Track Energy & Emissions of User Jobs on HPC/AI Platforms using CEEMS

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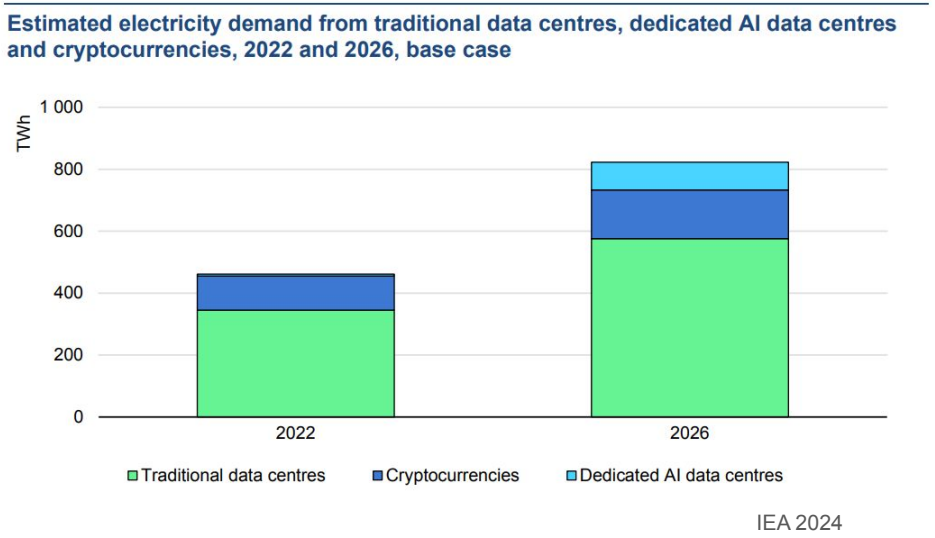
Context

- 40 % of DC consumption is due to servers
- Exploding usage of accelerators (GPUs) will only “accelerate” this snowball effect
- “Practical” solution is to engage the end users to optimize their workflows
- Need to provide relevant metrics and tools to encourage optimization



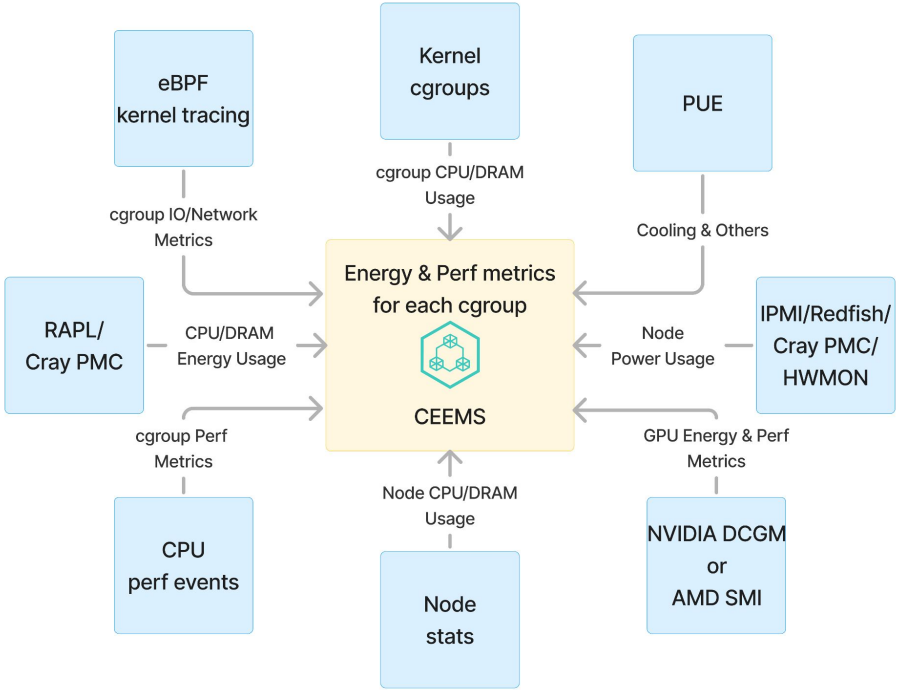
Compute Energy & Emissions Monitoring Stack (CEEMS)

CEEMS

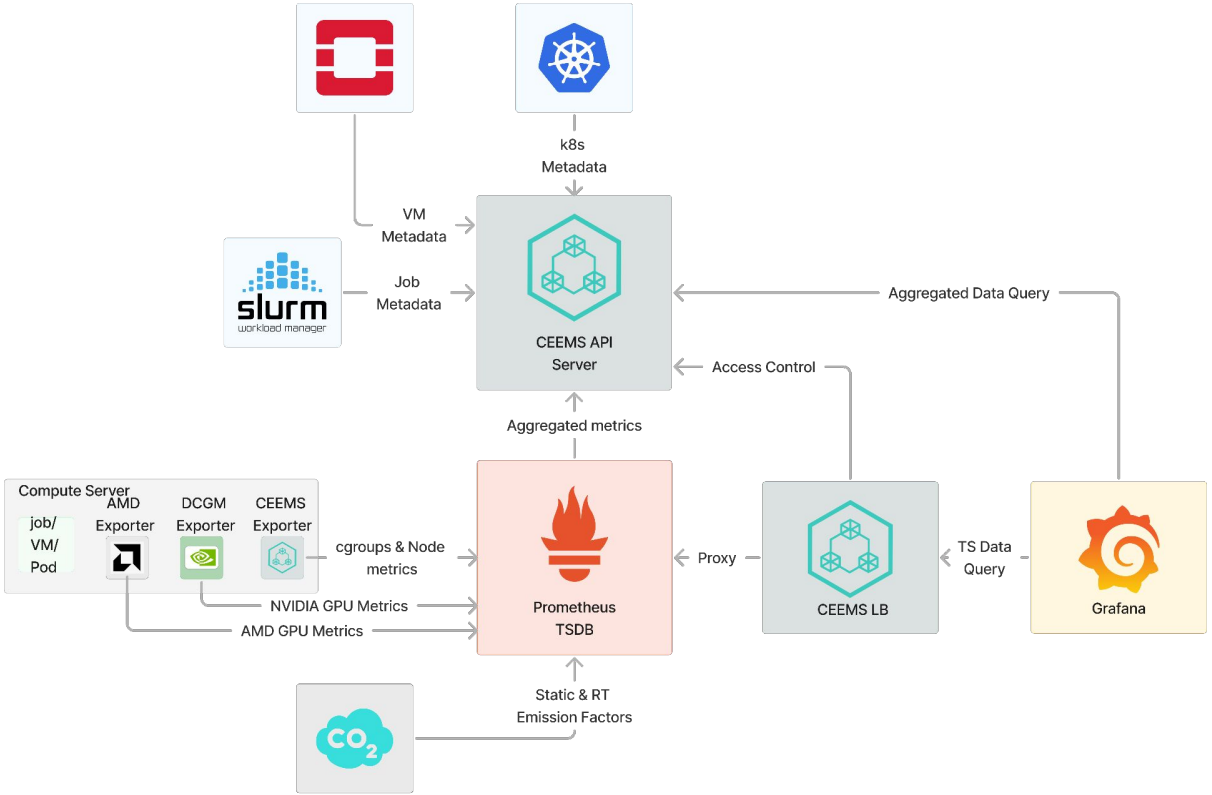
- Started as a tool to estimate energy consumption and equivalent emissions for HPC workloads
- Extended the stack to support Openstack and k8s
- A system level stack
- cgroups, perf subsystem, eBPF are at the heart of CEEMS
- Based on CNCF Opensource components. Prometheus as TSDB and Grafana for visualization. CLI client also available

CEEMS

Control Groups (cgroups) provide a mechanism for aggregating/partitioning sets of tasks, and all their future children, into hierarchical groups with specialized behaviour. For Linux, a SLURM job, an Openstack VM or a k8s pod is effectively a cgroup



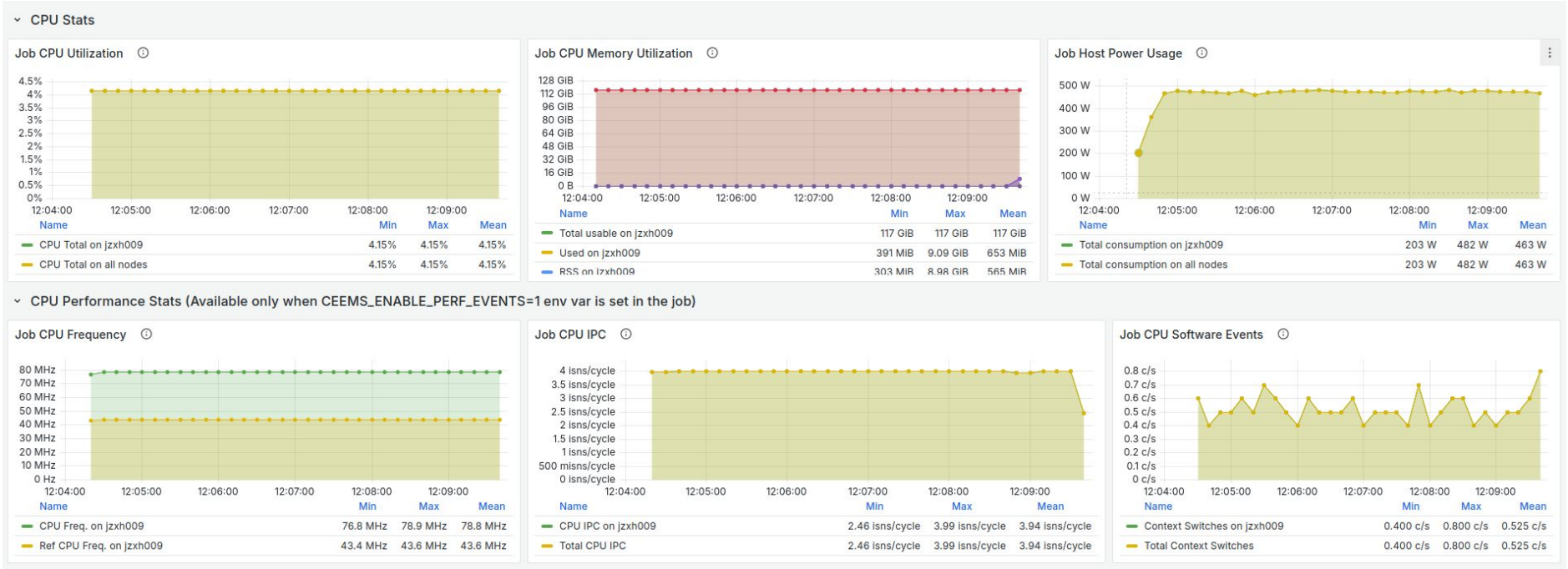
CEEMS Architecture



Features

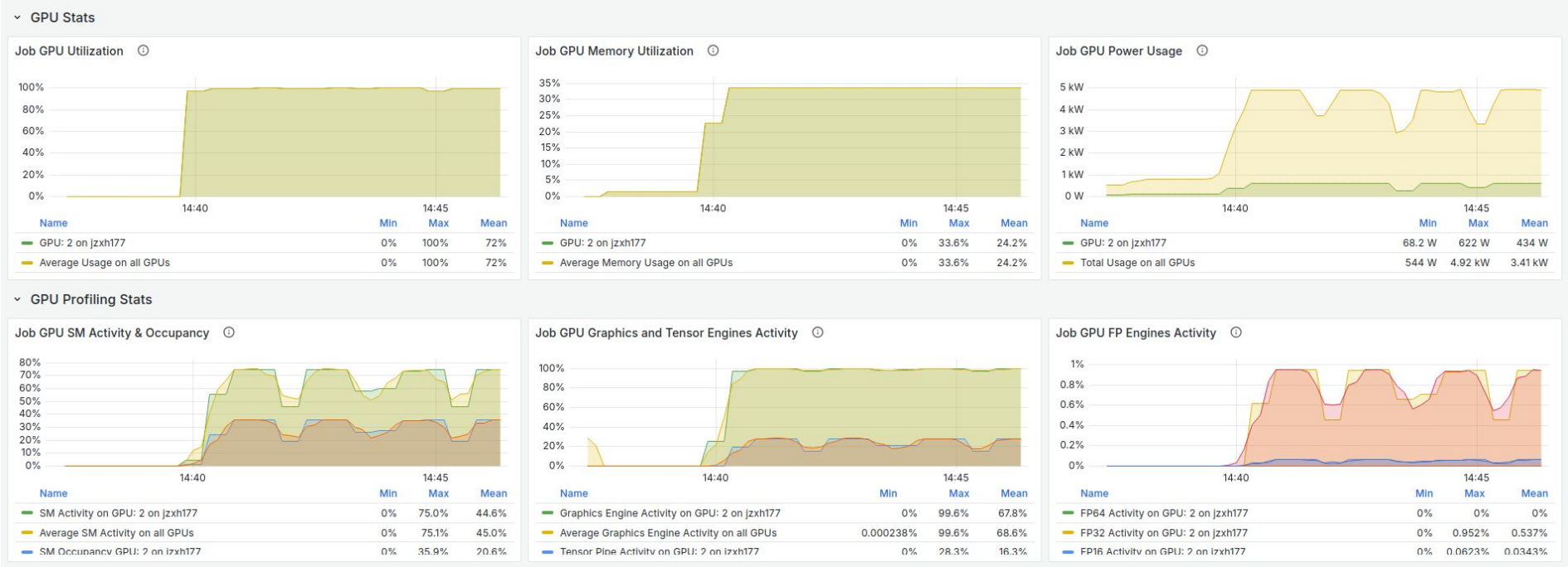
- Monitors energy and performance metrics for different types of resource managers
- IO metrics are monitored in a file system agnostic manner using eBPF
- Supports different energy sources like RAPL, HWMON, Cray's PM Counters and BMC via IPMI or Redfish
- Supports NVIDIA (MIG and vGPU) and AMD (QPX, TPX,...) GPUs
- Realtime access to metrics via Grafana dashboards or using a CLI client tool
- Access control to Prometheus datasource in Grafana

User Dashboards



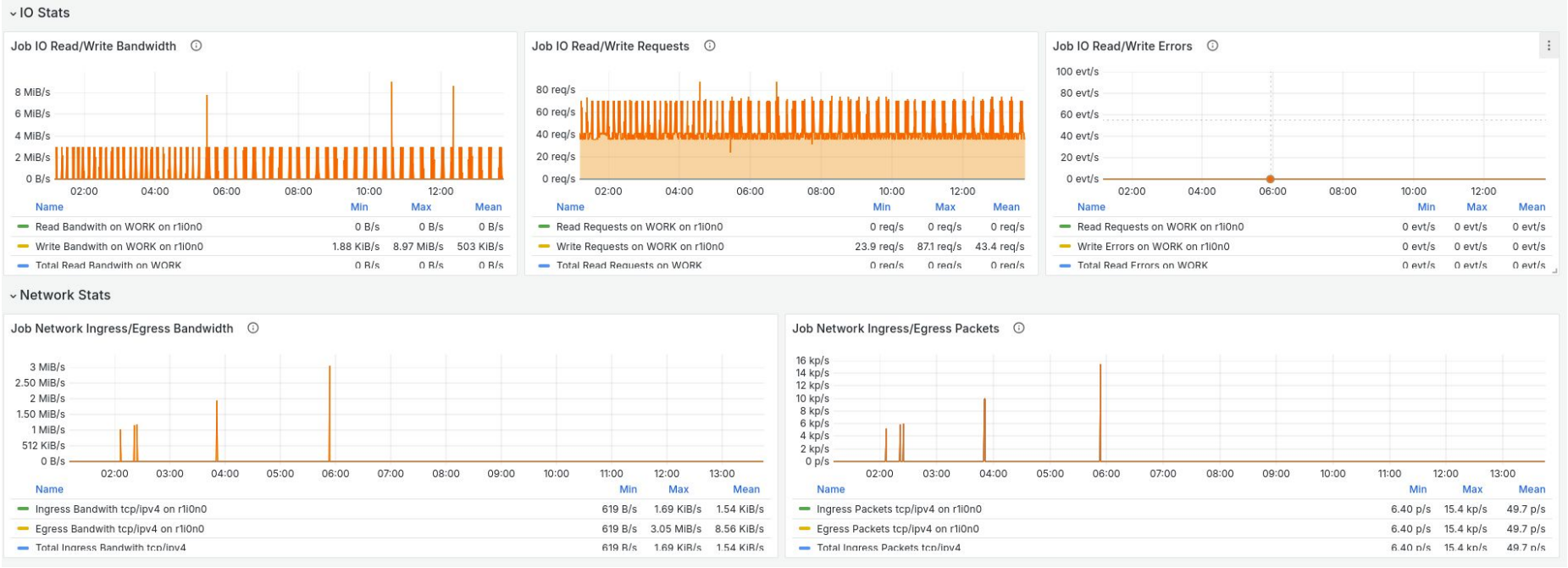
CPU Stats

User Dashboards



GPU Stats

User Dashboards



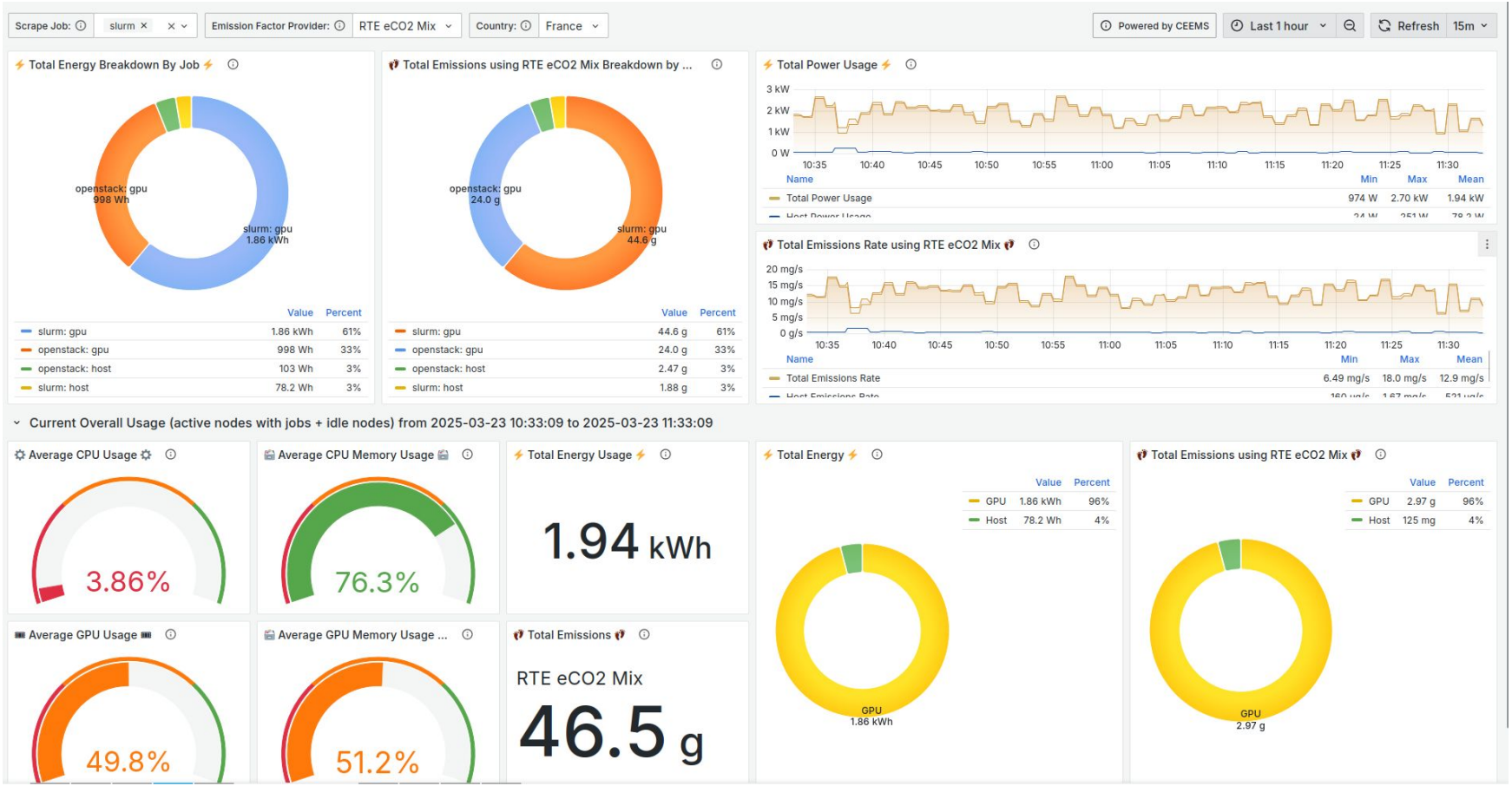
IO/Network Stats

CLI Client Tool

JOB ID	ACCOUNT	ELAPSED	CPU USAGE(%)	CPU MEM. USAGE(%)	HOST ENERGY(KWH)	HOST EMISSIONS(GMS)			GPU USAGE(%)	GPU MEM. USAGE(%)	GPU ENERGY(KWH)	GPU EMISSIONS(GMS)		
						EMAPS_TOTAL	OWID_TOTAL	RTE_TOTAL				EMAPS_TOTAL	OWID_TOTAL	RTE_TOTAL
106	bedrock	00:10:05	99.32	3.39	0.053818	4.725182	5.648855	3.860008						
108	bedrock	00:10:04	99.60	2.51	0.055842	5.091815	5.840380	4.197307						
118	bedrock	00:10:03	99.65	1.17	0.061474	4.450334	6.512757	3.683035						
131	bedrock	00:10:04	99.71	2.15	0.055742	1.835111	5.562944	1.245254						
134	bedrock	00:20:12	0.53	0.73	0.004463	0.030868	0.100538	0.021321						
138	bedrock	00:10:00	99.61	1.17	0.056302	2.595522	5.570695	1.837668						
150	bedrock	00:20:11	0.54	0.74	0.003862	0.076767	0.086878	0.058934						
154	bedrock	00:10:19	99.48	2.86	0.055671	4.906742	6.610783	4.127894						
162	bedrock	00:10:22	96.51	3.66	0.055507	3.274911	4.711376	2.497813						
163	bedrock	00:10:28	99.71	3.03	0.051746	3.673949	4.392128	2.780309						
169	bedrock	00:10:19	99.71	1.17										
181	bedrock	00:20:14	0.56	0.74	0.001518	0.115373	0.085070	0.081976	36.31	38.11	0.184776	14.042940	10.354560	9.977878
183	bedrock	00:10:09	99.68	1.17	0.049606	3.676648	2.779826	2.926728	37.87	37.97	0.187746	13.919683	10.521023	11.077016
229	bedrock	00:10:21	99.57	1.99	0.048258	1.930318	2.704308	1.109933	38.71	37.36	0.197287	7.891462	11.055660	4.537591
232	bedrock	00:10:24	99.63	1.17	0.050244	1.385482	2.815615	0.954640	31.90	35.88	0.131236	3.618456	7.354267	2.493479
269	bedrock	00:10:01	99.69	1.17	0.048866	2.738386	2.123290	22.18	24.35	0.026367	1.477547	1.141505		
274	bedrock	00:10:16	97.72	3.49	0.054060	3.029430	2.324568							
Summary														
20	bedrock	03:23:27	69.84	1.73	0.706980	37.769023	59.189969	33.830679	35.74	35.32	0.727410	39.472541	40.763058	29.227470

cacct - Exports time series data of metrics in CSV format

Cluster Dashboards - Operators



Cluster Dashboards - Operators

Supported Metrics

- CPU and GPU Energy Usages and Emissions
- CPU and GPU Usages and Memory Usages
- CPU Hardware/Software/Cache Perf Metrics
- GPU Profiling Metrics (for NVIDIA GPUs)
- IO (Read/Write bytes, bandwidth, requests, errors)
- Network (TCP/UDP, IPv4/IPv6, Ingress and Egress)
- Selected RDMA Metrics (QPs, MRs, requests)

All metrics are *per* cgroup (SLURM job, Openstack VM, k8s pod)

Metrics alone are not enough…

- Usage and perf metrics give a rudimentary idea of how application is behaving
- Need to profile the application to figure out the bottlenecks and hotspots
- Deterministic Profiling: Record call stack & memory stats, investigate and iterate
- Limitations of deterministic profiling:
  - Overhead
  - Hard to recreate problematic scenarios
  - Distributed systems make these only worst

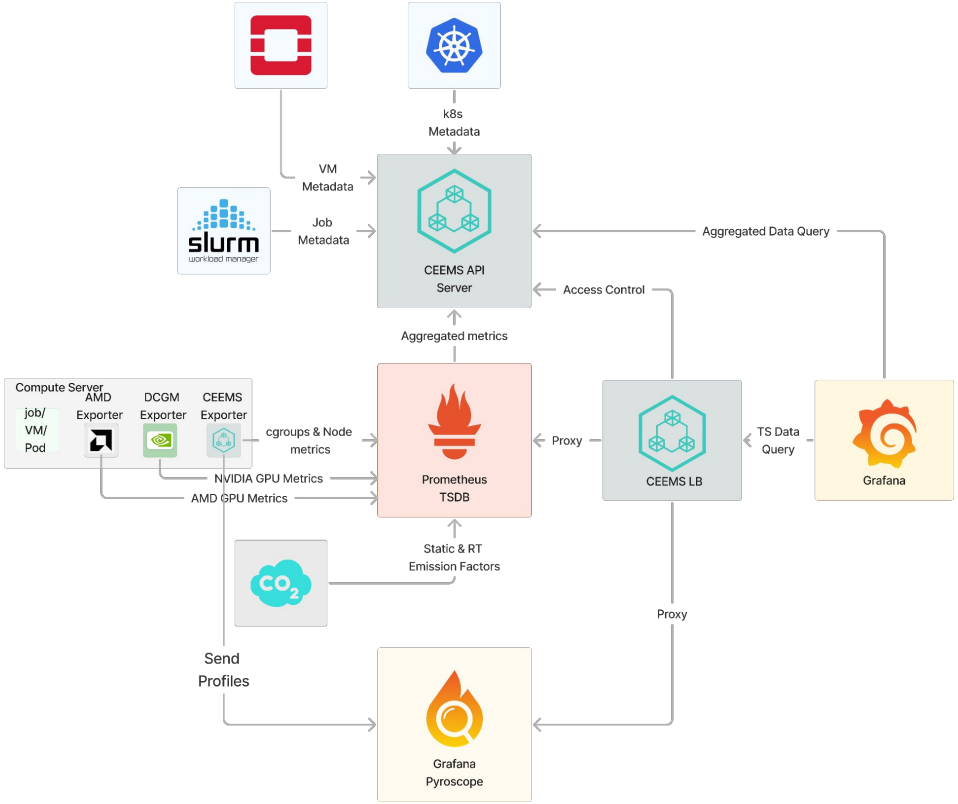
Continuous Profiling

Continuous Profiling

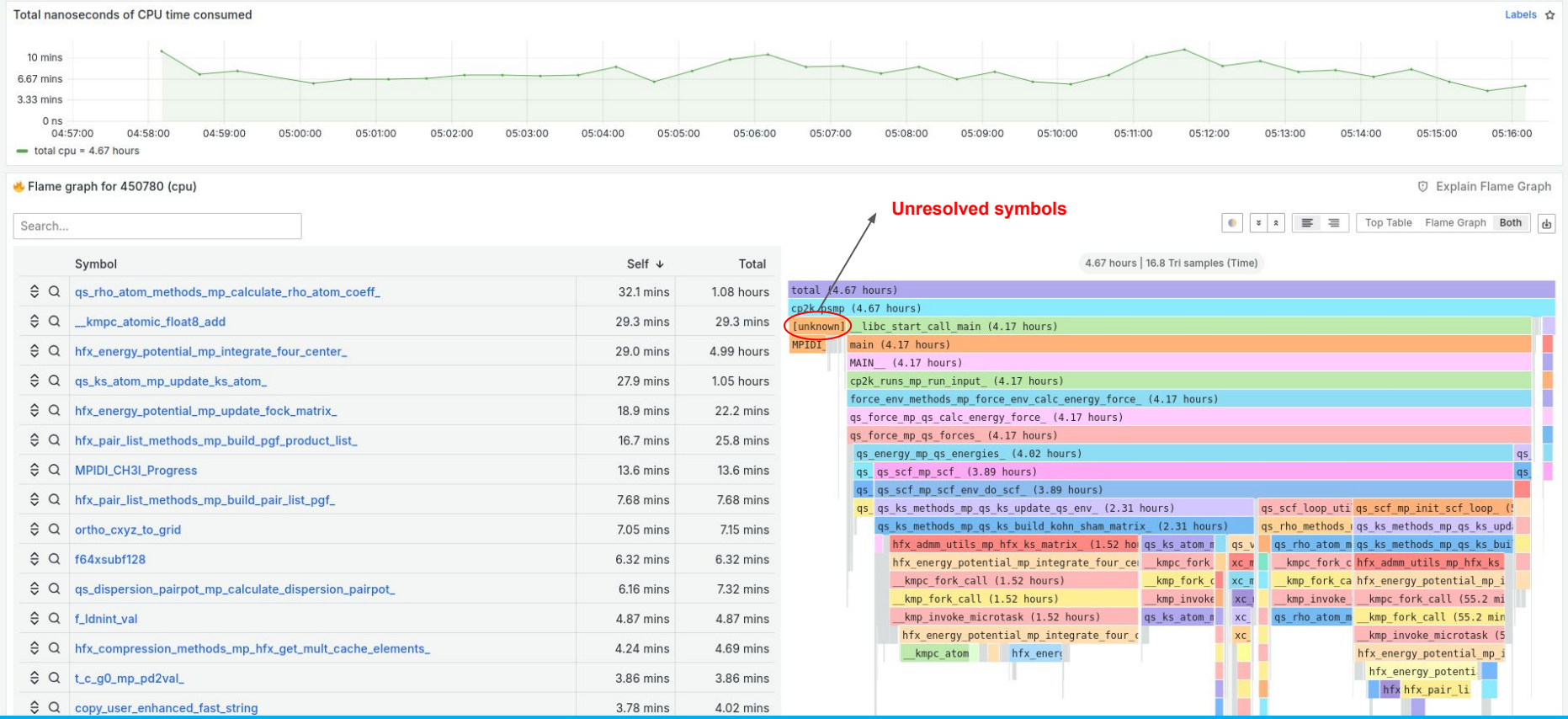
- Continuous profiling: Statistical profiling based on sampling call stack
  - eBPF based
  - No instrumentation needed
  - Very low overhead
  - “Always On” in production
- Works out-of-the-box for compiled languages like C, C++, FORTRAN, Go,...
- Championed by Google and heavily used in cloud native eco-system
- Grafana, Splunk, Datadog, Amazon, Polar signals offer Open Source profilers

CEEMS Exporter supports Grafana Pyroscope

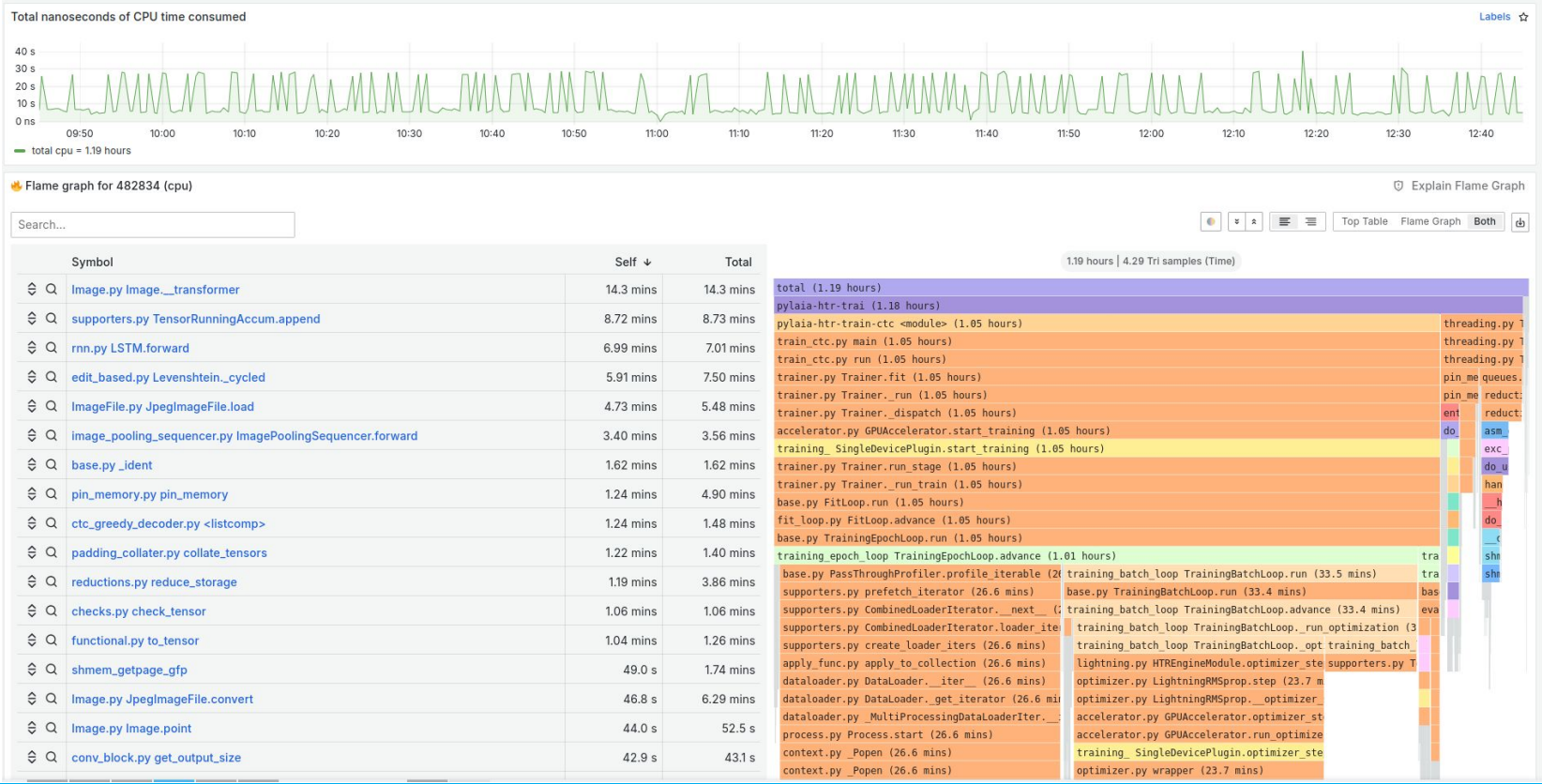
CEEMS Architecture with Continuous Profiling



Continuous Profiling of SLURM Jobs

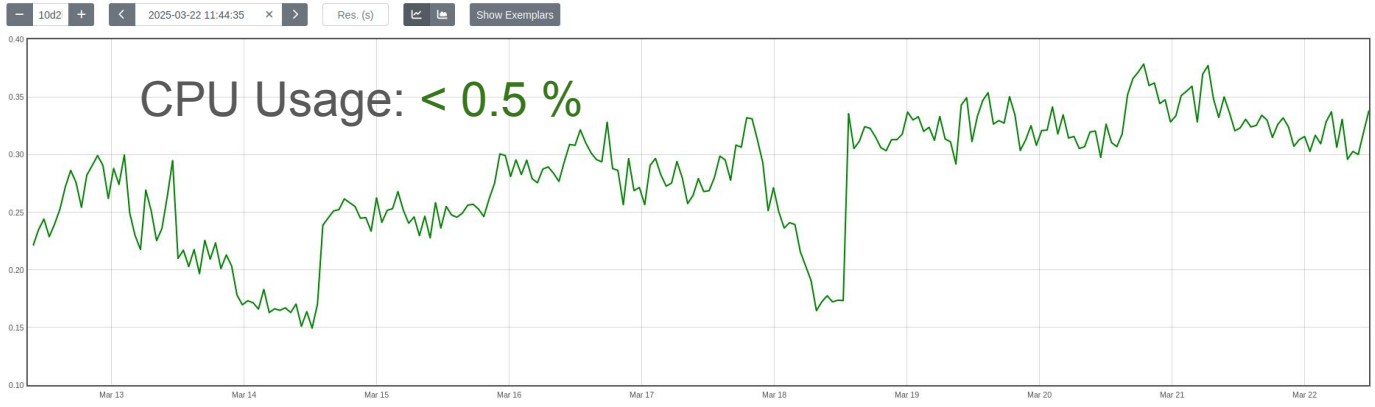


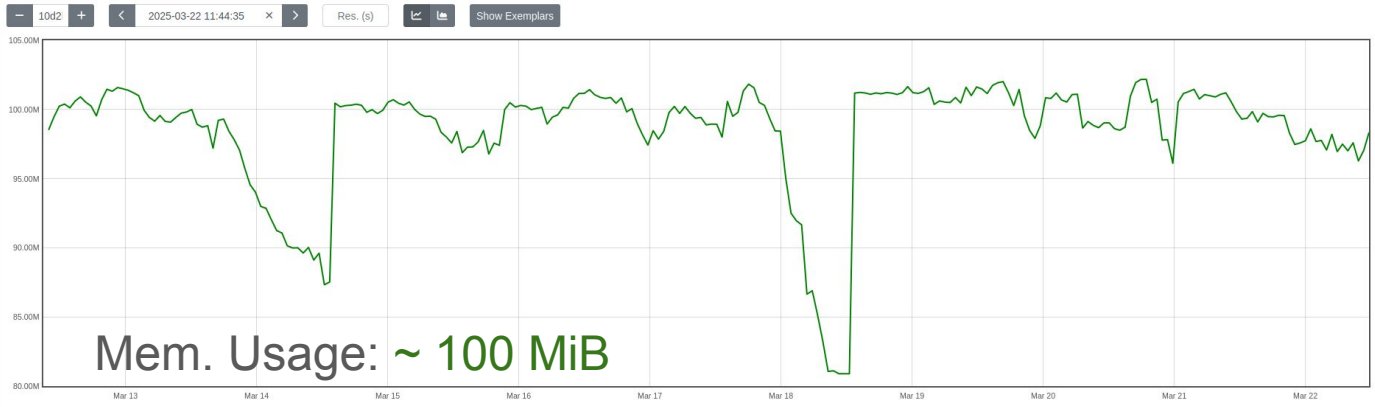
Continuous Profiling of SLURM Jobs



Exporter Overhead

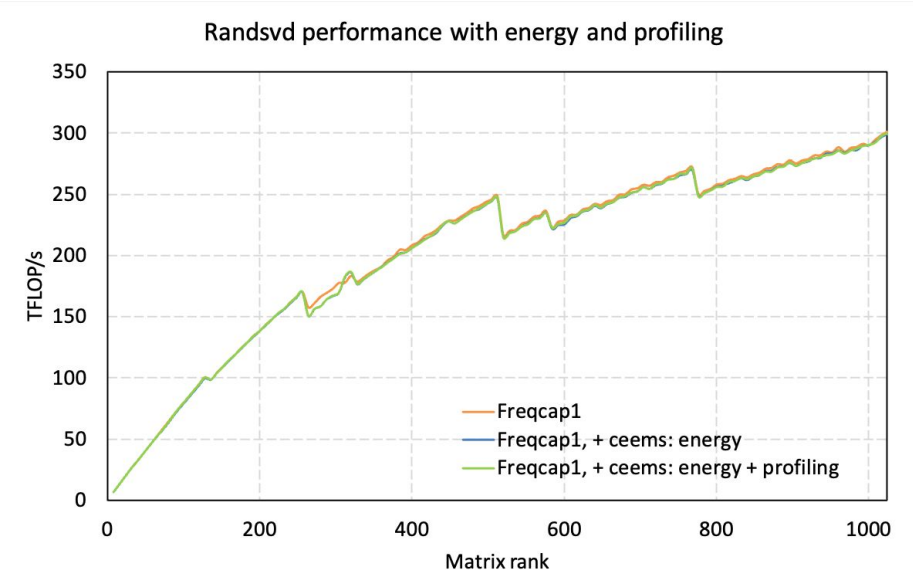
CPU and Memory Usage averaged over ~360 nodes.

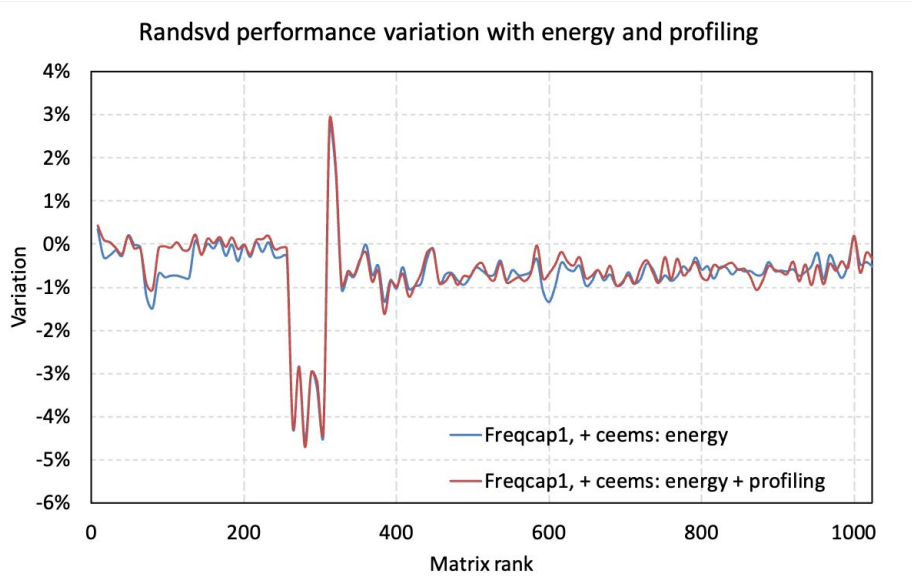




Benchmarks

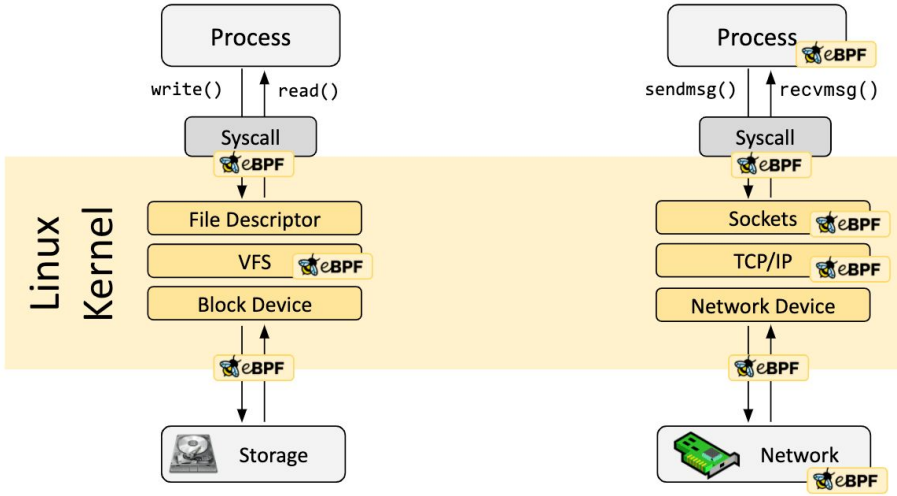
Randomised SVD with varying matrix size





Technical Details

- 100 % Go (except the bpf programs which are in C)
- CEEMS apps are **Capability Aware**
- Uses eBPF for IO and Network metrics

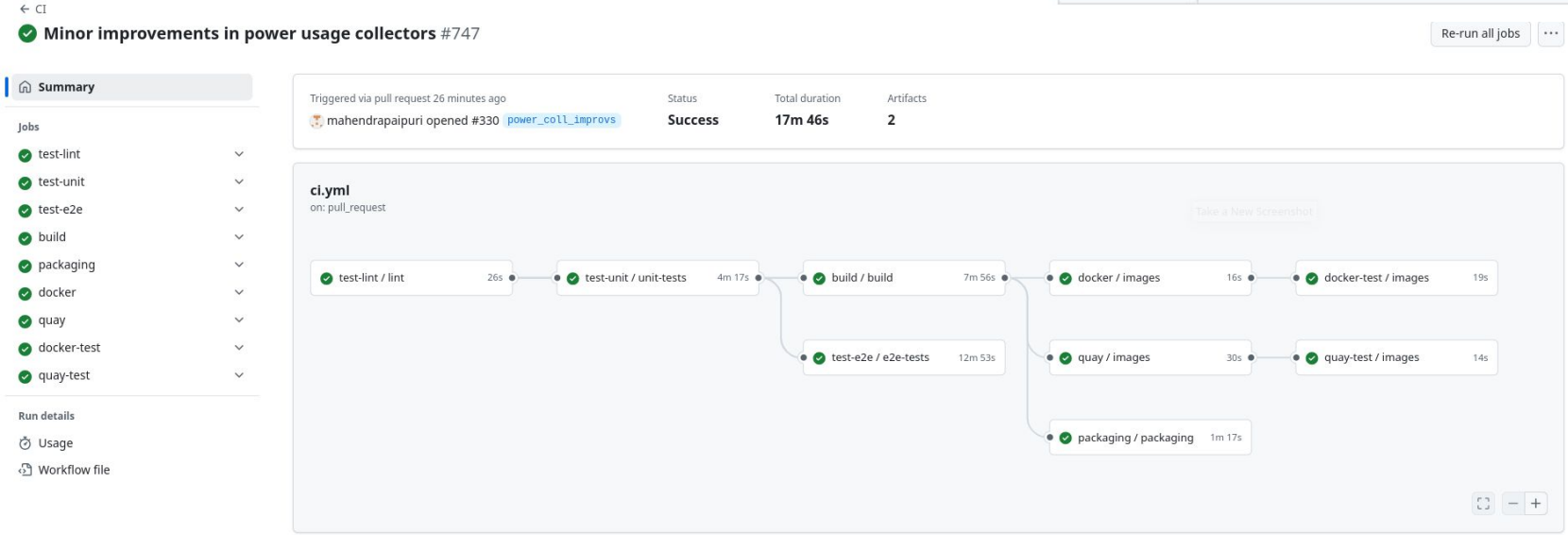


Testing & CI

Battle tested in CI. > 75 % of unit test coverage.

More than 60 e2e tests

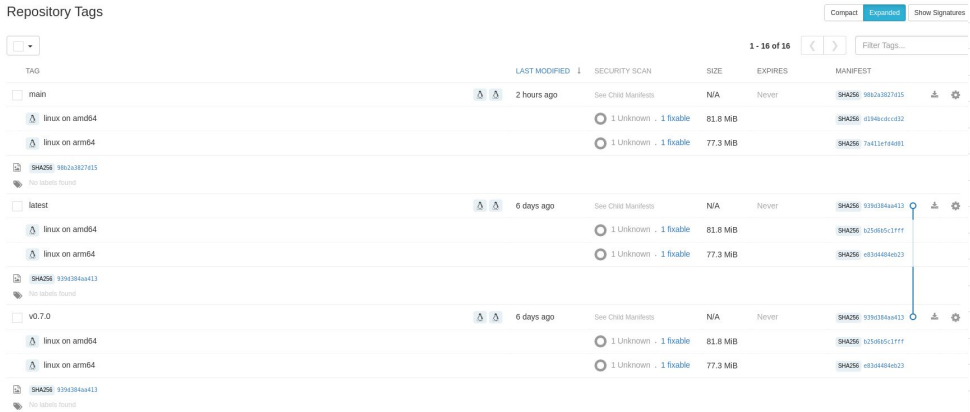
CI/CD	CI passing · PASSED · Coverage 75.6%
Docs	docs passing · go reference
Package	release v0.7.0
Meta	license GPL-3.0 · go report A+ · code style gofmt



Packaging

Pre-compiled binaries, RPM/DEB packages and OCI images are available for different archs.

Helm chart is also available



cacct-0.7.0-linux-amd64.deb	9.47 MB	last week
cacct-0.7.0-linux-amd64.rpm	9.66 MB	last week
cacct-0.7.0-linux-arm64.deb	8.81 MB	last week
cacct-0.7.0-linux-arm64.rpm	8.95 MB	last week
ceems-0.7.0.linux-386.tar.gz	74.2 MB	last week
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redfish_proxy-0.7.0-linux-arm64.deb	8.49 MB	last week
redfish_proxy-0.7.0-linux-arm64.rpm	8.63 MB	last week

Final Remarks

- CEEMS provide a “complete” monitoring solution
- Running on Jean Zay since ~ 1,5 years with a scrape frequency of 10s
- Currently working on support for cloud VMs using SPEC Power database.
- A demo instance is available to play around

Grid5000/SLICES-FR platform has been of immense use during the development of this stack.
A huge thanks to Grid5000/SLICES-FR team.

Demo

Thank you

Resources:

- CEEMS GitHub Repo
- CEEMS Docs
- CEEMS API Server Docs
- CEEMS Helm Chart
- CEEMS Exporter Metrics List
- CEEMS Demo

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