EAR : System software for energy management

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Topics

- EAR overview
- Running jobs with EAR
- Job Monitoring & optimization
- Data visualization

https://gitlab.bsc.es/ear_team/ear/-/wikis/home

What’s EAR: System software for energy management and optimization

3

Energy-efficient system

Runtime energy optimization,
Cluster power management and
Cluster and node powercap.

2

Powerful application performance and power monitoring

Runtime library to monitor performance and power dynamically **without any application modification**

1

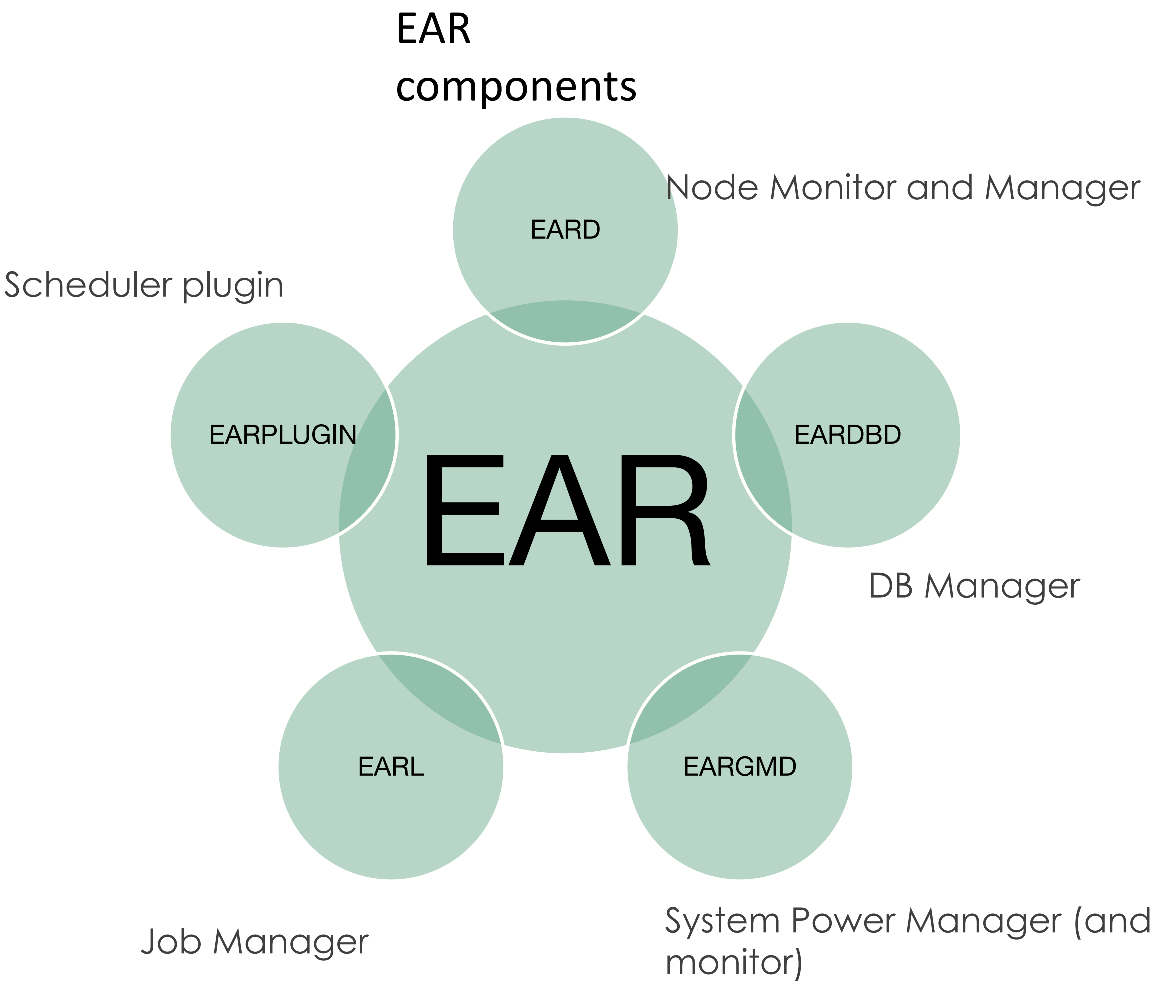
System monitoring and Job Accounting

Reports system power consumption

Job energy accounting

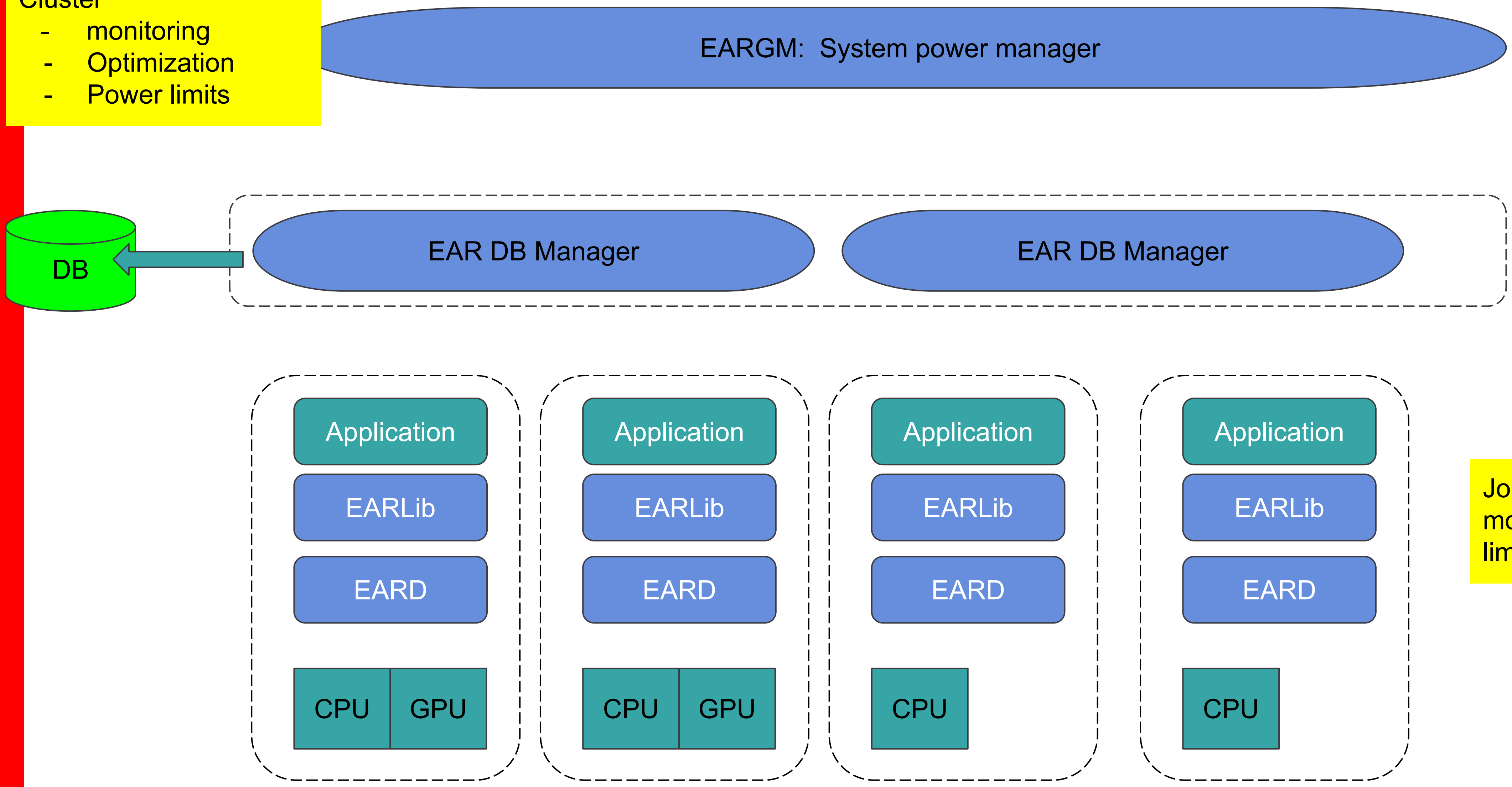
EAR Goals and Components

- To be
  - Easy to use
  - Transparent for users
  - Powerful for developers
- To optimize energy at runtime
- To be flexible and configurable
- Power management



EAR architecture

Cluster
- monitoring
- Optimization
- Power limits



Job Optimization, monitoring, power limits

EAR components

EARD: Node Manager

- Linux service running in all the compute nodes (1 x compute node)
- With **root privileges**
- EARD offers
  - **Node monitoring**
  - **Basic Job accounting**
  - **Node powercap**
  - API for local metrics readings and management operations (used by EAR library)
  - API for external power and management
- Applies energy settings described in ear conf file
  - Default policy, frequency
  - Controls EAR privileged users/groups/accounts

EARDBD: Data Base manager

- Linux service running in service nodes
- **Database manager**. Connects with DB server
- 1..N EARDBD can be run in the system
- EARDBD offers: Data aggregation and Data buffering

EARL: EAR Job Manager

- User-level Runtime library
- 100% transparent in most of the use cases with the scheduler plugin support
  - SLURM, PBS, OAR (REGALE)
- Energy and performance monitoring
- Dynamic energy optimization
- Extensible reporting mechanism
  - Multiple report plugins can be used: DB, CSV, etc

EARGMD: Global/System Power Manager

- Distributed service
- Heterogeneous cluster support : CPU and CPU+GPU
- Energy&Power monitoring for the whole cluster
- Cluster powercap

Scheduler plugin

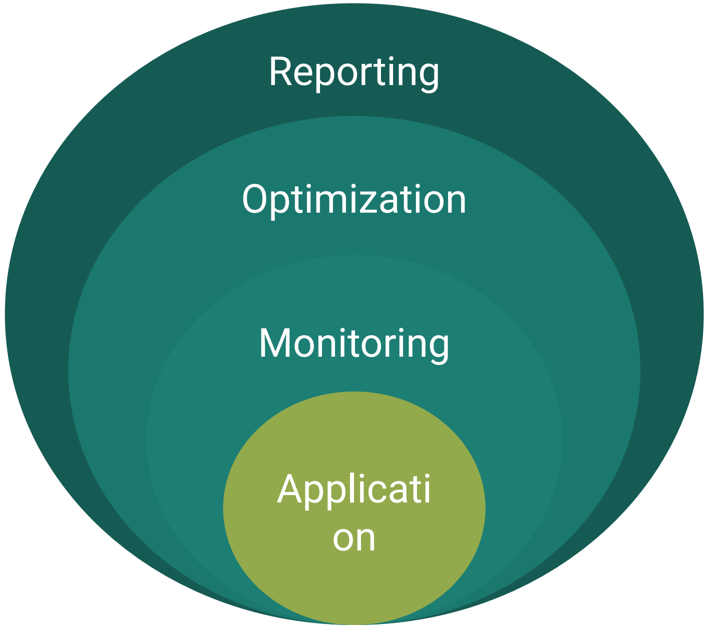
- SLURM SPANK plugin, PBS and OAR supported
- Intercepts job/step creation and
  - Connects with EARD to report scheduling events : new job / end job for example
  - Configures the environment for the automatic execution of EAR and environment variables

EAR Job Manager

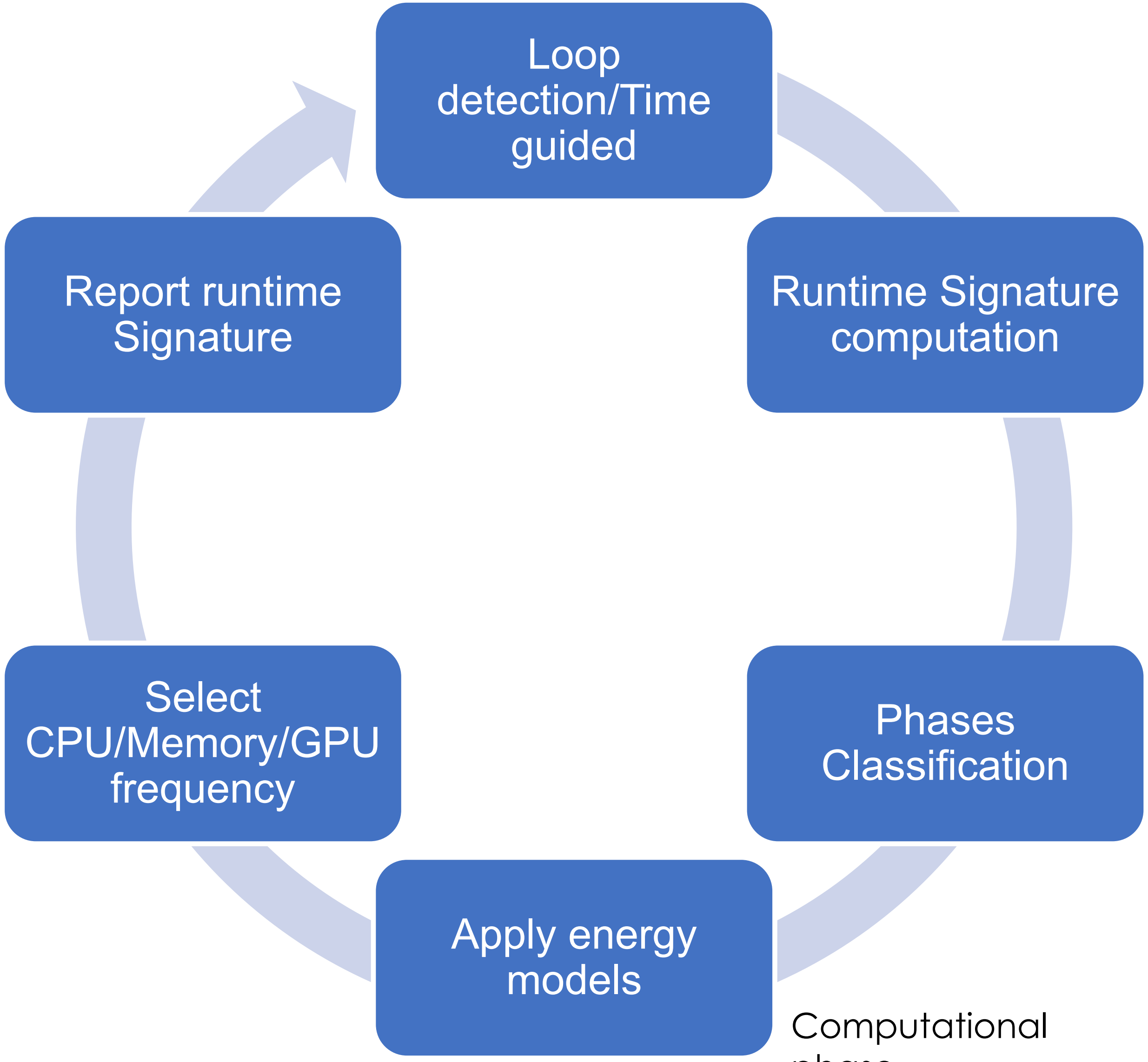
Performance metrics and energy optimization

EAR Library

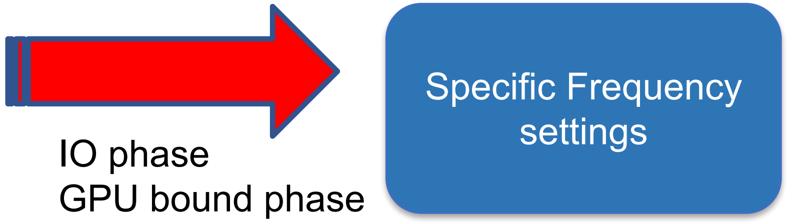
- User-level Runtime library
- Transparent to users through scheduler plugin (LD_PRELOAD used)
    - Few exceptions need some environment variables: Ex. Singularity
- Application energy and performance monitoring
- Application dynamic energy optimization
- Extensible design based on plugins
    - Policies, models, reporting, etc
- Compatible with other optimization tools
    - If requested, CNTD is loaded by EAR and both optimizations are applied (REGALE)



EAR JM lifecycle/stages



Computational phase



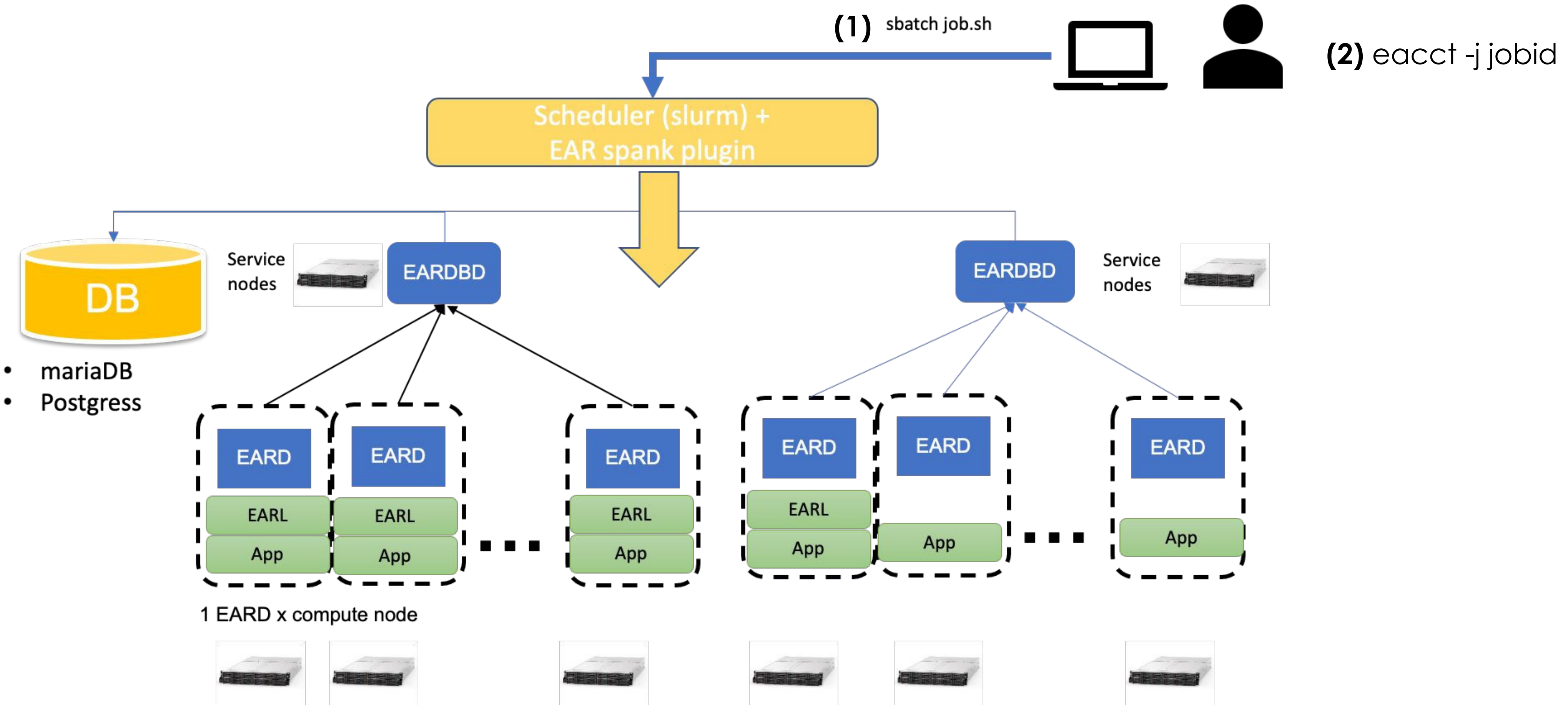
IO phase
GPU bound phase
GPU idle
CPU busy waiting
CPU and GPU

- Monitoring
  - Runtime loop detection (MPI only).
  - OR Time guided.
  - Automatic configuration of ***chunks*** for performance and power accuracy.
- Signatures report
  - Average per jobid/stepid/node.
  - Runtime metrics computed for **chunks**.

chunk = set of consecutive iterations with enough time to compute the power (def=10 sec.)

Running jobs with EAR

Jobs submission/accounting schema



- Cluster configuration: Default policy, default limits etc
- Optimization is 100% automatic based on application phases automatically detected

Job submission use cases

- **Without EAR library 100% transparent**
- **With EAR library**: To be 100% automatic EAR library needs
  - Symbol detection
  - Scheduler support (sbatch, srun or salloc)
- erun command or environment variables for not 100% automatic cases

	Use case	Bootstrap	Automatic
MPI	Intel/OpenMPI [+ others]	srun	yes
	Intel [+ others]	mpirun	yes
	OpenMPI [+ others]	mpirun	no : use erun
OpenMP		srun	yes (or use erun)
CUDA		srun	yes (or use erun)
python		srun	yes (or use erun)
Singularity (+any use case)		srun	yes + module or env var support

https://gitlab.bsc.es/ear_team/ear/-/wikis/User-guide#use-cases

Job submission + EAR library options

- Many of the job job scripts will work without modification.
- EAR flags in "help"

```
[julitac@int1 ~]$ sbatch --help|grep ear
      --ear=on|off                   Enables/disables Energy Aware Runtime Library (default OFF)
      --ear-policy=policy_name Selects an energy policy for EAR (monitoring, min_energy, min_time)
      --ear-cpufreq=frequency   Specifies the CPU frequency to be used by EAR , to be used with  monitoring
      --ear-user-db=file             Specifies the file to save the job applications metrics (csv format)
```

Memory and GPU frequency also supported with environment variables. See wiki

https://gitlab.bsc.es/ear_team/ear/-/wikis/home

Special cases (I)

- **MPI+Python is not transparent**, the user (or the module) should define the MPI version because it cannot be detected.
  - export EAR_LOAD_MPI_VERSION=”open mpi”
  - export EAR_LOAD_MPI_VERSION=”intel”
- **Singularity**: EAR can be used but EAR paths and env vars must be exported: APPTAINER_ENV_XXX, APPTAINER_BIND
  - export APPTAINER_BIND="$EAR_INSTALL_PATH:$EAR_INSTALL_PATH:ro,$EAR_TMP:$EAR_TMP:rw"
  - export APPTAINERENV_EAR_INSTALL_PATH=$EAR_INSTALL_PATH
  - export APPTAINERENV_EAR_TMP=$EAR_TMP
  - export APPTAINERENV_EAR_ETC=$EAR_TMP

Special cases (II)

- **OpenMPI**
  - srun recommended
  - use mpirun + erun
- Other use cases/frameworks
  - Force EAR to be loaded with env var
  - export EAR_LOADER_APPLICATION=”julia”

Monitoring: EAR metrics

https://gitlab.bsc.es/ear_team/ear/-/wikis/EAR-commands#ear-job-accounting-eacct

Monitoring

- Jobs executed without EAR JM (ear = off) report basic job accounting
  - Job/step/node identification
  - Job/step/node execution time
  - Job/step/node energy consumption
- Jobs executed with EAR JM (ear =on) report advanced job accounting
  - Job/step/node identification
  - Job/step/node/dynamic performance metrics (measured by EAR library)
  - Job/step/node/dynamic power metrics (measured by EAR library)
- Data is reported in EAR DB

How to get application data

1. **With EAR job accounting command eacct**: Command line with pre-defined queries. Multiple filters supported
   a. average
   b. per node
   c. runtime
   d. pre-selected column in stdout or full data in CSV file
2. **Directly from EAR library**
   a. csv with timestamp included: **--ear-user-db=filename** (prefix for the file)
   b. Additional report plugins can be used with env var.
      i. **EAR_REPORT_ADD**=plugin1.so:plug2.so

Example: https://gitlab.bsc.es/ear_team/ear/-/blob/master/src/report/log.c

Basic MPI example

```
#!/bin/bash

#SBATCH -p rome
#SBATCH -t 00:15:00
#SBATCH --nodes=1
#SBATCH --exclusive

#SBATCH --output=NPB.%j.out
#SBATCH --error=NPB.%j.err
#SBATCH --job-name=NPB
#SBATCH –ear=on

module load 2023
module load foss/2023a

PROJECT_DIR=/projects/0/energy-course

srun --ntasks=128 $PROJECT_DIR/NPB3.4-MZ-MPI/sp-mz.C.x
```

Job submission examples

```
#!/bin/bash
#SBATCH –ntasks=YYY
#### EAR=ON will load all the steps with EAR library
#SBATCH --ear=on

mkdir -p logs
# CASE 1: Default: EAR library on because of headers
srun application
# Runtime metrics reported ON
export EARL_REPORT_LOOPS=1
# CASE 2:  mpirun + ear-user-db → CSV file
export I_MPI_HYDRA_BOOTSTRAP_EXEC_EXTRA_ARGS="--ear-user-db=logs/app"
mpirun application
# CASE 3: Using srun + ear-user-db → CSV file
srun --ear-user-db=logs/bt.srun application
# CASE 4: Using erun
module load ear
mpirun -n XXXX  erun --ear=on --program="application arg1 arg2…argn”
# CASE 5: EAR library off for this steps
srun --ear=off application
```

eacct: Energy accounting

- SLURM jobid/stepid
- Users can only access its own data
- GPU support is per-cluster, Jobs executed in AMD partition will also show GPU metrics with null values.
- By default, average per job.step metrics: All nodes included. Most metrics are averaged, energy is accumulated.
- Main flags:
  - -l → per node
  - -r → runtime metrics (default is off in snellius. Use export EARL_REPORT_LOOPS=1
  - -c filename → save in CSV format in file

```
[julitac@int3 example]$ eacct -j 1483484
JOB-STEP USER      APPLICATION      POLICY NODES AVG/DEF/IMC(GHz)     TIME(s)    POWER(W) GBS     CPI      ENERGY(J)    GFLOPS/W IO(MBs) MPI%  G-POW(T/U)   G-FREQ
G-UTIL(G/MEM)
1483484-sb   julitac    128nodes_16cores NP     16    2.35/2.60/---      972.00     375.71   ---     ---        5843040      ---      ---     ---   ---          ---     ---
1483484-1    julitac    128nodes_16cores MT     16    2.35/2.40/1.47   492.26     373.53   28.44   0.46  2942015     0.0084   250.8   71.7  0.00/---      ---     ---
1483484-0    julitac    128nodes_16cores ME     16    2.55/2.60/1.47   460.68     381.00   30.37   0.47  2808271     0.0088   268.2   71.7  0.00/---      ---     ---
```

eacct metrics

- CPU metrics
  - AVG/DEF/IMC(GHz): **Average** CPU frequency, default frequency and average memory frequency. Includes all the nodes for the step. In KHz.
  - TIME(s): Step execution time, in **seconds**.
  - **POWER: Average DC node power. (in Watts)**.
  - **GBS: CPU Main memory bandwidth (GB/second). Hint for CPU/Memory bound classification.**
  - **CPI: CPU Cycles per Instruction. Hint for CPU/Memory bound classification**.
  - ENERGY(J): Accumulated node energy. Includes all the nodes. In Joules.
  - **GFLOPS/WATT : CPU GFlops per Watt. Hint for energy efficiency.**
  - IO(MBs) : IO (read and write) Mega Bytes per second.
  - MPI% : **Percentage of MPI time** over the total execution time. It's the average including all the processes and nodes.
- GPU metrics
  - G-POW (T/U) : Average GPU power. Accumulated per node and average of all the nodes.
    - T = Total (GPU power consumed even if the process is not using them).
    - U = GPUs used by the job.
  - G-FREQ : Average GPU frequency. Per node and average of all the nodes.
  - G-UTIL(G/MEM) : GPU utilization and GPU memory utilization.

https://gitlab.bsc.es/ear_team/ear/-/wikis/User%20guide#job-accounting-eacct

Tensorflow energy evaluation

```
#!/bin/bash
#SBATCH -p gpu
#SBATCH -n 1
#SBATCH  --ntasks-per-node=1
#SBATCH --gpus=1
#SBATCH --cpus-per-task=18
#SBATCH  -t 8:00:00
#SBATCH --ear-user-db=tensorflow_exps → Metrics reported in DB and User local CSV file
module load 2021
module load TensorFlow/2.6.0-foss-2021a-CUDA-11.3.1
module list

export OMP_NUM_THREADS=18
export EARL_REPORT_LOOPS=1 → Disabled by default in this cluster

srun -J ResNet50 python benchmark.py  --model=ResNet50 --num-iters=100
srun -J ResNet50_mixed python benchmark.py --mixed-prec --num-iters=100
srun -J ResNet50_disable-tf32 python benchmark.py --model=ResNet50 --disable-tf32 --num-iters=100
srun -J VGG19 python benchmark.py  --model=VGG19 --num-iters=100
srun -J VGG19_mixed python benchmark.py  --model=VGG19 --mixed-prec --num-iters=100
srun -J VGG19_disable-tf32 python benchmark.py  --model=VGG19 --disable-tf32 --num-iters=100
srun -J DenseNet121 python benchmark.py  --model=DenseNet121 --num-iters=100
srun -J DenseNet121_mixed python benchmark.py  --model=DenseNet121 --mixed-prec --num-iters=100
srun -J DenseNet121_disable-tf32 python benchmark.py  --model=DenseNet121 --disable-tf32 --num-iters=100
```

Tensorflow: GPU application

[julitac@int5 ~]$ eacct -j 5687690

JOB-STEP	USER	APPLICATION	POLICY	NODES	AVG/DEF/IMC(GHz)	TIME(s)	POWER(W)	GBS	CPI	ENERGY(J)	GFLOPS/W	IO(MBs)	MPI%	G-POW (T/U)	G-FREQ	G-UTIL(G/MEM)
5687690-sb	julitac	run_tensor.sh	NP	1	2.43/2.40/---	**2612.00**	448.98	---	---	**1172725**	---	---	---	---	---	---
5687690-8	julitac	DenseNet121_disa	MO	1	2.38/2.40/2.19	**358.55**	897.17	2.03	0.66	**321685**	0.0000	0.1	0.0	257.92 /257.92	1.410	92%/44%
5687690-7	julitac	DenseNet121_mixe	MO	1	2.38/2.40/2.19	**189.30**	876.59	0.82	0.67	**165936**	0.0000	0.2	0.0	238.88 /238.88	1.410	80%/52%
5687690-6	julitac	DenseNet121	MO	1	2.38/2.40/2.19	**249.38**	890.48	0.59	0.66	**222070**	0.0000	0.1	0.0	251.56 /251.56	1.410	88%/73%
5687690-5	julitac	VGG19_disable-tf	MO	1	2.38/2.40/2.19	**646.86**	877.18	2.33	0.52	**567419**	0.0000	0.1	0.0	238.58 /238.58	1.410	98%/26%
5687690-4	julitac	VGG19_mixed	MO	1	2.38/2.40/2.19	**248.40**	897.64	0.52	0.67	**222972**	0.0000	0.1	0.0	257.04 /257.04	1.410	96%/51%
5687690-3	julitac	VGG19	MO	1	2.38/2.40/2.19	**261.37**	907.44	3.21	0.61	**237176**	0.0000	0.1	0.0	267.94 /267.94	1.410	96%/59%
5687690-2	julitac	ResNet50_disable	MO	1	2.38/2.40/2.19	**302.42**	920.38	4.22	0.65	**278338**	0.0000	0.1	0.0	279.54 /279.54	1.410	94%/43%
5687690-1	julitac	ResNet50_mixed	MO	1	2.38/2.40/2.19	**149.26**	873.35	0.80	0.66	**130356**	0.0000	0.2	0.0	233.60 /233.60	1.403	84%/50%
5687690-0	julitac	ResNet50	MO	1	2.38/2.40/2.19	**196.33**	904.09	0.62	0.65	**177504**	0.0000	0.2	0.0	261.45 /261.45	1.372	87%/70%

EACCT metrics

- **CPU Bound phases**
  - Very low CPI , Cycles per instruction, (less than 0.5)
  - Low Memory bandwidth (depends on the architecture)
  - Percentage of MPI influences the CPI (MPI waitings are implemented with busy waiting, reduces the CPI)
  - High Gflops
  - Scale linearly with CPU frequency. Not too much opportunities for energy savings
- **Memory bound phases**
  - Medium/High CPI (CPU has to wait for data → increases cycles per instructions)
  - High Memory bandwidth
  - Medium/High Gflops
  - Can take profit of reducing the CPU frequency. Do not scale linearly with CPU frequency

Job Energy Efficiency metric: CPU jobs

- PUE is the ratio of the total amount of power used by a computer data center facility to the power delivered to computing equipment
    - It's not a job metric!!

- **Being energy efficient is not consuming less power, is doing an optimal utilization of the power we consume**

- For CPU HPC applications, a traditional metric could be the GFLOPS/Watt
    - GFlops characterize the CPU activity
    - Watts the power consumption
- Not valid for
    - Data intensive jobs
    - Non-CPU intensive jobs

Job Energy Efficiency metric: GPU jobs

- GPU metrics reported by default (per-GPU)
  - GPU utilization
  - GPU memory utilization
  - GPU frequency
  - GPU power consumption

- GPU Utilization is not representative enough of the GPU activity
  - NVIDIA GPUs provides more metrics, but many of them are ratios (0…1), for example the FP activity
  - Any action on the GPU increases the GPU utilization

EACCT metrics: what else can be observed?

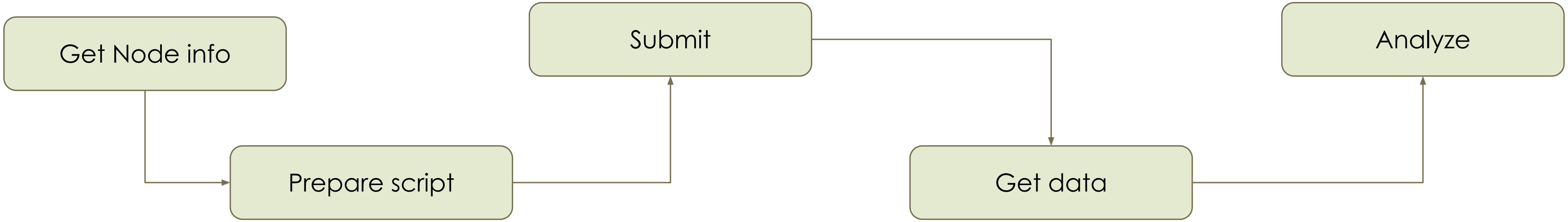
- Are nodes homogeneous ? Same signatures in all the nodes (-l)
- Are there phases, is it constant? Are runtime signatures the same? (-r)
- How much time my application is in MPI calls??
- GPU utilization
- Impact on power and performance of changing job configuration
  - Example: Problem with GPU utilization in GROMACS-GPU

```
[julitac@int3 ~]$ eacct -j 1387089
JOB-STEP USER       APPLICATION      POLICY NODES AVG/DEF/IMC(GHz) TIME(s)    POWER(W) GBS     CPI   ENERGY(J)     GFLOPS/W IO(MBs) MPI%  G-POW
(T/U)   G-FREQ  G-UTIL(G/MEM)
1387089-sb   julitac    rfm_GROMACS_GPU_ NP     1     2.35/2.40/---     6634.00    879.52    ---      ---    5834703       ---       ---       ---    ---            ---      ---
1387089-2    julitac    rfm_GROMACS_GPU_ MT     1     2.35/2.20/2.02    2886.16    803.91    24.39    0.37  2320201      0.0091    0.1      71.0  333.42/333.42 1.409    10%/0%
1387089-1    julitac    rfm_GROMACS_GPU_ ME     1     2.35/2.40/2.10    2880.70    847.76    37.46    0.38  2442131      0.0129    0.1      68.1  359.00/359.00 1.409    14%/0%
1387089-0    julitac    rfm_GROMACS_GPU_ MO     1     2.38/2.40/2.19    833.64     1260.21   152.87   0.56  1050561      0.0425    0.4      26.4  650.88/650.88 1.409    73%/0%
```

Energy optimization

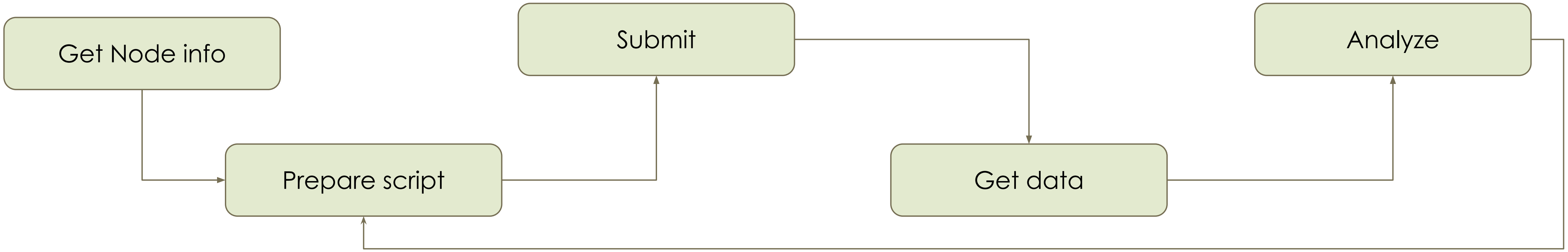
Static vs Dynamic energy optimization

- Optimal CPU/Memory/GPU depends on the application, input data, architecture, number of nodes etc etc
- However, you can be interested in applying DVFS in specific case
- With EAR is easy to ask for CPU frequencies
- EAR offers in some architectures more CPU frequencies than available from the OS
- The enode_info command reports the EAR technical specification for the computational node



Static vs Dynamic energy optimization

Static optimization loop



Dynamic optimization

```
$EAR_INSTALL_PATH/bin/tools/enode_info --cpu
EAR CPU info in node tcn2
EAR CPU info Topology: cpu_count      : 128
core_count      : 128
socket_count     : 2
….. // CPU details
EAR CPU info load
EAR CPU info API: EARD
EAR CPU info num devices:128
EAR CPU info list of CPU frequencies
PS0: id0, 2600000 KHz
PS1: id1, 2500000 KHz
PS2: id2, 2400000 KHz
PS3: id3, 2300000 KHz
PS4: id4, 2200000 KHz
PS5: id5, 2100000 KHz
PS6: id6, 2000000 KHz
PS7: id7, 1900000 KHz
PS8: id8, 1800000 KHz
PS9: id9, 1700000 KHz
PS10: id10, 1600000 KHz
PS11: id11, 1500000 KHz
EAR CPU info pstate nominal is 0, CPU freq = 2600000 KHz
EAR CPU info governor CPU[0] = conservative
….
EAR CPU info governor CPU[127] = conservative
EAR CPU info curr CPUF[0] = 2601000
..
EAR CPU info curr CPUF[127] = 2601000
```

```
#!/bin/bash
#SBATCH --job-name=sp
#SBATCH --ntasks=128
#SBATCH --ear=on
module purge
module load 2022
module load iimpi/2022a

export OMP_NUM_THREADS=1
export EARL_REPORT_LOOPS=1
srun --ear-policy=monitoring --ear-cpufreq=2500000 ./sp-mz.D.128
srun --ear-policy=monitoring --ear-cpufreq=2400000 ./sp-mz.D.128
srun --ear-policy=monitoring --ear-cpufreq=2300000 ./sp-mz.D.128
srun --ear-policy=monitoring --ear-cpufreq=2200000 ./sp-mz.D.128
```

Energy policies: Computational phases

- Monitoring:
  - Application analysis
  - Static energy optimization (Manual CPU/Memory/GPU freq selection)

- Minimize energy to solution (min_energy)
  - EAR **reduces CPU frequency** to save energy with a maximum time penalty
  - Applications start at default frequency and CPU frequency is (potentially) reduced
  - default frequency = nominal frequency
  - Memory frequency selected with a linear search

- Minimize time to solution (min_time)
  - EAR **increases CPU frequency** to minimize time for "*frequency efficient*" codes
  - Applications that scale well with CPU frequency
  - Default frequency = lower than nominal frequency
  - Application will never run at CPU frequency below the default CPU frequency
  - Memory frequency selected with a linear search

Common to both policies

- GPU optimization when GPU idleness.
- IO phases detected.
- Turbo can be enabled if configured and CPU bound application.
- Intra-node Load balance .

- GPU frequency selection:
  - Maximum if GPU utilization > 0
  - Minimum if GPU utilization == 0 (power consumption is lower.)

- Version 5.0 will include GPU optimization

sbatch --ntasks=192 --partition=rome sp.D.sh
sbatch --ntasks=192 --partition=rome **–ear-policy=min_energy** sp.D.sh

KERNEL SP-MZ.D : ROME (Min_energy vs Nominal): Must be the same node for comparison

```
[julitac@int5]$ eacct -j 4896747.0
    JOB-STEP USER      APPLI      POLICY NODES AVG/DEF/MEM  TIME(s)   POWER(W) GBS     CPI   ENERGY(J)    GFLOPS/W IO(MBs) MPI%  G-POW (T/U)
G-FREQ  G-UTIL(G/MEM)
4896747-0    julitac    sp            ME     1     2.16/2.60/1.47   336.75     457.62   197.79  0.69  154102      2.9608   0.0     12.0  0.00/---        ---
---
[julitac@int5]$ eacct -j 4896738.0
    JOB-STEP USER      APPLI     POLICY NODES AVG/DEF/MEM TIME(s)    POWER(W)  GBS     CPI   ENERGY(J)    GFLOPS/W IO(MBs) MPI%  G-POW (T/U)
G-FREQ  G-UTIL(G/MEM)
4896738-0    julitac    sp            MO     1     2.57/2.60/1.47   329.67     519.01   202.73  0.79  171103      2.6666   0.0     11.0  0.00/---        ---
---
```

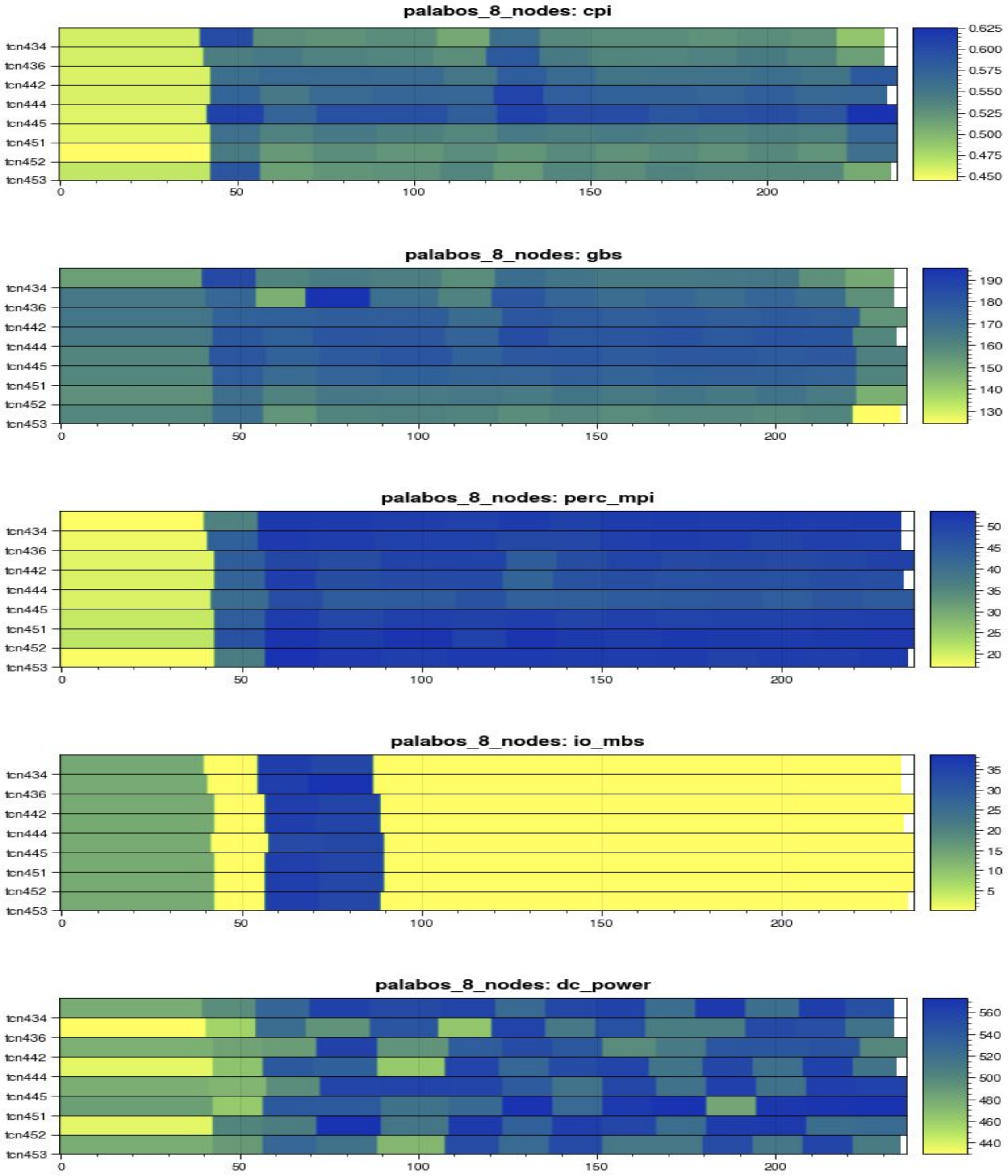
EAR Data visualization

- https://github.com/sara-nl/ISC-2024-EAR-tutorial/blob/main/tutorials/visualization/README.md
- ear-job-analytics: EAR tool to create images with runtime data visualization and paraver traces

- Grafana
  - Running at DC and executing SQL queries (more powerful, but depends on Data Center permissions)
  - Local installation:
    - Grafana server installed and running locally
    - Data gathered in CSV format with eacct and using CSV plugin
    - Not mandatory but more information if loops are in DB
    - Can be use also without EAR DB: –ear-user-db=filename
-

Example:
Palabos: Strong Scaling Benchmark

- Per-node, Per-iteration ”traces”
  - CPI (Cycles per instruction)
  - Main memory BW (GB/s)
  - MPI% (percentage spent in MPI calls)
  - I/O (Disk)
  - Node Power



Thanks!

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