The Price of Meltdown and Spectre: Energy Overhead of Mitigations at Operating System Level

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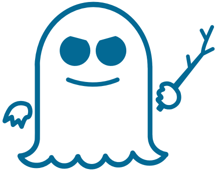
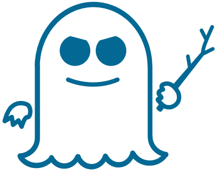
The Price of Meltdown and Spectre



The Price of Meltdown and Spectre



The Price of Meltdown and Spectre (2)

The goal of this work is to put a price tag on the Meltdown/Spectre software mitigations in terms of their energy overhead.

Research Questions

Q1 **How much energy overhead** is introduced by Meltdown/Spectre mitigations?

Q2 Is the energy overhead **related to specific subsystems** (e.g., CPU, block I/O)?

Q3 Is the energy overhead **correlated with the execution time** overhead?

Q4 Is the energy overhead **predictable** for a given application?

Agenda

Motivation

Meltdown and Spectre Mitigations

Energy Overhead Analysis

Energy Overhead Prediction

Conclusion

Meltdown and Spectre Attacks and Mitigations

Attacks

- class of hardware vulnerabilities
- (time) side-channel based
- bypass memory access protection

Mitigations

- full mitigation at hardware-level
- partial mitigation at software-/firmware-level

Meltdown and Spectre Attacks and Mitigations (2)

Attacks

Mitigations

Meltdown: → Linux `[no]pti`

Kernel Page Table Isolation

Spectre v1: → Linux `[no]spectre_v1`

`swapgs`/usercopy barriers, pointer sanitization

Spectre v2: → Linux `[no]spectre_v2`

retpolines, Indirect Branch Restricted Speculation (IBRS), Return Stack Buffer (RSB) refilling

Measurement Methodology

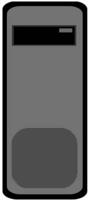
Benchmarks

Training/Analysis		Evaluation
sysbench	**stress-ng**	**Phoronix**
4 benchmarks	24 benchmarks	10 benchmarks
20 s-300 s exec. time	20 s-300 s exec. time	2 m-15 m exec. time
10 (50) iterations	10 (50) iterations	10 iterations

intermingle

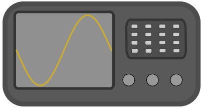
```
$> ./sysbench-1
$> ./stress-ng-1
$> ./sysbench-2
[...]
```

execute



- Intel Core i5 8400 (2,8GHz)
- 8GB RAM
- 2TB HDD
- 1Gbit Ethernet
- Ubuntu 18.04 LTS
  - nopti
  - nospectre_v1
  - nospectre_v2

perf + **Intel RAPL**

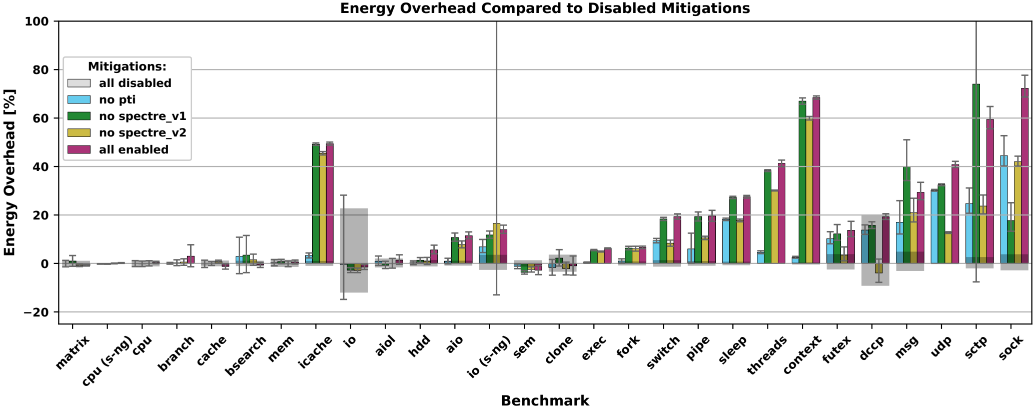


- 4 perf. counters
- one iteration
- 1 ms sampling rate
- CPU package

measure energy

collect performance counters

Q1: Energy Overhead of Spectre/Meltdown



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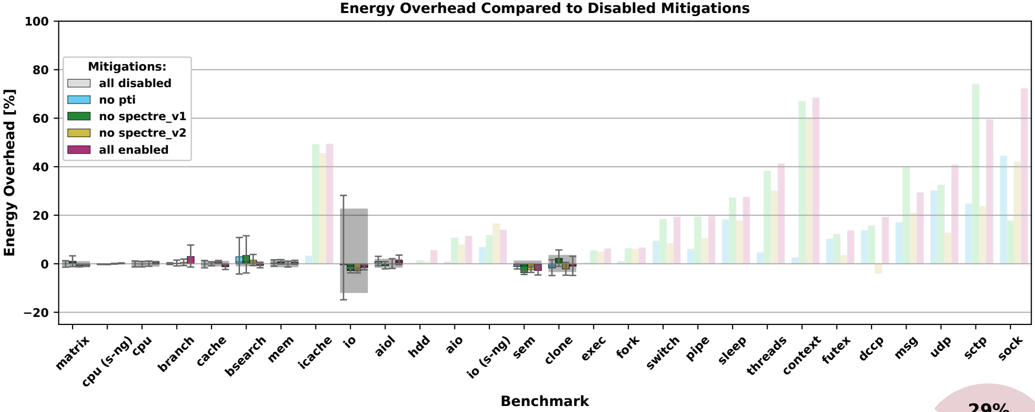
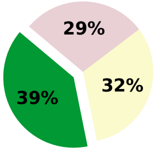


→ **11 out of 28 benchmarks have an overhead below 5 %**



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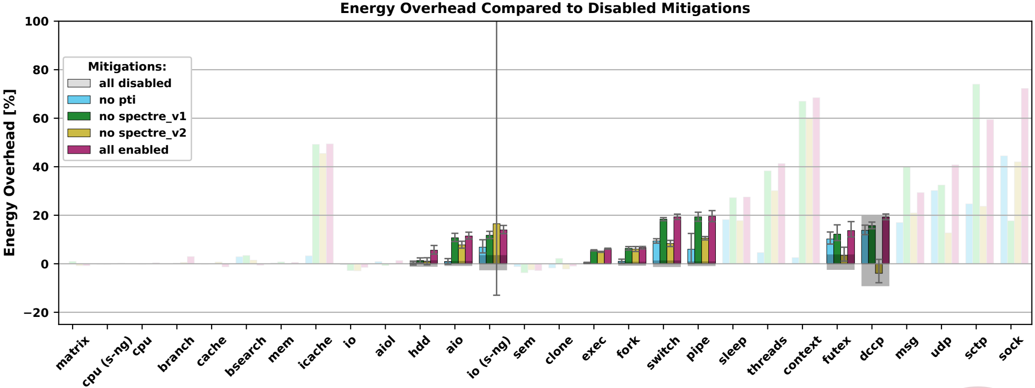
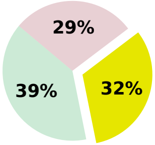


→ 9 out of 28 benchmarks have an overhead between 5 % and 25 %



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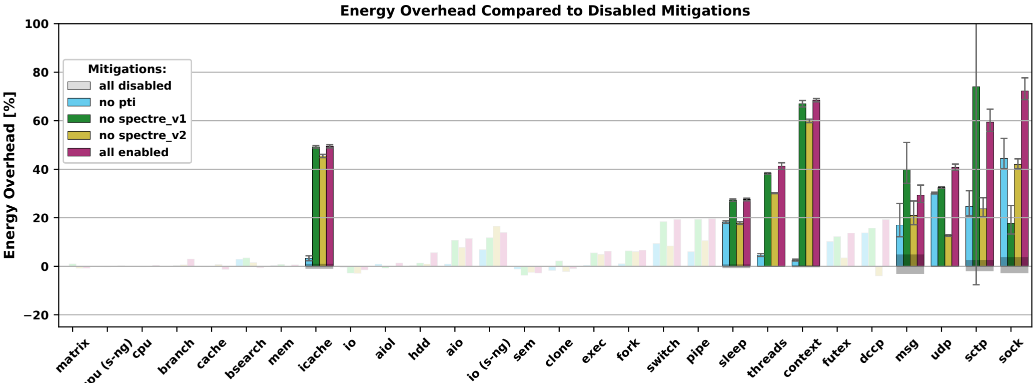
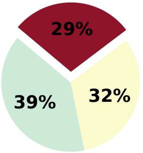
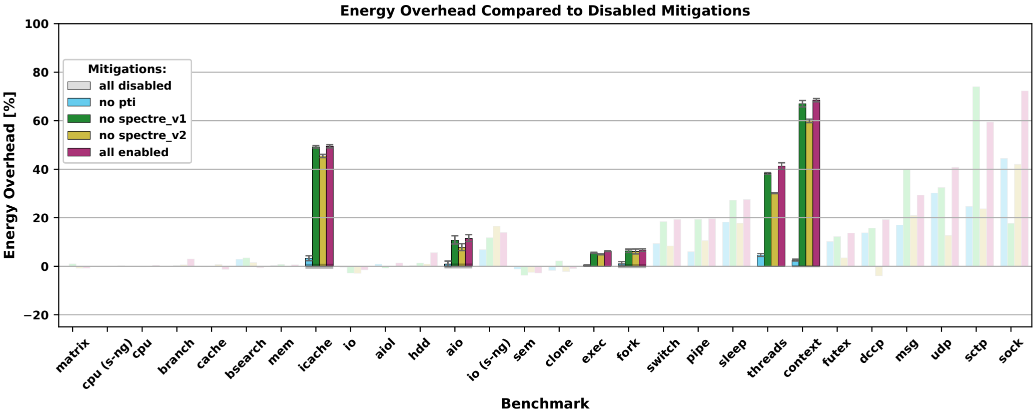




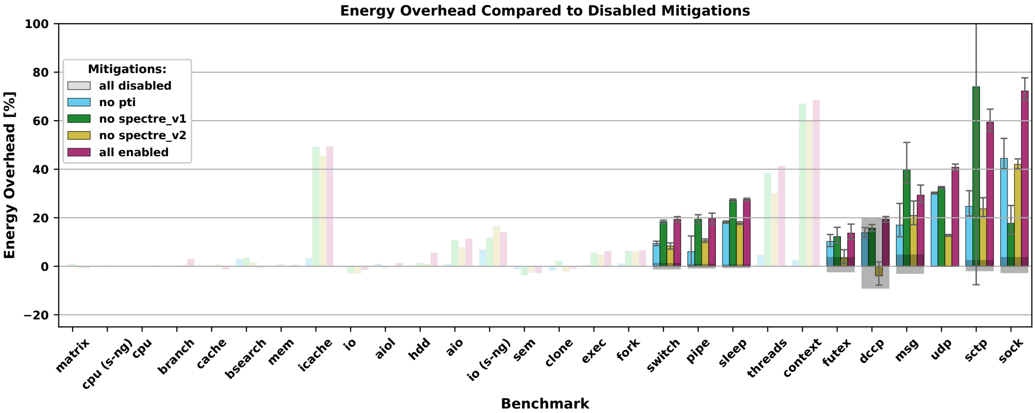
→ 8 out of 28 benchmarks have an overhead above 25 %

Q1: Energy Overhead of Spectre/Meltdown



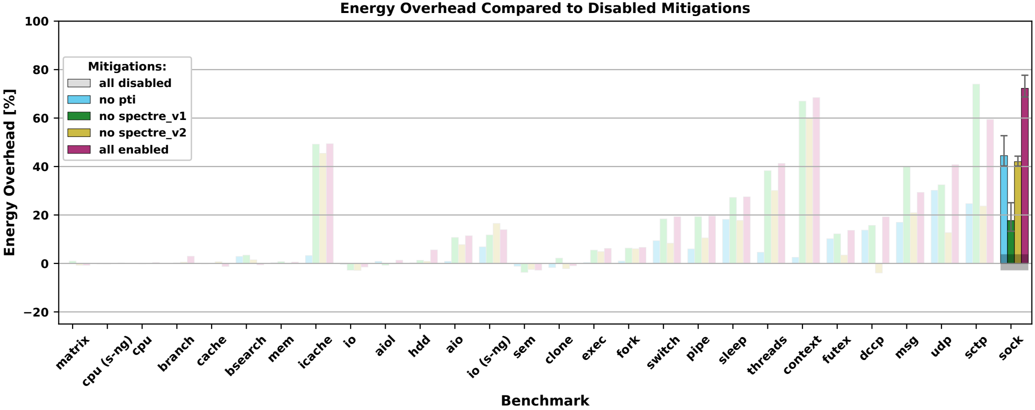
→ **KPTI often has the greatest influence**

Q1: Energy Overhead of Spectre/Meltdown



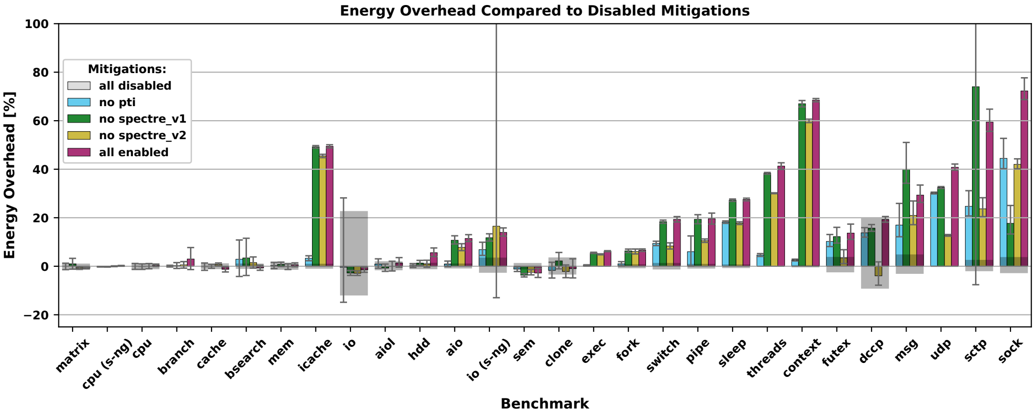
→ **Spectre v2 contributes also to the overhead**

Q1: Energy Overhead of Spectre/Meltdown



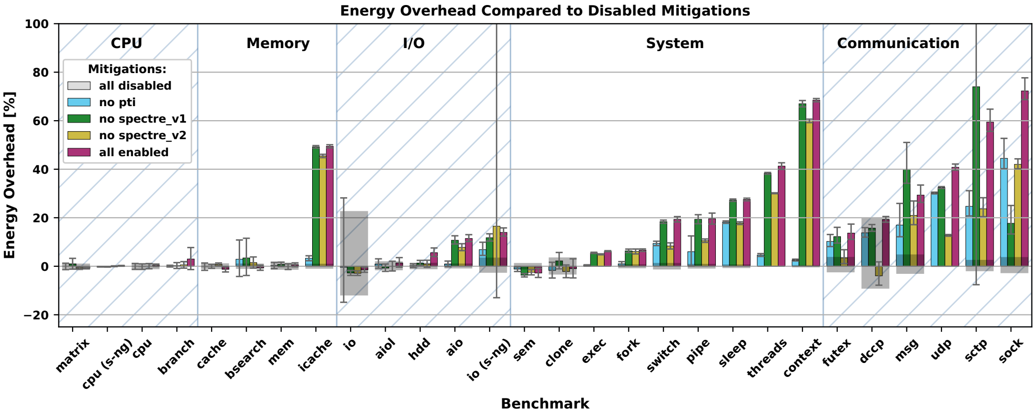
→ **Spectre v1 only influences one benchmark**

Q1: Energy Overhead of Spectre/Meltdown



The overhead is highly application-dependent and lies between ~0 % and 72 %.

Q2: Relation between Mitigations Overhead and Subsystem



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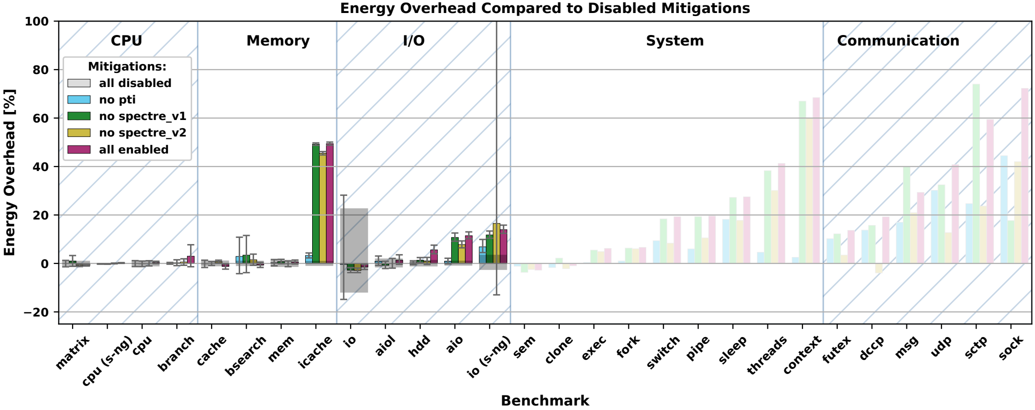
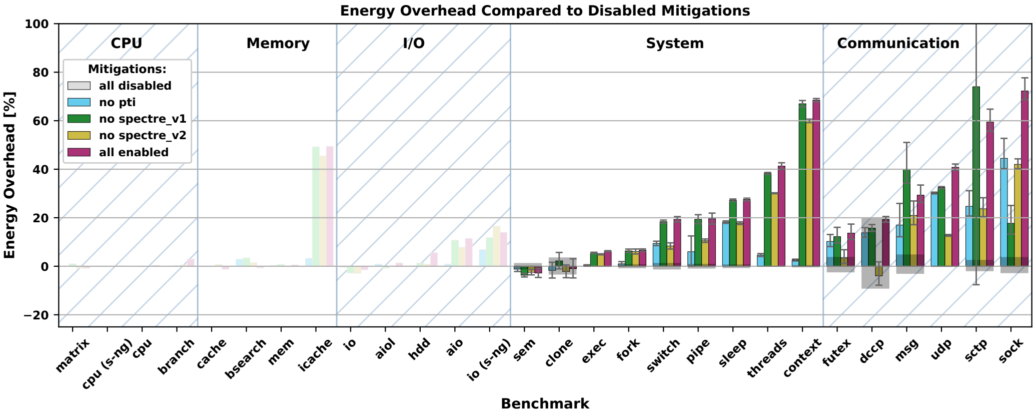


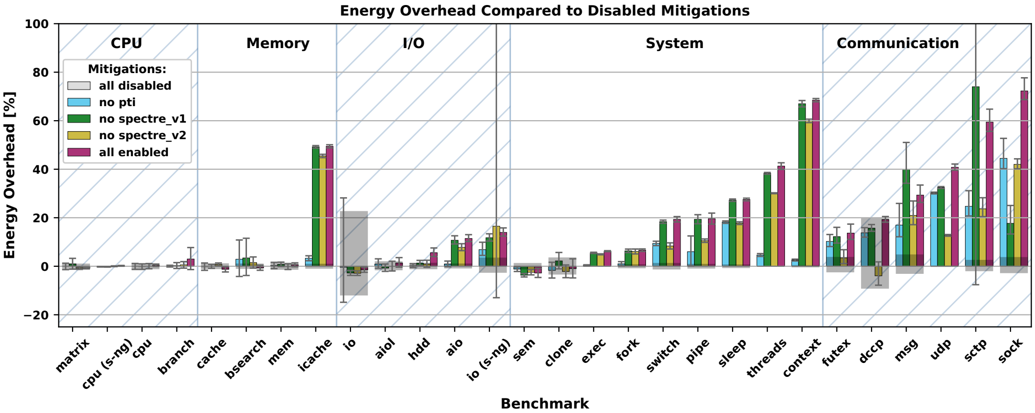
→ **CPU-, memory-, and I/O-heavy benchmarks have (mostly) no or small overheads**

Q2: Relation between Mitigations Overhead and Subsystem



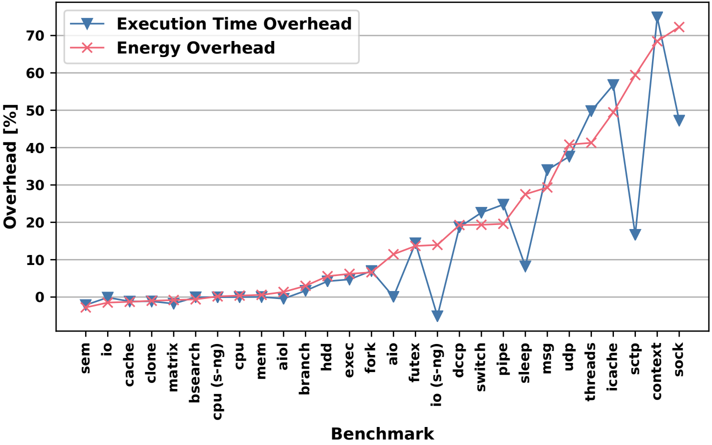
→ **System- and communication-heavy benchmarks have in general higher overheads**

Q2: Relation between Mitigations Overhead and Subsystem



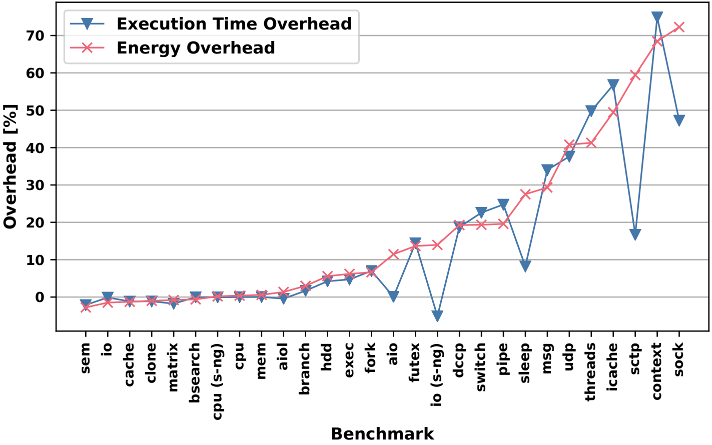
System interactivity greatly influences the mitigations’ overhead

Q3: Correlation between Energy and Execution Time Overhead



- positive correlation
- Spearman correlation coefficient: 0.88
- 5 noticeable exceptions

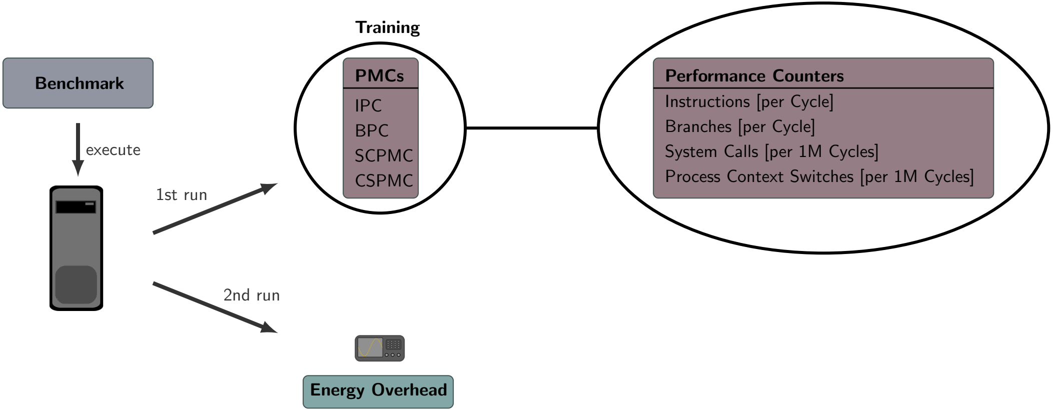
Q3: Correlation between Energy and Execution Time Overhead



- positive correlation
- Spearman correlation coefficient: 0.88
- 5 noticeable exceptions

Energy and Execution Time Overhead are correlated (exceptions apply)

Energy Prediction Model



Benchmark

execute

1st run

2nd run

Training

PMCs

IPC

BPC

SCPMC

CSPMC

Performance Counters

Instructions [per Cycle]

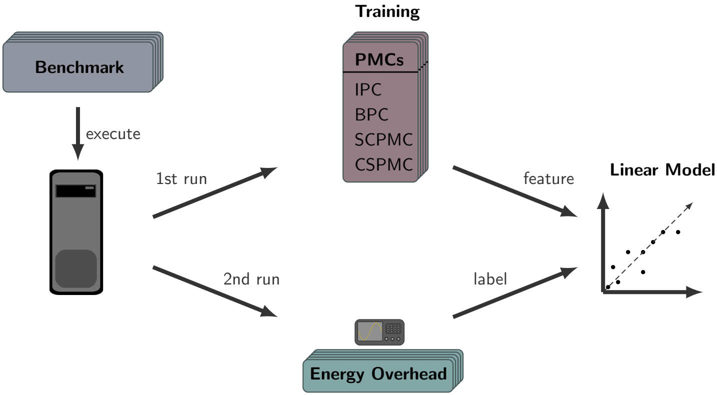
Branches [per Cycle]

System Calls [per 1M Cycles]

Process Context Switches [per 1M Cycles]

Energy Overhead

Energy Prediction Model



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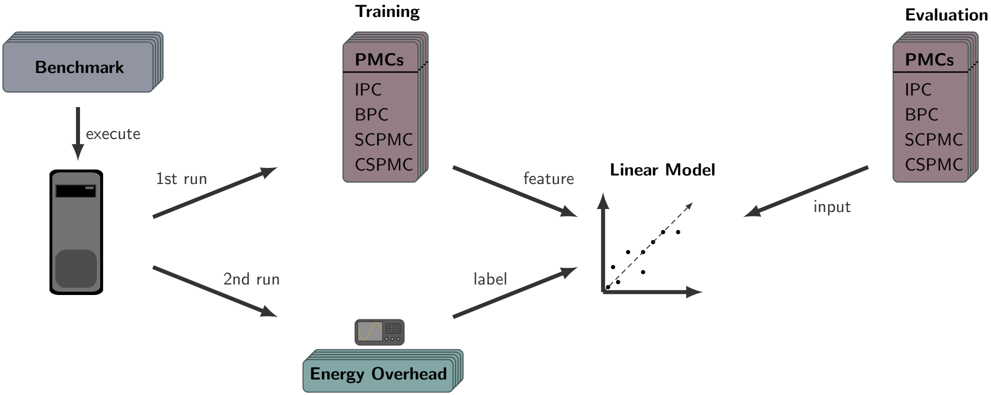

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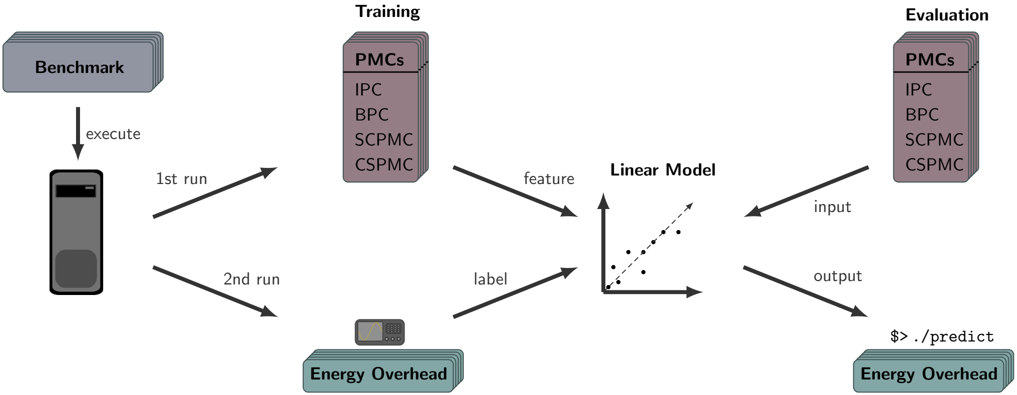
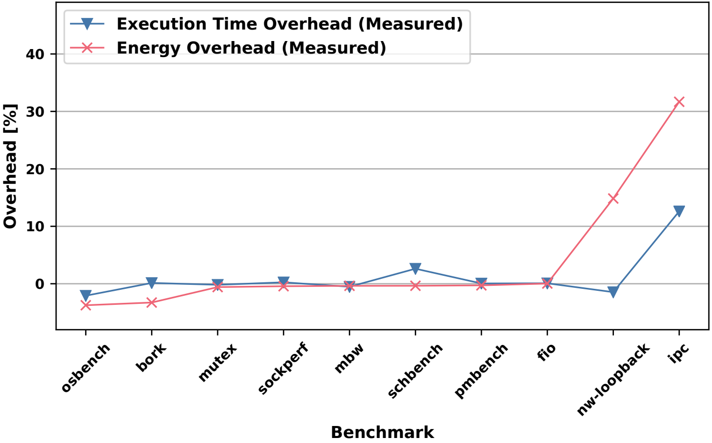
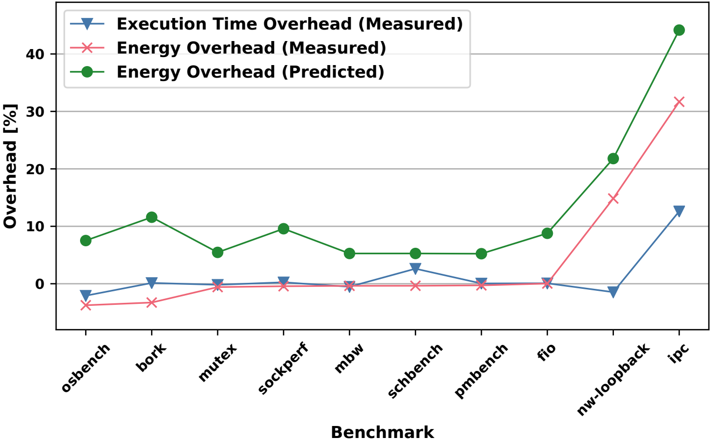


Q4: Energy Overhead Prediction



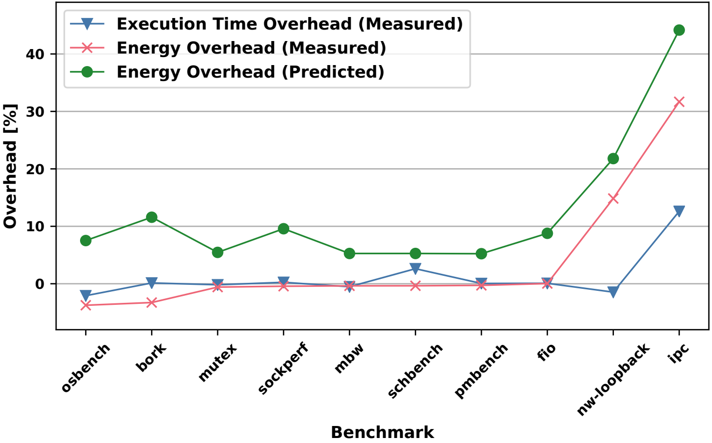
- 10 Phoronix benchmarks
- mostly no overhead
- `nw-loopback`: energy but no time overhead
- `ipc`: energy and time overhead

Q4: Energy Overhead Prediction



- overestimation of ~5 %
- identifies benchmarks with energy overhead

Q4: Energy Overhead Prediction



- overestimation of ~5 %
- identifies benchmarks with energy overhead

Linear Model can identify applications with induced energy overheads

Performance Counter Correlation

Performance Counters	Energy Overhead	Time Overhead
Instructions [per Cycle]	-0.06	-0.02
Branches [per Cycle]	-0.02	-0.03
System Calls [per 1M Cycles]	0.64	0.64
Process Context Switches [per 1M Cycles]	0.41	0.33

Spearman Correlation Coefficient

no correlation:	0.00
strong correlation:	±1.00

Conclusion

Q1 Energy Overhead?

→ application-dependent; between ~0 % and 72 %

→ especially mitigations against Meltdown and Spectre v2

Q2 Subsystem Related?

→ operating system interactivity increases overhead

Q3 Execution Time correlated?

→ exec. time and energy overhead correlated; exceptions apply

Q4 Predictable?

→ applications with overheads predictable