Hasso Plattner Institut
Digital Engineering · Universität Potsdam

Energy-Aware Resource Management in Heterogeneous Computing Systems
Part 1: Measuring Energy at Runtime

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Energy-Aware Computing Team at the Professorship for Operating Systems and Middleware


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We try to understand energy demand as a critical operating resource of computer systems, under the consideration of hardware aspects.

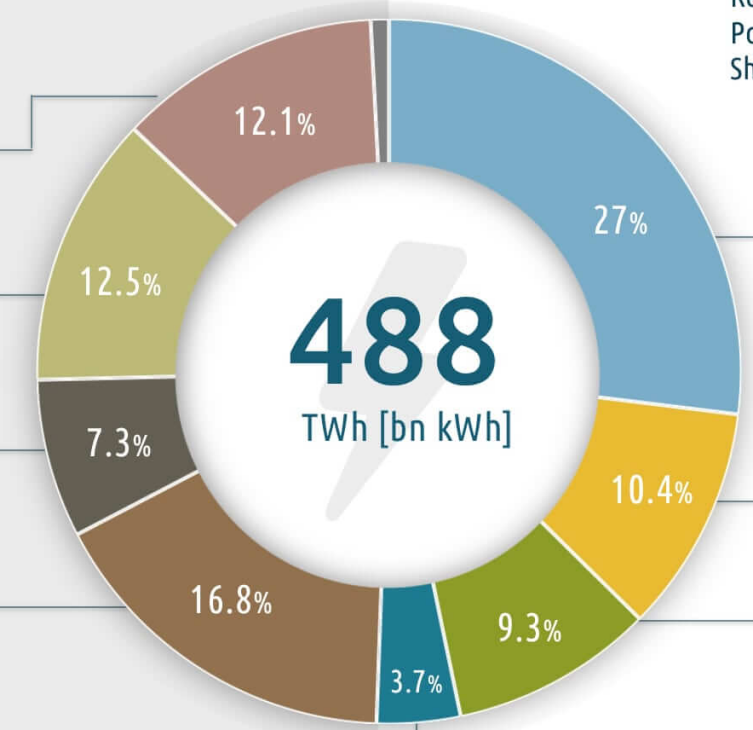
`osm.hpi.de/energy`

GERMANY'S POWER MIX 2020 [NETTO]

Share of energy sources in power production: 50.5% Renewables

Fossil Fuels: 242 TWh

Renewable Energy: 246 TWh
Power mix share: 50.5%
Share 2019: 46.1%

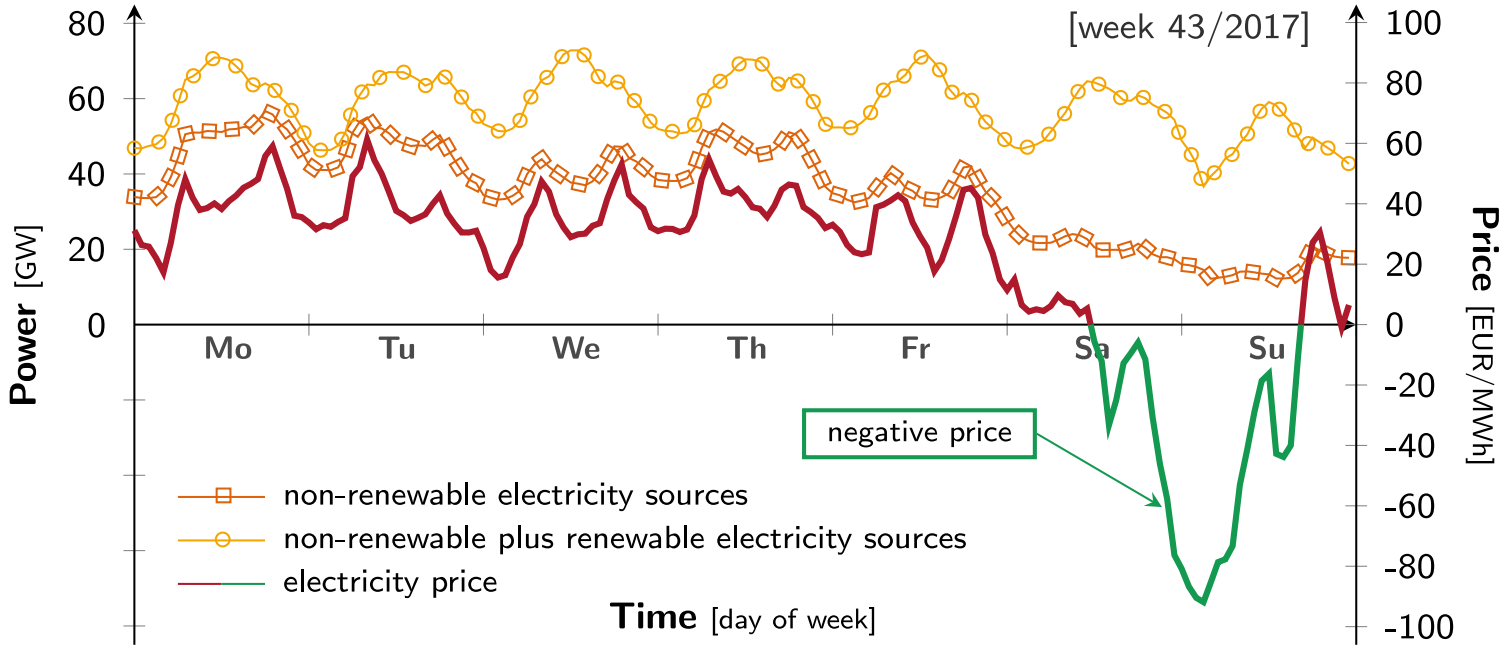


- Natural gas: 59 TWh
- Nuclear: 61 TWh
- Hard coal: 36 TWh
- Lignite: 82 TWh
- Wind power: 132 TWh
- Solar power: 51 TWh
- Biomass: 45 TWh
- Hydropower: 18 TWh

Es wird die Nettoproduktion aller Kraftwerke dargestellt.

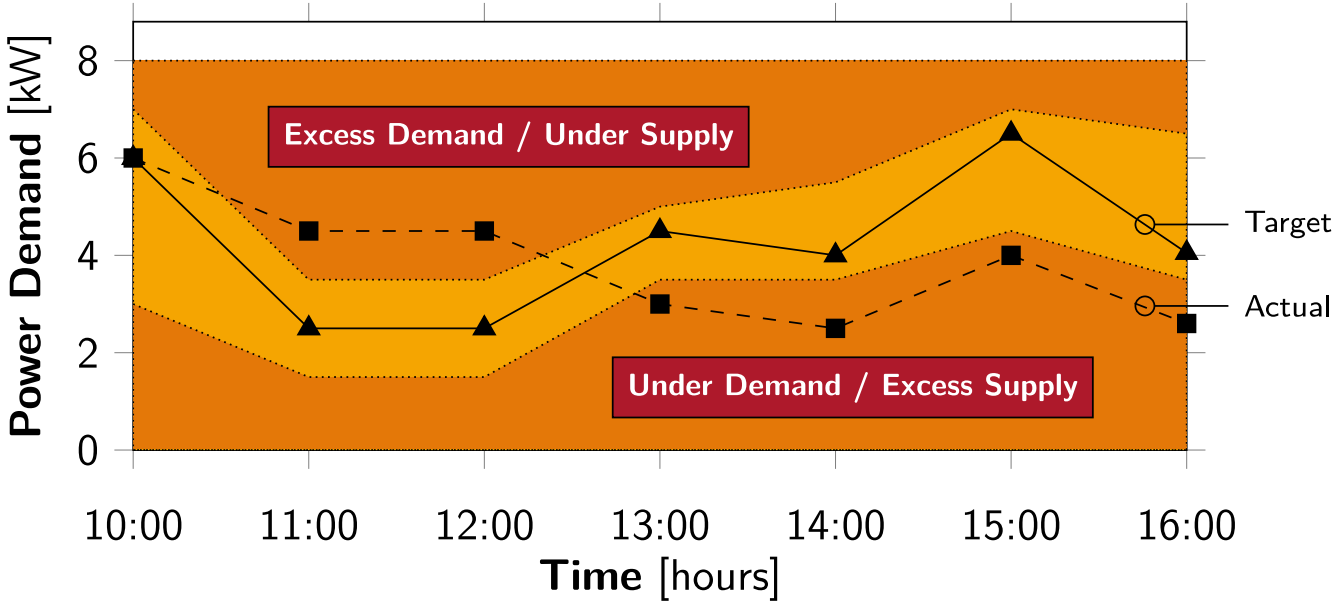
Data: Fraunhofer ISE 2021 https://strom-report.de/.cyl STROM-REPORT

Motivation
Energy Price Over Time



Fluctuating energy supply leads to highly variable energy prices

Motivation
Energy Management in Data Center Operation



Variable power-target and penalty zones must be considered in computing laboratory operation

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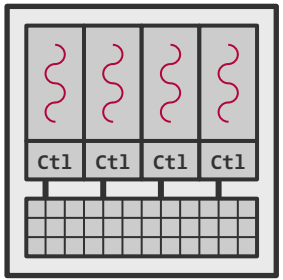
How to control power consumption of computing lab operation?

1. **Work differently:** Use fewer/additional compute resources (commonly used to scale depending on operating requirements)
2. **Work another time:** Defer/pick jobs with matching energy profile (popular research in embedded systems, requires known and deferrable jobs)
3. **Work elsewhere:** Use other hardware components

Focus of our research at the OSM group

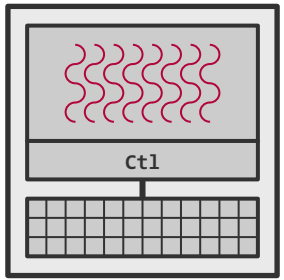
Motivation
Different Hardware Classes



CPU

+ extremely flexible

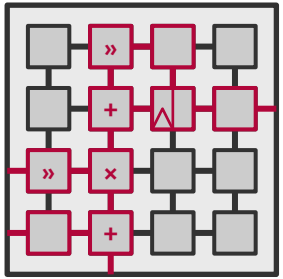
- less specialized / efficient for a certain task



GPU

+ high throughput

- only suitable for data-parallel workloads



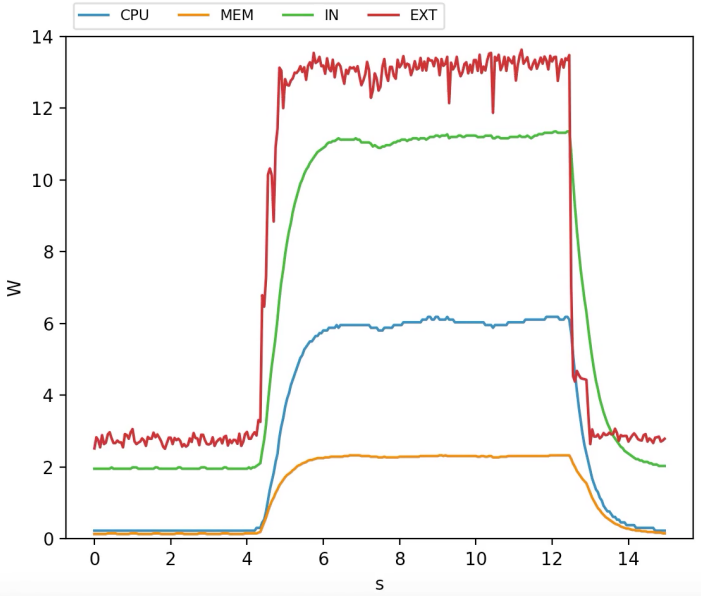
FPGA

+ highly optimized

- hard to program

Available programming interfaces available for measuring power draw or energy consumption of different platforms are not standardized.

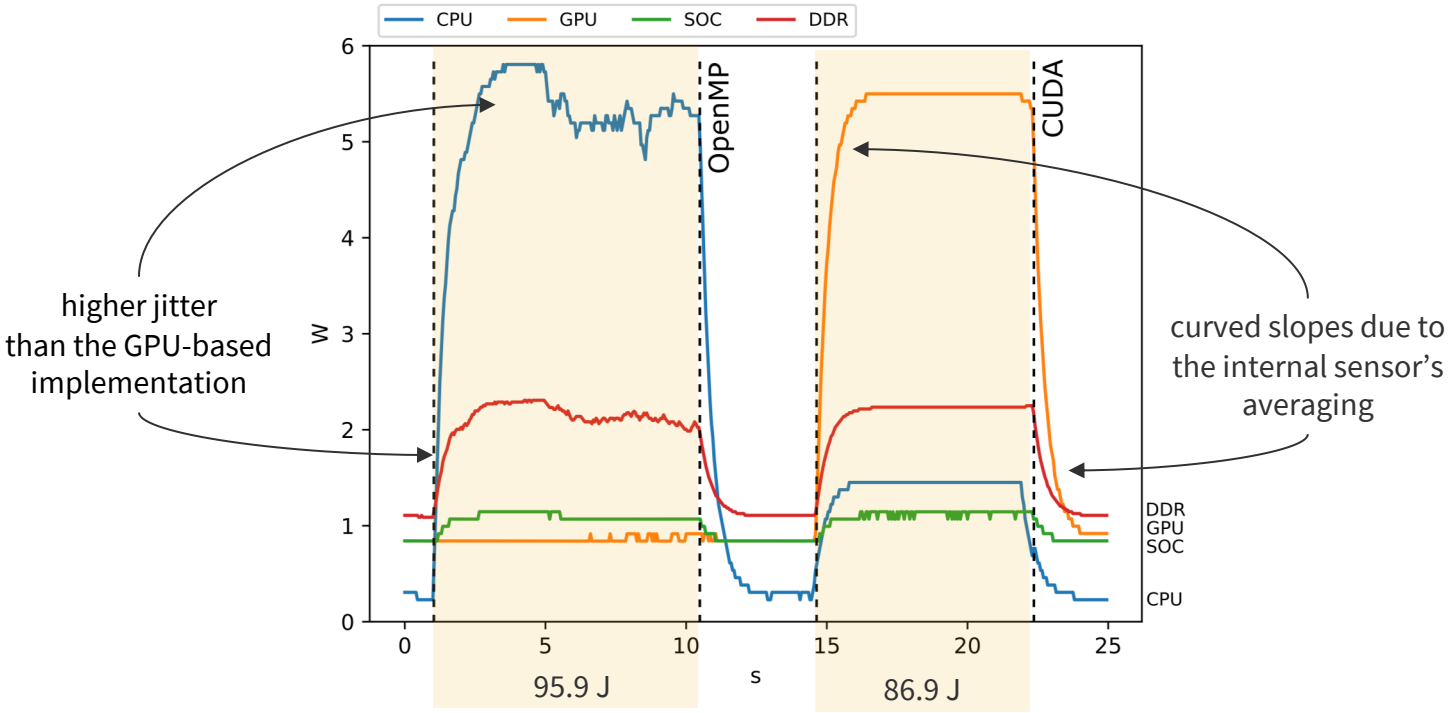
jetson-tx2-01:live



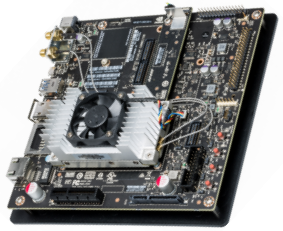
jetson-tx2-01: ~

```
jetson-tx2:~$ pinpoint -i 50 -e CPU,MEM,IN,EXT ./heat 1000 1000 10000 in.csv
Energy counter stats for './heat 1000 1000 10000 in.csv':
[interval: 50ms, before: 0 ms, after: 0 ms, delay: 0 ms, runs: 1]

        44668.45 mJ     CPU
        18967.85 mJ     MEM
        87475.30 mJ     IN
        109235.00 mJ    EXT

        8.61876501 seconds time elapsed

jetson-tx2:~$
```

Measuring Power and Energy to Compare Different Workload Implementations



CPU-based vs GPU-based implementation of a heatmap simulation on NVIDIA Jetson TX2. Internal Jetson counters, sampling at 50ms.



NVIDIA Jetson TX2

Energy-Aware Resource Management

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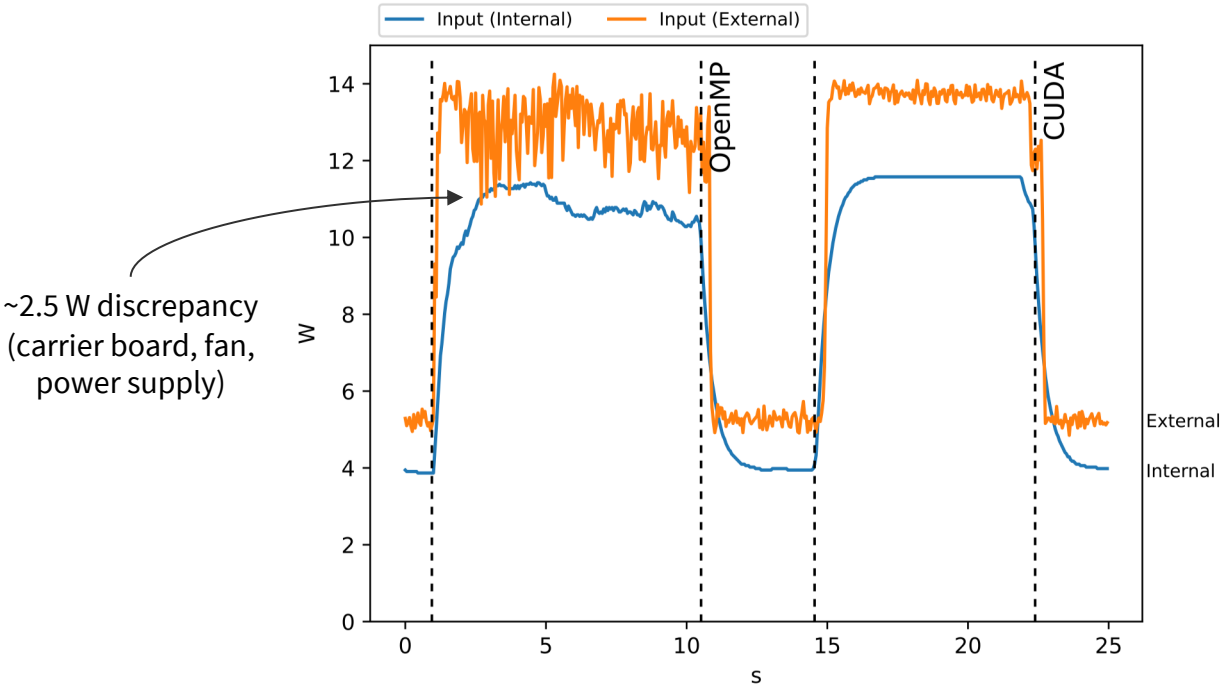
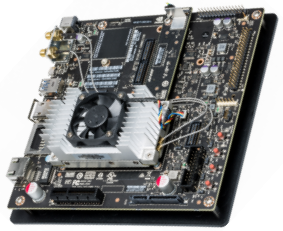
OSM Group

Measuring Power and Energy to Compare Different Power Data Sources

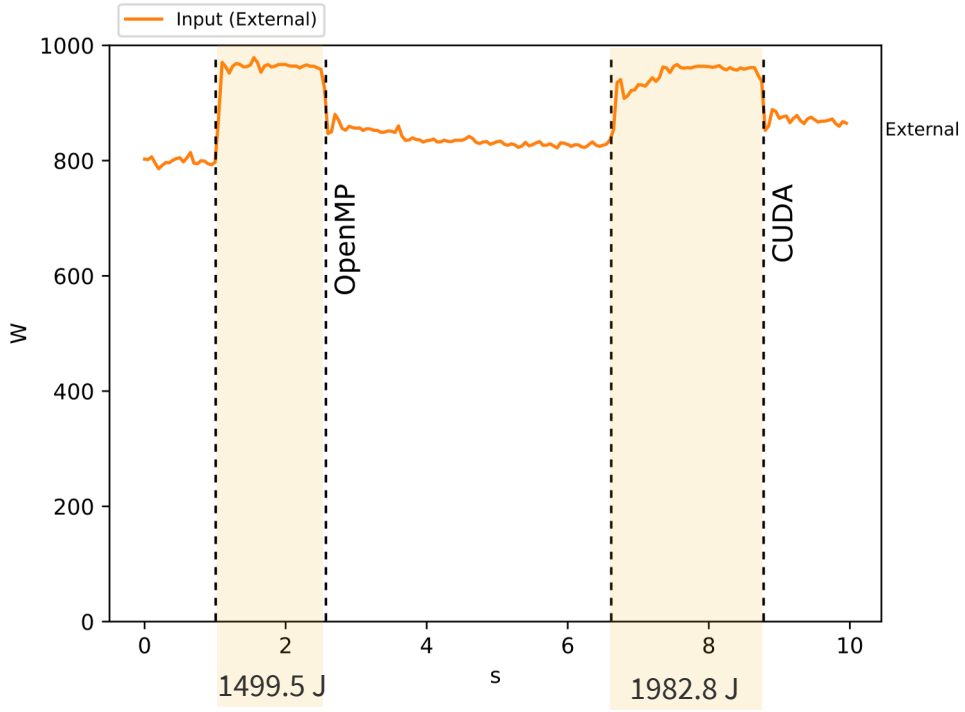


CPU-based vs GPU-based implementation of a heatmap simulation on NVIDIA Jetson TX2. Internal & external counters, sampling at 50ms.



NVIDIA Jetson TX2

Measuring Power and Energy to Compare Different Computing Platforms



CPU-based vs GPU-based implementation of a heatmap simulation on IBM S824L, sum of four external channels, sampling at 50ms.

IBM S824L
with NVIDIA Tesla K80

Measuring Power and Energy
Using PINPOINT for a Unified Measurement Interface

A Perf-inspired Energy Profiling Tool (PINPOINT):

- A cross-platform tool for measuring energy consumption of applications
- Unifies varying measurement methods available for different platforms / hardware
- Available on GitHub: github.com/osmhpi/pinpoint

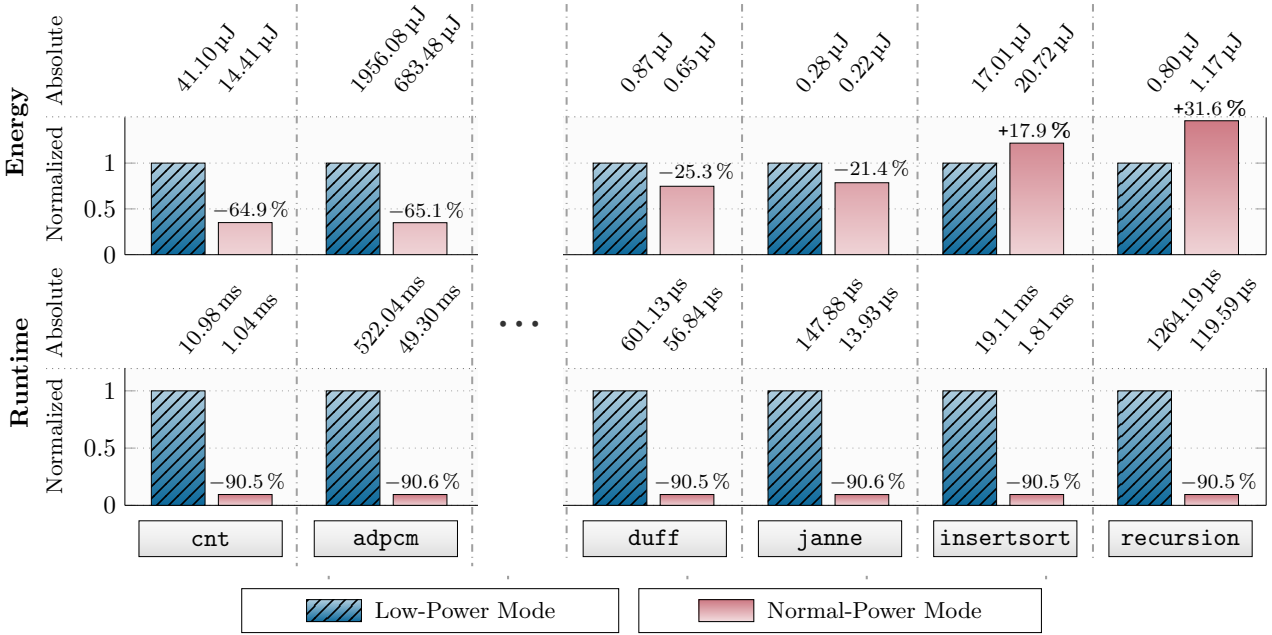
```
$> pinpoint -i 50 -r 10 ./heat 1000 1000 10000 in.csv
[interval: 50ms, repetitions: 10, before: 0ms, after: 0ms]

         47436.04 mJ CPU   ( +- 4.65% )
          8084.43 mJ GPU   ( +- 5.22% )
          9904.58 mJ SOC   ( +- 4.26% )
         19315.06 mJ DDR   ( +- 3.58% )
         95933.73 mJ INPUT ( +- 4.63% )

         8.91673945 seconds time elapsed ( +- 5.92% )
```


Sven Köhler, Benedict Herzog, Timo Hönig, Lukas Wenzel, Max Plauth, Jörg Nolte, Andreas Polze, and Wolfgang Schröder-Preikschat, "Pinpoint the Joules: Unifying Runtime-Support for Energy Measurements on Heterogeneous Systems," 2020 IEEE/ACM International Workshop on Runtime and Operating Systems for Supercomputers (ROSS), GA, USA, 2020, pp. 31-40, doi: 10.1109/ROSS51935.2020.00009.

Side Note:
Consider Measuring Energy Consumption, Not Runtime



Mälardalen WCET benchmark suite executed on an
ARM Cortex-M0+ microcontroller (Freescale Kinetis KL02)

Timo Hönig, Heiko Janker, Christopher Eibel, Wolfgang Schröder-Preikschat, Oliver Mihelic, and Rüdiger Kapitza. "Proactive Energy-Aware Programming with PEEK." 2014 Conference on Timely Results in Operating Systems (TRIOS'14), CO, USA. 2014

Summary

- With the growing degree of heterogeneity in computing systems, choosing the best hardware at the right time for each task will be increasingly important.
  - Applications need to support a larger number of hardware targets.
  - Tooling/infrastructure is needed that makes placement decisions easier.
- Being able to quantify energy demand of applications is a first but important step that helps developers to not only to improve for performance, but also for energy-efficiency.