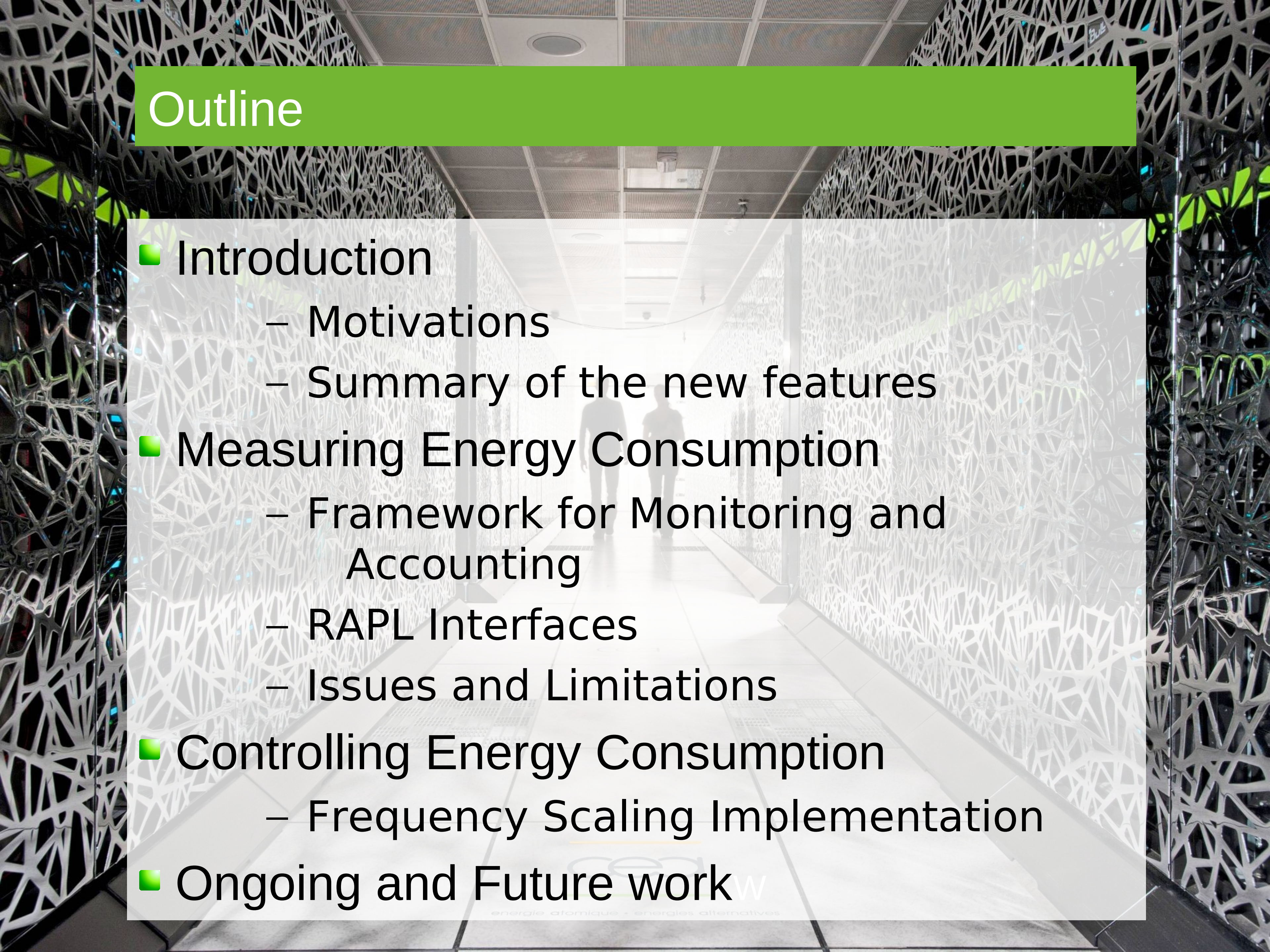
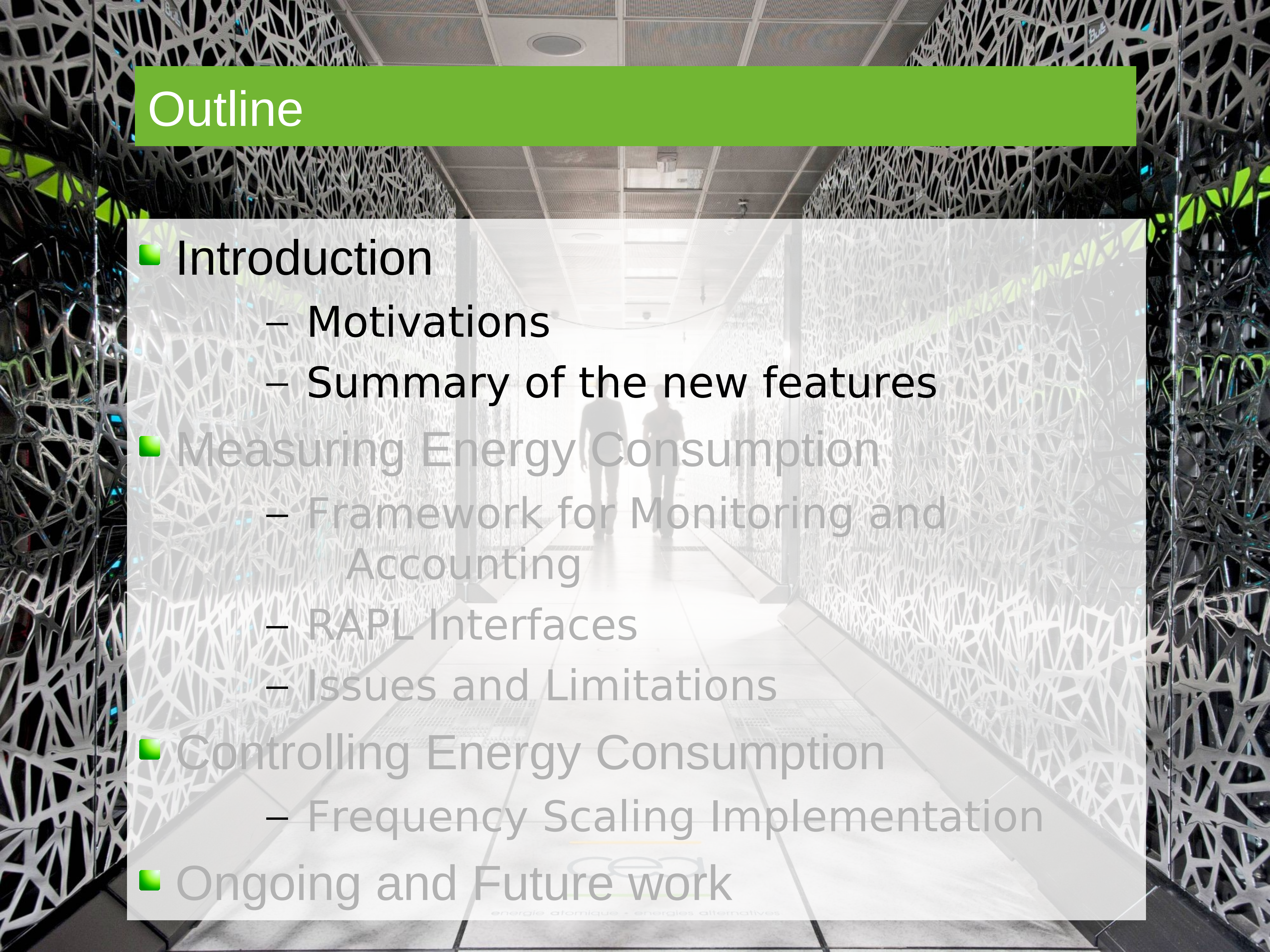
Enhancing SLURM with Energy Consumption Control and Monitoring Features

Yiannis Georgiou
email: yiannis.georgiou@bull.net

Architect of an Open World



Outline



Outline

Motivations for Power Management

Why do we care?

- HPC systems use important amounts of power

The Goal

- Reduce Energy Consumption in HPC systems

What can we do?

- Resource and Job Management System holds a strategic place on the HPC software stack
  - Knowledge and control over **Resources and Jobs**
  - Merge of **System and User** needs and views

Power Management with SLURM

Existing energy saving mechanism in SLURM

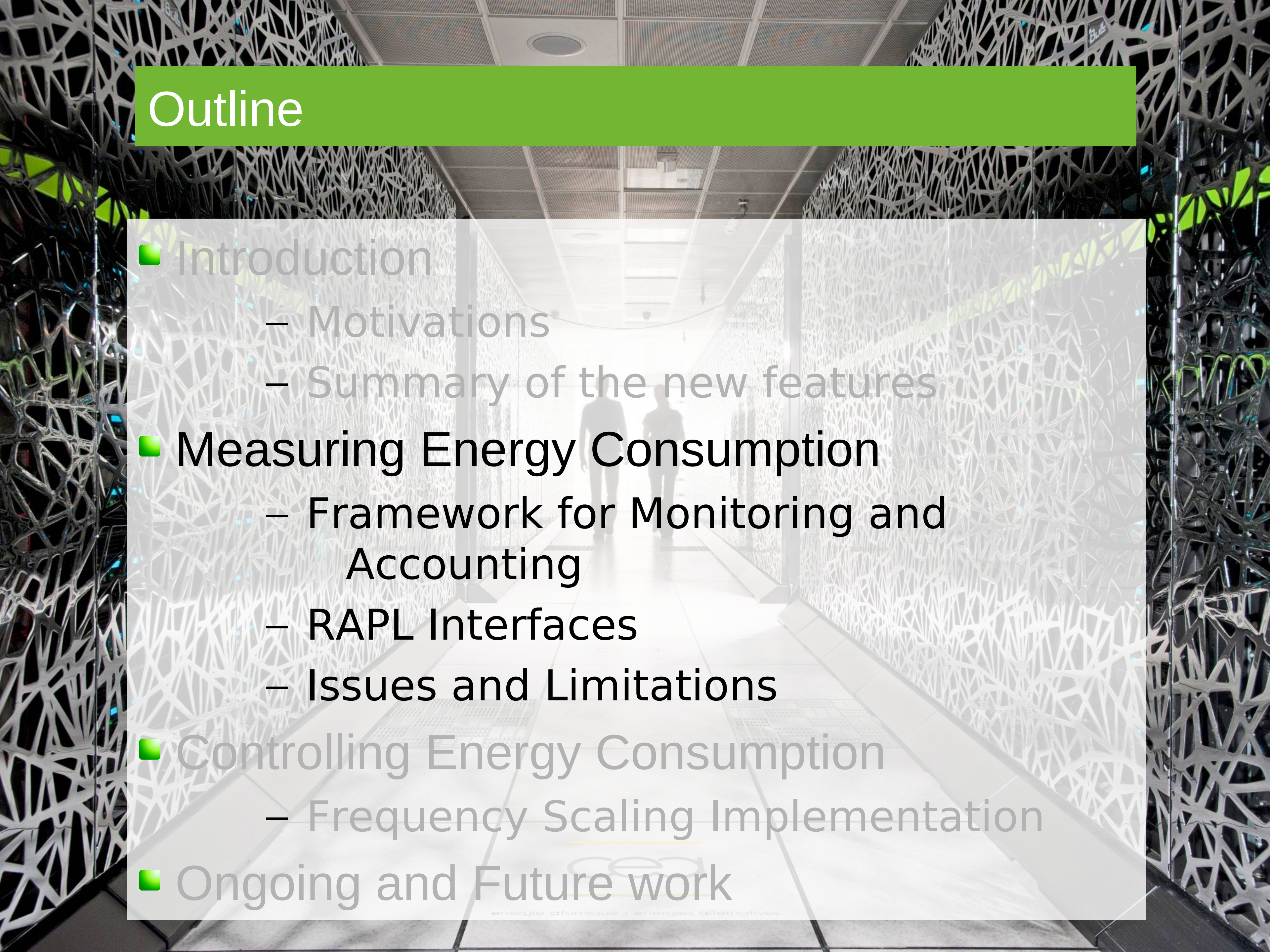
- **System** side feature
- Framework for energy saving through **unutilized** nodes
  - Administrator configurable actions (hibernate,frequency scaling, power off,etc)
  - Automatic “Wake up” when jobs arrive

Important Need:

- Make energy saving a **User** concern:
  1. Monitor and report node and jobs energy consumption
  2. Control over the jobs energy usage

Summary of the new features

- **New framework** to allow **per job** energy consumption and **node** power monitoring
  - Different types of energy capturing mechanisms currently 2 plugins supported:
    - from **RAPL** Interfaces
    - Through **IPMI** protocol (still under development)
- New parameter (for srun) to allow **CPU frequency scaling** for job execution
- **Reporting** of step's average CPU frequency and energy consumption



Outline

- Introduction
  - Motivations
  - Summary of the new features
- Measuring Energy Consumption
  - Framework for Monitoring and Accounting
  - RAPL Interfaces
  - Issues and Limitations
- Controlling Energy Consumption
  - Frequency Scaling Implementation
- Ongoing and Future work

Power/energy consumption monitoring

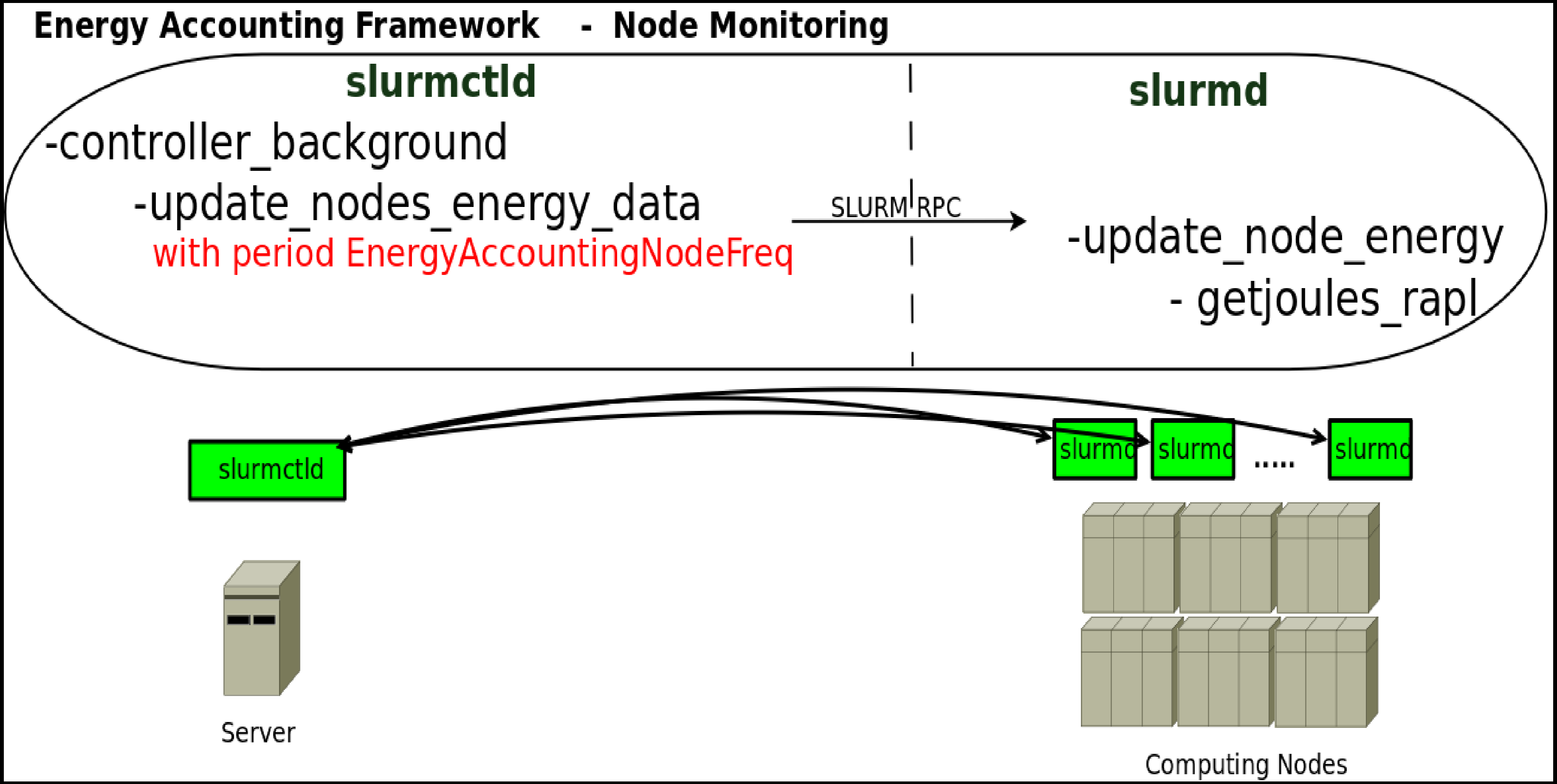
- Framework to support the **capturing** of power/energy consumption from the computing nodes
  - Captures and reports the **per node** power/energy consumption (scontrol show node)
  - Calculates the **per step** (job) energy consumption and stores on the DB along with the other execution characteristics (sstat / sacct)

Framework: Per node power/energy monitoring

- Framework launched from slurmctld as a background task (like scheduler,ping-nodes,healthcheck,etc)
- The update is executed periodically according to *EnergyAccountingNodeFreq* parameter of slurm.conf file
  - It makes a call to update_energy on every computing node through SLURM RPC
  - This function collects energy/power measures (RAPL,etc)
- The energy/power measures may be reported to the user as new information with scontrol show node

```
#slurm.conf
...
EnergyAccountingType=energy_accounting/rapl
EnergyAccountingNodeFreq=30
```

Architecture of the Framework - Node Monitoring



Usage Power/energy Node Monitoring

```
[root@berlin19 georgioy]# scontrol show node
NodeName=berlin47 Arch=x86_64 CoresPerSocket=8
   CPUAlloc=0 CPUErr=0 CPUTot=32 Features=(null)
   Gres=(null)
   NodeAddr=berlin47 NodeHostName=berlin47
   OS=Linux RealMemory=1 Sockets=2 Boards=1
   State=IDLE ThreadsPerCore=2 TmpDisk=0 Weight=1
   BootTime=2012-09-28T11:04:32 SlurmdStartTime=2012-10-
  08T10:59:45
   CurrentWatts=33 LowestJoules=106789 ConsumedJoules=1652356
```

Measuring power and energy on node

- Interested in accurate **internal node mechanisms** that may give us power and energy measurements of the entire node or independent components of it
- Two solutions seemed adjusted
  - IPMI protocol collecting info from the BMC of the node
  - RAPL interfaces (Intel Sandy Bridge processors)
- IPMI may have overhead when contacting the BMC
- RAPL has less overhead higher accuracy and was simpler to support

RAPL interfaces

•RAPL (**Running Average Power Limit**) are particular interfaces on Intel Sandy Bridge processors implemented to provide a mechanism for keeping the processors in a particular user-specified power envelope.

•RAPL Interfaces have **power capping** capabilities (not exploited yet through our developments)

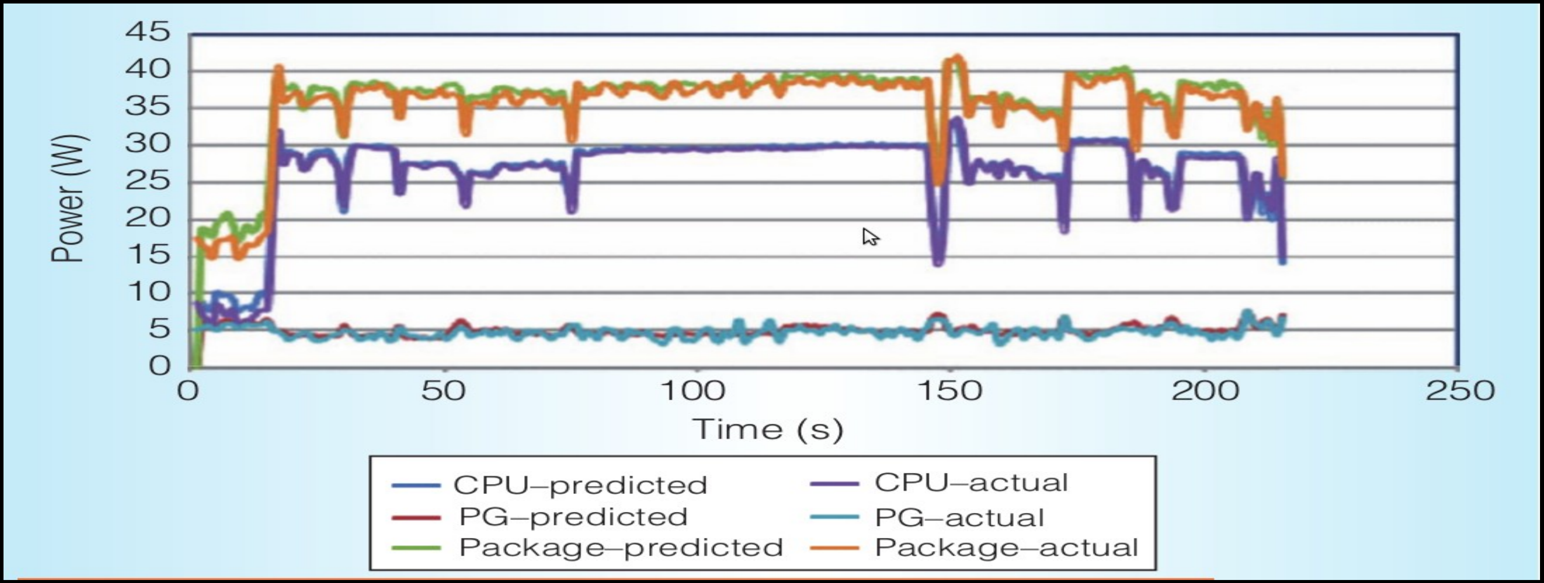
•RAPL Interfaces can estimate current energy usage **based on a software model** driven by hardware performance counters, temperature and leakage models

RAPL – power/energy measurments

- **PP0_ENERGY:** energy used by “power plane 0” which includes all cores and caches of a socket
- **PP1_ENERGY:** energy used by the ”uncores” (this may include on-chip Intel GPU)
- **PACKAGE_ENERGY:** total energy consumed by entire package (PP0 + PP1)
- **DRAM_ENERGY:** energy drawn by the memory controller inside the processor chip (the actual power fed into the main memory DIMMs is not included in the current measurment)

RAPL Interfaces Accuracy

- Intel indicates that power/energy readings are updated every milisecond (1kz)
- Rotem et al. experiments show good accuracy [1]



[1] Rotem et al. IEEE Micro-2012 "Power Management Architecture of the Intel Microarchitecture code named Sandy Bridge"

SLURM - Power and Energy Capturing from RAPL Interfaces

SLURM-RAPL Interfacing

•Access to RAPL data requires reading a CPU MSR register. This requires OS support

•Linux supports an 'MSR' driver and access to the register can be made through */dev/cpu/*/msr* with priviledged read permissions

•Inspired by PAPI support to RAPL Interfaces [3]

[3]Weaver et al. International Workshop on Power-aware systems and architectures, 2012 ”Measuring power and energy with PAPI”

SLURM - Power and Energy Capturing from RAPL Interfaces

Advantages:

•No overhead during capturing power/energy data

•**Measuring in energy units** simplifies the process in calculating energy consumption per step/job basis

– 2 values are sufficient (start/end of the job), no need of collecting big number of instant watts (IPMI case)

•**Accuracy** of Measurements

Disadvantages:

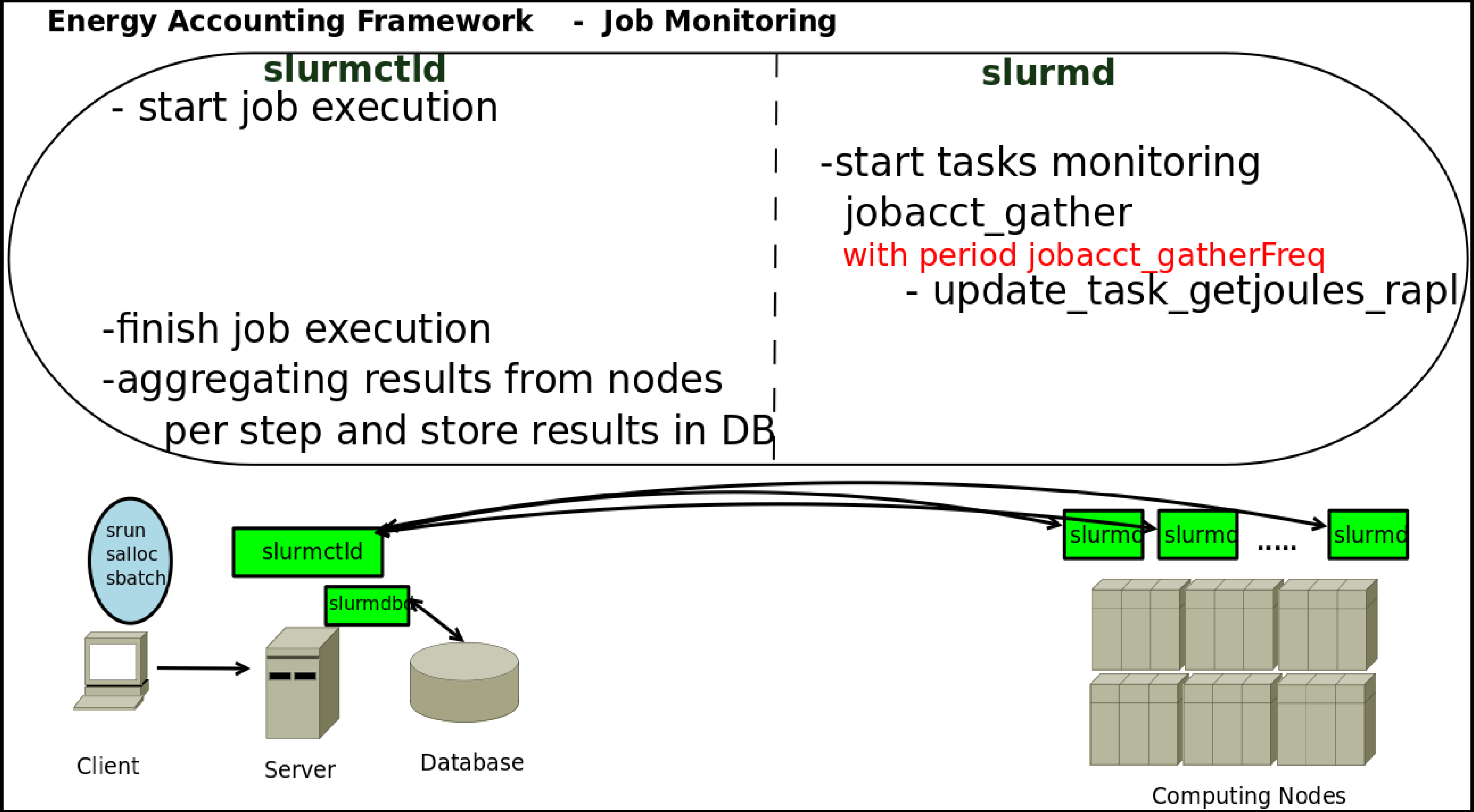
•Only processor and part of memory (DRAM) is supported (no motherboard, disk, external GPU, etc)

•Per socket granularity (not per core)

Framework: Per step energy consumption

- During job/step/task monitoring the energy accounting plugin is called by jobacct_gather
- Results aggregated per node considering the measurement of all packages (sockets + DRAM)
  - Initially the framework will give accurate results for **exclusive allocations** (whole nodes usage)
- One consideration in the beginning of the job and one in the end will be enough to have an accurate result
- Change in jobacct_gather to be certain that in the beginning and in the end of the job we collect results from RAPL Interfaces

Architecture of the RAPL Plugin



Energy Accounting Framework - Job Monitoring

slurmctld

- start job execution

-finish job execution

-aggregating results from nodes
per step and store results in DB

slurmd

-start tasks monitoring
jobacct_gather
with period jobacct_gatherFreq
- update_task_getjoules_rapl

RAPL Plugin Usage for Job Energy Accounting

```
[root@berlin19 bin]# srun  --resv-ports -N2 -n64 ./cg.C.64&
[1] 18060
[root@berlin19 bin]# sstat -j 58
       JobID   JobName ... Elapsed ... ConsumedEnergy
        58     cg.C.64 ... 00:04.000        1886
[root@berlin19 bin]# sacct -j 58
   JobID   JobName ... Elapsed ... ConsumedEnergy
        58     cg.C.64 ... 00:00:14      5033
```

Issues and Limitations

- Energy consumption results may be misleading in case of node sharing
  - Through RAPL possible to go upto socket granularity (not supported yet)
- RAPL does not give the energy consumption of the complete node but only that of CPU and DRAM (motherboard, network, GPU cannot be reported yet through these sensors)
  - GPU energy can be captured through NVIDIA Management Library (NVML)

Outline

Controlling Energy Consumption

- Measuring Energy Consumption and reporting it per step/job level is an important step, but users should have means to influence it as well.
- How can we do it. Various ways:
  - CPU Frequency Scaling (Static or Dynamic)
  - CPU P/C States modifications (Static or Dynamic)
  - Activation/desactivation of CPU Turbo Mode
  - Memory?

Static Frequency Scaling with SLURM jobs

- Introduced **–cpu-freq** parameter in srun
- **Static** since it may not be changed during the execution (user does not usually have root access on the computing nodes)
- The user may ask either a particular value in kilohertz or use low/medium/high and the request will match the closest possible numerical value

Frequency Scaling Design/Configuration Details

- Implemented as a **request** that the job step initiated by this srun be run at the requested frequency (if possible), on the cpus selected for the step. Or else the job will be executed nonetheless without setting frequency
- Tasks confinement to those cpus. If task confinement (i.e., TaskPlugin=task/affinity or TaskPlugin=task/cgroup with the "ConstrainCores" option) is not configured, this parameter will be ignored
- Implemented through manipulation of the /sys/devices/system/cpu/cpu0/cpufreq/scaling_cur_freq and governors drivers

Calculating Step's Average Frequency

•Capturing tasks' CPU association and collecting the cpu time spending on a particular frequency.

•Calculate a weighted average of the number of cycles used time spent on a particular frequency for each CPU.

•Sum up the results for each CPU and divide with the total number of used cores to calculate the average frequency per step.

•Values in Average Frequency will be influenced by the CPU time utilization(in case of no CPU usage the average frequency of the CPUS among all of them will be returned)

Frequency Scaling Usage

```
[root@berlin47 georgioy]# cat
  /sys/devices/system/cpu/cpu0/cpufreq/scaling_cur_freq
1200000
[root@berlin19 bin]# srun --cpu-freq=2700000 --resv-ports -N2 -n64 ./cg.C.64&
[1] 18060
[root@berlin47 georgioy]# cat
  /sys/devices/system/cpu/cpu0/cpufreq/scaling_cur_freq
2700000
[root@berlin19 bin]# sacct -j 60
   JobID    JobName ... Elapsed ... ConsumedEnergy
        58      cg.C.64 ... 00:00:14      3065
[root@berlin19 bin]#sacct -j 58 -format=jobid,elapsed,aveCPUFreq,consumedenergy
       JobID    Elapsed AveCPUFreq ConsumedEnergy
------------ ---------- ---------- ---------------
66              00:00:49    2640340          19668
[root@berlin47 georgioy]# cat
  /sys/devices/system/cpu/cpu0/cpufreq/scaling_cur_freq
 1200000
```

Summary

The described features will appear on the **stable release of 2.5** in November. They are currently under testing/debugging in the development track: 2.5.0-pre3 release - branch energy of the Schedmd git:

•**Monitoring** Energy consumption

– Energy accounting framework

– RAPL plugin for energy monitoring and job accounting

•**Controling** Energy consumption

– Static CPU Frequency Scaling for jobs

Usage Examples

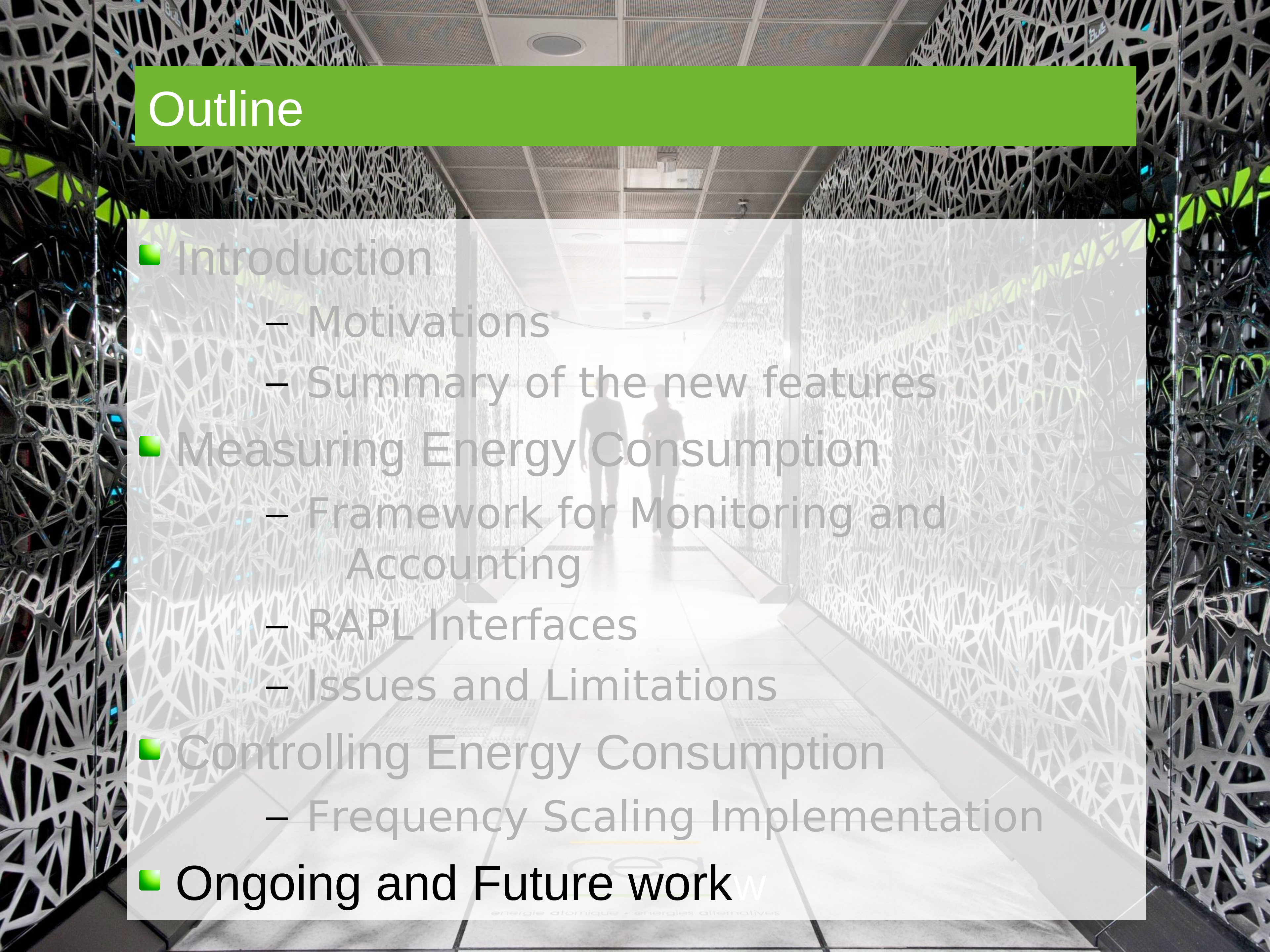
- The new features may be used for job/application profiling in order to find the best trade-off between requested CPU Frequency and Execution Time which may defer depending the codes of each job/application.
- Usage Examples with NAS Benchmarks execution (sp.C.64 and bt.C.64):

sp.C.64

AverageCPU Frequency	Elapsed Time	Consumed Energy(J)
1200000	00:01:35	19366
1396460	00:01:23	19018
1780477	00:01:09	19353
1996186	00:01:05	19817
2200000	00:01:02	20494
2362500	00:00:59	21408
2653125	00:00:56	23125

bt.C.64

AverageCPU Frequency	Elapsed Time	Consumed Energy(J)
1200000	00:01:35	17411
1386008	00:01:22	16990
1586343	00:01:64	16961
1783580	00:01:07	17119
1996875	00:00:58	17993
2231250	00:00:53	18531
2512500	00:00:49	19626



Outline

Current Ongoing Works

Energy accounting framework and monitoring

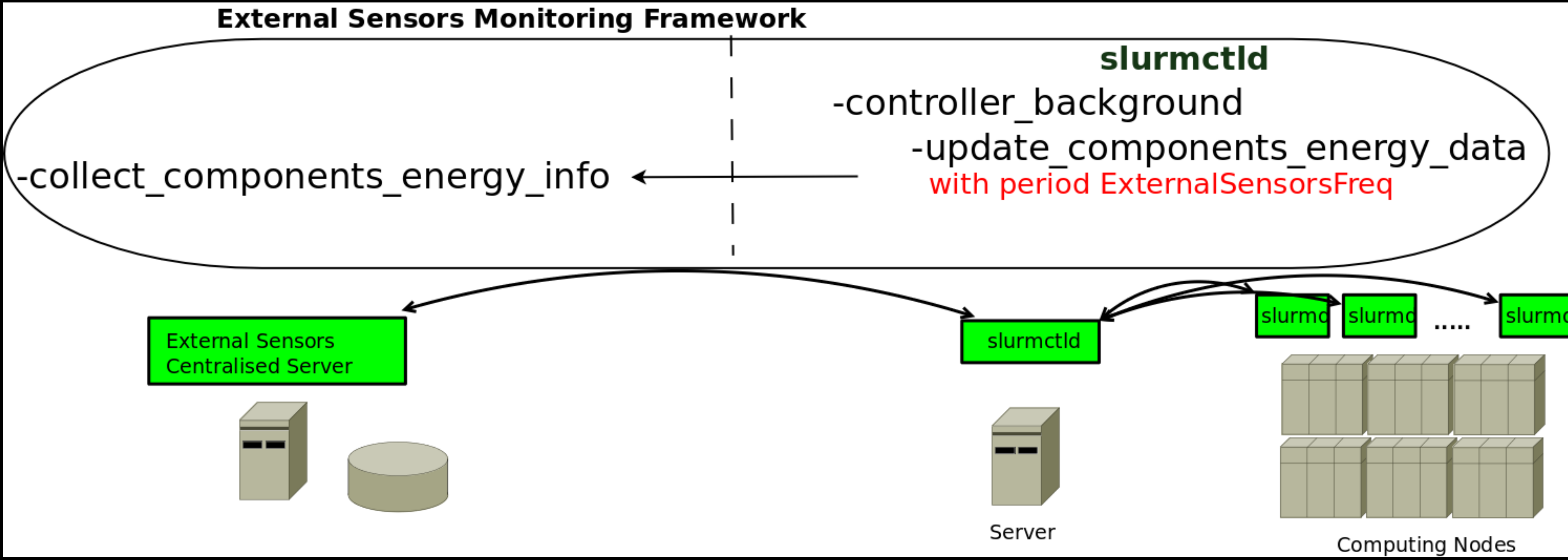
- Support IPMI protocol with a new plugin: Energyaccounting/ipmi
  - Issues with kipmi0 thread overhead → seems to be resolved lately
  - More complex architecture because of the measurements in Watt → it can be addressed with:
    - averaging energy window
    - Or by keeping values in files or DB for later usage (reporting, profiling)
  - Evaluating which project would be better to integrate in SLURM: Ipmitool or freeipmi
- RAPL Interfaces plugin: Extend the current plugin to support the energy consumption upto socket granularity (supported by RAPL but not from the current SLURM-RAPL integration)
  - Jobs that allocate cores from different sockets on the same node would have different and accurate energy consumption

Future Works

Energy aware scheduling

- Take into account power thresholds and job energy needs
  - The power thresholds may be set in the level of cluster, account and or user
  - The energy needs could be either defined in the beginning of the job (new srun/sbatch/salloc parameter), or estimated automatically from the jobs previous runs
- Take into account exterior environmental measurements (not only computing nodes energy but switches energy
- Take into account node temperatures and placing jobs on cold spots rather than hot spots of the cluster
- External sensors plugin to collect energy data from external source
  - Less overhead
  - More information (energy of switches temperature of room, other components)

External Sensors Plugin Architecture


External Sensors Monitoring Framework
slurmctld
-controller_background
-update_components_energy_data
with period ExternalSensorsFreq
-collect_components_energy_info
External Sensors Centralised Server
slurmctld
slurmd
slurmd
.....
slurmd
Server
Computing Nodes

People Involved

Research and Development:

-Dan Rusak(Bull, USA)

-Don Albert(Bull, USA)

-Martin Perry (Bull, USA)

-Yiannis Georgiou (Bull, France)

-Xavier Bru (Bull, France)

Design and Integration:

-Nancy Kritkausky (Bull, France)

-Moe Jette (SchedMD, USA)

-Danny Auble (SchedMD, USA)

Research and Design Ideas:

-Matthieu Hautreux (CEA, France)

-Francis Belot (CEA, France)