Automatic Detection of Performance Anomalies in Task-Parallel Programs

Work in progress on the Aftermath trace analysis tool

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Albert Cohen, Nathalie Drach

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Context

Hardware and software environment

- Multi-core / many-core systems
- How to exploit the hardware efficiently?
- Task-parallel languages based on fine-grained tasks

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- Possible solution: Record dynamic events to a trace file
- Post-mortem (offline) analysis

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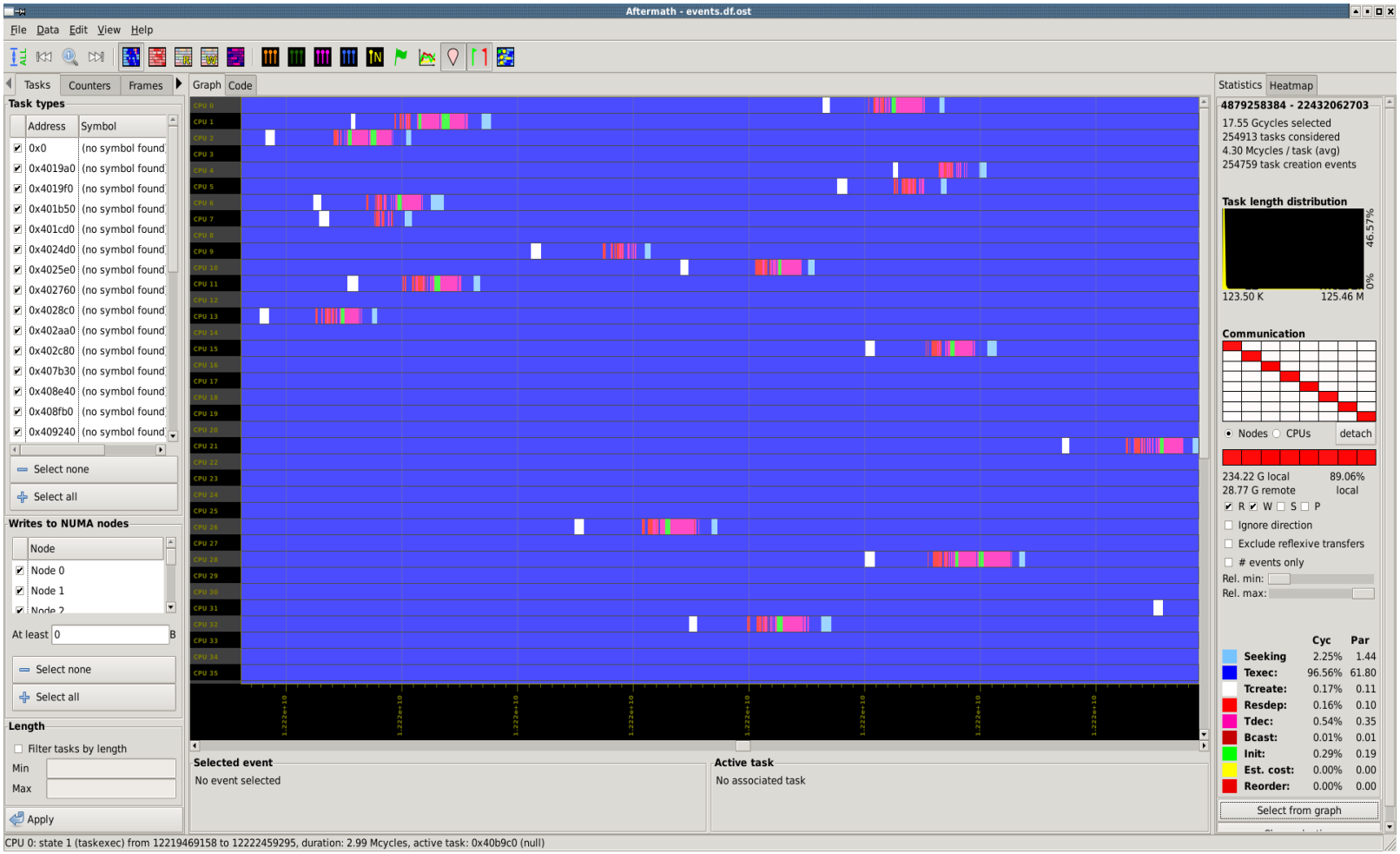
Aftermath

- Trace visualization and support for manual analysis
- Originally developed for OpenStream language & run-time
- Work in progress: Automate repetitive tasks

Outline

1. Aftermath
2. Insufficient parallelism and its causes
3. Performance anomalies during task execution
4. Work in progress: Status
5. Summary & Questions

Aftermath


Aftermath - events.df.ost
File Data Edit View Help
Tasks Counters Frames
Task types
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Graph Code
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4879258384 - 22432062703
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Est. cost: 0.00% 0.00
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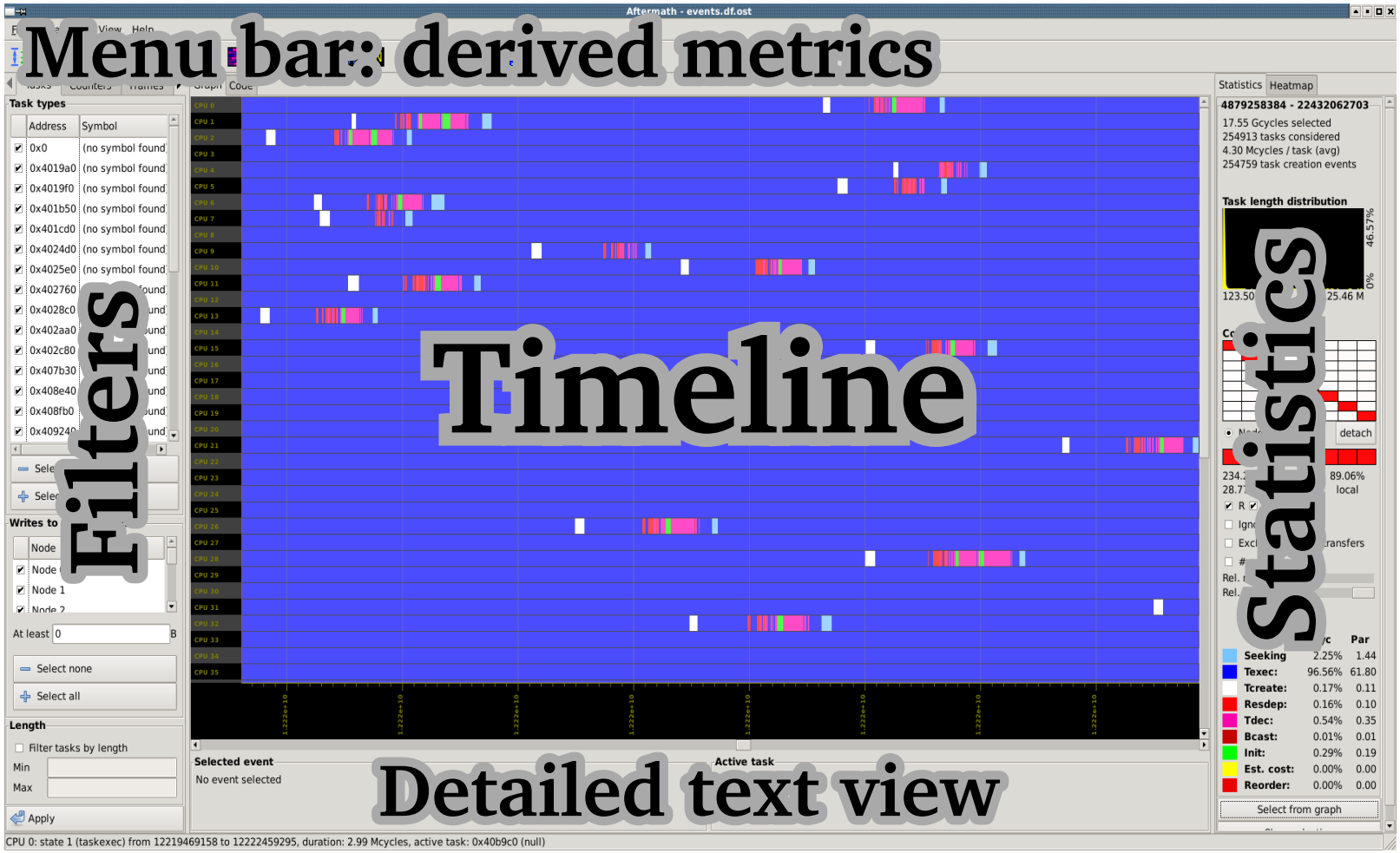
Menu bar: derived metrics
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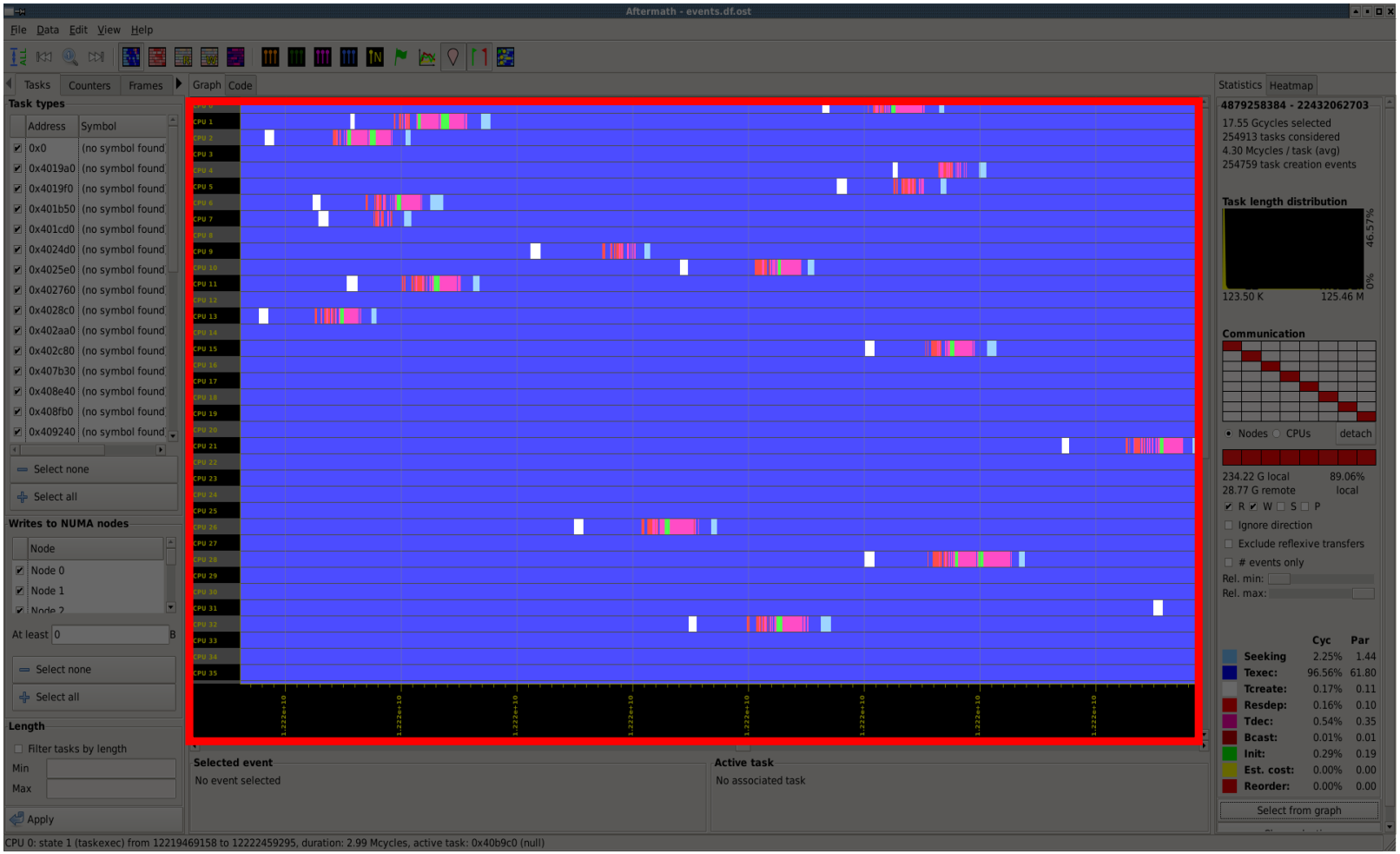
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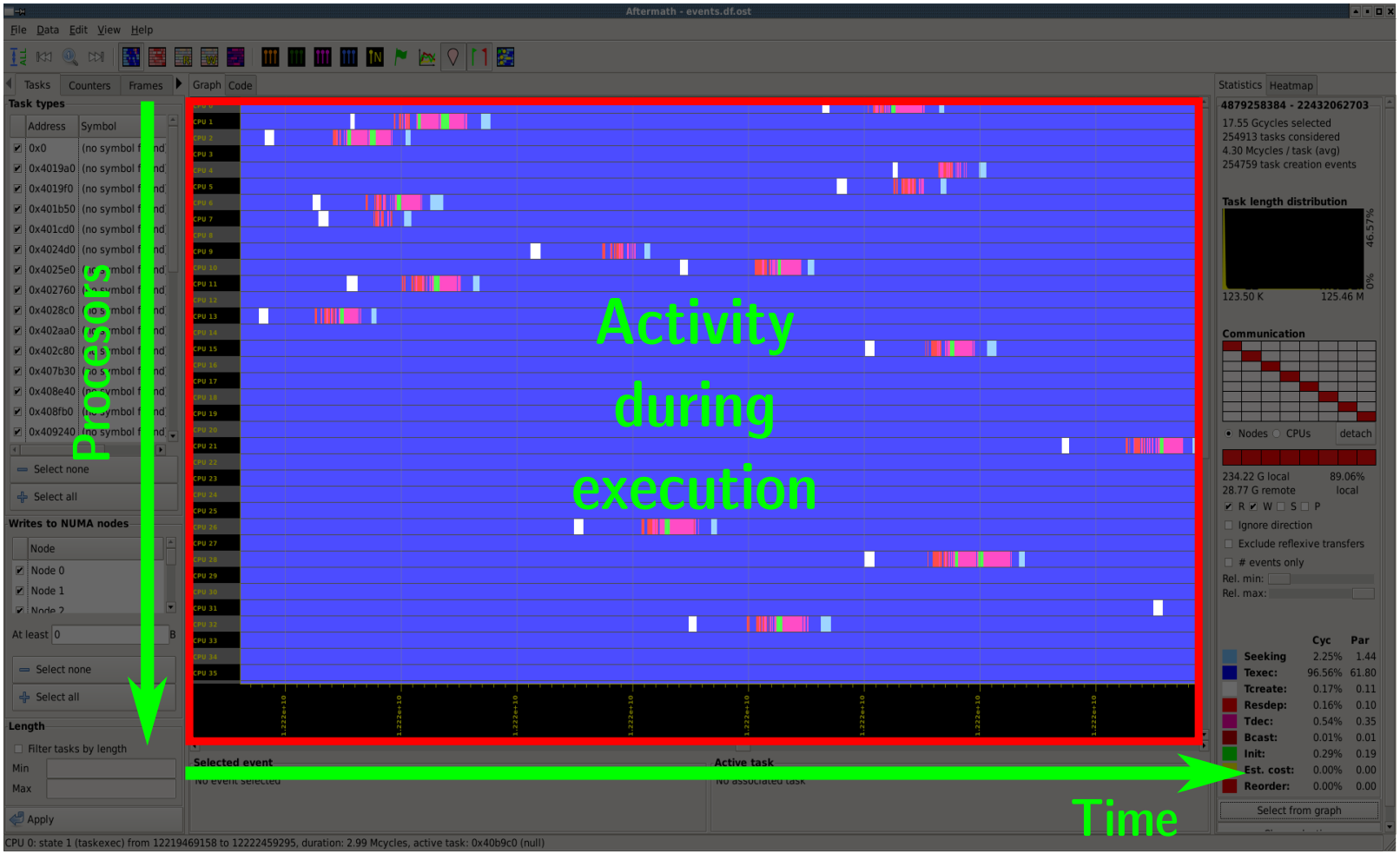
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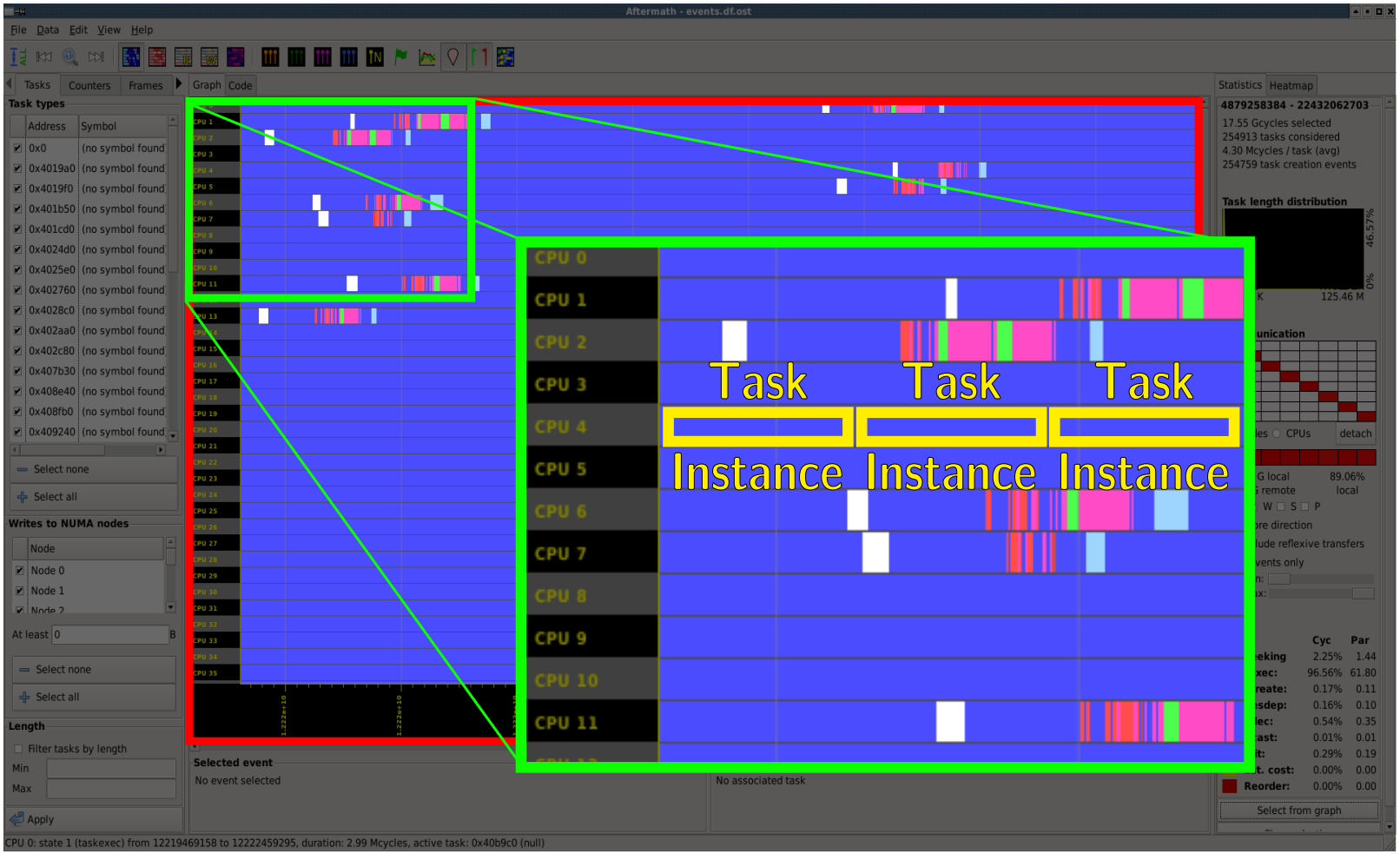
Task execution (dark blue)

Aftermath



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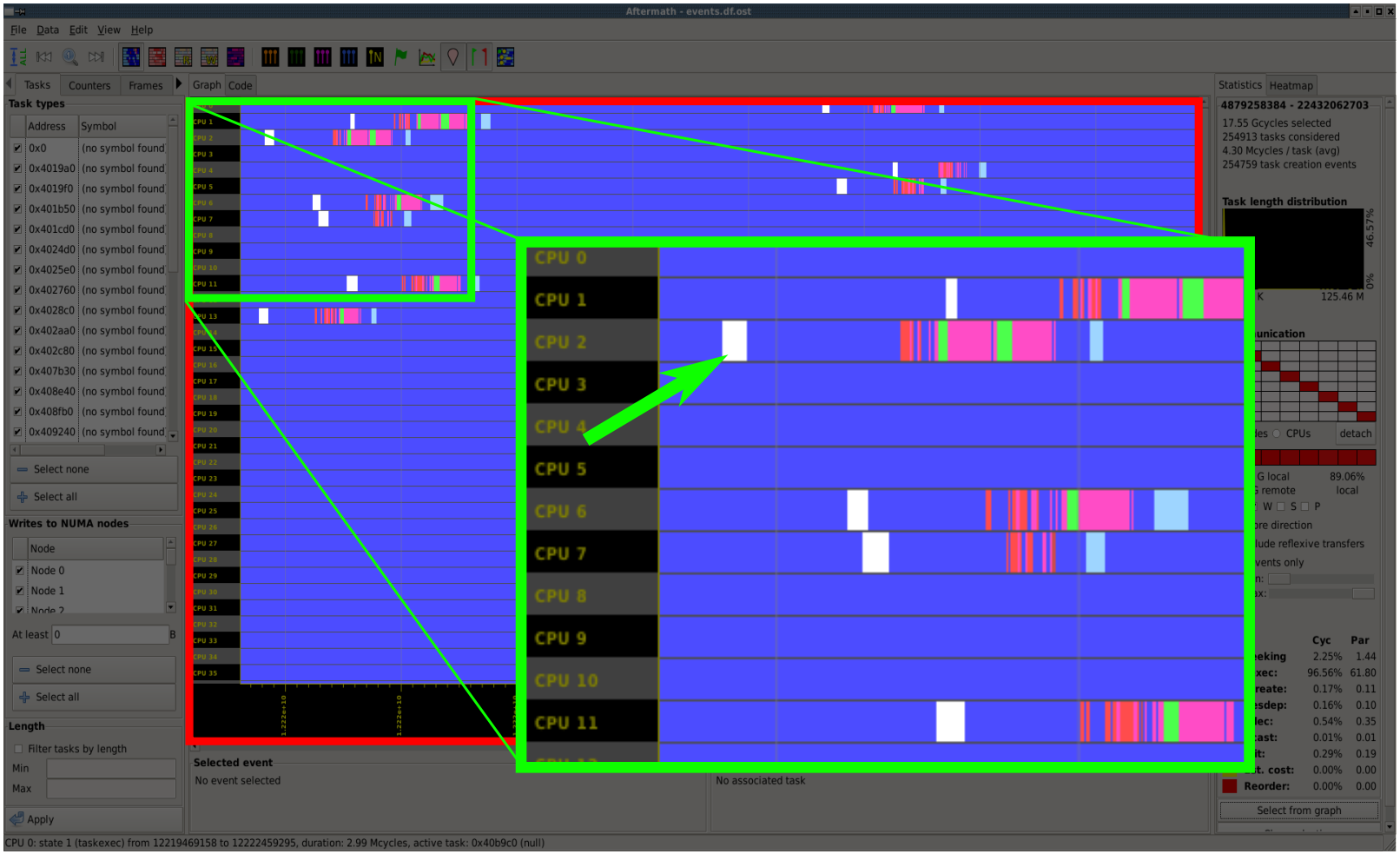
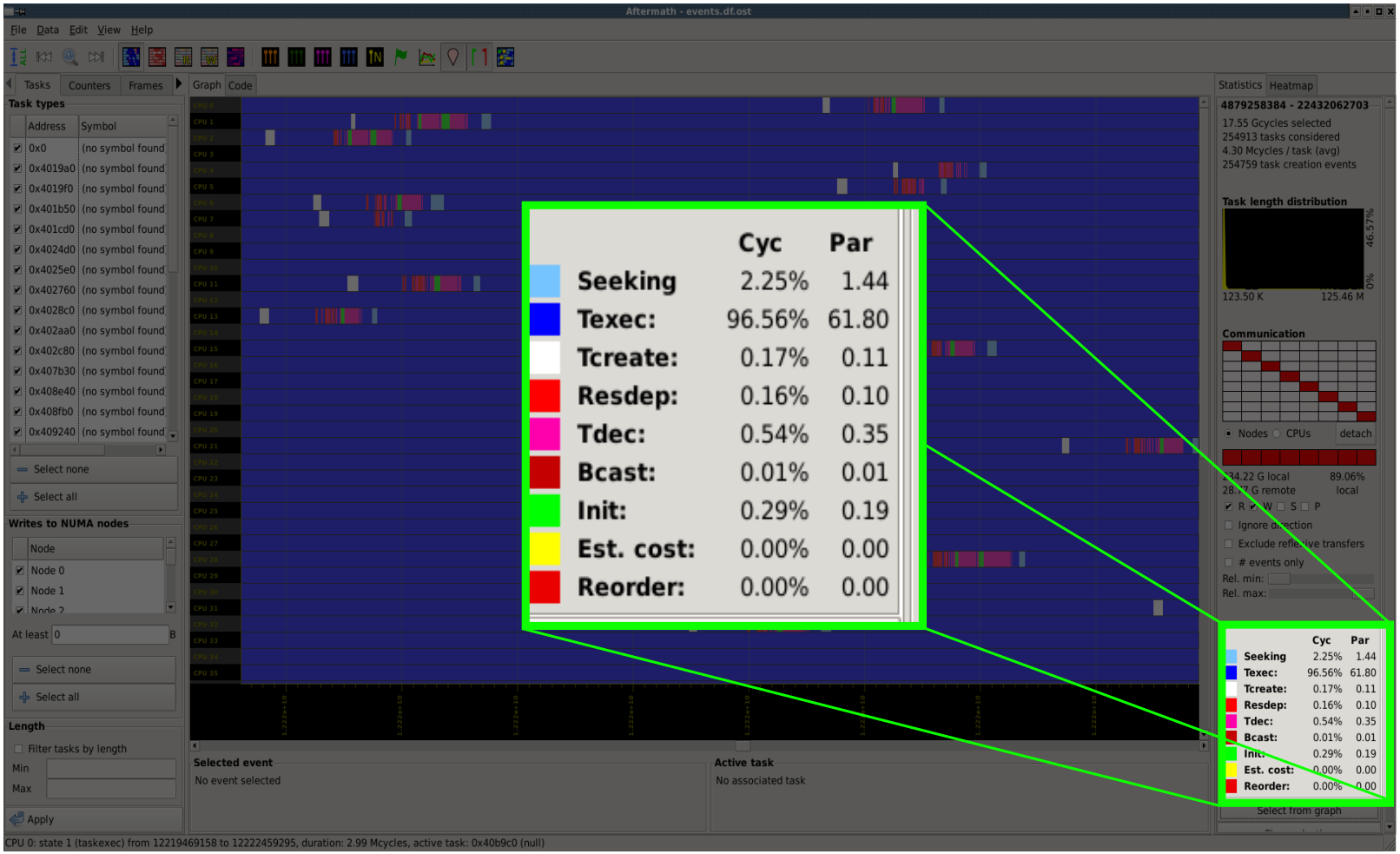


Task creation (white)

Aftermath

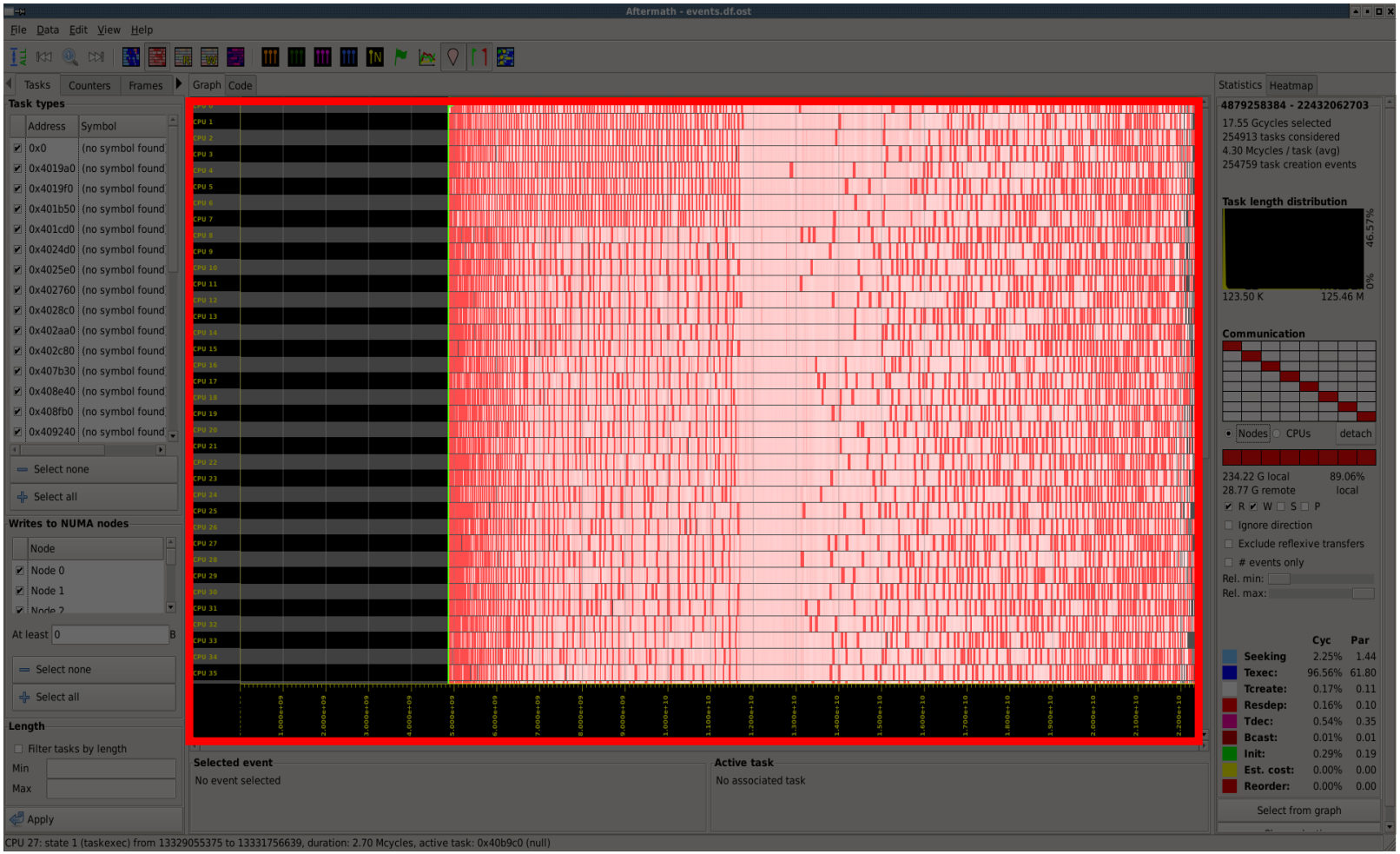
Searching for work (light blue)

Aftermath



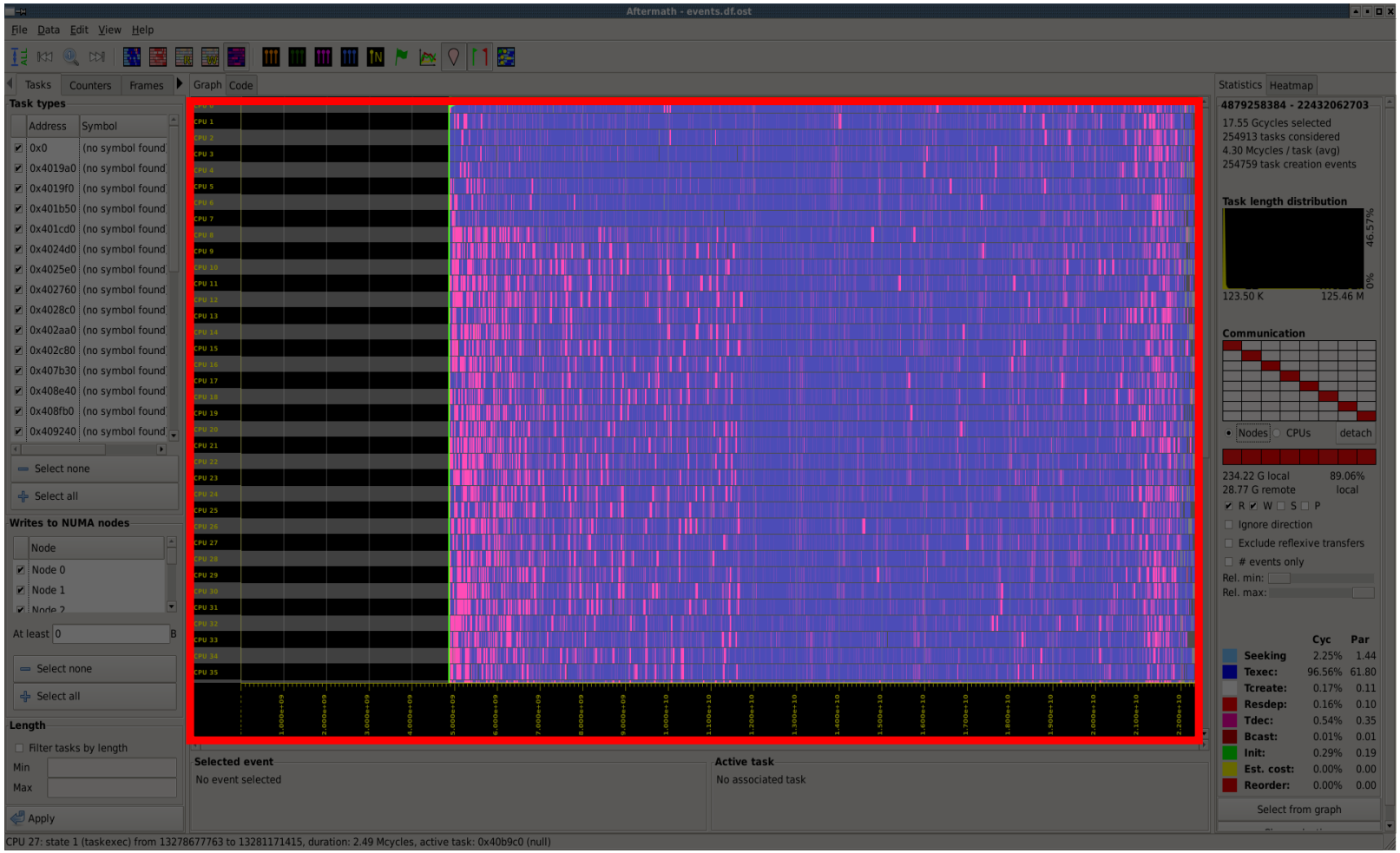
Basic statistics for run-time states

Aftermath

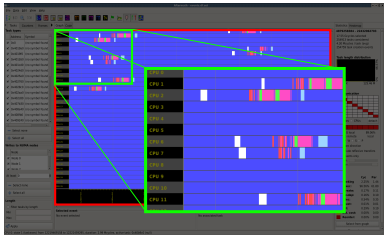
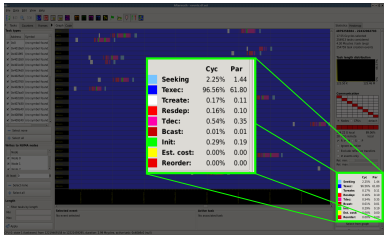


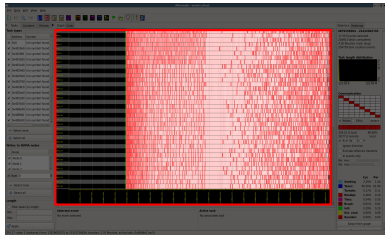
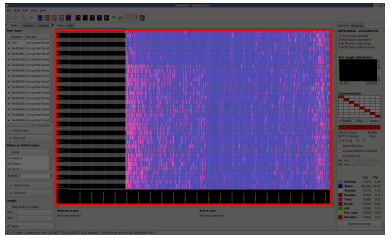
Heatmap indicating task duration (white: fast, red: slow)

Aftermath



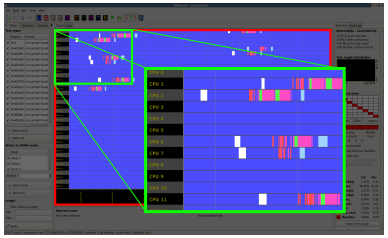
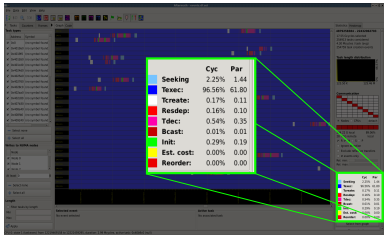
NUMA heatmap indicating locality of memory accesses (blue: local, pink: remote)

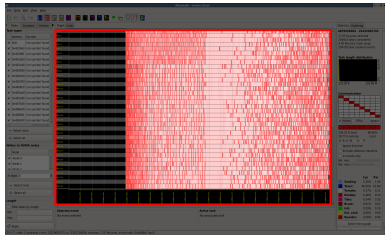
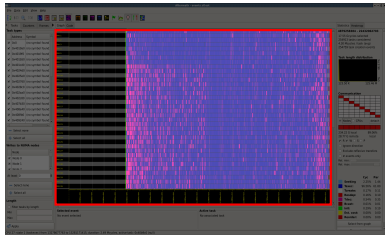



Navigating through a trace

- Huge amounts of high-dimensional data
- Lots of features $\rightarrow$ lots of possibilities for analysis
- Where to look? What to look for?
- Expertise & lots of time required

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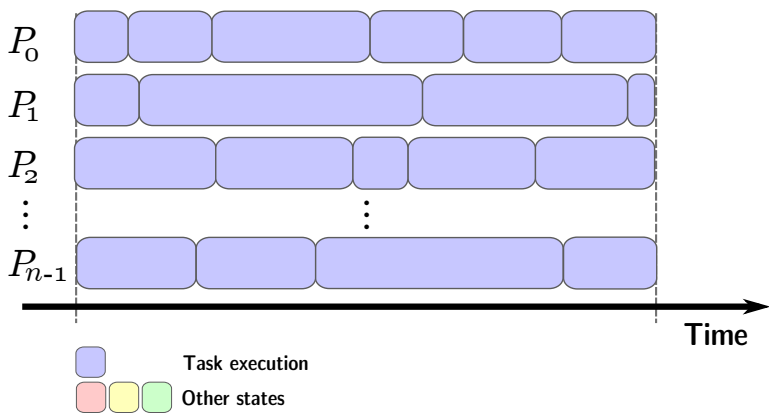
Guide the user through performance analysis

- Refine analysis in several steps
  - Start by analyzing parallelism
  - Analyze what happens inside tasks
- Automate repetitive tasks

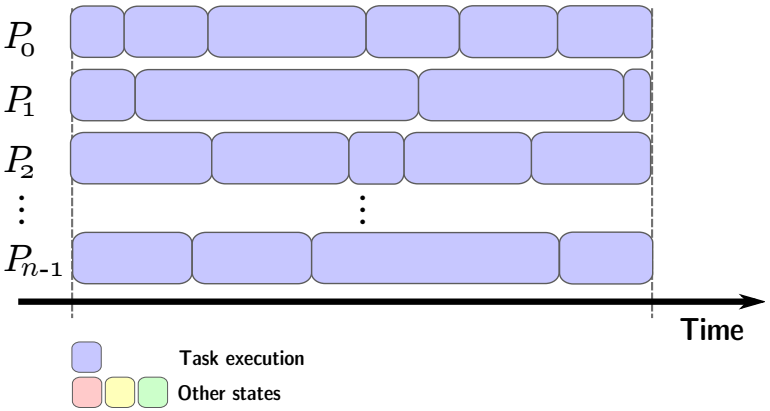
Detecting insufficient parallelism



Ideal situation

All CPUs are in task execution state without any interruption

Detecting insufficient parallelism



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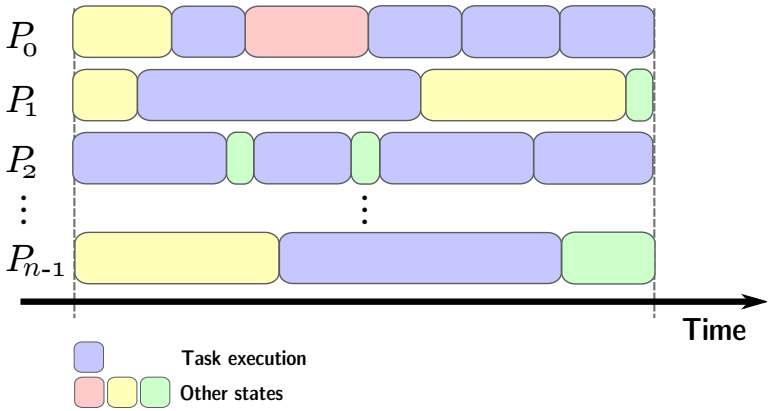

Realistic scenario

Task creation, memory allocation, idle time, over-synchronization, ...

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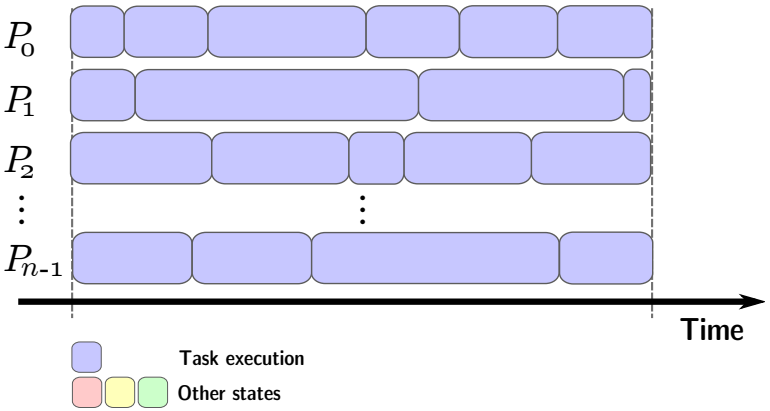

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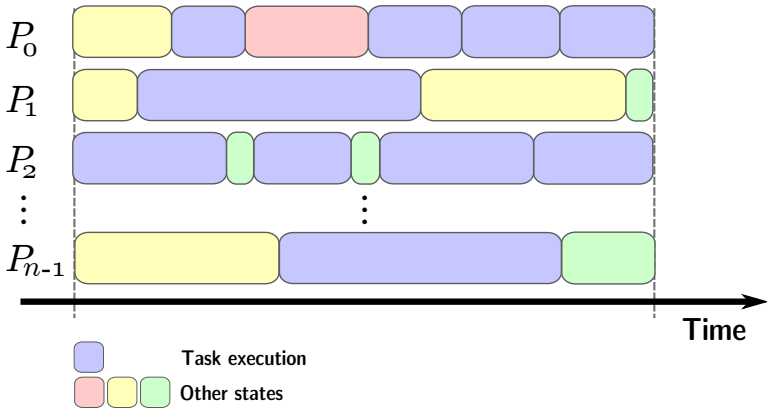

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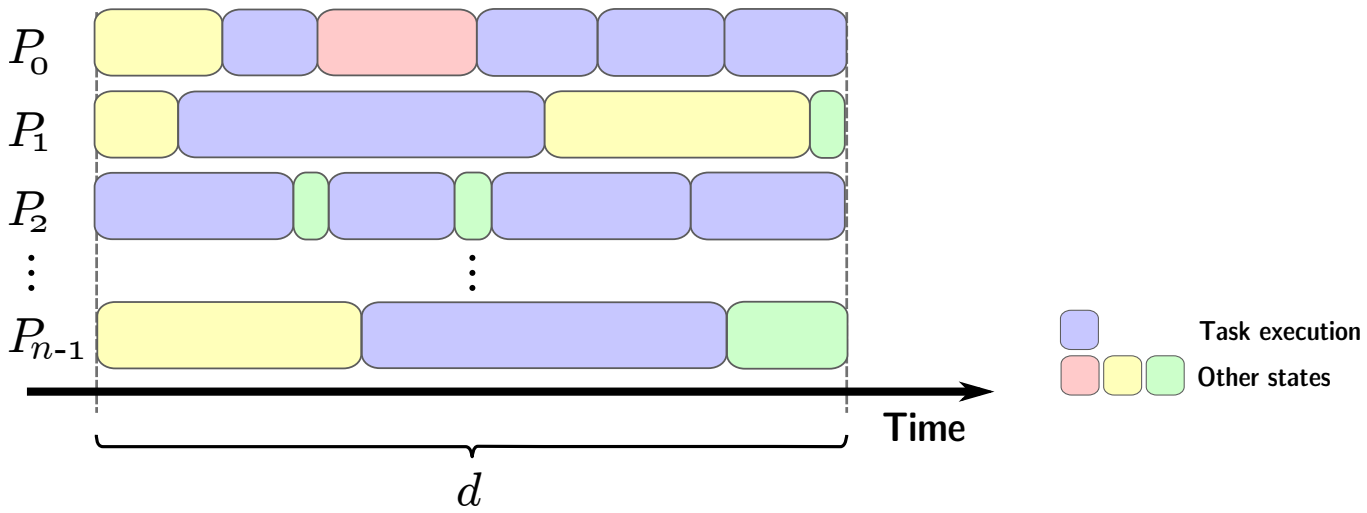
Detect insufficient parallelism / high overhead automatically

Threshold-based analysis of parallelism



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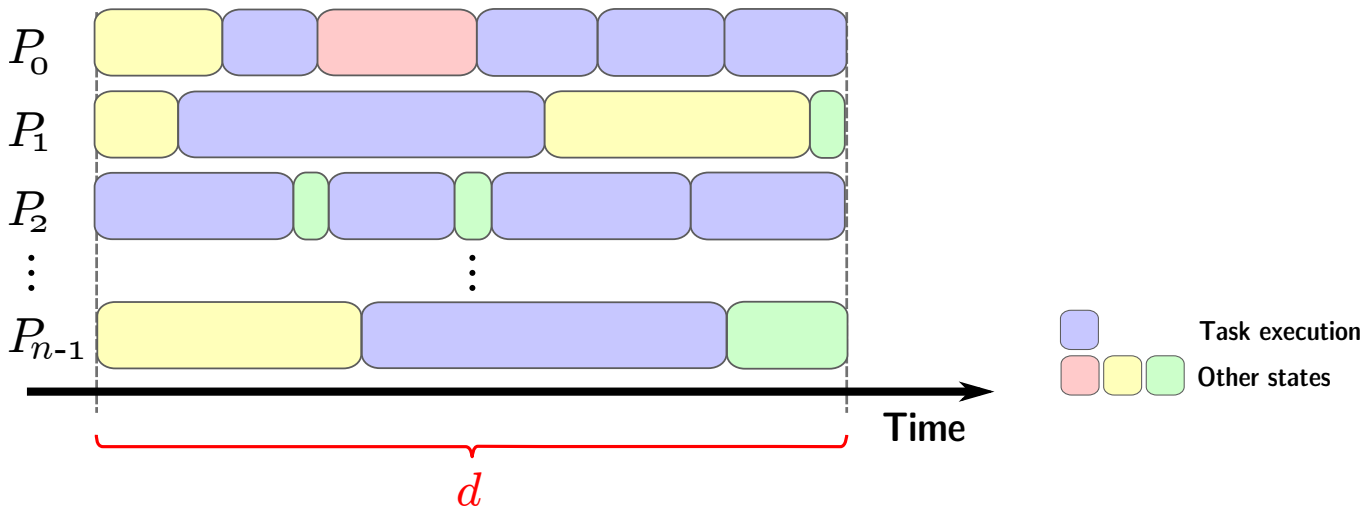

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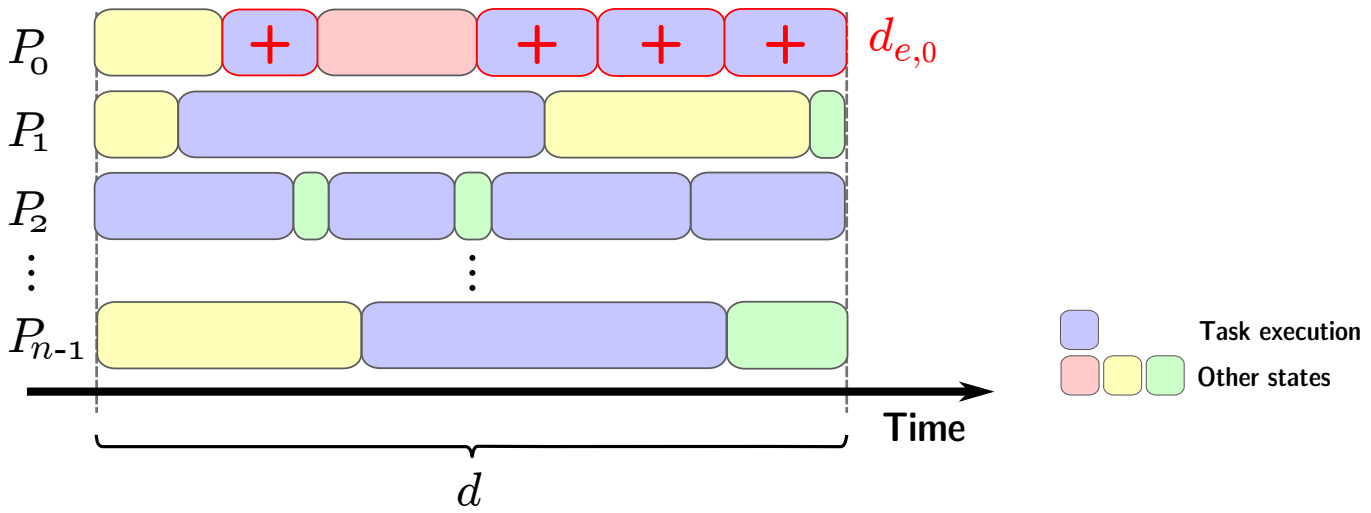

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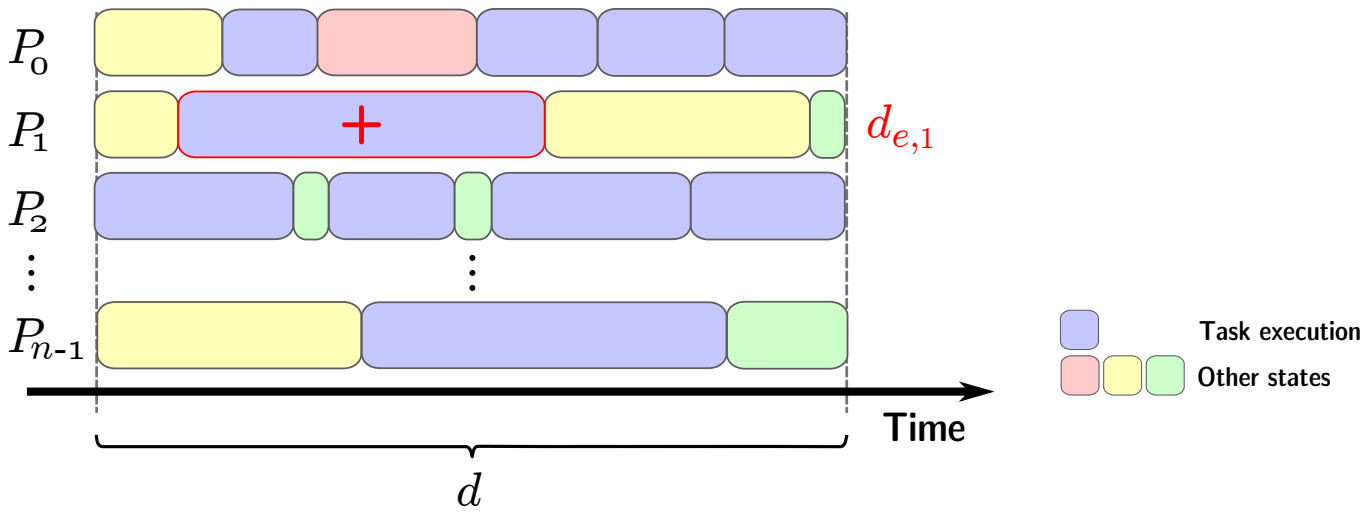

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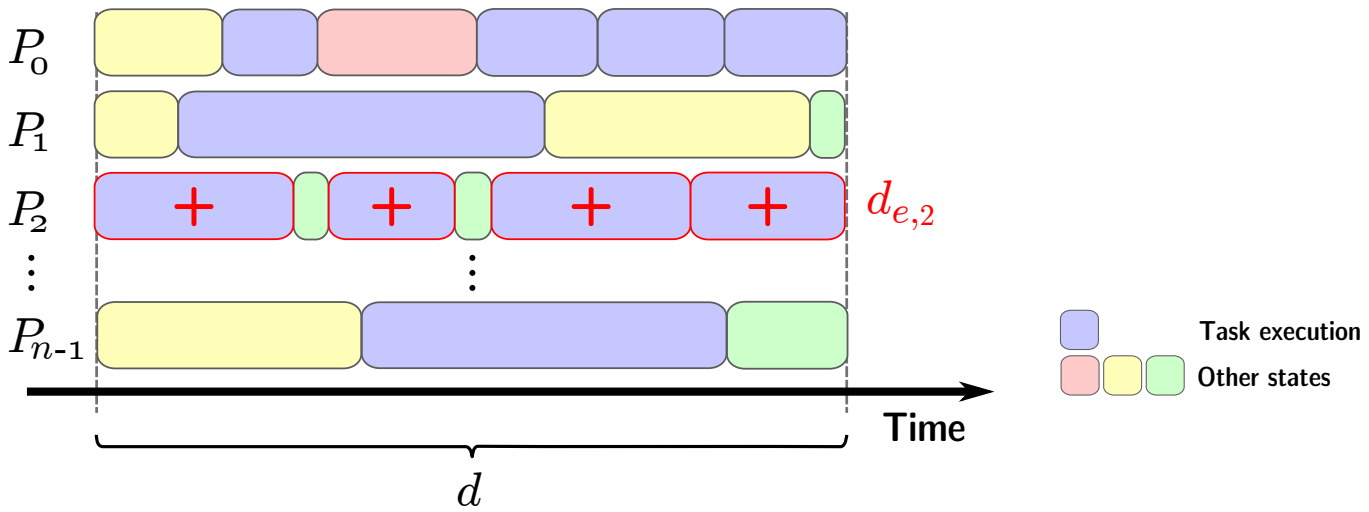

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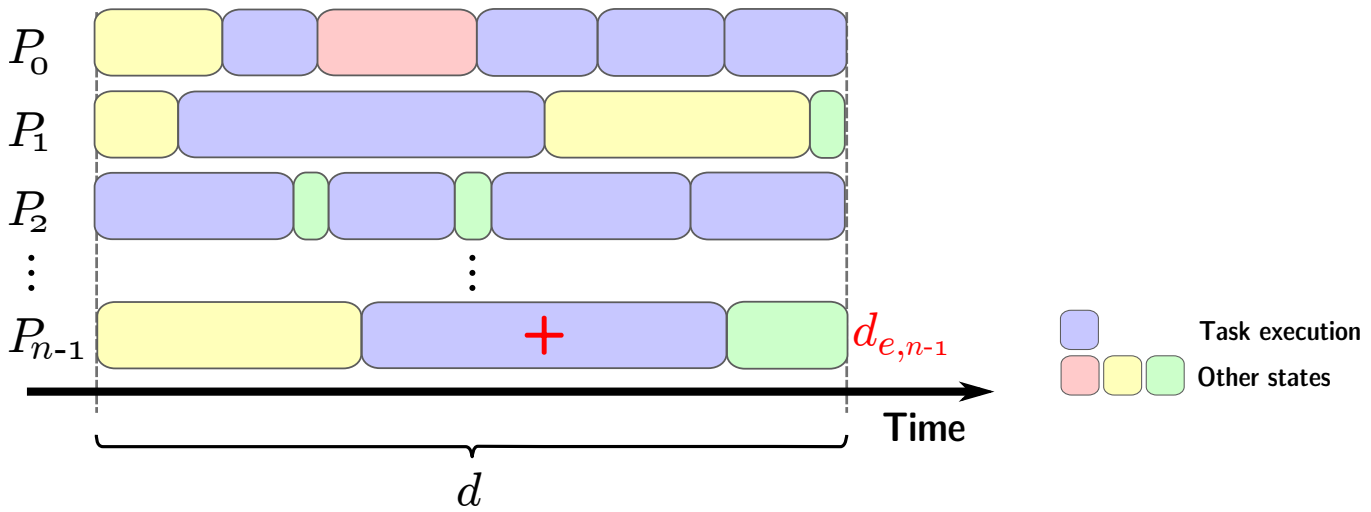

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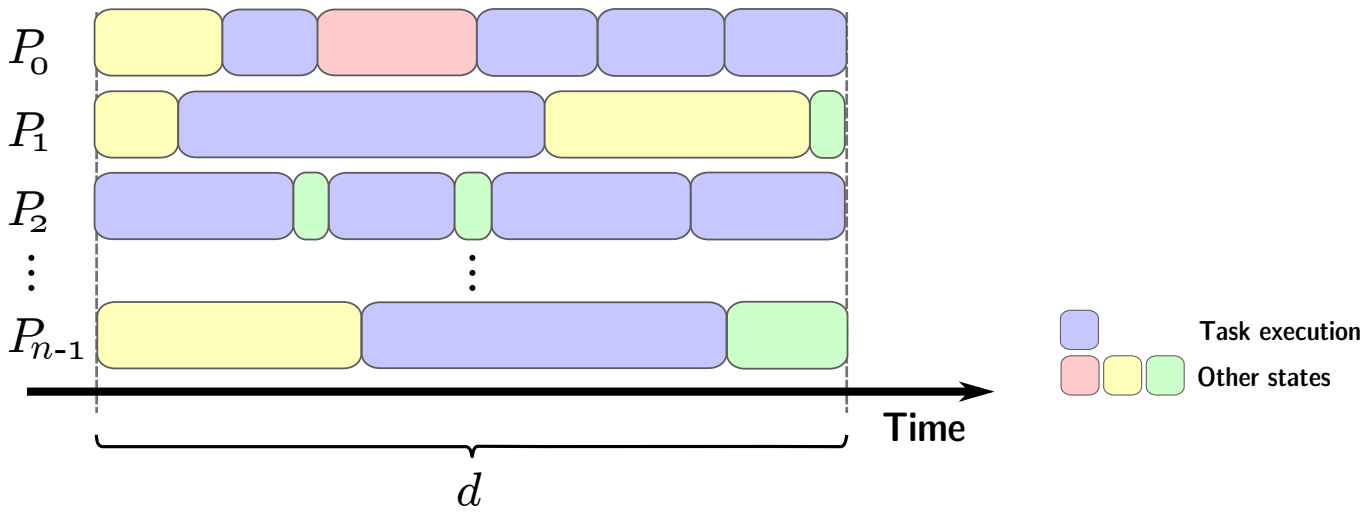

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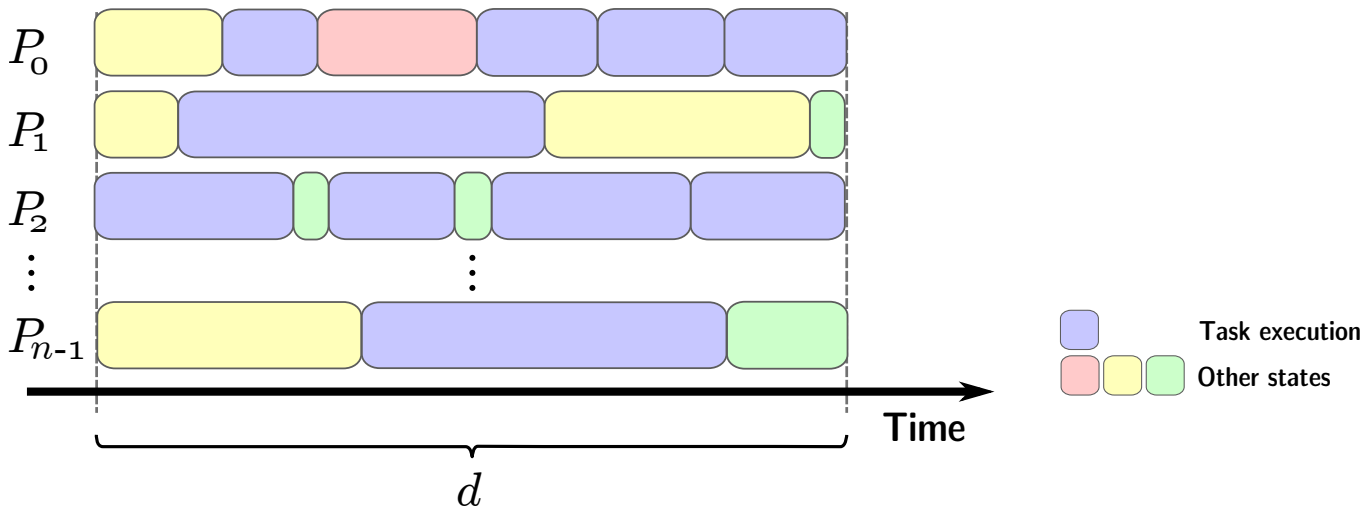

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Consider that there is sufficient parallelism if inequation holds:

$$\sum_{i=1}^{n} d_{e,i} > t_e \cdot n \cdot d$$

Detecting the cause of insufficient parallelism

Multiple stages during analysis

- If inequation does not hold, find out why
- Possible causes: task creation overhead, memory allocation, not enough tasks available for execution, ...
- Use thresholds for associated states:
  t_c (task creation), t_i (idle time)

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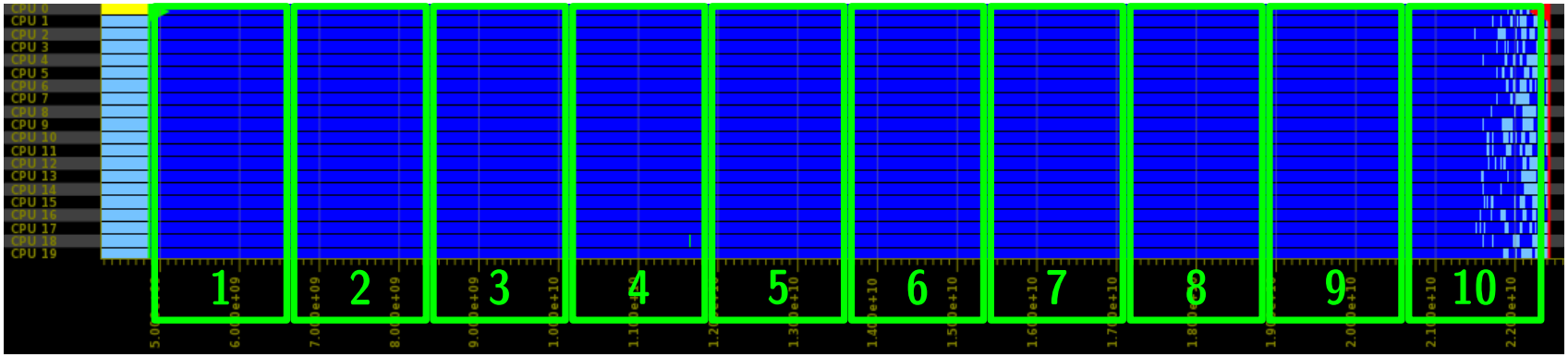

Interval selection

- Multiple intervals: initialization, termination, etc.
- Repeat analysis for different intervals

Per-interval analysis of parallelism & overhead

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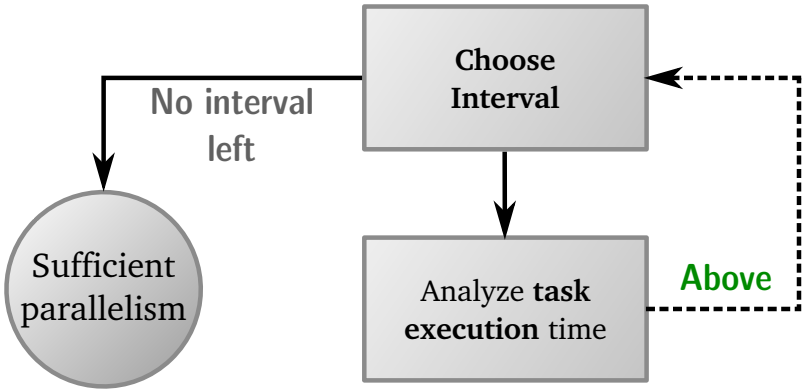

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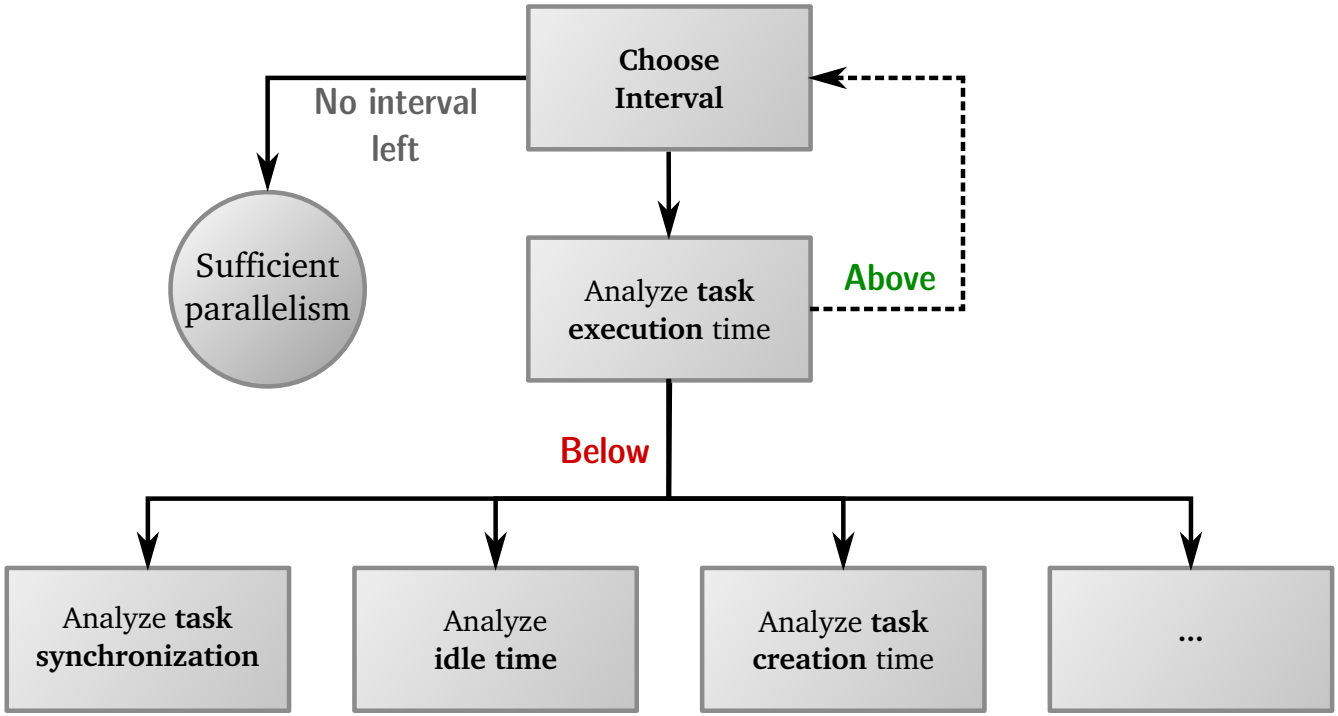
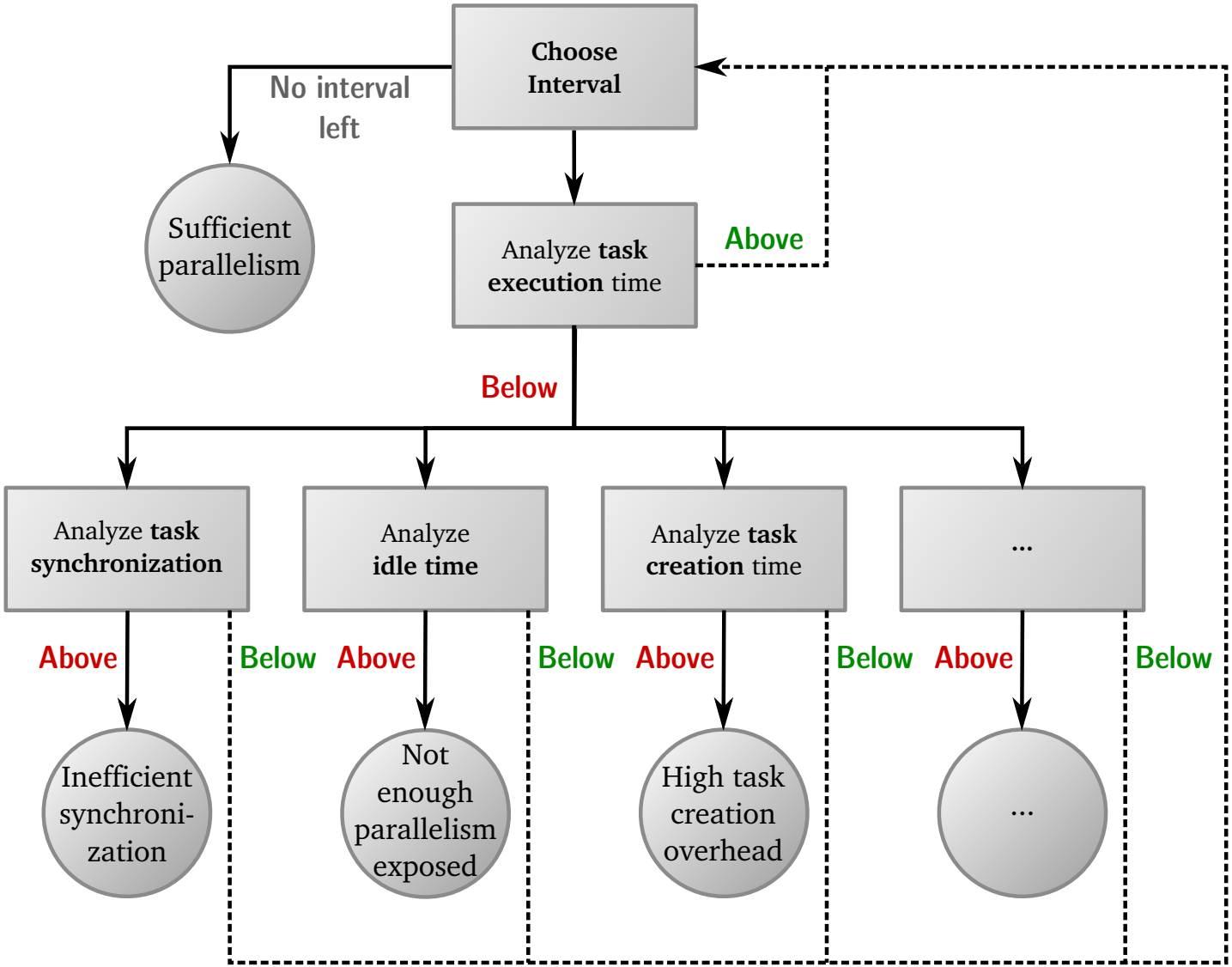


Per-interval analysis of parallelism & overhead



Detecting performance anomalies during task execution

During task execution

- Performance anomaly possible even at 100% task execution (ineffective use of caches, remote memory accesses, branch misprediction)

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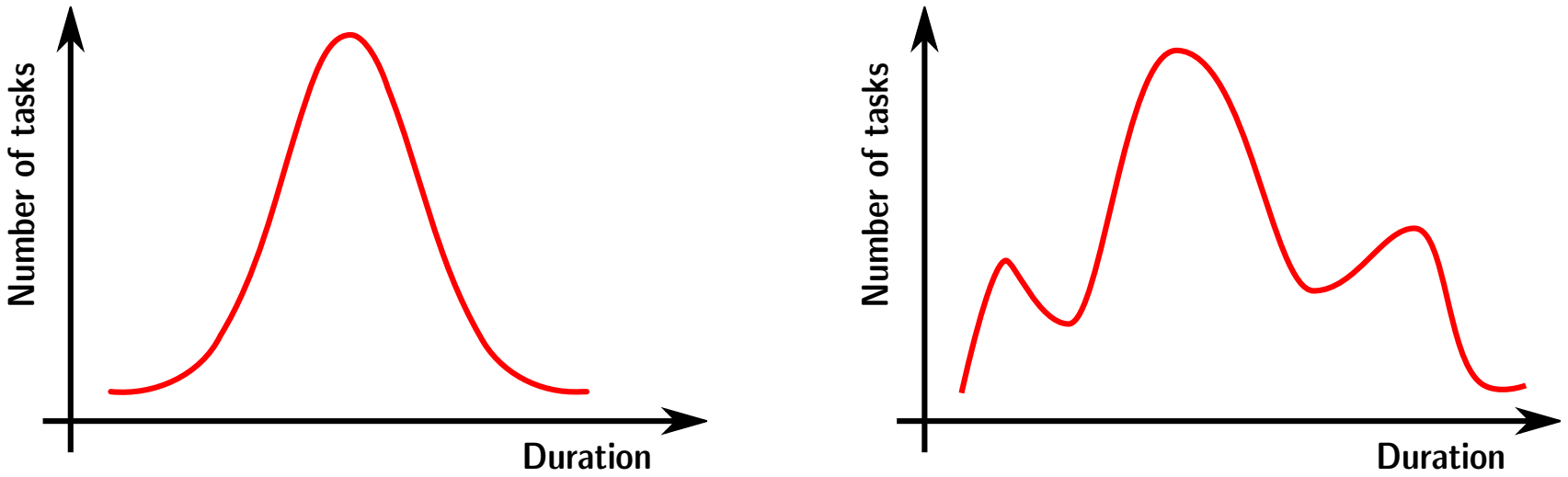

Impact on the distribution of task duration

- Slowdown of all tasks
- Different groups / peaks

Using performance counters

Hardware performance counters

- Implemented in hardware, no slowdown of the application
- Low tracing overhead if sampled at beginning / end of a task
- Dozens of hardware events can be monitored

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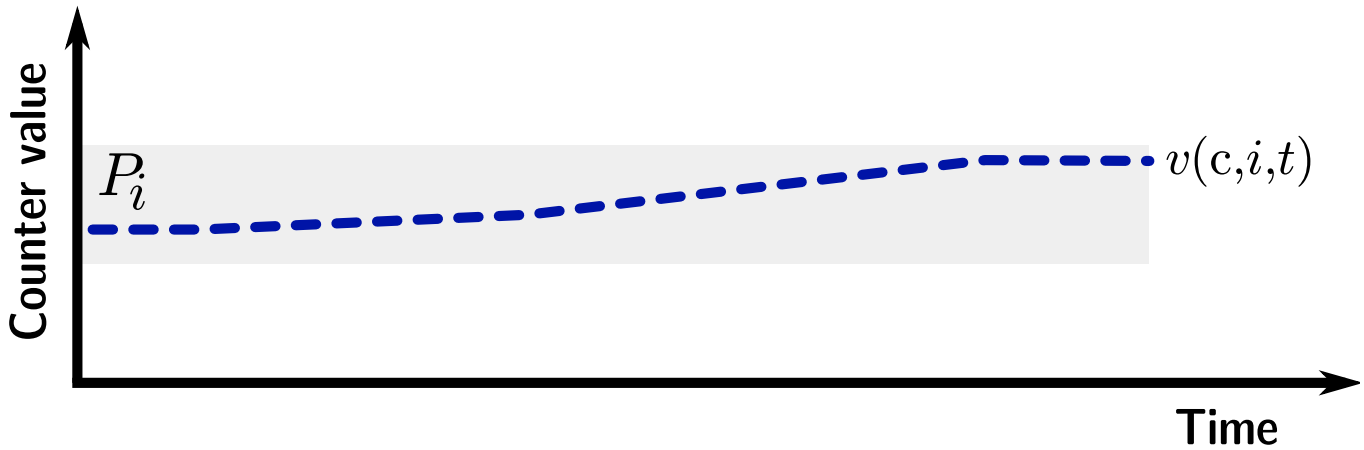
Automatic analysis of performance counters

- Which hardware events are relevant?
- Manual testing tedious & time consuming

Analyzing performance counters



Per-CPU performance counter

- Absolute value $v(c, i, t)$, monotonically increasing
  - c: Counter (e.g. cache misses)
  - i: Processor identifier
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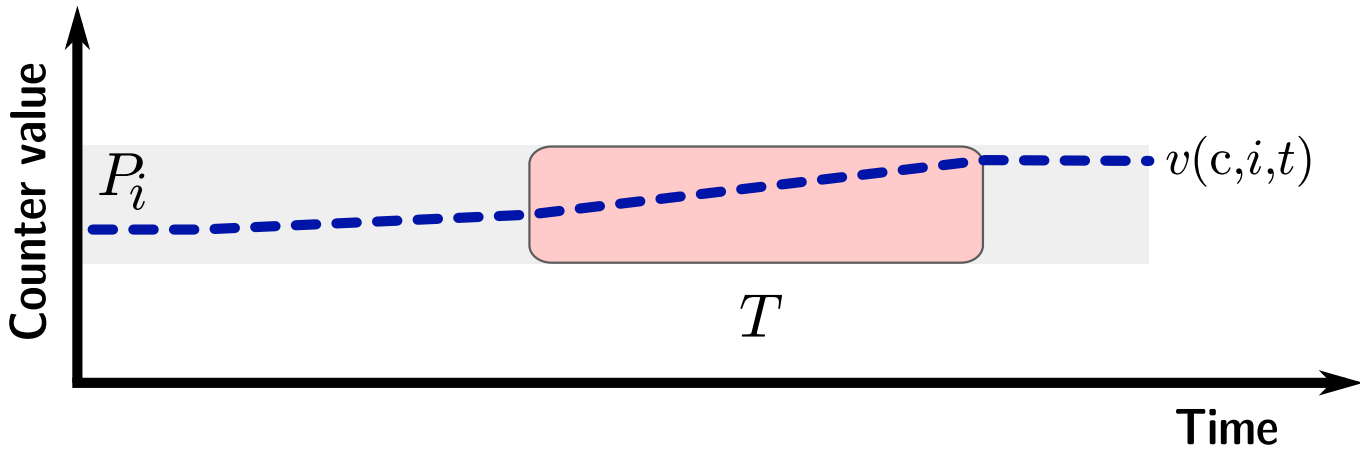

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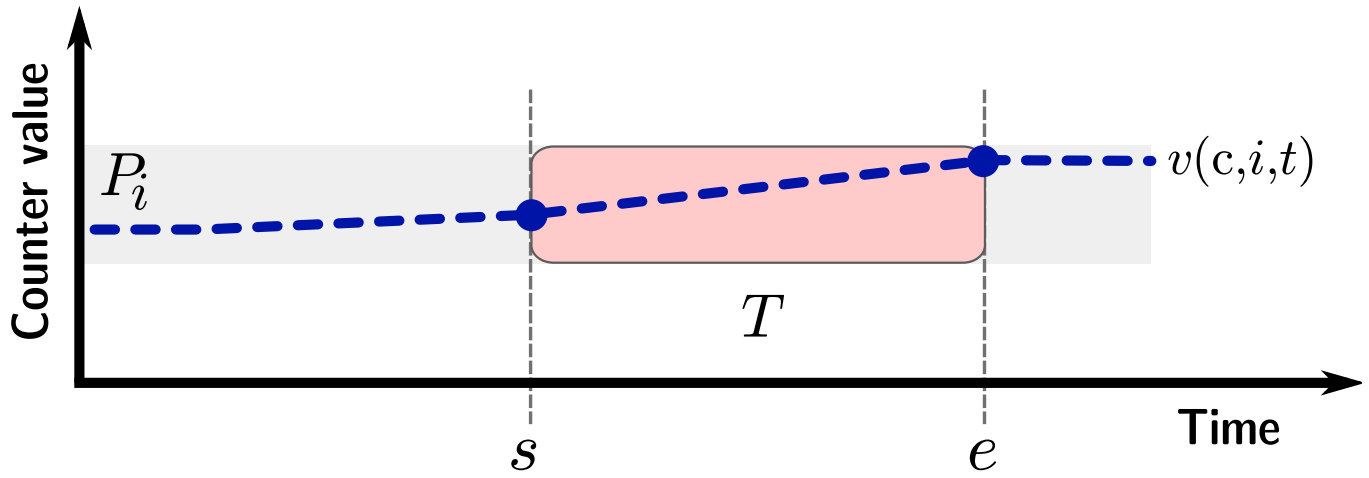

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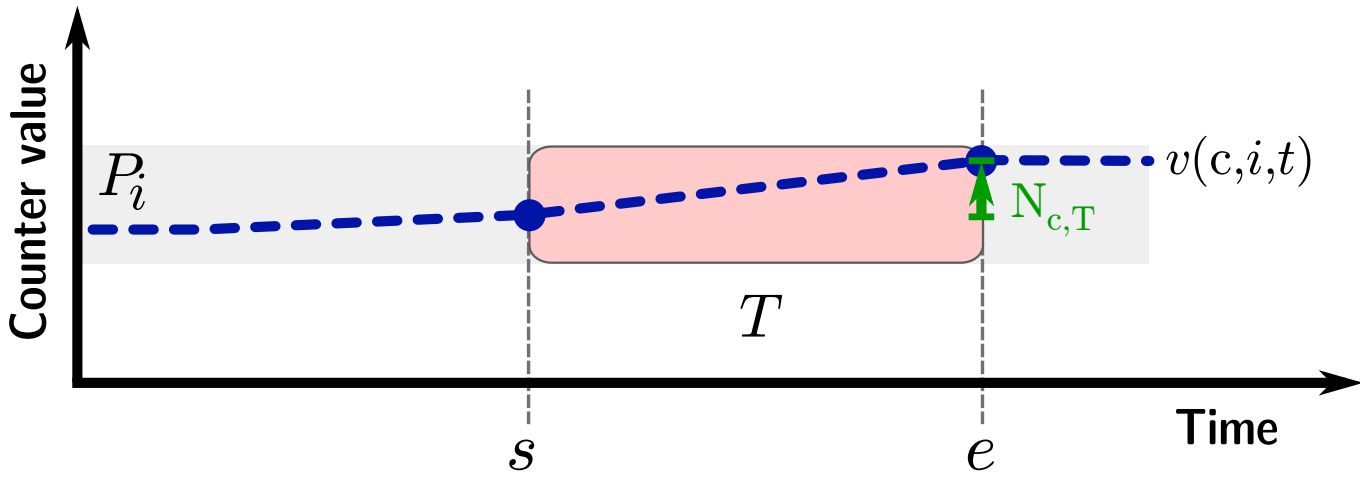

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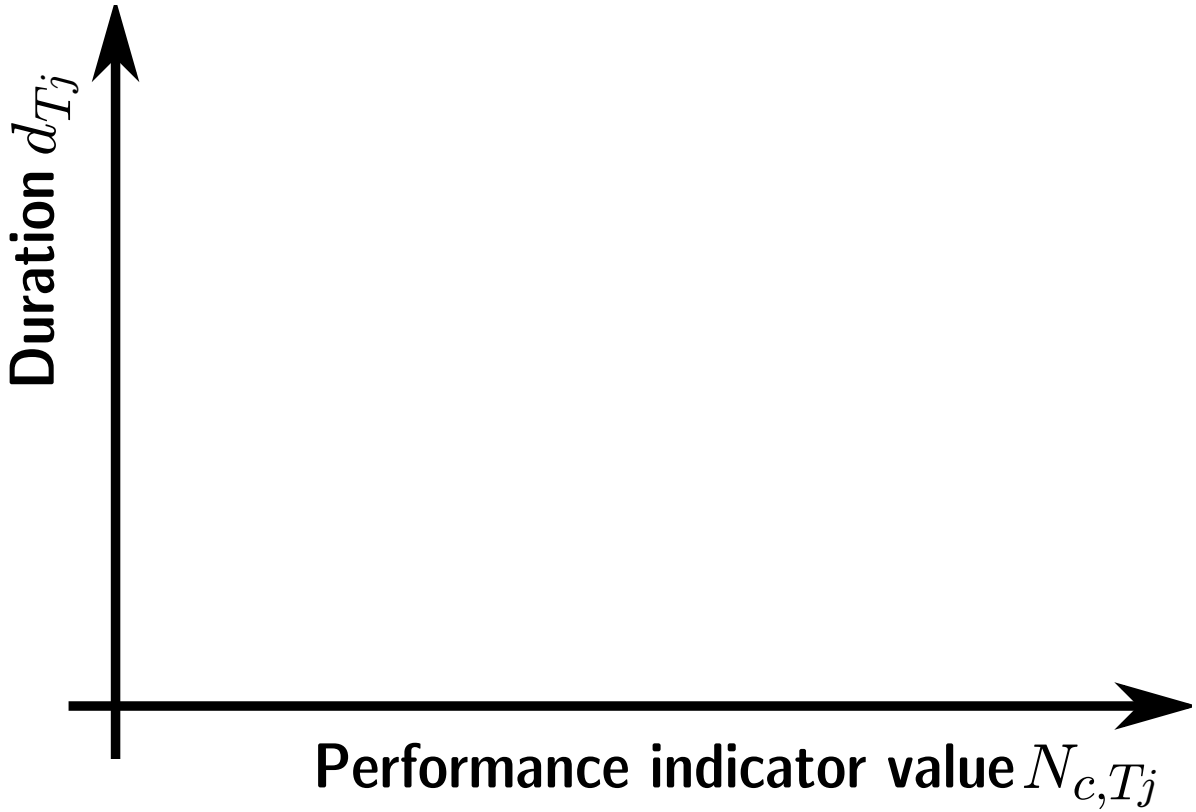
Break down counter evolution to task instances

- Increase of c by task T: $N_{c,T} = v(c, i, e) - v(c, i, s)$

Linear regression



Perform linear regression

- Assume linear model: $d_{T_j} = \alpha \cdot N_{c,T_j} + \beta$ (α and β constant)
- Compare coefficient of determination with threshold

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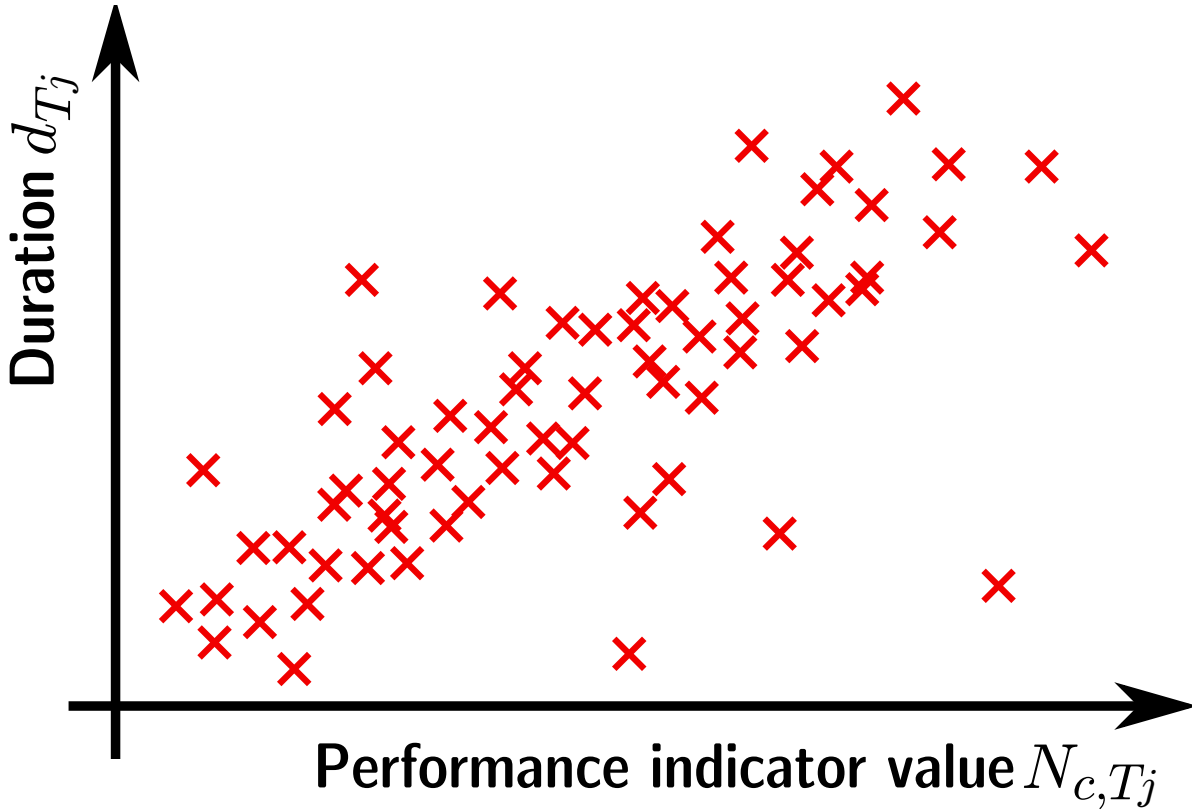

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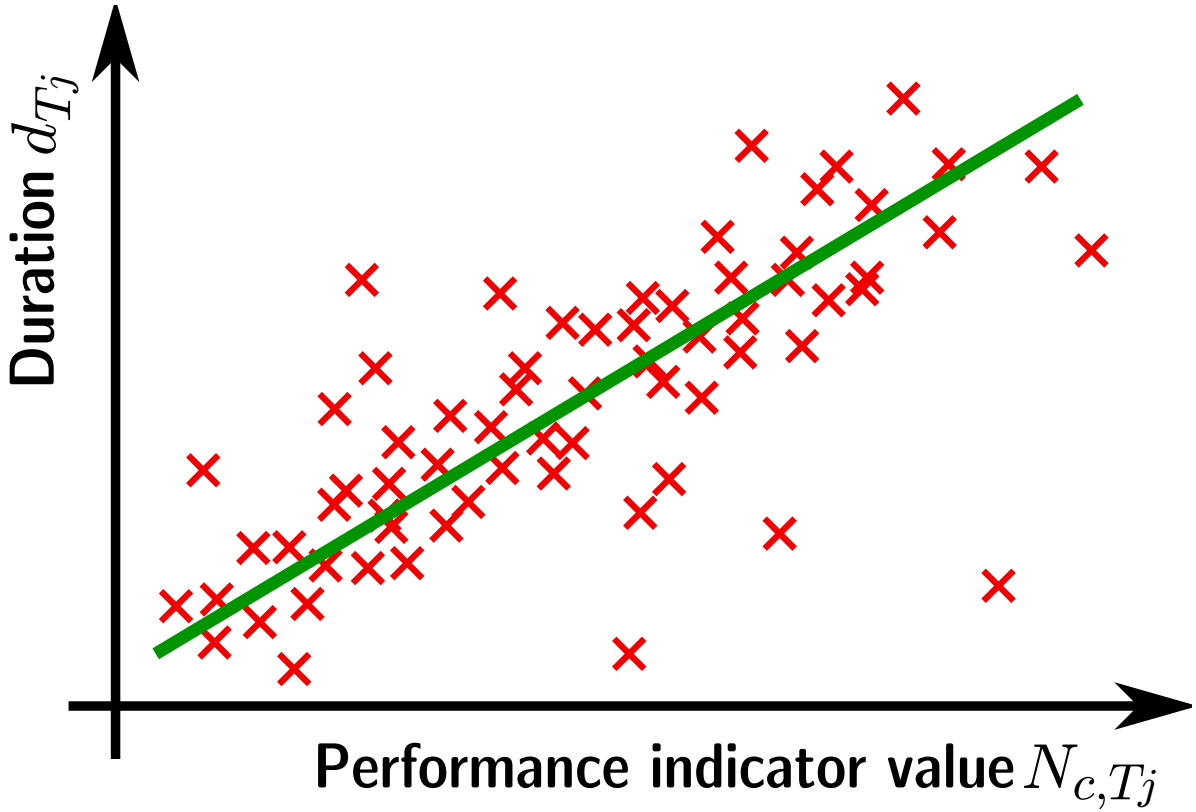

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Shortcuts & refinement

Variation of task duration

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Task types

- Different task types in an application
  - Auxiliary tasks: initialization, termination
  - Work tasks: matrix multiplication, decomposition, etc.
- Performance anomaly not necessarily present in *all* types

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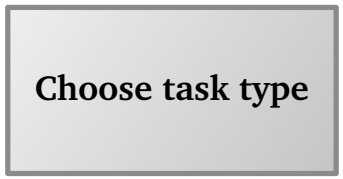
Topology of the machine

- Anomaly only present on subset of processors
- Example: Memory accesses local for one NUMA node, remote on another

Per-interval analysis of parallelism & overhead



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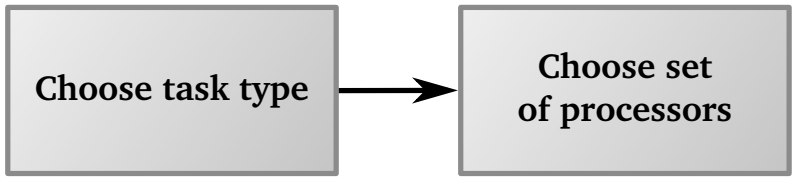

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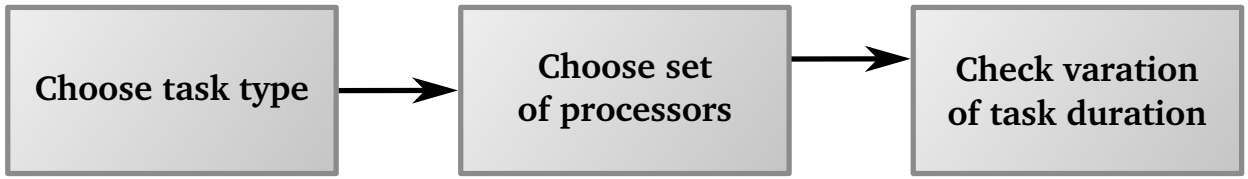

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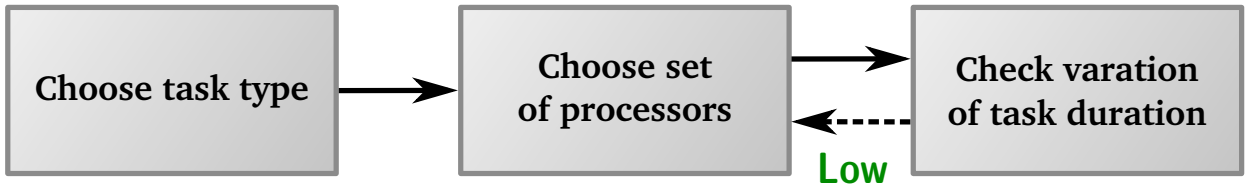

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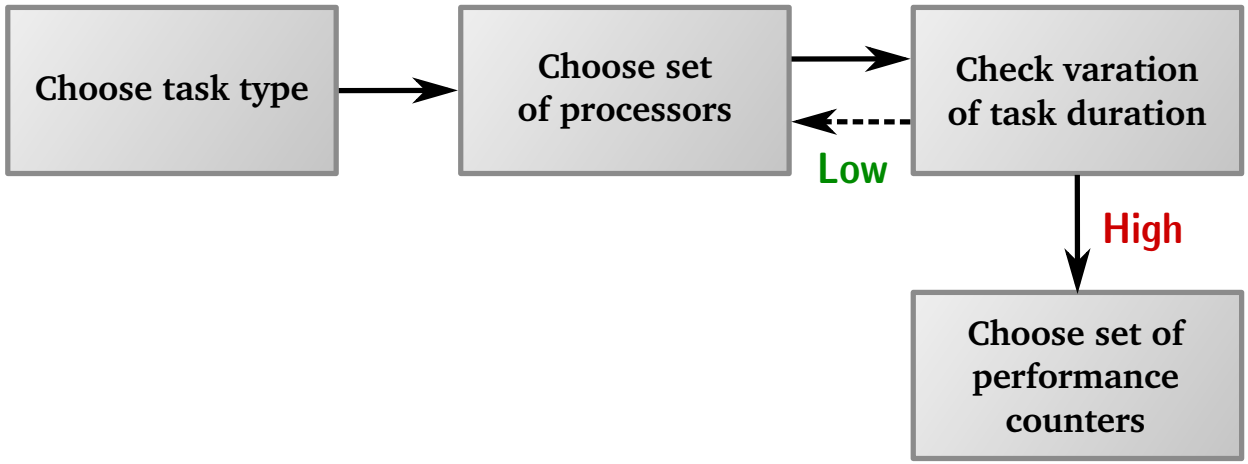

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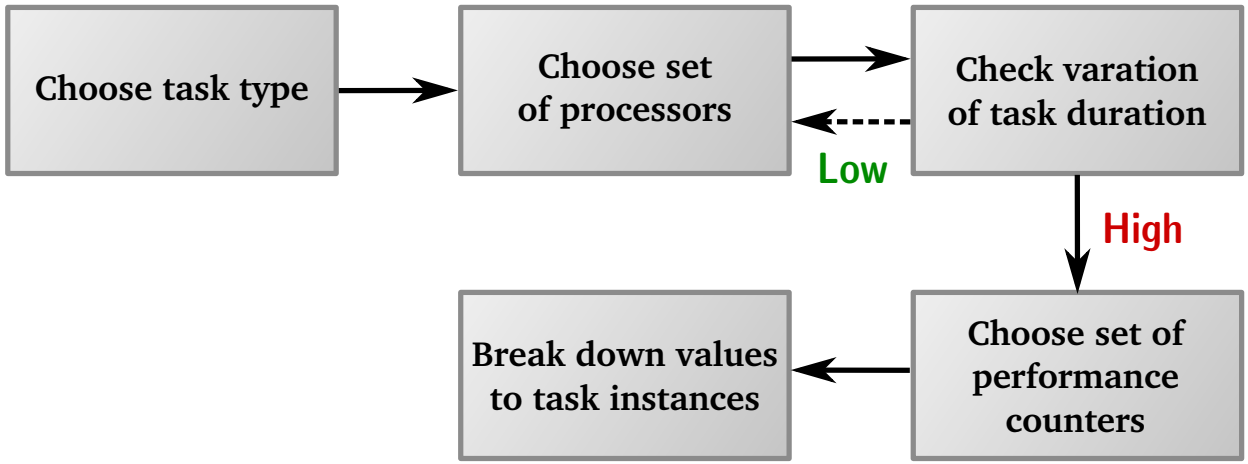

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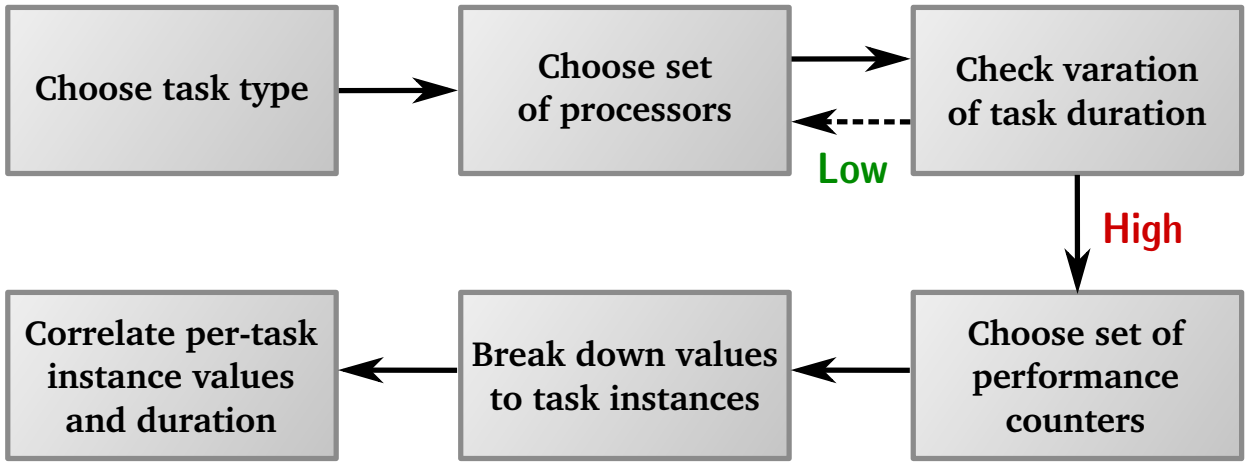

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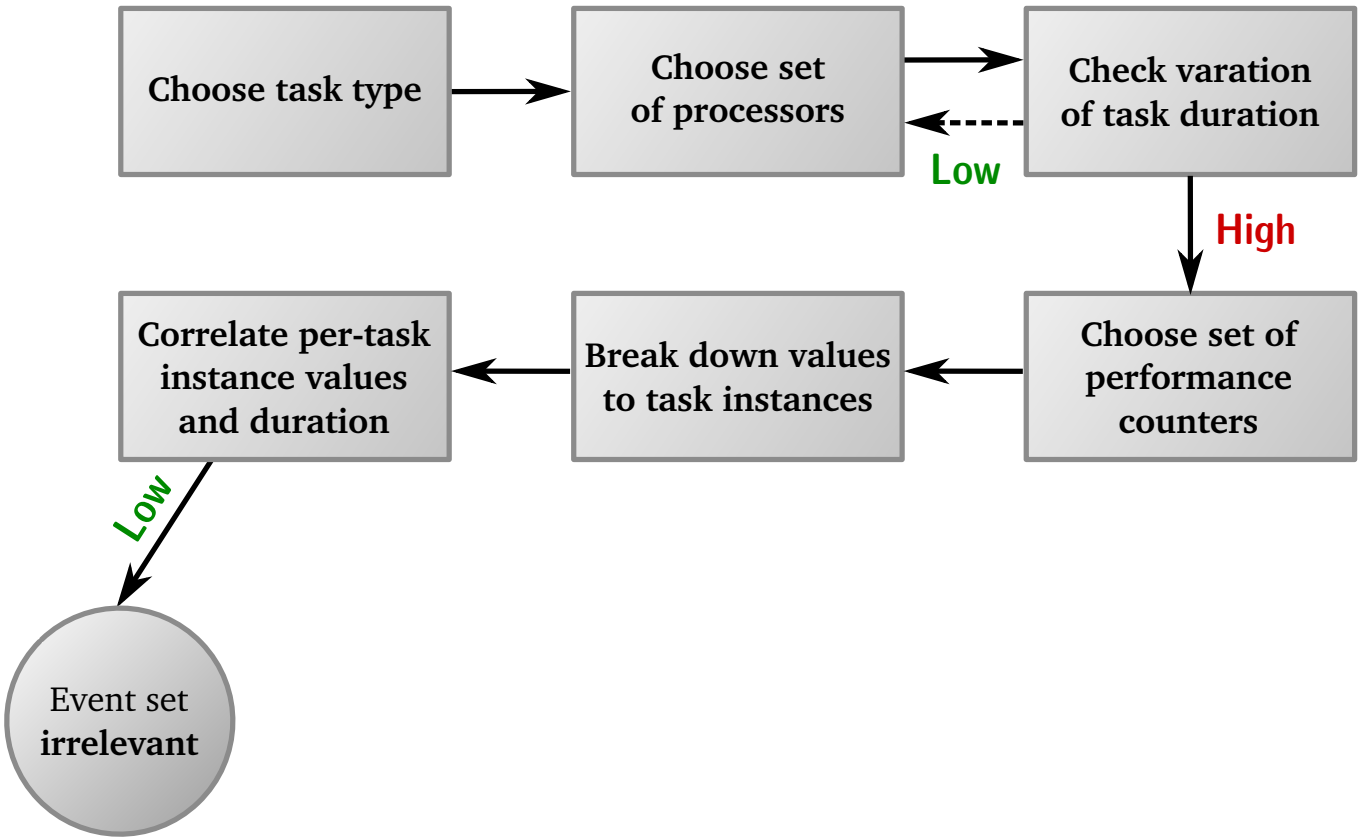

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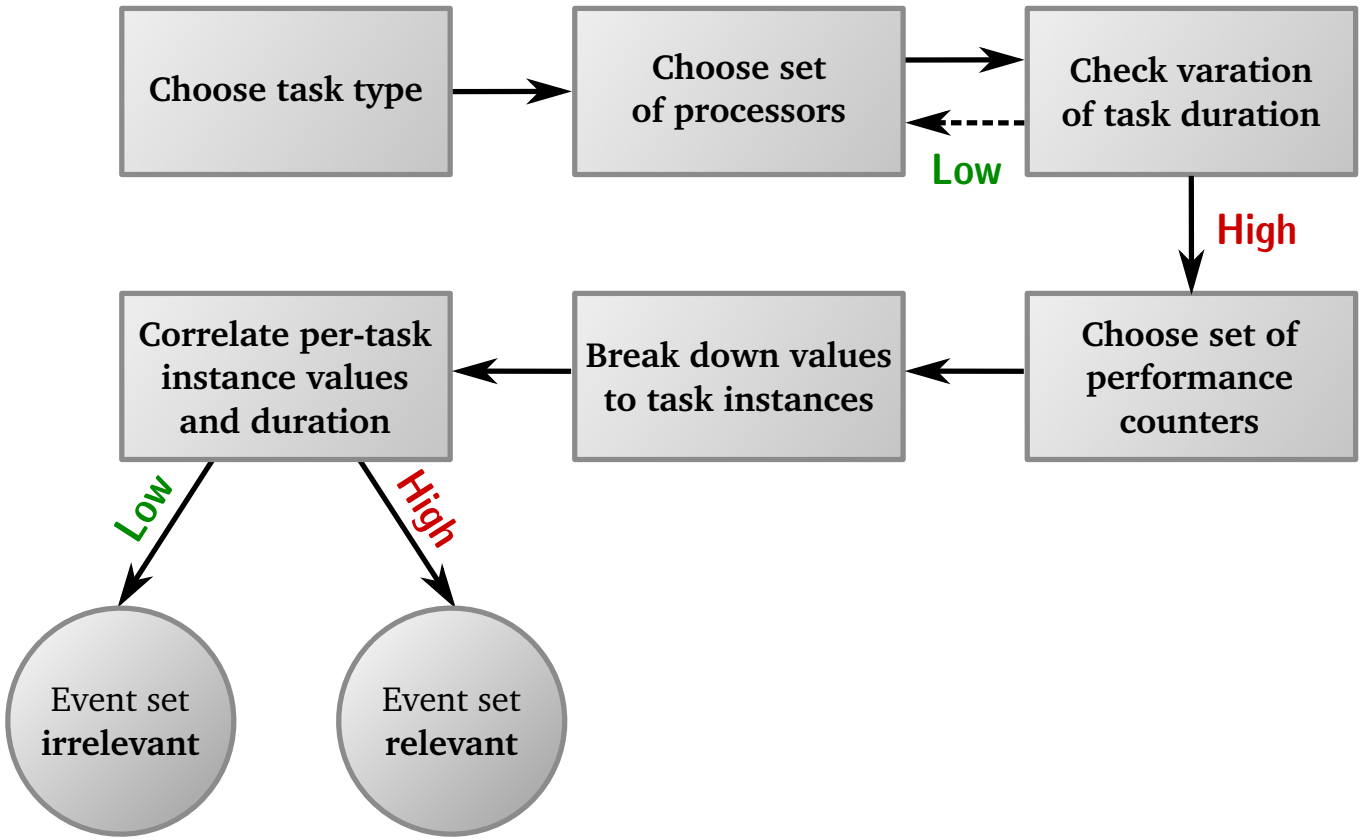

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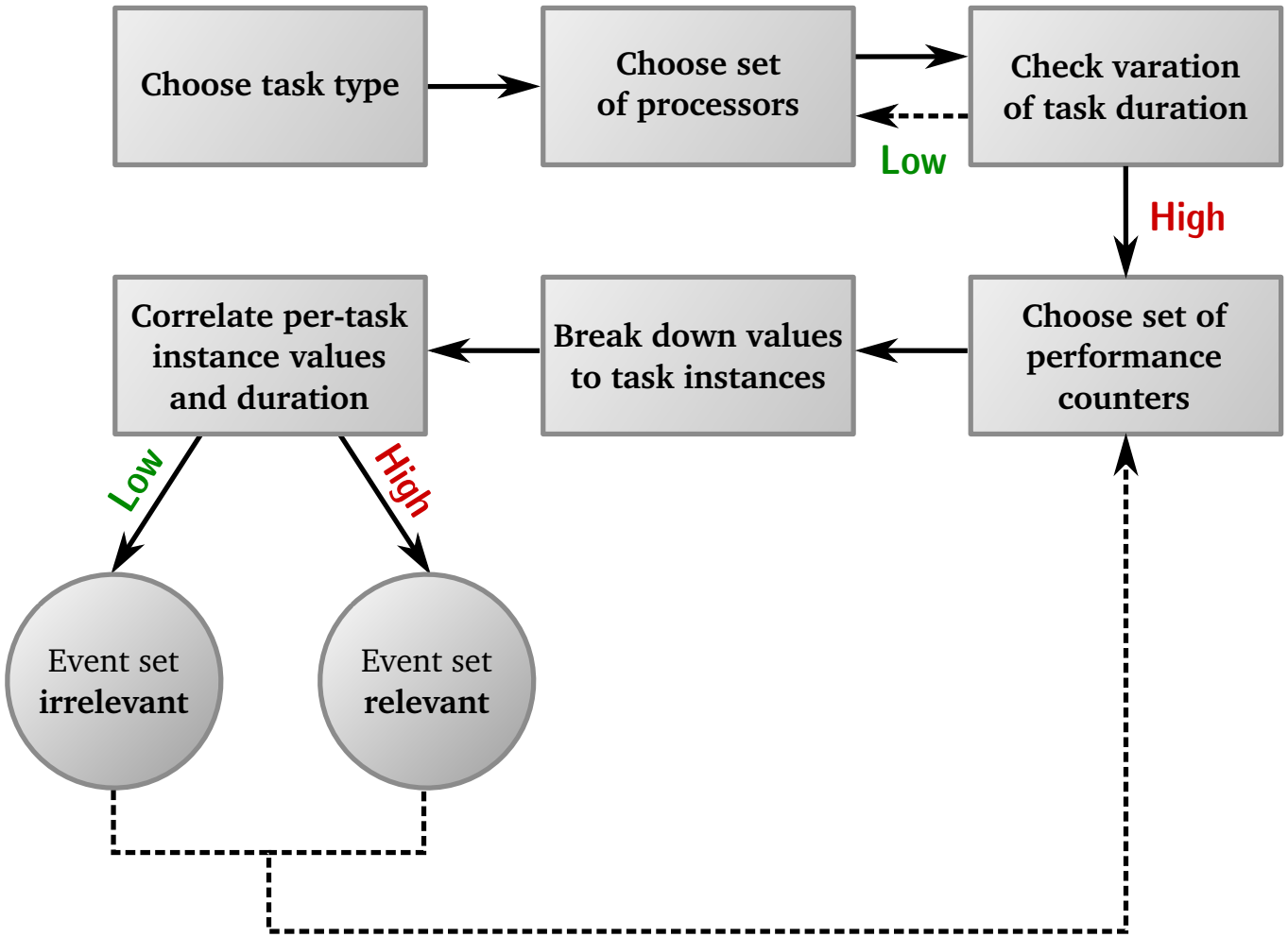

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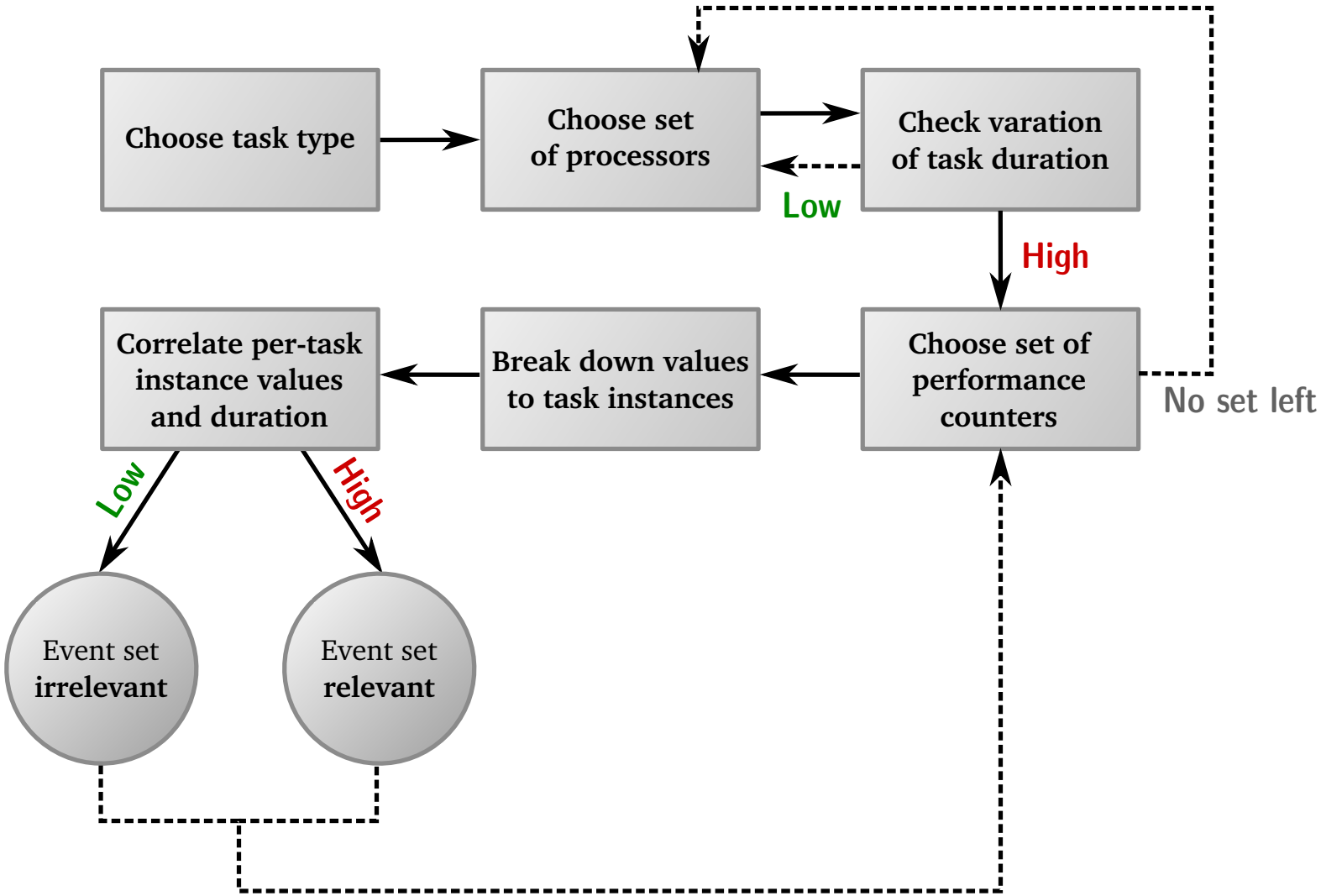

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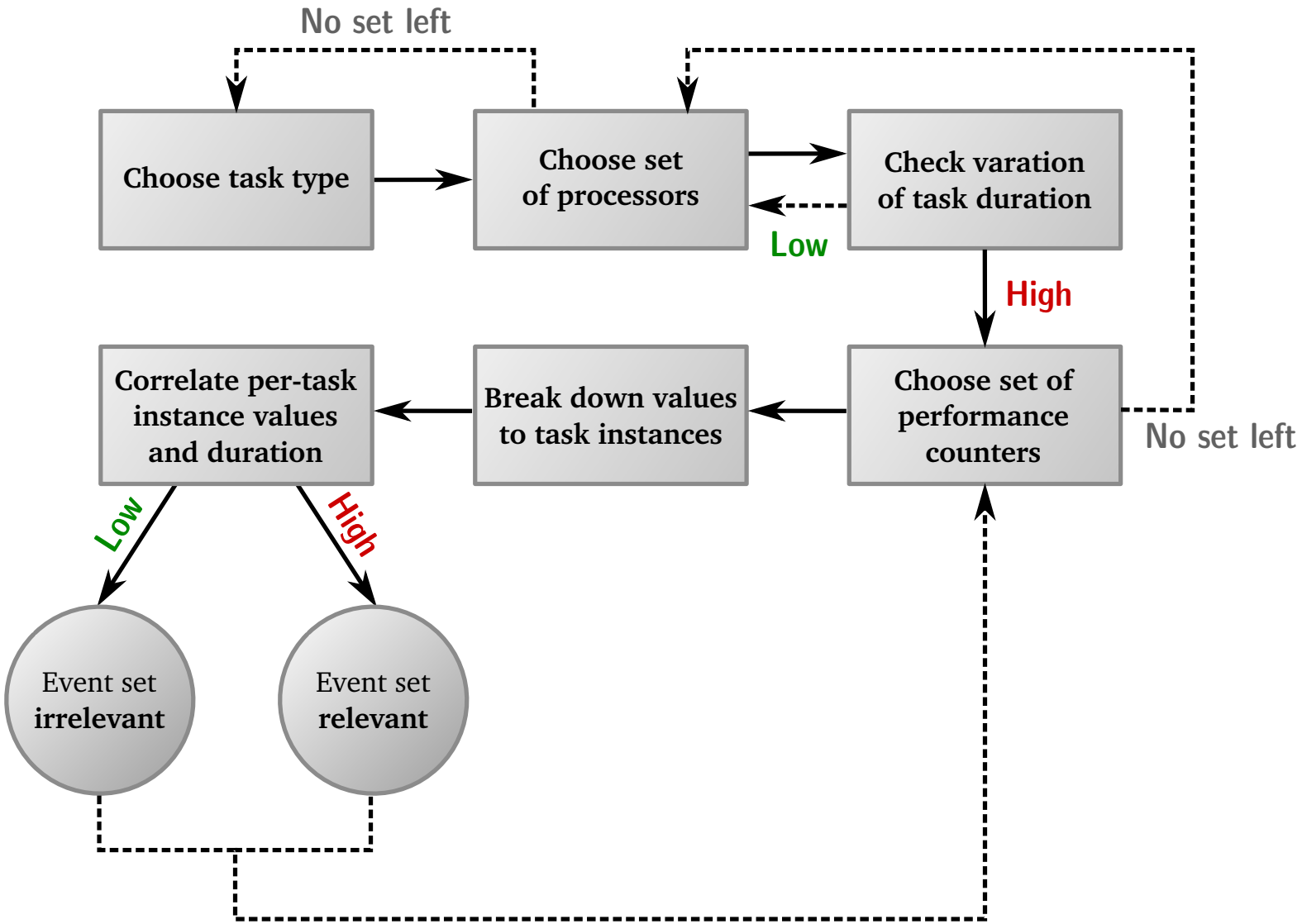
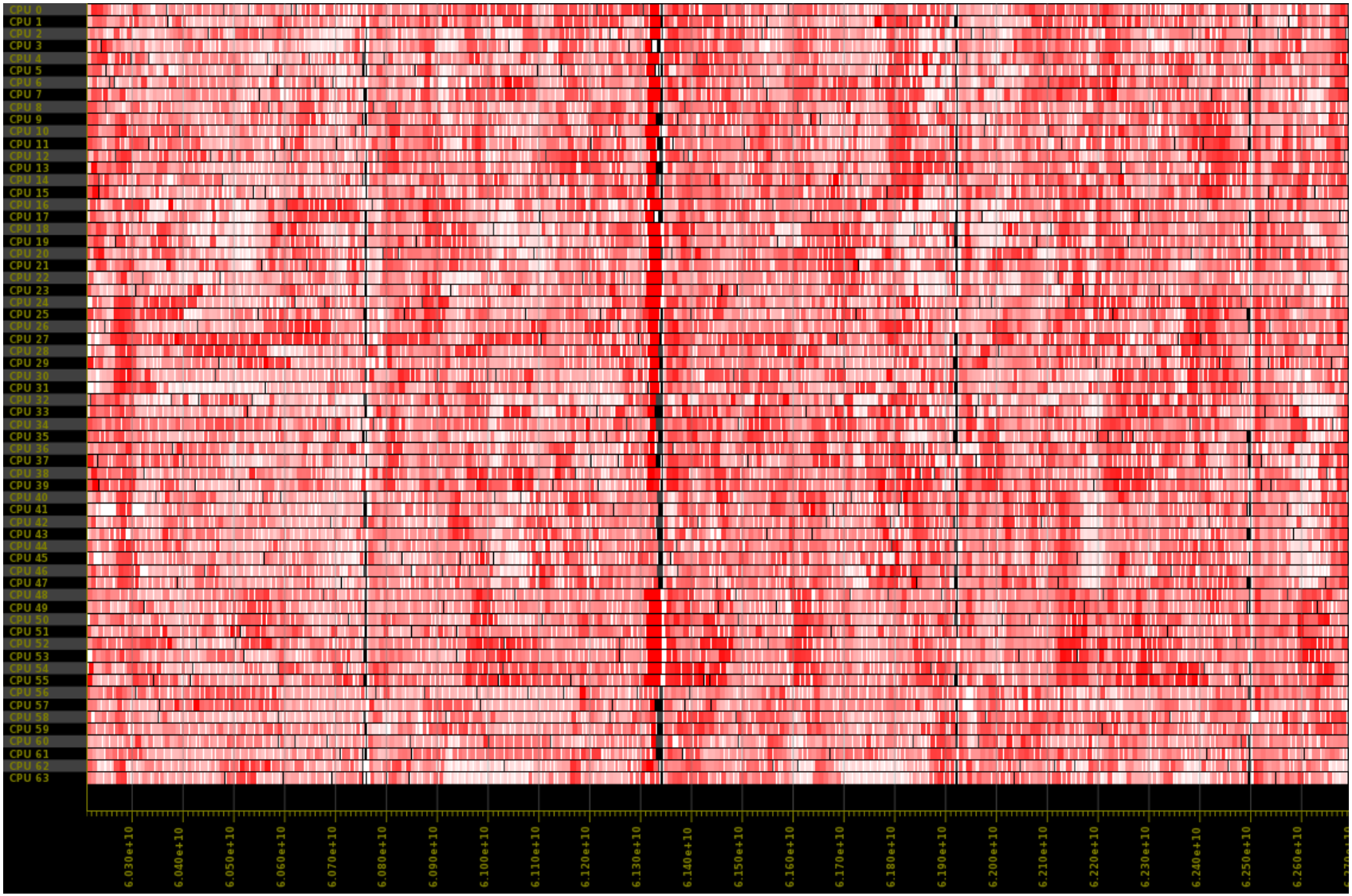


Example: K-means branch misprediction



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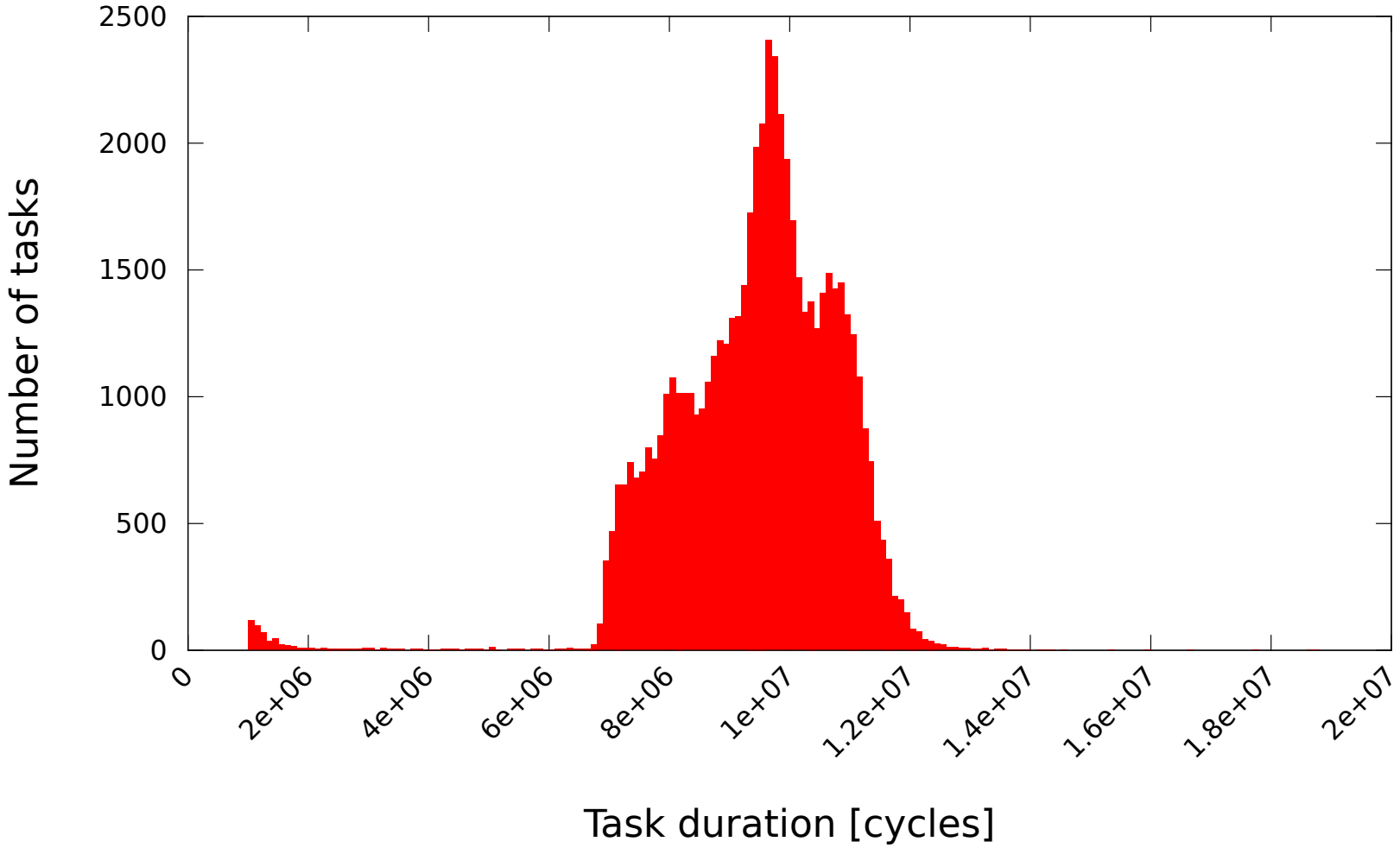

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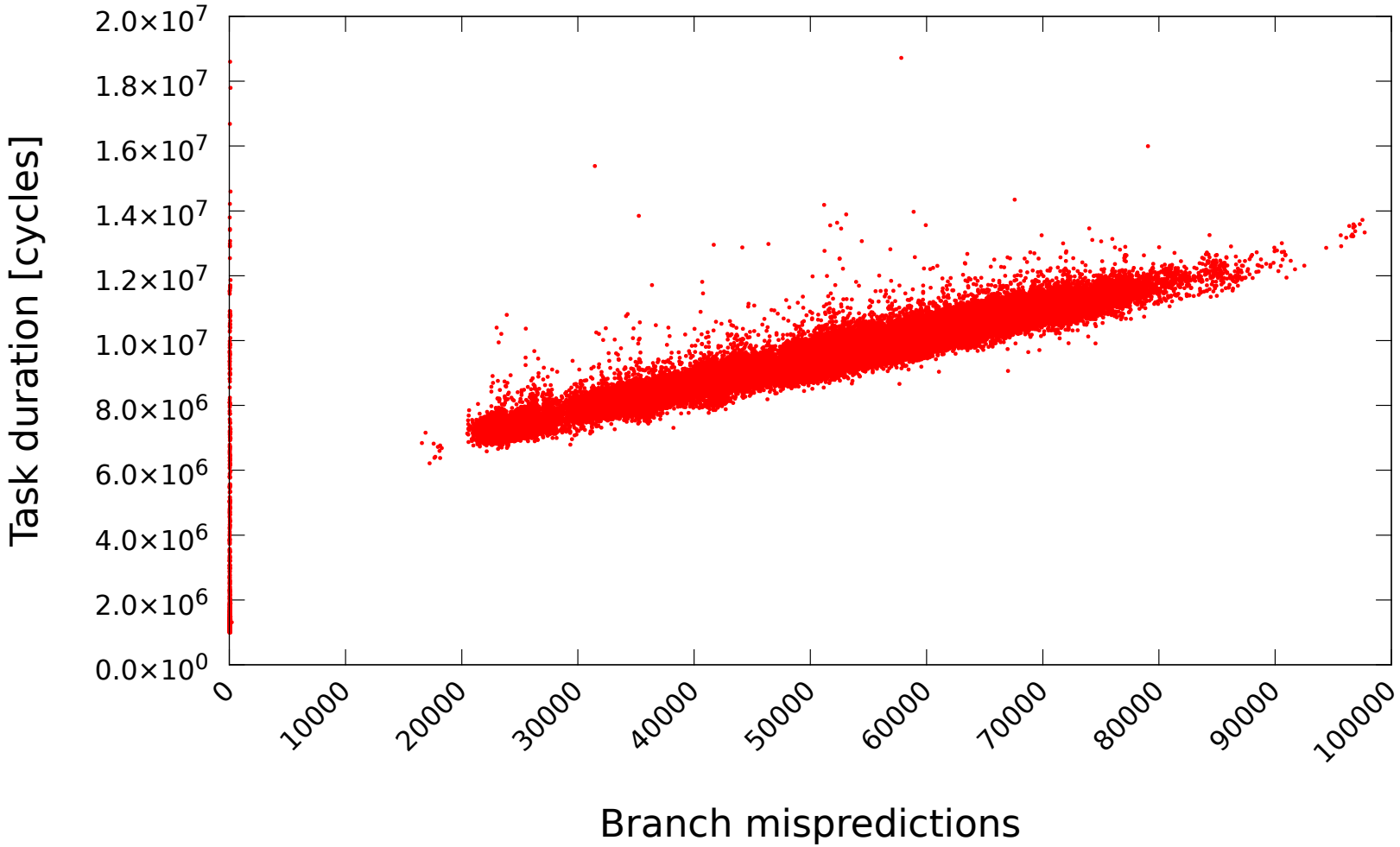

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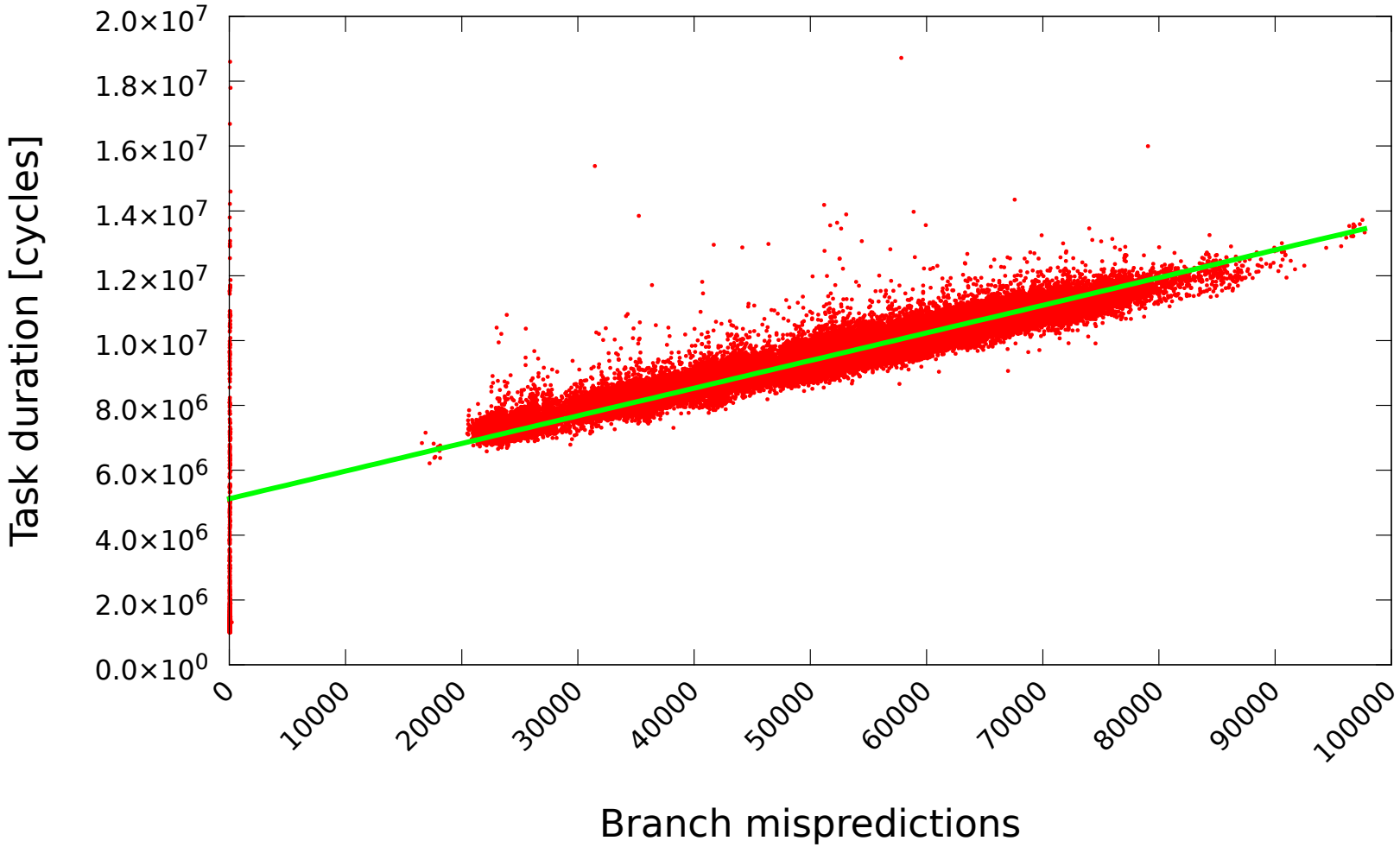

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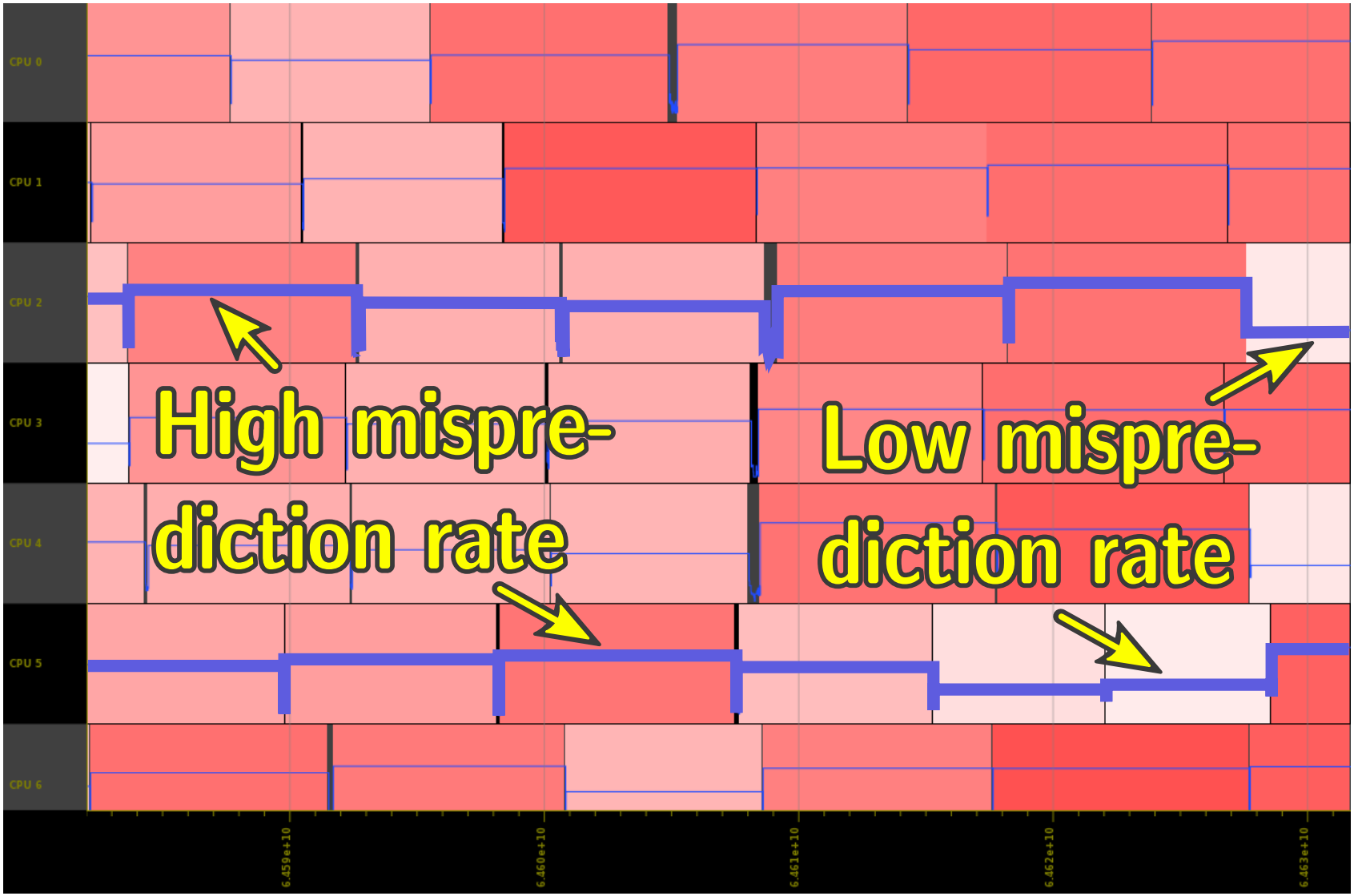

Work in progress: Status

Analysis of parallelism

- Per-interval analysis of time spent on task execution
- Per-interval analysis of time spent in run-time states

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- Analysis of the variation of task durations
- Breaking down performance counter values to task instances
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Aftermath

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- Currently provides only support for manual analysis
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Automatic correlation of performance indicators

- Indicate which events are relevant
- Break down counter evolution to task instances
- Correlate with task duration