + ((0.25 - 0.0) * 35 / 60) = 0.1458

Slurm Fairshare Example

The effective usage for **each user** is calculated using the same formula:

$F = 2^{**}(-U_E/S)$ (Effective Usage Formula)

$U_E = U_{Achild} + ((U_{Eparent} - U_{Achild}) * S_{child}/S_{all\_siblings})$

```
User 1 effective usage: 0.2 + ((0.3875 - 0.2) * 1 / 1) = 0.3875
User 2 effective usage: 0.25 + ((0.3 - 0.25) * 1 / 2) = 0.275
User 3 effective usage: 0.0 + ((0.3 - 0.0) * 1 / 2) = 0.15
User 4 effective usage: 0.25 + ((0.25 - 0.25) * 1 / 1) = 0.25
User 5 effective usage: 0.0 + ((.1458 - 0.0) * 1 / 1) = 0.1458
```

Slurm Fairshare Example

Using the Slurm fair-share formula,

```
F = 2**(-U_E/S)   (Effective Usage Formula)
```

```
User 1 fair-share factor: 2**(-.3875 / .3) = 0.408479
User 2 fair-share factor: 2**(-.275 / .05) = 0.022097
User 3 fair-share factor: 2**(-.15 / .05) = 0.125000
User 4 fair-share factor: 2**(-.25 / .25) = 0.500000
User 5 fair-share factor: 2**(-.1458 / .35) = 0.749154
```

From this example, once can see that users 1,2, and 3 are over-serviced while user 5 is under-serviced. Even though user 3 has yet to submit a job, his/her fair-share factor is negatively influenced by the jobs users 1 and 2 have run.

Based on the fair-share factor alone, if all 5 users were to submit a job charging their respective accounts, user 5's job would be granted the highest scheduling priority.

Slurm Fairshare Configuration Parameters

- PriorityType
  - priority/basic or priority/multifactor
- PriorityDecayHalfLife
  - min, hr:min:00, days-hr:min:00, or days-hr (Default=7 days)
- PriorityCalcPeriod
  - The period of time in minutes in which the half-life decay will be re-calculated. Default=5 minutes

Slurm Fairshare Configuration Parameters

- PriorityUsageResetPeriod
  - At this interval the usage of associations will be reset to 0
  - NONE, NOW, DAILY, WEEKLY, MONTHLY, QUARTERLY, YEARLY
- PriorityFavorSmall
  - Specifies that small jobs should be given preferential scheduling priority. Values=yes/no
- PriorityMaxAge
  - The job age which will be given the maximum age factor in computing priority. Default=7 Days

Slurm Fairshare Configuration Parameters

- PriorityWeightAge
  - the degree to which the queue wait time component contributes to the job's priority
- PriorityWeightFairshare
  - the degree to which the fair-share component contributes to the job's priority
- PriorityWeightJobSize
  - the degree to which the job size component contributes to the job's priority

Slurm Fairshare Configuration Parameters

- PriorityWeightPartition
  - Partition factor used by priority/multifactor plugin in calculating job priority
- PriorityWeightQOS
  - the degree to which the Quality Of Service component contributes to the job's priority
- PriorityWeightTRES
  - A comma separated list of TRES Types and weights that sets the degree that each TRES Type contributes to the job's priority:

    `PriorityWeightTRES=CPU=1000,Mem=2000,GRES/gpu=3000`

Slurm Fairshare Configuration Example 1

- This example is for running the plugin applying decay over time to reduce usage. Hard limits can be used in this configuration, but will have less effect since usage will decay over time instead of having no decay over time

```
# Activate the Multi-factor Job Priority Plugin with decay
PriorityType=priority/multifactor

# 2 week half-life
PriorityDecayHalfLife=14-0
```

Slurm Fairshare Configuration Example 1 -Cont'd

```
# The larger the job, the greater its job size priority.
PriorityFavorSmall=NO
# The job's age factor reaches 1.0 after waiting in the
# queue for 2 weeks.
PriorityMaxAge=14-0

# This next group determines the weighting of each of the
# components of the Multi-factor Job Priority Plugin.
# The default value for each of the following is 1.
PriorityWeightAge=1000
PriorityWeightFairshare=10000
PriorityWeightJobSize=1000
PriorityWeightPartition=1000
PriorityWeightQOS=0 # don't use the qos factor
```

Slurm Fairshare Configuration Example 2

- This example is for running the plugin with no decay on usage, thus making a reset of usage necessary

```
# Activate the Multi-factor Job Priority Plugin with decay
PriorityType=priority/multifactor

# apply no decay
PriorityDecayHalfLife=0

# reset usage after 1 month
PriorityUsageResetPeriod=MONTHLY
```

Slurm Fairshare Configuration Example 2-Cont’d

```
# The larger the job, the greater its job size priority.
PriorityFavorSmall=NO

# The job's age factor reaches 1.0 after waiting in the
# queue for 2 weeks.
PriorityMaxAge=14-0
```

Slurm Fairshare Configuration Example 2-Cont’d

```
# This next group determines the weighting of each of the
# components of the Multi-factor Job Priority Plugin.
# The default value for each of the following is 1.
PriorityWeightAge=1000
PriorityWeightFairshare=10000
PriorityWeightJobSize=1000
PriorityWeightPartition=1000
PriorityWeightQOS=0 # don't use the qos factor
```

Agenda

- Job Prioritization
- Fairshare
- Fair Tree

Fair Tree

- Developed by Ryan Cox and Levi Morrison at BYU (Thanks!)
- Submitted to Slurm branch 14.03
- Algorithm includes a rooted plane tree (rooted ordered tree) being created then sorted by Level Fairshare
- Now the default fairshare algorithm in Slurm 19.05 release
- To revert to old-style fairshare: *PriorityFlags=NO_FAIR_TREE*

Fair Tree - GO BYU!

Thanks for hosting SLUG!

Fair Tree

- Benefits of Fair Tree:
    - All users from a higher priority account receive a higher fair share factor than all users from a lower priority account
    - Users are sorted and ranked to prevent errors due to precision loss. Ties are allowed
    - Account coordinators cannot accidentally harm the priority of their users relative to users in other account
    - Users are extremely unlikely to have exactly the same fairshare factor as another user due to loss of precision in calculations
    - New jobs are immediately assigned a priority

Fair Tree

- To see the effect of Fair Tree:
    - sshare -l (Long) parameter now shows Level FS, showing fairshare calculated values for each association at each level

Account	User	Raw Shares	Norm Shares	Raw Usage	Norm Usage	Effectv Usage	FairShare	**Level FS**
root			0.000000	1230		1.000000		**1.000000**
bedrock		500	0.500000	676	0.549593	0.549593		**0.909763**
bedrock	fred	25	0.250000	301	0.244715	0.445266	0.200000	**0.561462**
bedrock	barney	25	0.250000	102	0.082927	0.150888	0.600000	**1.656863**
bedrock	wilma	25	0.250000	37	0.030081	0.054734	0.800000	**4.567568**
bedrock	betty	25	0.250000	236	0.191870	0.349112	0.400000	**0.716102**
managers		500	0.500000	554	0.450407	0.450407		**1.110108**
slate	slate	1	1.000000	554	0.450407	1.000000	1.000000	**1.000000**

Summary

- You should now have working knowledge of Slurm Priority and Fairshare, and Fair Trees

- Questions?