TECHNISCHE UNIVERSITÄT DRESDEN

DRESDEN concept

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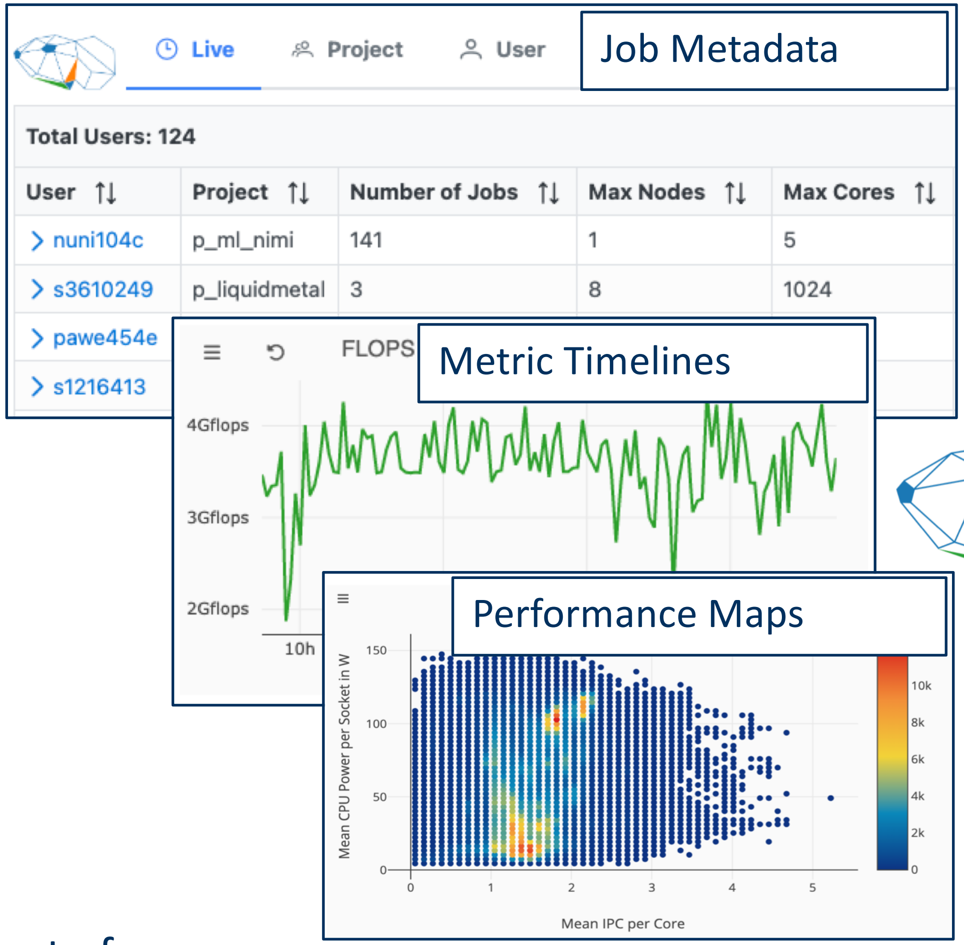
# Automatic Detection of HPC Job Inefficiencies at TU Dresden's HPC center with PIKA

NHR@TUD
MODA23 on May 25, 2023

ZIH

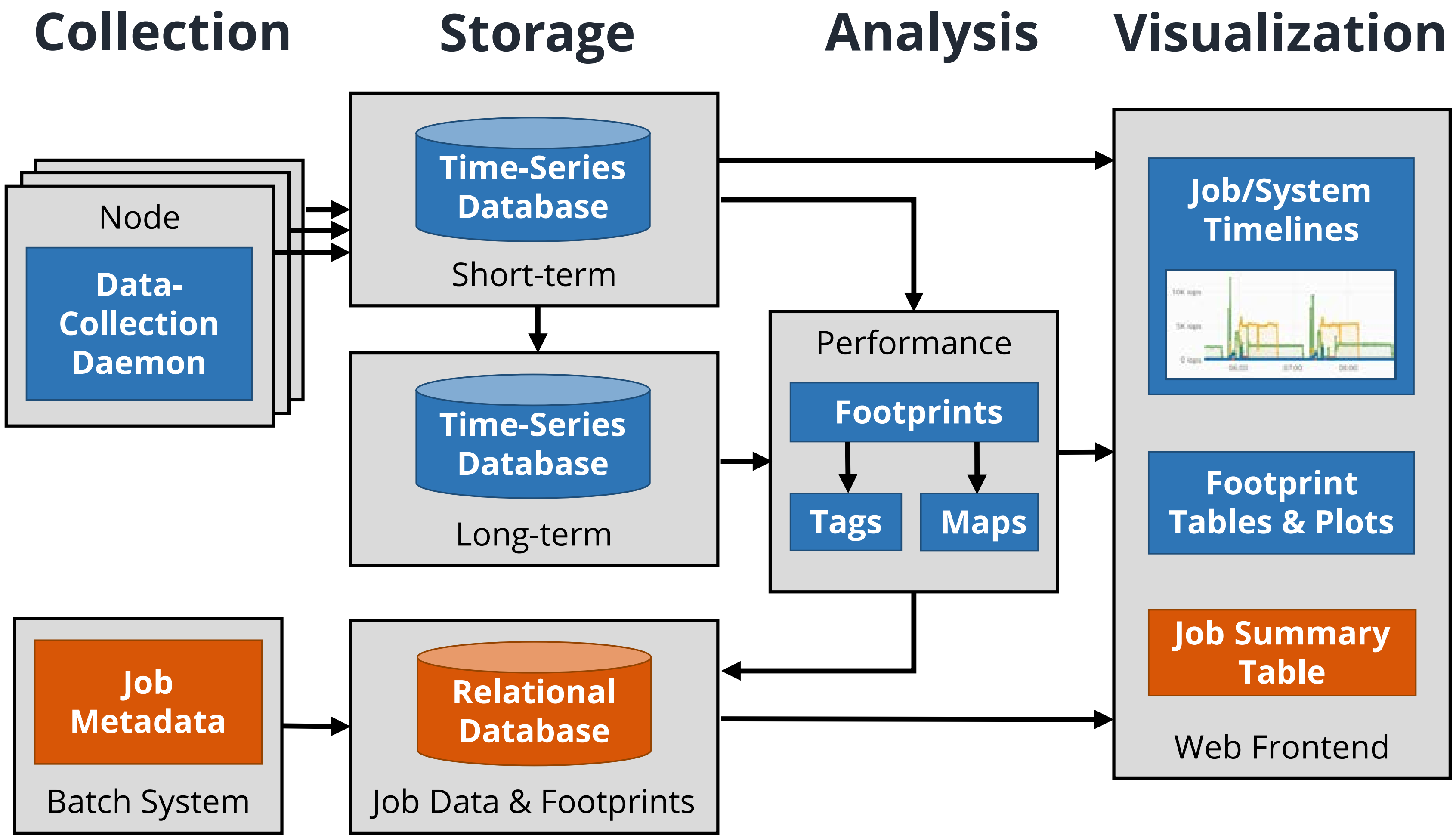
# PIKA: Continuous HPC Job Monitoring

- Non-intrusive **data acquisition** on all cluster nodes
- Continuous **data collection**
- Web frontend for live and post-mortem **visualization**
- Detection of pathological jobs
- Automatic **job analysis and classification**
- Long-term **data storage**




Funded by the DFG project ProPE, continued as part of NHR@TUD at ZIH.

# PIKA Architecture Overview



# PIKA Metadata Collection

**Slurm PrEp Plugin** to capture job metadata:

- Unique job identifier, ArrayID
- Project, user, job name
- Start and end time, walltime
- Status (running, completed, timeout, failed, OOM, cancelled)
- Requested resources
  - Partition
  - Allocated compute nodes
  - Allocated CPUs on each node
  - Exclusive nodes
  - Main memory
  - GPUs per node

# PIKA Runtime Data Collection

| Monitored Metrics | Data Source | Hardware Unit |
|---|---|---|
| Instructions per Cycle (IPC) | LIKWID | Hardware Thread |
| FLOPS (SP Normalized) | | Hardware Thread |
| Main Memory Bandwidth | | CPU/Socket |
| Power Consumption | | CPU/Socket |
| CPU Usage | proc & sysfs | Hardware Thread |
| Main Memory Utilization | | Node |
| Network Bandwidth | | Node |
| File I/O Bandwidth & Metadata | Local disk, Filesystems (Lustre, BeeGFS) | Disk, Lustre Instance |
| GPU Usage | NVML | GPU |
| GPU Memory Utilization | | |
| GPU Power Consumption | | |
| GPU Temperature | | |

Collection daemon **collectd**

- One collector/plugin for each metric source
- CPU counters are collected with LIKWID
- Hardware thread metrics are summarized to the physical CPU core

# PIKA Job Visualization – Tables

Live | Project | User | Job | Footprint | Search | Issue

07/05/2022 23:03 - 12/05/2023 13:27

**Total Projects: 492**

| Project ↑↓ | Number of Jobs ↑↓ | Max Nodes ↑↓ | Max Cores ↑↓ | Overall Core Time ↑↓ | Max Pending ↑↓ | Overall Runtime ↑↓ | #Footprints ↑↓ |
|---|---|---|---|---|---|---|---|
| > p_... | 1375 | 1 | 8 | 0003y 355d 09:54h | 02d 07:24:28h | 0001y 006d 21:42h | 818 |
| > swt... | 1735 | 4 | 128 | 0010y 247d 07:39h | 02d 01:43:24h | 0000y 065d 13:13h | 159 |
| > hp... | 4720 | 41 | 4096 | 0032y 173d 12:01h | 05d 16:02:24h | 0001y 129d 09:50h | 2420 |
| > p_... | 21417 | 2 | 96 | 0010y 059d 09:04h | 03d 06:12:31h | 0003y 049d 21:20h | 14003 |
| > p_... | 2011 | 3 | 36 | 0013y 161d 00:09h | 11d 17:16:13h | 0002y 071d 05:35h | 812 |

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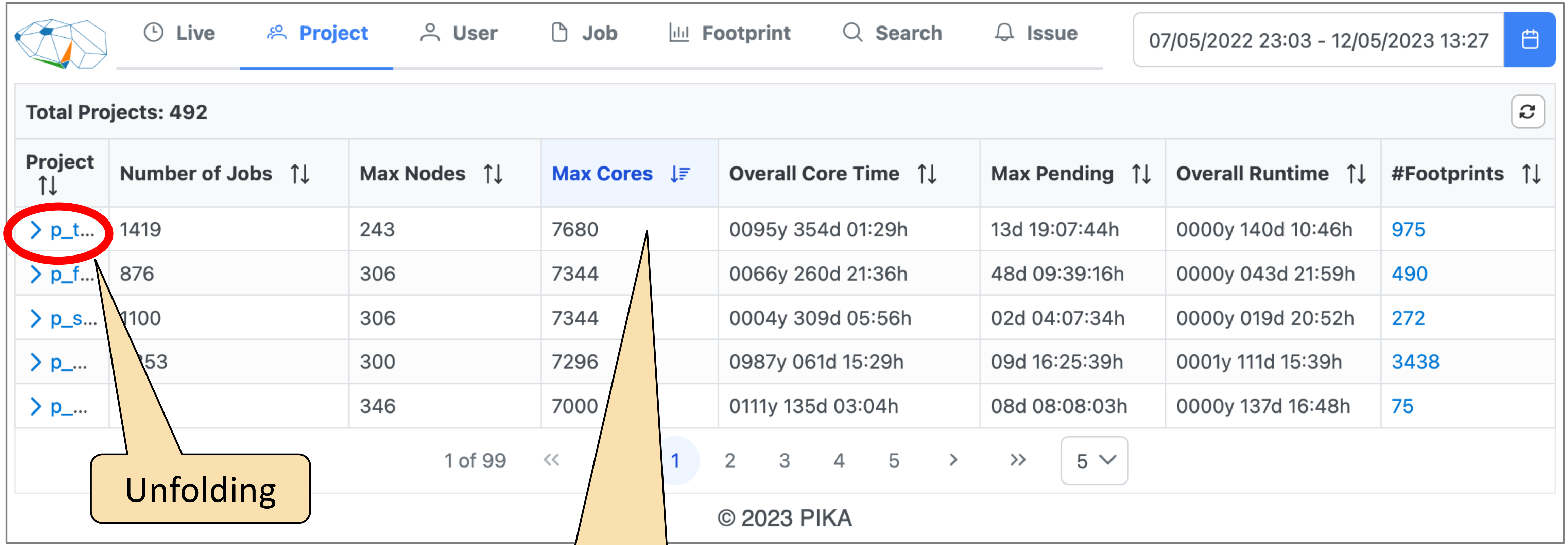
Jobs of 492 projects have been recorded for the selected time interval (top right).

# PIKA Job Visualization – Tables




| Project | Number of Jobs | Max Nodes | Max Cores | Overall Core Time | Max Pending | Overall Runtime | #Footprints |
|---|---|---|---|---|---|---|---|
| p_t... | 1419 | 243 | 7680 | 0095y 354d 01:29h | 13d 19:07:44h | 0000y 140d 10:46h | 975 |
| p_f... | 876 | 306 | 7344 | 0066y 260d 21:36h | 48d 09:39:16h | 0000y 043d 21:59h | 490 |
| p_s... | 1100 | 306 | 7344 | 0004y 309d 05:56h | 02d 04:07:34h | 0000y 019d 20:52h | 272 |
| p_... | [illegible]53 | 300 | 7296 | 0987y 061d 15:29h | 09d 16:25:39h | 0001y 111d 15:39h | 3438 |
| p_... | [illegible] | 346 | 7000 | 0111y 135d 03:04h | 08d 08:08:03h | 0000y 137d 16:48h | 75 |

Unfolding

Get project with the highest number of cores.

# PIKA Job Visualization – Tables

Live | Project | User | Job | Footprint | Search | Issue

07/05/2022 23:03 - 12/05/2023 13:27

**Project: p_t** **Total Users: 2**

| User | Number of Jobs | Max Nodes | Max Cores | Overall Core Time | Max Pending | Overall Runtime | #Footprints |
|---|---|---|---|---|---|---|---|
| ja... | 294 | 4 | 96 | 0003y 213d 06:33h | 00d 10:05:19h | 0000y 063d 22:50h | 143 |
| to... | 1125 | 243 | 7680 | 0092y 140d 18:56h | 13d 19:07:44h | 0000y 076d 11:56h | 832 |

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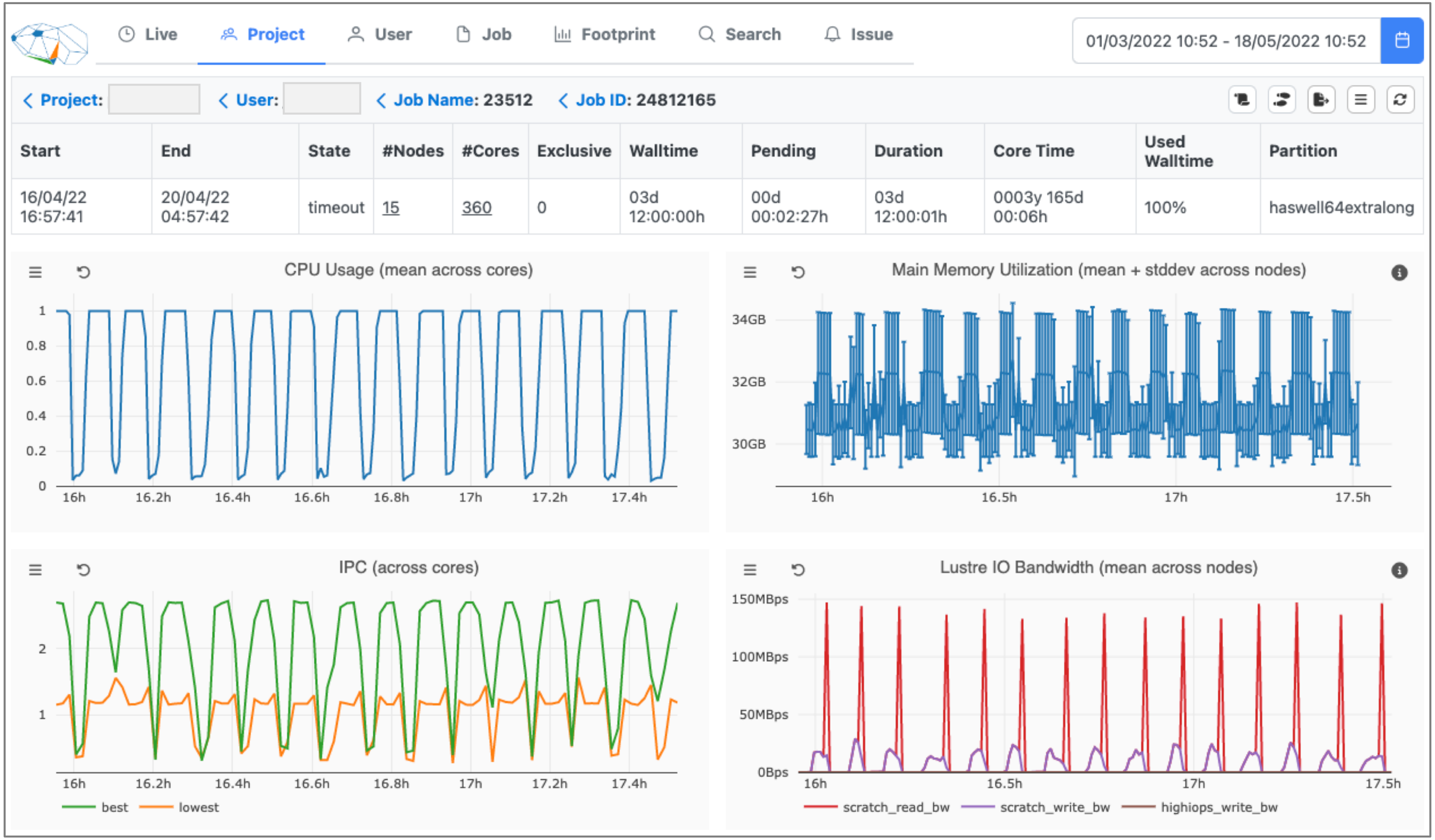
Project "p_t" has two users.

# PIKA Job Visualization – Metadata & Timelines



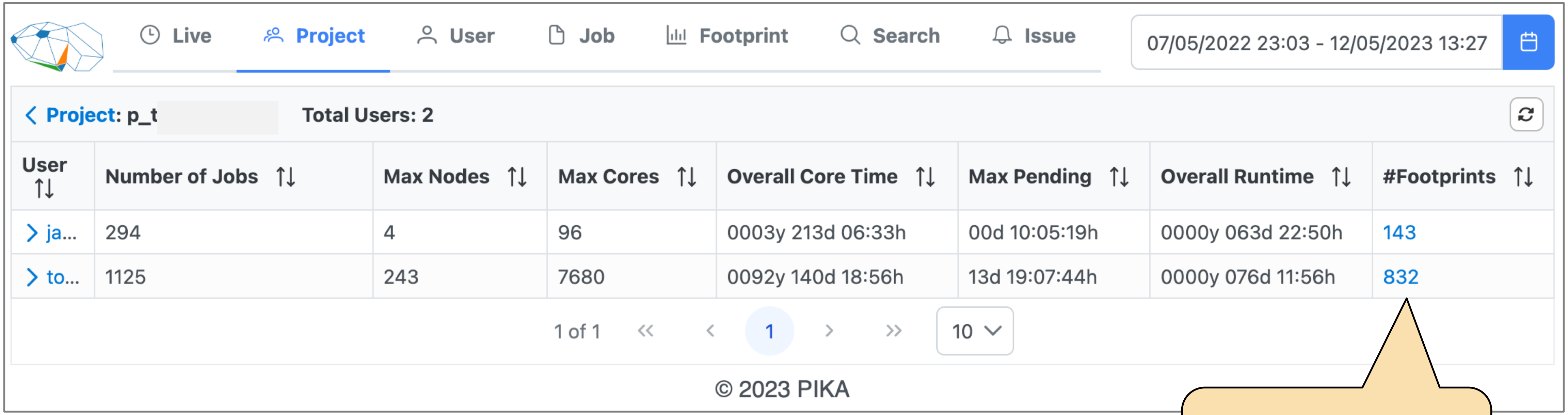
# PIKA Post Processing

**Job characterization via tagging**

- **Footprints** based on summarized runtime data
  - **Average** (CPU and GPU usage, IPC, FLOPS, main memory bandwidth, CPU and GPU power, InfiniBand traffic)
  - **Total** (file IO read/write)
  - **Maximum** (host and GPU memory usage)
- Job tags based on formulas and thresholds

| Tag Name | Formula and Threshold |
|---|---|
| unrestrained | - |
| memory-bound | $\frac{\texttt{memory bandwidth (measured)}}{\texttt{memory bandwidth (maximum)}} > 80\%$ |
| compute-bound | $\frac{\texttt{FLOP/s (measured)}}{\texttt{FLOP/s (maximum)}} > 70\%$ or $\frac{\texttt{IPC (measured)}}{\texttt{IPC (optimal)}} > 60\%$ |
| GPU-bound | $\texttt{GPU utilization} > 70\%$ or<br>$\texttt{GPU utilization} > \texttt{CPU utilization}$ |
| IO-heavy | $\frac{\texttt{IO bandwidth (measured)}}{\texttt{IO bandwidth (maximum)}} > 60\%$ |
| network-heavy | $\frac{\texttt{network bandwidth (measured)}}{\texttt{network bandwidth (maximum)}} > 60\%$ |

# PIKA Post Processing




| User | Number of Jobs | Max Nodes | Max Cores | Overall Core Time | Max Pending | Overall Runtime | #Footprints |
|---|---|---|---|---|---|---|---|
| ja... | 294 | 4 | 96 | 0003y 213d 06:33h | 00d 10:05:19h | 0000y 063d 22:50h | 143 |
| to... | 1125 | 243 | 7680 | 0092y 140d 18:56h | 13d 19:07:44h | 0000y 076d 11:56h | 832 |



832 user jobs are tagged.

# PIKA Job Visualization – Footprints

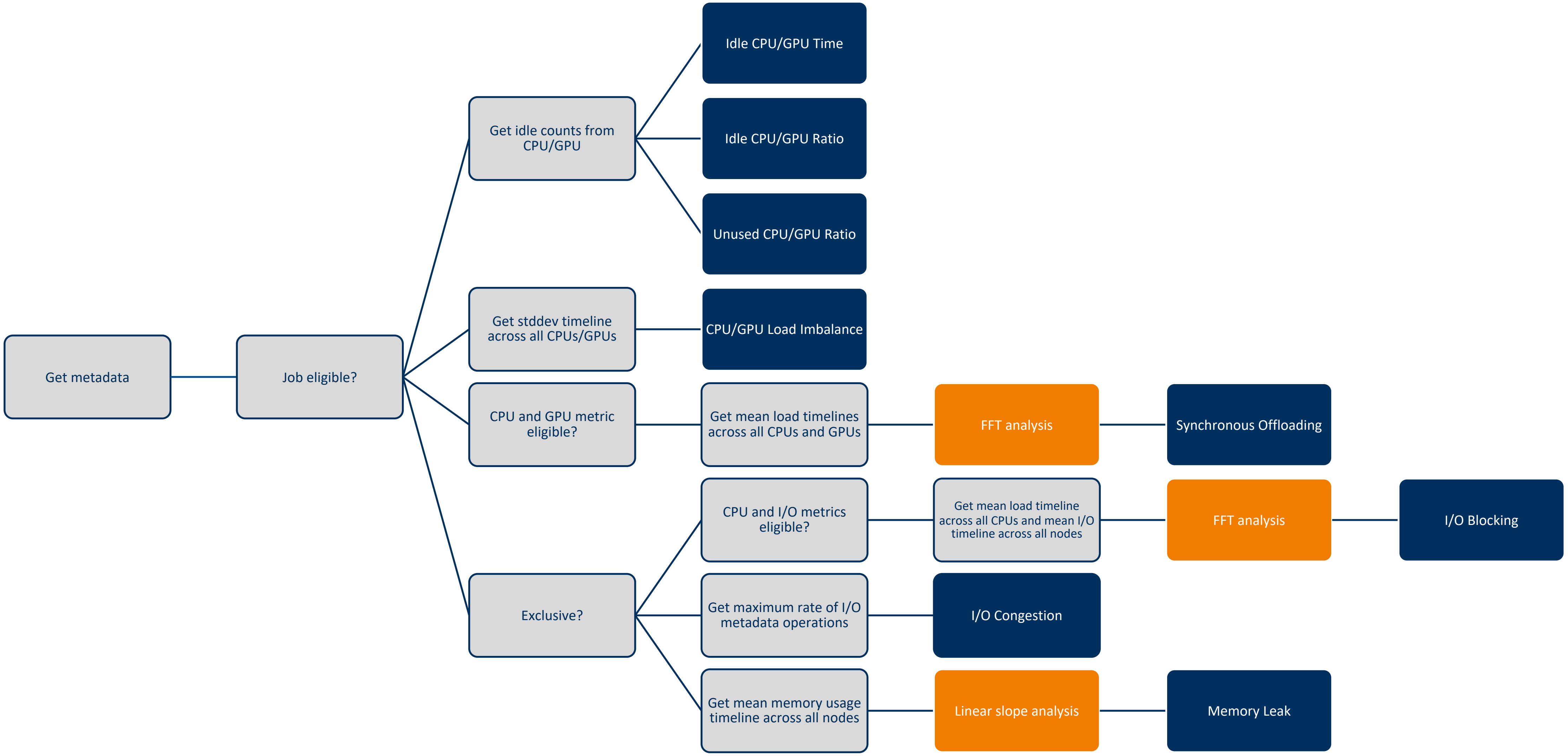
# PIKA Issue Analysis

**Automatic detection of job performance issues on eligible jobs**

- **Prerequisite:**
  - Duration >= 1 hour
  - Number of physical cores > 1
  - Slurm Status: completed, out of memory, timeout
  - Metric timeline vectors*: CPU/GPU load, memory usage, I/O bandwidths and I/O metadata operations
- **Heuristics** to detect inefficient jobs
- **Criteria for efficient usage**
  - Shortest possible runtimes (compared to similar jobs)
  - High utilization of the hardware
  - Even distribution of computational workloads across processing units

* Sampled every 30 seconds

# PIKA Issue Analysis - Workflow per Job



# PIKA Issue Analysis - Straightforward Heuristics

**Prerequisite to detect jobs with idle CPU/GPU time and load imbalances**

- A measuring point of a CPU is idle, if the usage is below **0.01**.
- A measuring point of a GPU is idle, if the usage has the value **0**.
- A CPU/GPU is unused, if the idle count per measurement point is greater than **(n – 2)** measurement points.
- A load imbalance is attributed to a job, if the average standard deviation of CPUs/GPUs is greater than **0.2**.

# PIKA Issue Analysis - Straightforward Heuristics

| Performance Issue | Description |
|---|---|
| Idle CPU/GPU Time | Summed time intervals of all CPUs/GPUs in which the load was close to zero. Internally, we multiply the idle counts of each CPU/GPU with 30 seconds and sum them up. |
| Idle CPU/GPU Ratio | Quotient of “Idle CPU/GPU Time” and “Total CPU/GPU Time”. |
| Unused CPU/GPU Ratio | Ratio of “unused” to “used” CPUs/GPUs. |
| CPU/GPU Load Imbalance | Average standard deviation of CPU/GPU load. |
| I/O Congestion | Maximum rate of metadata (open+close) operations at a measuring point. |

# PIKA Issue Analysis – Periodic Performance Issues

**Heuristic for detecting periodic phases with an inverse correlation between two performance metric vectors**

- I/O blocking (CPU load ↔ I/O metric)
- Synchronous Offloading (CPU load ↔ GPU load)

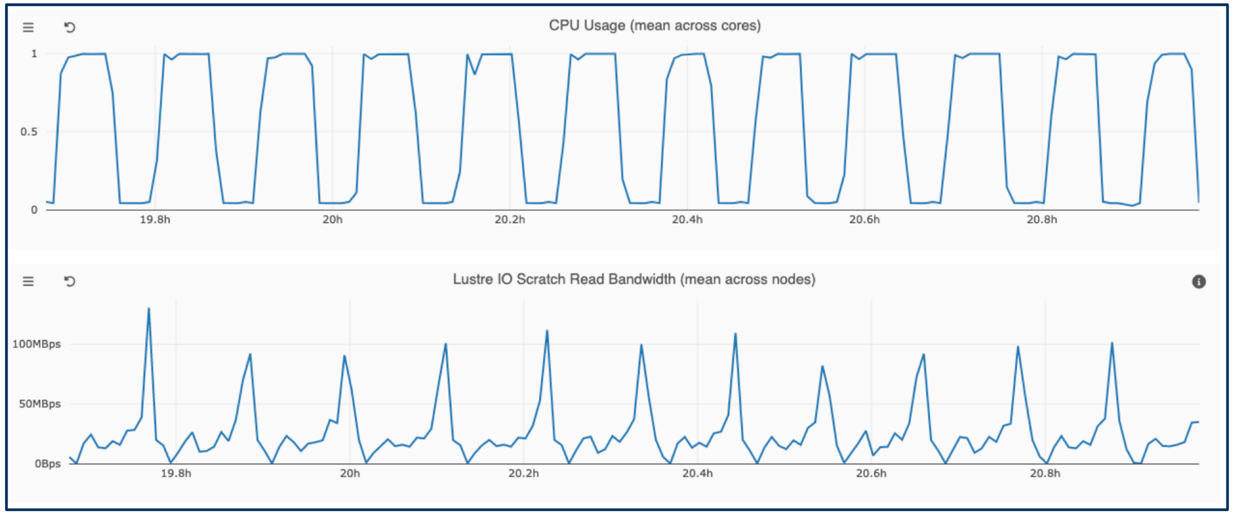
We round all CPU load values to the first decimal place and set all I/O metric values that are less than the average to zero.

**Prerequisite for metric vectors:**

- The mean value of the CPU/GPU load vector is at least **0.1**.
- The difference of the max and min value of the mean CPU/GPU load vector is at least **0.7**.
- The mean value of an I/O bandwidth vector is at least **1 MB/s**.
- The mean value of an I/O metadata vector is at least **1 OPS**.
- All vectors are aligned (each timestamp has a valid value)

# PIKA Issue Analysis – Periodic Performance Issues

1. Acquire two mean metric vectors (signals) to be analyzed and check whether they are suitable for further analysis.




$\boldsymbol{cpu\_load} = [val_1 val_2, \dots, val_n]$

$\boldsymbol{read\_bw} = [val_1, val_2, \dots, val_n]$

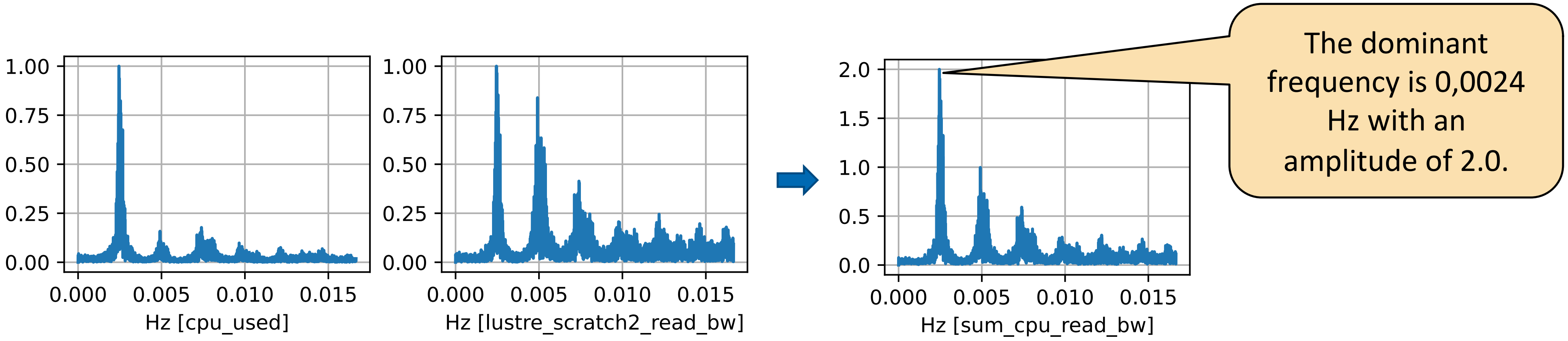
$\boldsymbol{timestamps} = [ts_1, ts_2, \dots, ts_n]$

2. Compute the FFT* of both signals using a fast Fourier transform algorithm.
3. Compute the frequency spectrum of both signals from the FFT output.

*SciPy Python packages

# PIKA Issue Analysis – Periodic Performance Issues

4. Normalize the amplitudes of each frequency spectrum to 1 and calculate the element-wise sum of both frequency spectra.



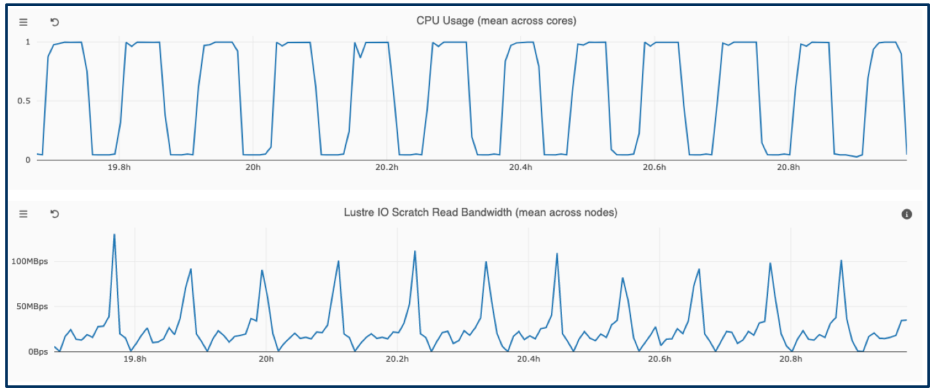

5. Find the maximum amplitude of the summed frequency spectrum and check if this is a dominant frequency (DF).
   - DF is located at the maximum amplitude of the normalized summed frequency spectrum
   - Valid if the maximum amplitude is in the range between 1.8 and 2.0 and the median over all amplitudes does not exceed the value 0.1

6. If the conditions of a dominant frequency are met, determine the Pearson correlation coefficient* between both signals.

*NumPy Python packages

# PIKA Issue Analysis – Periodic Performance Issues

A correlation coefficient between two metrics ranges from -1 to 1, where a value of -1 indicates a perfect inverse correlation, 0 indicates no correlation, and 1 indicates a perfect correlation.




$$\boldsymbol{corr\_coef} = \begin{pmatrix} 1 & \mathbf{-0.46} \\ -0.46 & 1 \end{pmatrix}$$

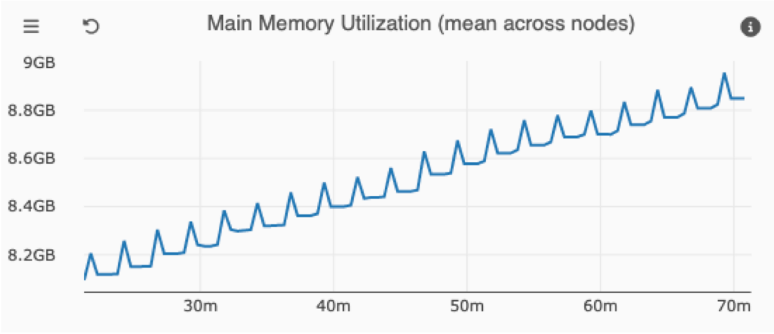
$$\boldsymbol{period\_num} = dom\_frequency * job\_duration$$

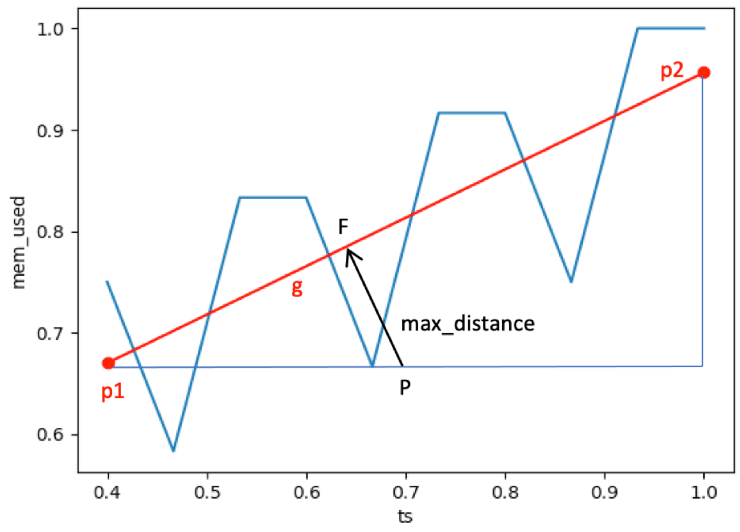
Thresholds:
**corr_coef <= -0.4**
**period_num >= 10**

| Performance Issue | Description |
| --- | --- |
| I/O Blocking | Periodic number of phases with an inverse correlation between CPU load and I/O metrics. |
| Synchronous Offloading | Periodic number of phases with an inverse correlation between CPU and GPU load. |

# PIKA Issue Analysis – Memory Leak Suspicion

Heuristic that checks whether memory usage increases linearly over time




1. Normalize *ts* and *mem_used* with maximum 1
2. Determine slope trend via ***np.polyfit***(*ts*, *mem_used*, 1) to get the slope m and the y-intercept n of the linear function f(x) = mx + n
3. Determine p1 and p2 based on linear function for **m ∈ [0.01; 1]**
4. Calculate euclidean distance **dis** of each measuring point to the slope line
5. Determine **P** based on slope m and calculate distance **max_distance** for **m ∈ [0.1; 1]**
6. if **np.max(dis)** < **max distance** → suspected memory leak

$$max\_distance = d(P; g) = |(\overrightarrow{PF})|$$

$$P(ts, mem\_used) = (p1_{ts} + ((p2_{ts} - p1_{ts}) * \frac{1}{m*10}), p1_{mem-used})$$

$$if\ m < 0.1 \rightarrow P_{ts} = 1$$

# PIKA Issue Analysis – Summarized User View

Possible performance issues with the inefficient HPC jobs of a user

| Performance Issue | Description |
|---|---|
| Idle CPU/GPU Time (**ICT/IGT**) | Summed time intervals of all CPUs/GPUs across all jobs in which the load was close to zero. |
| Idle CPU/GPU Ratio (**ICR/IGR**) | Quotient of "Idle CPU/GPU Time" and "Total CPU/GPU Time" across all jobs. |
| Maximum Unused CPU/GPU Ratio (**Max UCR/UGR**) | Maximum ratio of "unused" to "used" CPUs/GPUs across all jobs. |
| Maximum CPU/GPU Load Imbalance (**Max CLI/GLI**) | Maximum of the average standard deviation of CPU/GPU load across all jobs. |
| Maximum I/O Congestion (**Max IOC**) | Maximum rate of metadata operations at a measuring point across all jobs. The attribution per job starts with 40 operations. |
| Maximum I/O Blocking Phases (**Max IOB**) | Maximum periodic number of phases with an inverse correlation between CPU load and I/O metrics across all jobs. The attribution per job starts with 10 periodic phases. |
| Maximum Synchronous Offloading (**Max SO**) | Maximum periodic number of phases with an inverse correlation between CPU and GPU load across all jobs. The attribution per job starts with 10 periodic phases. |
| Maximum Memory Leak (**Max ML**) | Maximum of the linear increase of memory usage over time across all jobs. |

# PIKA Issue Analysis – Issue Table

User jobs are sorted by idle CPU time

Live | Project | User | Job | Footprint | Search | **Issue**

12/05/2022 23:19 - 17/05/2023 13:43

**Total Issue Users: 946**

| User | Project | #Runs | ICT | ICR | Max UCR | Max CLI | Max IOB | Max IOC | Max ML | IGT | IGR | Max UGR | Max GLI | Max SO | Max S |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| diw... | p_fun... | 23752 | 0230y 166d 14:01h | 0.36 | 1 | 0.57 | 0 | 2503 | 0.05 | 00d 00:00:00h | 0 | 0 | 0 | 0 | 0 |
| pa... | p_sca... | 11523 | 0180y 200d 02:44h | 0.69 | 1 | 0.7 | 0 | 0 | 0.06 | 174d 18:24:30h | 0.45 | 0 | 0 | 0 | 0 |
| lau... | p_sra | 30561 | 0167y 271d 03:22h | 0.57 | 1 | 0.82 | 0 | 2765 | 0.93 | 00d 00:00:00h | 0 | 0 | 0 | 0 | 0 |
| s2... | p_ml_rl | 1775 | 0147y 150d 21:10h | 0.48 | 0.5 | 0.5 | 0 | 38 | 0.74 | 00d 00:12:30h | 0 | 0 | 0 | 0 | 0 |
| s5... | p_am... | 3017 | 0131y 062d 20:17h | 0.9 | 1 | 0.5 | 0 | 44 | 0.02 | 00d 00:00:00h | 0 | 0 | 0 | 0 | 0 |

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# PIKA Issue Analysis – Issue Table

User jobs are sorted by idle GPU time

Live | Project | User | Job | Footprint | Search | **Issue**

12/05/2022 23:19 - 17/05/2023 13:43

**Total Issue Users: 946**

| User | Project | #Runs | ICT | ICR | Max UCR | Max CLI | Max IOB | Max IOC | Max ML | IGT | IGR | Max UGR | Max GLI | Max SO | Max S |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| sek... | p_sca... | 406 | 0002y 096d 03:59h | 0.05 | 0.83 | 0.45 | 0 | 39226 | 0.86 | 96d 05:14:30h | 0.04 | 1 | 0.6 | 0 | 0 |
| s12... | p_da... | 79 | 0000y 099d 19:02h | 0.18 | 0.54 | 0.22 | 0 | 0 | 0.1 | 91d 07:31:30h | 0.98 | 1 | 0 | 0 | 0 |
| s9... | p_sca... | 8781 | 0078y 345d 18:15h | 0.84 | 1 | 0.85 | 0 | 0 | 0 | 919d 09:55:30h | 0.98 | 1 | 0 | 0 | 0 |
| s6... | zihfor... | 27 | 0000y 341d 19:04h | 0.41 | 0.6 | 0.63 | 0 | 336 | 0.01 | 90d 04:47:30h | 0.65 | 0.88 | 0.46 | 0 | 0 |
| s3... | zihfor... | 413 | 0005y 337d 04:12h | 0.39 | 1 | 0.38 | 0 | 19464 | 0.04 | 893d 10:59:30h | 0.61 | 1 | 0.54 | 0 | 0 |

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# PIKA Issue Analysis – Issue Table

User jobs are sorted by maximum I/O congestion

Live | Project | User | Job | Footprint | Search | Issue

12/05/2022 23:19 - 17/05/2023 13:43

**Total Issue Users: 946**

| User | Project | #Runs | ICT | ICR | Max UCR | Max CLI | Max IOB | Max IOC | Max ML | IGT | IGR | Max UGR | Max GLI | Max SO | Max S |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| s81... | p_sp_... | 56 | 0000y 211d 04:57h | 0.49 | 0.88 | 0.47 | 0 | 92007 | 0.02 | 00d 00:00:00h | 0 | 0 | 0 | 0 | 0 |
| s4... | nano-10 | 1158 | 0099y 020d 01:17h | 0.57 | 0.89 | 0.5 | 0 | 56928 | 0.16 | 00d 00:00:00h | 0 | 0 | 0 | 0 | 0 |
| dm... | p_lv_... | 3 | 0000y 029d 13:05h | 0.23 | 0 | 0 | 0 | 51677 | 0.09 | 00d 00:00:00h | 0 | 0 | 0 | 0 | 0 |
| sek... | p_sca... | 406 | 0002y 096d 03:59h | 0.05 | 0.83 | 0.45 | 0 | 39226 | 0.86 | 96d 05:14:30h | 0.04 | 1 | 0.6 | 0 | 0 |
| sek... | p_dar... | 54 | 0011y 028d 20:22h | 0.06 | 0.99 | 0.5 | 0 | 34343 | 0.16 | 04d 21:20:00h | 0.98 | 1 | 0 | 0 | 0 |

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# PIKA Issue Analysis – Issue Table

User jobs are sorted by maximum I/O blocking

Live | Project | User | Job | Footprint | Search | Issue

12/05/2022 23:19 - 17/05/2023 13:43

**Total Issue Users: 946**

| User | Project | #Runs | ICT | ICR | Max UCR | Max CLI | Max IOB | Max IOC | Max ML | IGT | IGR | Max UGR | Max GLI | Max SO | Max S |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| s14... | molec... | 1660 | 0035y 281d 04:28h | 0.19 | 0.82 | 0.51 | 688 | 2535 | 0.05 | 00d 00:00:00h | 0 | 0 | 0 | 0 | 0 |
| lne... | p_nu... | 265 | 0004y 253d 22:56h | 0.21 | 0.75 | 0.47 | 62 | 236 | 0 | 00d 00:00:00h | 0 | 0 | 0 | 0 | 0 |
| s13... | p_insi... | 14 | 0000y 095d 21:53h | 0.46 | 0.93 | 0.43 | 60 | 106 | 0.17 | 00d 00:00:00h | 0 | 0 | 0 | 0 | 0 |
| s4... | prime | 908 | 0007y 311d 04:51h | 0.02 | 1 | 0.7 | 11 | 5809 | 0.04 | 00d 06:22:30h | 0.8 | 0 | 0 | 0 | 0 |
| diw... | p_fun... | 23752 | 0230y 166d 14:01h | 0.36 | 1 | 0.57 | 0 | 2503 | 0.05 | 00d 00:00:00h | 0 | 0 | 0 | 0 | 0 |

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# PIKA Issue Analysis – Issue Table

User jobs with I/O blocking issues

Live | Project | User | Job | Footprint | Search | **Issue** | 12/05/2022 23:19 - 17/05/2023 13:43

**User:** **Total Issue Jobs: 1**

| Job Name | Project | #Runs | ICT | ICR | Max UCR | Max CLI | Max IOB | Max IOC | Max ML | IGT | IGR | Max UGR | Max GLI | Max SO | Max S |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| hP_Sta... | p_in... | 14 | 0000y 095d 21:53h | 0.46 | 0.93 | 0.43 | 60 | 106 | 0.17 | 00d 00:00:00h | 0 | 0 | 0 | 0 | 0 |

1 of 1 « ‹ 1 › » 10

# PIKA Issue Analysis – Issue Table

User jobs with I/O blocking issues

Live | Project | User | Job | Footprint | Search | Issue

12/05/2022 23:19 - 17/05/2023 13:43

User: Job Name: Total Issue Runs: 14

| Job ID | Project | ICT | ICR | UCR | CLI | IOB | IOC | ML | IGT | IGR | UGR | GLI | SO | S |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 32966983 | p_insitu | 0000y 008d 01:21h | 0.53 | 0 | 0 | 60 | 41 | 0.17 | 00d 00:00:00h | 0 | 0 | 0 | 0 | 0 |
| 32962249 | p_insitu | 0000y 005d 17:58h | 0.48 | 0 | 0 | 60 | 55 | 0.11 | 00d 00:00:00h | 0 | 0 | 0 | 0 | 0 |
| 32963697 | p_insitu | 0000y 004d 15:27h | 0.24 | 0 | 0 | 60 | 55 | 0 | 00d 00:00:00h | 0 | 0 | 0 | 0 | 0 |
| 32960189 | p_insitu | 0000y 004d 07:11h | 0.24 | 0 | 0 | 56 | 58 | 0 | 00d 00:00:00h | 0 | 0 | 0 | 0 | 0 |
| 32959720 | p_insitu | 0000y 004d 08:25h | 0.24 | 0 | 0 | 55 | 59 | 0 | 00d 00:00:00h | 0 | 0 | 0 | 0 | 0 |

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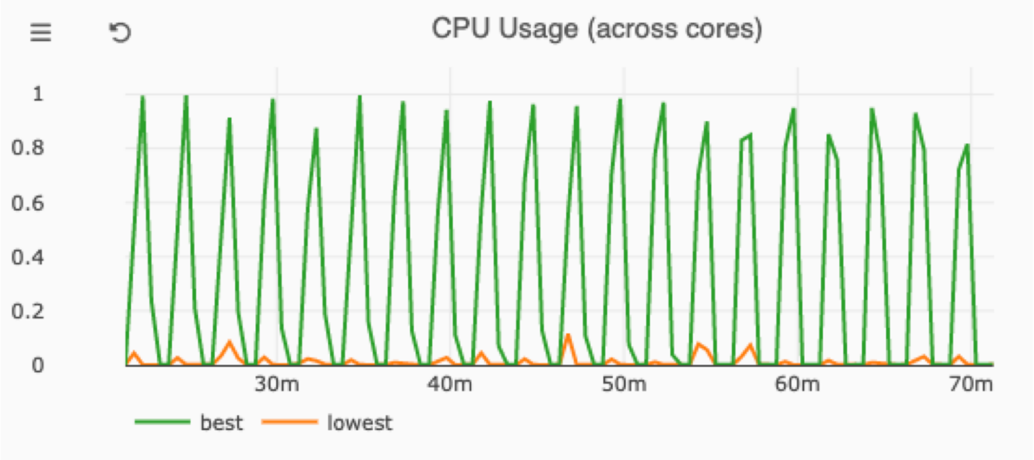
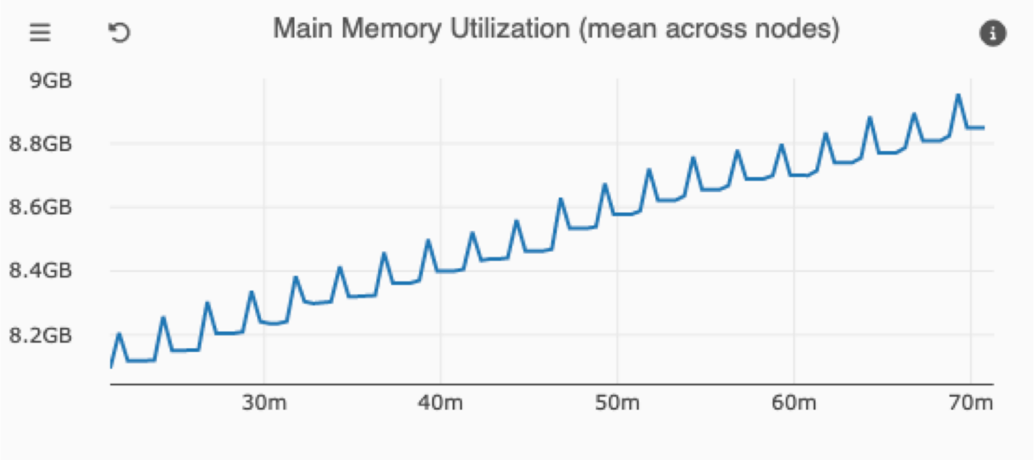
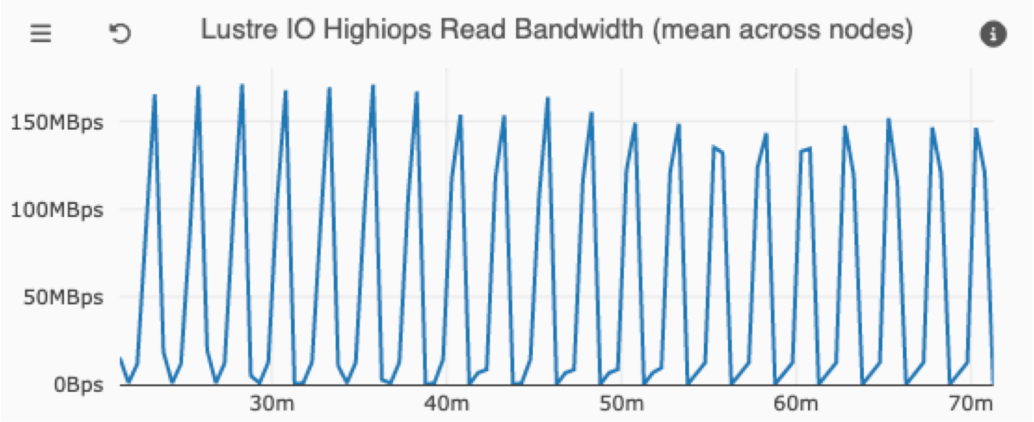
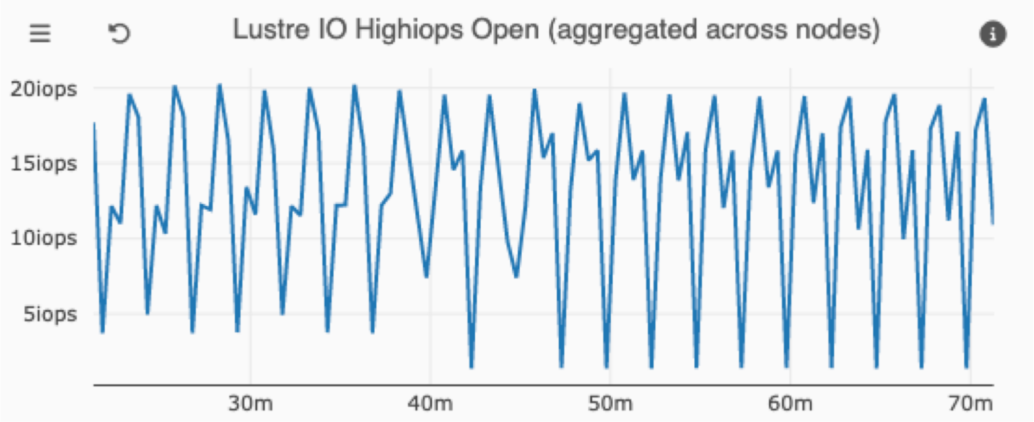
# PIKA Issue Analysis – Metadata & Timelines

| Pro | Start | End | State | #Nodes | #Cores | Exclusive | Walltime | Pending | Duration | Core Time | Used | Partition |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| p... | 09/02/23 22:27:43 | 10/02/23 00:58:26 | com... | 6 | 144 | 0 | 00d 04:00 | 00d 01:57 | 00d 02:30:43h | 0000y 015d 01:43h | 62.8% | haswell... |



# Conclusion

**PIKA** is a hardware performance monitoring stack in order to identify potentially inefficient jobs.

- **Job Metadata Collector:** Centralized capture of job metadata for both exclusive and node-sharing jobs using a Slurm PrEp Plugin
- **Metric Data Collector:** An extension of the collection daemon collectd to record metric data on each compute node
- **Frontend:** Powerful interactive GUI with top-down approach
- **Post-processing:** Python analysis engine for job tagging and automatic detection of job performance issues
  - Scan jobs for performance issues on a weekly basis
  - Heuristics identify jobs that are using excessive idle CPU/GPU hours or have load imbalances, periodic blocking I/O phases, synchronous offloading, or suspected memory leaks
  - HPC user support contacts and advises HPC users on how to improve the performance of their jobs

# Outlook

- Provide an additional severity column in the issue table that better prioritizes problem jobs according to defined characteristics, e.g., highly scalable or very long jobs
- Mark problematic jobs where users have already been contacted to see if future jobs have resolved those issues
- Plan to enrich the recorded jobs with application-specific parameters with **XALT*** to be able to classify jobs by application type
- **No Blackbox AI Approach**

* XALT is a lightweight software tool for any Linux cluster, workstation, or high-end supercomputer to track executable information and linkage of static shared and dynamically linked libraries.
https://github.com/xalt/xalt

# Automatic Detection of HPC Job Inefficiencies with PIKA

R. Dietrich, F. Winkler, A. Knüpfer and W. Nagel, "PIKA: Center-Wide and Job-Aware Cluster Monitoring," 2020 IEEE International Conference on Cluster Computing (CLUSTER), Kobe, Japan, 2020, pp. 424-432.

https://gitlab.hrz.tu-chemnitz.de/pika

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