SchedMD

Bull

Architect of an Open World™

Energy Accounting & External Sensors Plugins

Slurm 2013 User Group

Danny Auble, SchedMD
Thomas Cadeau, Bull
Yiannis Georgiou, Bull
Martin Perry, Bull
martin.perry@bull.com

© Bull

Introduction

- Two new plugins added in Slurm versions 2.5 and 2.6.
- The **Energy Accounting Plugin** collects energy consumption data generated in-band from hardware sensors.
- The **External Sensors Plugin** collects energy and temperature data generated out-of-band by an external system manager such as Nagios, or external sensors such as wattmeters.
- Initial versions of each plugin provide limited functionality; may be enhanced in the future to provide additional data types and more detailed data.
- Future enhancements to Slurm will allow the use the energy and temperature data collected by these plugins for resource management (allocation and scheduling decisions).

© Bull, 2013, © SchedMD, 2013

Energy & Power

- Informally, the terms *energy* and *power* are often used interchangeably, but they have distinct technical definitions.

- **Energy** is a *quantity* that represents the capacity to perform work. The standard (SI) unit of energy is the **joule**.

- **Power** is the *rate* at which energy is consumed (transferred or converted). The standard unit of power is the **watt**.
1 watt = 1 joule/second.

- Electrical energy is often expressed in units of **kilowatt-hours** (kWh).
1 kWh = 1000 watts for 3600 seconds = 3.6 megajoules.

© Bull, 2013, © SchedMD, 2013

Energy Accounting Plugin - Purpose

Plugin Name: acct_gather_energy

Purpose: To collect energy consumption data for the following uses:

- Job/step accounting – Running and total energy consumption by a job or step.
- Job/step profiling – Profile of power use by a job/step over time, per node.
- Hardware monitoring – Instantaneous power and cumulative energy consumption for each node.

© Bull, 2013, © SchedMD, 2013

acct_gather_energy Plugin - Overview

- One of a new family of **acct_gather** plugins that collect resource usage data for accounting, profiling and monitoring.
- Loaded by **slurmd** on each compute node.
- Called by **jobacct_gather** plugin to collect energy consumption accounting data for jobs and steps.
- Called separately via RPC from the **slurmctld background** thread to collect energy consumption data for nodes.
- Calls **acct_gather_profile** plugin to provide energy data samples for profiling.

© Bull, 2013, © SchedMD, 2013

acct_gather_energy Plugin – Data Reporting

- For running jobs, energy accounting data is reported by **sstat**.
- If accounting database is configured, energy accounting data is included in accounting records and reported by **sacct** and **sreport** (version 13.12).
- If **acct_gather_profile** plugin is configured, energy profiling data is reported by the method specified by the profile plugin type.
- Energy consumption data for nodes is reported by **scontrol show node**.
- Cumulative/total energy consumption is reported in units of **joules**.
- Instantaneous rate of energy consumption (power) is reported in units of **watts**.

acct_gather_energy Plugin - Versions

- Two versions of **acct_gather_energy** plugin supported:

acct_gather_energy/rapl

  - Energy consumption data is collected from hardware sensors using the Running Average Power Limit (RAPL) interface.
  - Requires Intel Sandy Bridge or later Intel CPU type.
  - Linux MSR module must be loaded.

acct_gather_energy/ipmi

  - Energy consumption data is collected from the Baseboard Management Controller (BMC) using the Intelligent Platform Management Interface (IPMI) protocol.
  - IPMI is a message-based, hardware-level interface specification providing for in-band and out-of-band collection of platform data.
  - Requires BMC hardware and FreeIPMI version 1.2.1 or later.

- Plugin API is described in Slurm developer documentation:
  - http://slurm.schedmd.com/acct_gather_energy_plugins.html

acct_gather_energy Plugin - Configuration

- In **slurm.conf**

To configure plugin:

`AcctGatherEnergyType=acct_gather_energy/rapl` *or*
`AcctGatherEnergyType=acct_gather_energy/ipmi`

Frequency of node energy sampling controlled by:
`AcctGatherNodeFreq=<seconds>`
Default value is 0, which disables node energy sampling

Collection of energy accounting data for jobs/steps requires:
`JobAcctGatherType=jobacct_gather/linux` *or*
`JobAcctGatherType=jobacct_gather/cgroup`
Frequency of job accounting sampling controlled by:
`JobAcctGatherFrequency=task=<seconds>`
Default value is 30 seconds

- In **acct_gather.conf** (new config file), for **acct_gather_energy/ipmi** only:

```
EnergyIPMIFrequency
EnergyIPMICalcAdjustment
EnergyIPMIPowerSensor
EnergyIPMIUsername
EnergyIPMIPassword
```

acct_gather_energy Plugin – Major Limitations

- The granularity of IPMI and RAPL data is node. Therefore, energy accounting and profiling data is reliable only for jobs/steps using unshared whole node allocation (select/linear, --exclusive).
  Future enhancements may support finer granularity (socket, core) for acct_gather_energy/rapl.
- RAPL energy data includes CPU, DRAM and cache energy consumption only. IPMI energy data includes all energy consumption by each node.
- Poor precision of energy accounting measurements for short jobs with few samples (depends on configured values of JobAcctGatherFrequency and EnergyIPMIFrequency).
- Asynchronous IPMI calls to eliminate potential delays.

External Sensors Plugin - Purpose

Plugin Name: ext_sensors

Purpose: To collect environmental-type data from external sensors or sources for the following uses:

- Job/step accounting – Total energy consumption by a completed job or step (no energy data while job/step is running).
- Hardware monitoring – Instantaneous power and cumulative energy consumption for nodes; instantaneous temperature of nodes.
- Future work will add additional types of environmental data, such as energy and temperature data for network switches, cooling system, etc. Environmental data may be used for resource management.

ext_sensors Plugin - Overview

- Loaded by **slurmctld** on management node.

- Collects energy accounting data for jobs and steps independently of the **acct_gather** plugins.
  - Called by slurmctld request handler when step starts.
  - Called by slurmctld step manager when step completes.

- Since energy use by jobs/steps is measured only at completion (i.e., no sampling), does not support power profiling or energy reporting for running jobs/steps (sstat).

- Called separately from the **slurmctld background** thread to sample energy consumption and temperature data for nodes.

ext_sensors Plugin – Data Reporting

- If accounting database is configured, energy data is included in accounting records and reported by **sacct** and **sreport** (in version 13.12).

- Energy consumption data for nodes is reported by **scontrol show node**.

- Cumulative/total energy consumption reported in **joules**.
- Instantaneous energy consumption rate (power) for nodes reported in **watts**.
- Node temperature reported in **celsius**.

© Bull, 2013, © SchedMD, 2013

ext_sensors Plugin - Versions

- One version of **ExtSensorsType** plugin currently supported:
  - **ext_sensors/rrd**

    External sensors data is collected using RRD. RRDtool is GNU-licensed software that creates and manages a linear database used for sampling or logging. The database is populated with energy data using out-of-band IPMI collection.

- Plugin API is described in Slurm developer documentation:
  - http://slurm.schedmd.com/ext_sensorsplugins.html

ext_sensors Plugin - Configuration

- In **slurm.conf**

  To configure plugin:
  `ExtSensorsType=ext_sensors/rrd`

  Frequency of node energy sampling controlled by:
  `ExtSensorsFreq=<seconds>`
  Default value is 0, which disables node energy sampling

  Collection of energy accounting data for jobs/steps requires:
  `JobAcctGatherType=jobacct_gather/linux` *or* **`cgroup`**

- In **ext_sensors.conf** (new configuration file)

  `JobData`=**`energy`** Specify the data types to be collected by the plugin for jobs/steps.
  `NodeData`=**`[energy|temp]`**Specify the data types to be collected by the plugin for nodes.
  `SwitchData`=**`energy`** Specify the data types to be collected by the plugin for switches.
  `ColdDoorData`=**`temp`** Specify the data types to be collected by the plugin for cold doors.
  `MinWatt`=**`<number>`** Minimum recorded power consumption, in watts.
  `MaxWatt`=**`<number>`** Maximum recorded power consumption, in watts.
  `MinTemp`=**`<number>`** Minimum recorded temperature, in celsius.
  `MaxTemp`=**`<number>`** Maximum recorded temperature, in celsius.
  `EnergyRRA`=**`<name>`** Energy RRA name.
  `TempRRA`=**`<name>`** Temperature RRA name.
  `EnergyPathRRD`=**`<path>`** Pathname of energy RRD file.
  `TempPathRRD`=**`<path>`** Pathname of temperature RRD file.

ext_sensors Plugin – Major Limitations

- The granularity of RRD energy data is node. Therefore, energy accounting data is reliable only for jobs/steps using unshared whole node allocation (select/linear, --exclusive).

- Potential for inaccuracy due RRD energy sampling interval.

© Bull, 2013, © SchedMD, 2013

Plugin Configuration Cases

- For node energy monitoring:

```
AcctGatherEnergyType=acct_gather_energy/ipmi or rapl
AcctGatherNodeFreq=<seconds>
or
ExtSensorsType=ext_sensors/rrd
ExtSensorsFreq=<seconds>
```

- For job/step energy accounting:

```
JobAcctGatherType=jobacct_gather/linux or cgroup
AcctGatherEnergyType=acct_gather_energy/ipmi or rapl
JobAcctGatherFrequency=task=<seconds>
or
JobAcctGatherType=jobacct_gather/linux or cgroup
ExtSensorsType=ext_sensors/rrd
```

- For job/step power profiling:

```
AcctGatherEnergyType=acct_gather_energy/ipmi or rapl
AcctGatherProfileType=acct_gather_profile/hdf5
JobAcctGatherFrequency=energy=<seconds>
```

Use of the **`acct_gather_energy/ipmi`** or **`acct_gather_profile`** plugins requires **`acct_gather.conf`**.
Use of the **`ext_sensors`** plugin requires **`ext_sensors.conf`**.
Use of the **`jobacct_gather/cgroup`** plugin requires **`cgroup.conf`**.
Command line option **`acctg-freq`** may be used to override any value from **`JobAcctGatherFrequency`**.

Examples

Configuration and Use Examples

Example 1 – Node energy monitoring using acct_gather_energy/rapl

```
[sulu] (slurm) mnp> scontrol show config
...
AcctGatherEnergyType    = acct_gather_energy/rapl
AcctGatherNodeFreq      = 30 sec
...

[sulu] (slurm) mnp> scontrol show node n15
NodeName=n15 Arch=x86_64 CoresPerSocket=8
   CPUAlloc=0 CPUErr=0 CPUTot=32 CPULoad=0.00 Features=(null)
   Gres=(null)
   NodeAddr=drak.usrnd.lan NodeHostName=drak.usrnd.lan
   OS=Linux RealMemory=1 AllocMem=0 Sockets=4 Boards=1
   State=IDLE ThreadsPerCore=1 TmpDisk=0 Weight=1
   BootTime=2013-08-28T09:35:47 SlurmdStartTime=2013-09-05T14:31:21
   CurrentWatts=121 LowestJoules=69447 ConsumedJoules=8726863
   ExtSensorsJoules=n/s ExtSensorsWatts=0 ExtSensorsTemp=n/s
```

Example 2 – Energy accounting using acct_gather_energy/rapl

```
[sulu] (slurm) mnp> scontrol show config
...
JobAcctGatherType       = jobacct_gather/linux
JobAcctGatherFrequency  = task=10
AcctGatherEnergyType    = acct_gather_energy/rapl
AccountingStorageType   = accounting_storage/slurmdb
...

[sulu] (slurm) mnp> srun test/memcputest 100 10000 &
[1] 20712
[sulu] (slurm) mnp> 100 Mb buffer allocated

[sulu] (slurm) mnp> squeue
             JOBID PARTITION     NAME     USER  ST       TIME  NODES NODELIST(REASON)
               120 drak-only memcpute    slurm   R       0:03      1 n15

[sulu] (slurm) mnp> sstat -j 120 -o ConsumedEnergy
ConsumedEnergy
--------------
          2149

[sulu] (slurm) mnp> sstat -j 120 -o ConsumedEnergy
ConsumedEnergy
--------------
          2452

[sulu] (slurm) mnp> sstat -j 120 -o ConsumedEnergy
ConsumedEnergy
--------------
          2720
[sulu] (slurm) mnp> Finished: j = 10001, c = 2990739969

[1]+  Done                    srun test/memcputest 100 10000

[sulu] (slurm) mnp> sacct -j 120 -o ConsumedEnergy
ConsumedEnergy
--------------
          3422
```

Example 3 – Energy accounting using acct_gather_energy/ipmi

```
[root@cuzco108 bin]# scontrol show config
...
JobAcctGatherType       = jobacct_gather/linux
JobAcctGatherFrequency  = task=10
AcctGatherEnergyType    = acct_gather_energy/ipmi
AccountingStorageType   = accounting_storage/slurmdb
...

[root@cuzco108 bin]# cat /usr/local/slurm2.6/etc/acct_gather.conf

EnergyIPMIFrequency=10
#EnergyIPMICalcAdjustment=yes
EnergyIPMIPowerSensor=1280


[root@cuzco108 bin]# srun -w cuzco113 memcputest 100 10000 &
[1] 26138
[root@cuzco108 bin]# 100 Mb buffer allocated

[root@cuzco108 bin]# squeue
             JOBID PARTITION     NAME     USER ST       TIME  NODES NODELIST(REASON)
               101 exclusive memcpute     root  R       0:04      1 cuzco113
[root@cuzco108 bin]# sstat -j 101 -o ConsumedEnergy
ConsumedEnergy
--------------
           570

[root@cuzco108 bin]# sstat -j 101 -o ConsumedEnergy
ConsumedEnergy
--------------
         1.74K
```

© Bull, 2013, © SchedMD, 2013

Example 3 – continued

```
[root@cuzco108 bin]# Finished: j = 10001, c = 2990739969

[1]+  Done                    srun -w cuzco113 memcputest 100 10000
[root@cuzco108 bin]# sacct -j 101 -o ConsumedEnergy
ConsumedEnergy
--------------
         1.74K
```

Example 4 – Node energy and temperature monitoring using ext_sensors/rrd

```
[root@cuzco0 ~]# scontrol show config
...
ExtSensorsType          = ext_sensors/rrd
ExtSensorsFreq          = 10 sec
...

[root@cuzco108 slurm]# cat /usr/local/slurm2.6/etc/ext_sensors.conf
#
# External Sensors plugin configuration file
#

JobData=energy
NodeData=energy,temp

EnergyRRA=1
EnergyPathRRD=/BCM/data/metric/%n/Power_Consumption.rrd

TempRRA=1
TempPathRRD=/BCM/data/metric/%n/Temperature.rrd

MinWatt=4
MaxWatt=200


[root@cuzco0 ~]# scontrol show node cuzco109

NodeName=cuzco109 Arch=x86_64 CoresPerSocket=4
   CPUAlloc=0 CPUErr=0 CPUTot=8 CPULoad=0.00 Features=(null)
   Gres=(null)
   NodeAddr=cuzco109 NodeHostName=cuzco109
   OS=Linux RealMemory=24023 AllocMem=0 Sockets=2 Boards=1
   State=IDLE ThreadsPerCore=1 TmpDisk=0 Weight=1
   BootTime=2013-09-03T17:39:00 SlurmdStartTime=2013-09-10T22:58:10
   CurrentWatts=0 LowestJoules=0 ConsumedJoules=0
   ExtSensorsJoules=4200 ExtSensorsWatts=105 ExtSensorsTemp=66
```

Example 5 – Energy accounting comparison using ext_sensors/rrd and acct_gather_energy/ipmi

The accuracy/consistency of energy measurements may be inaccurate if the run time of the job is short and allows for only a few samples. This effect should be reduced for longer jobs.

The following example shows that the **ext_sensors/rrd** and **acct_gather_energy/ipmi** plugins produce very similar energy consumption results for a MPI benchmark job using 4 nodes and 32 CPUs, with a run time of ~9 minutes.

Example 5 – continued

acct_gather_energy/ipmi

```
[root@cuzco108 bin]# scontrol show config | grep acct_gather_energy
AcctGatherEnergyType    = acct_gather_energy/ipmi

[root@cuzco108 bin]# srun -n32 --resv-ports ./cg.D.32 &

[root@cuzco108 bin]# squeue
             JOBID PARTITION     NAME     USER ST       TIME  NODES NODELIST(REASON)
               122 exclusive  cg.D.32     root  R       0:02      4 cuzco[109,111-113]

[root@cuzco108 bin]# sacct -o "JobID%5,JobName,AllocCPUS,NNodes%3,NodeList%22,State,Start,End,Elapsed,ConsumedEnergy%9"
JobID    JobName  AllocCPUS NNo               NodeList      State               Start                 End    Elapsed ConsumedE
----- ---------- ---------- --- ---------------------- ---------- ------------------- ------------------- ---------- ---------
  127    cg.D.32         32   4     cuzco[109,111-113]  COMPLETED 2013-09-12T23:12:51 2013-09-12T23:22:03   00:09:12   490.60K
```

ext_sensors/rrd

```
[root@cuzco108 bin]# scontrol show config | grep ext_sensors
ExtSensorsType          = ext_sensors/rrd

[root@cuzco108 bin]# srun -n32 --resv-ports ./cg.D.32 &

[root@cuzco108 bin]# squeue
             JOBID PARTITION     NAME     USER ST       TIME  NODES NODELIST(REASON)
               128 exclusive  cg.D.32     root  R       0:02      4 cuzco[109,111-113]

[root@cuzco108 bin]# sacct -o "JobID%5,JobName,AllocCPUS,NNodes%3,NodeList%22,State,Start,End,Elapsed,ConsumedEnergy%9"
JobID    JobName  AllocCPUS NNo               NodeList      State               Start                 End    Elapsed ConsumedE
----- ---------- ---------- --- ---------------------- ---------- ------------------- ------------------- ---------- ---------
  128    cg.D.32         32   4     cuzco[109,111-113]  COMPLETED 2013-09-12T23:27:17 2013-09-12T23:36:33   00:09:16   498.67K
```

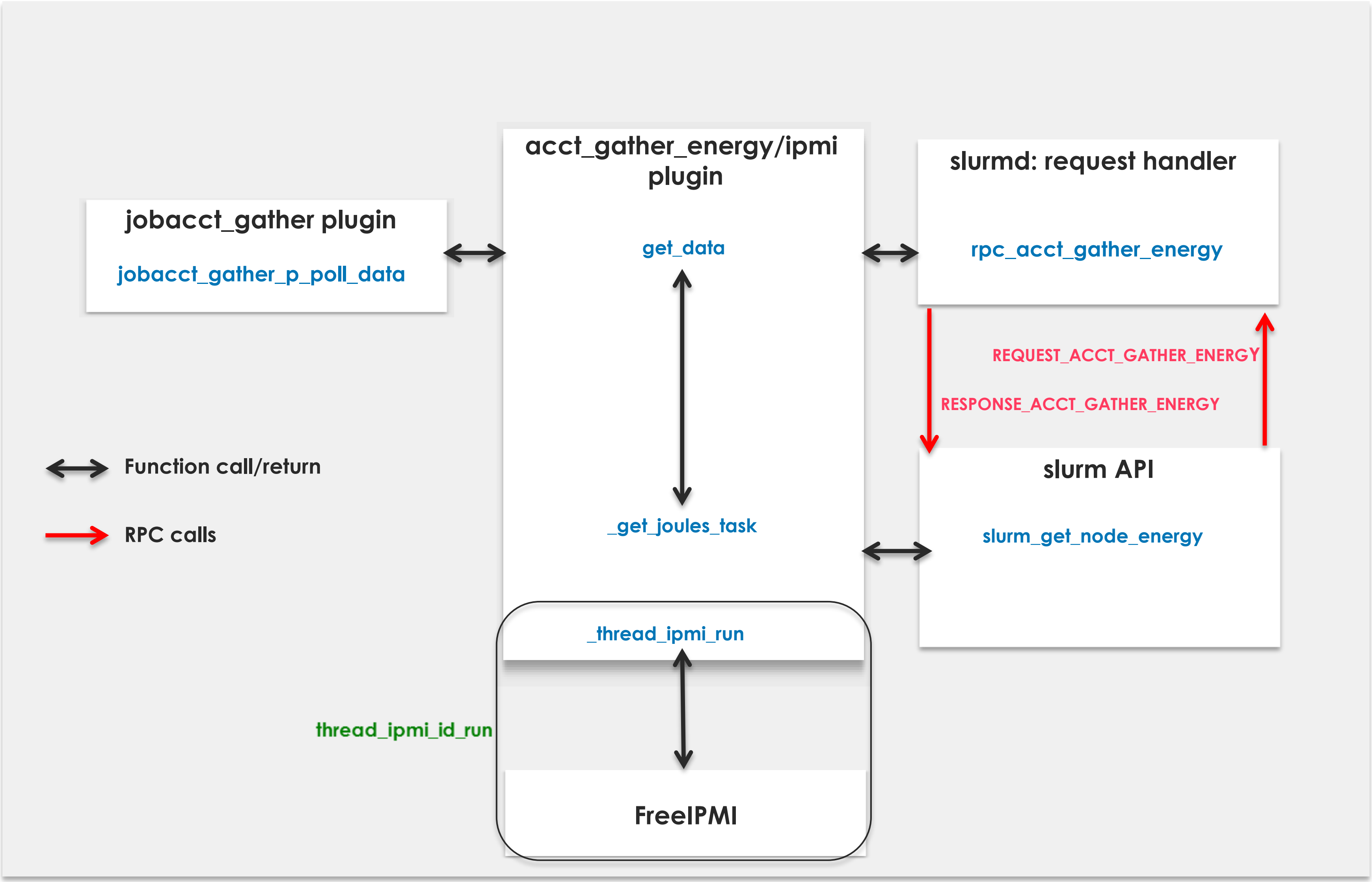
© Bull, 2013, © SchedMD, 2013

Questions

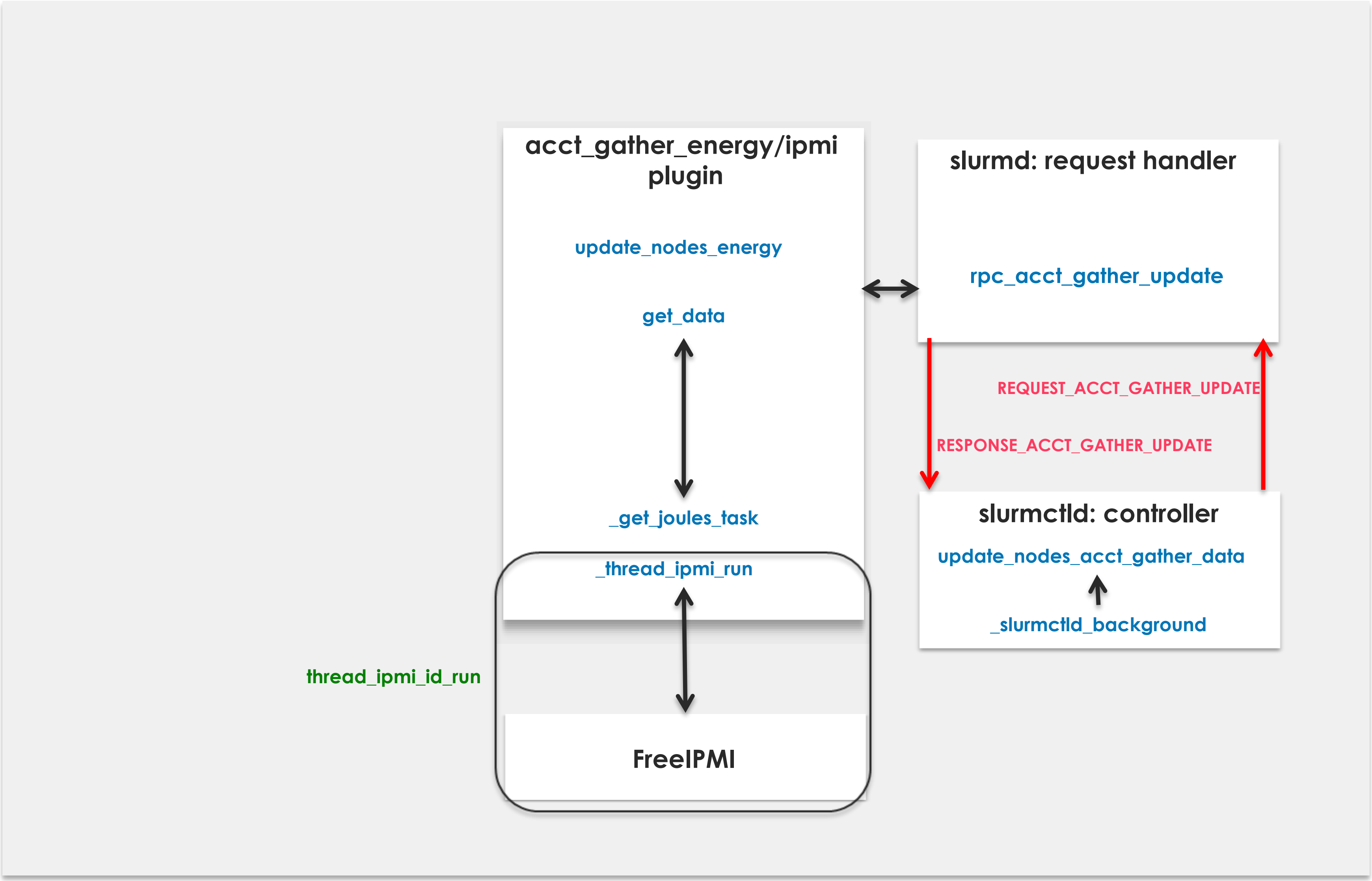
Supplementary Slides

The following slides illustrate the basic data collection architecture for each plugin version

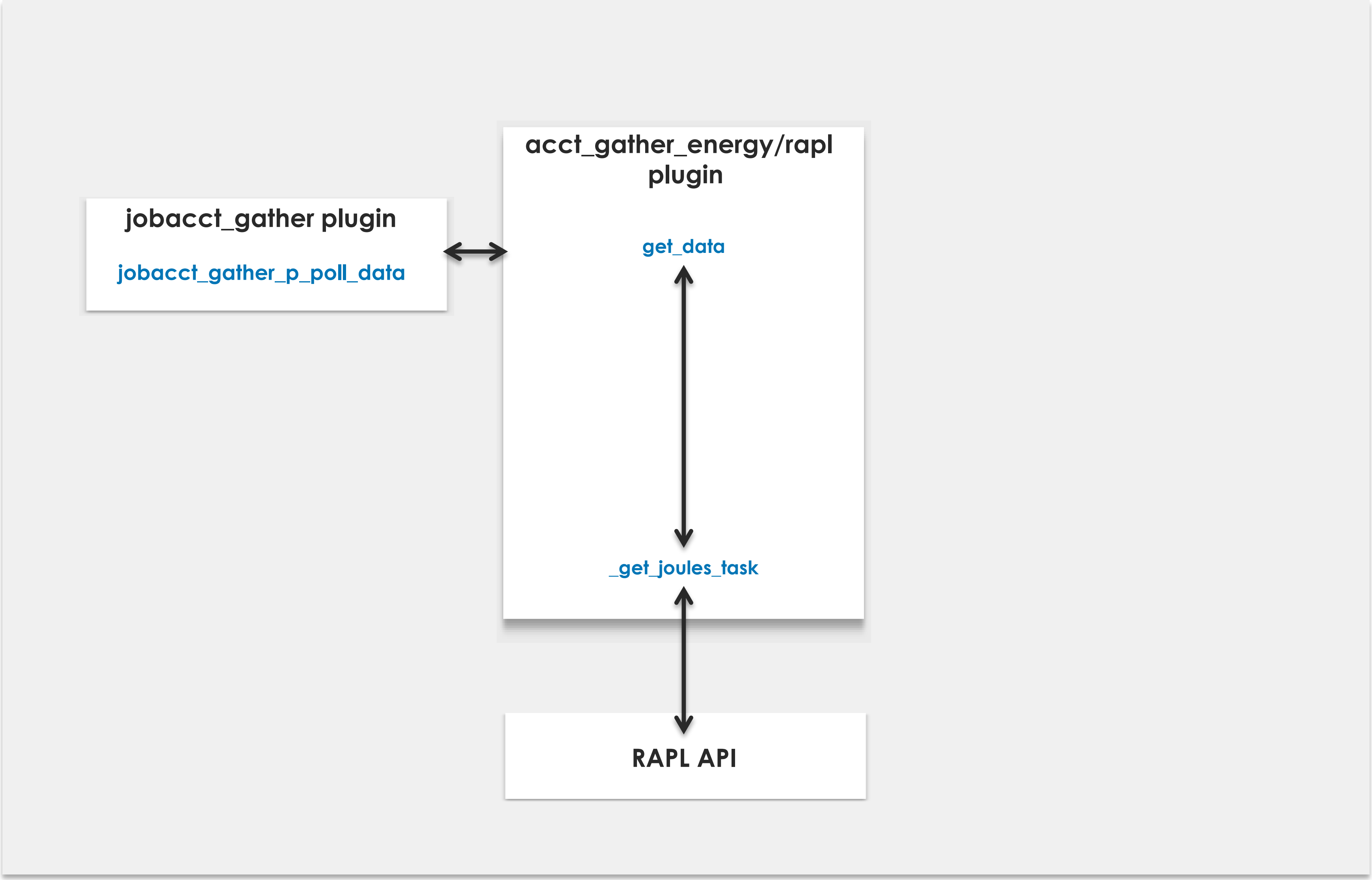
acct_gather_energy/ipmi - Accounting Data Collection Architecture



acct_gather_energy/ipmi - Node Data Collection Architecture



acct_gather_energy/rapl - Accounting Data Collection Architecture



jobacct_gather plugin

jobacct_gather_p_poll_data

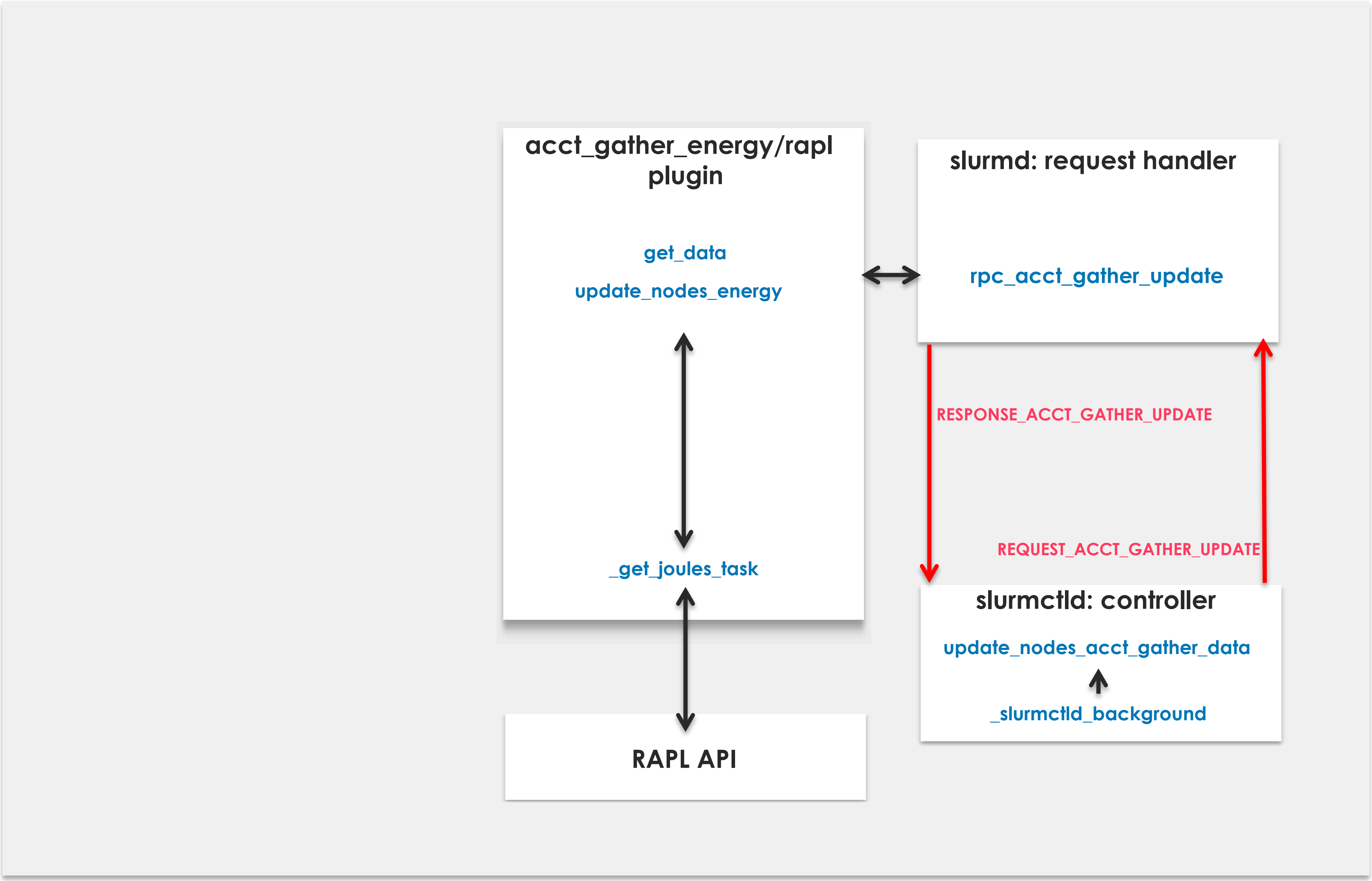
acct_gather_energy/rapl plugin

get_data

_get_joules_task

RAPL API

acct_gather_energy/rapl - Node Data Collection Architecture


acct_gather_energy/rapl plugin

get_data

update_nodes_energy

_get_joules_task

RAPL API

slurmd: request handler

rpc_acct_gather_update

RESPONSE_ACCT_GATHER_UPDATE

REQUEST_ACCT_GATHER_UPDATE

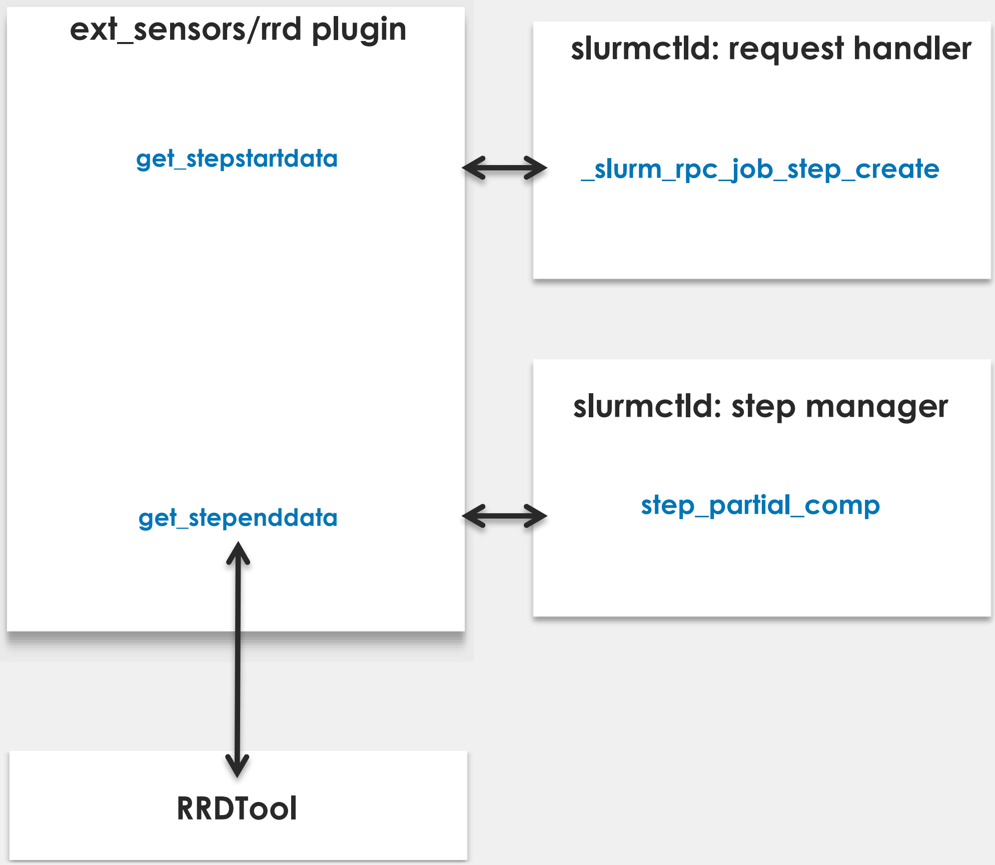
slurmctld: controller

update_nodes_acct_gather_data

_slurmctld_background

ext_sensors/rrd - Accounting Data Collection Architecture

The RRD database provides time-based platform data. Energy accounting values are calculated from the start and end timestamps of jobs/steps.



ext_sensors/rrd plugin

get_stepstartdata

get_stependdata

slurmctld: request handler

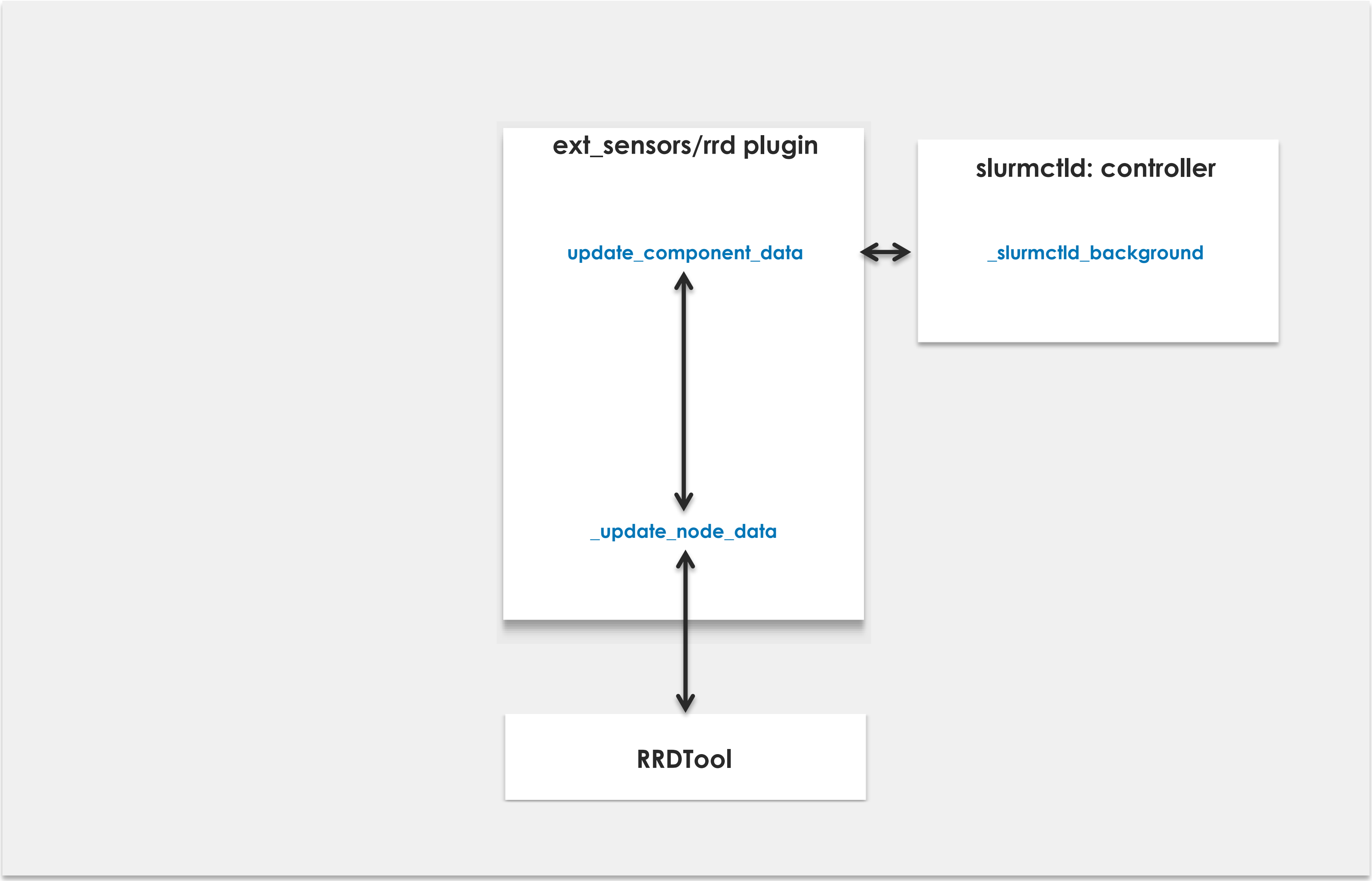
_slurm_rpc_job_step_create

slurmctld: step manager

step_partial_comp

RRDTool

ext_sensors/rrd - Node Data Collection Architecture



ext_sensors/rrd plugin

update_component_data

_update_node_data

slurmctld: controller

_slurmctld_background

RRDTool