# Measuring Energy Consumption of Software

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# Why do we care?

- Battery powered devices
  - Less energy use = longer device uses
- Performance
  - Less energy use = less thermal throttling
- Climate impact
  - See one of Joseph’s talk on just how big that is for IT

# Software impact on energy consumption

- Use of hardware resources during workloads
  - CPU, GPU, memory, I/O, etc
- Hardware power management settings
  - CPU frequency, screen brightness, switching off unused things
- Idle behavior
  - Wakeups, continuously running timers

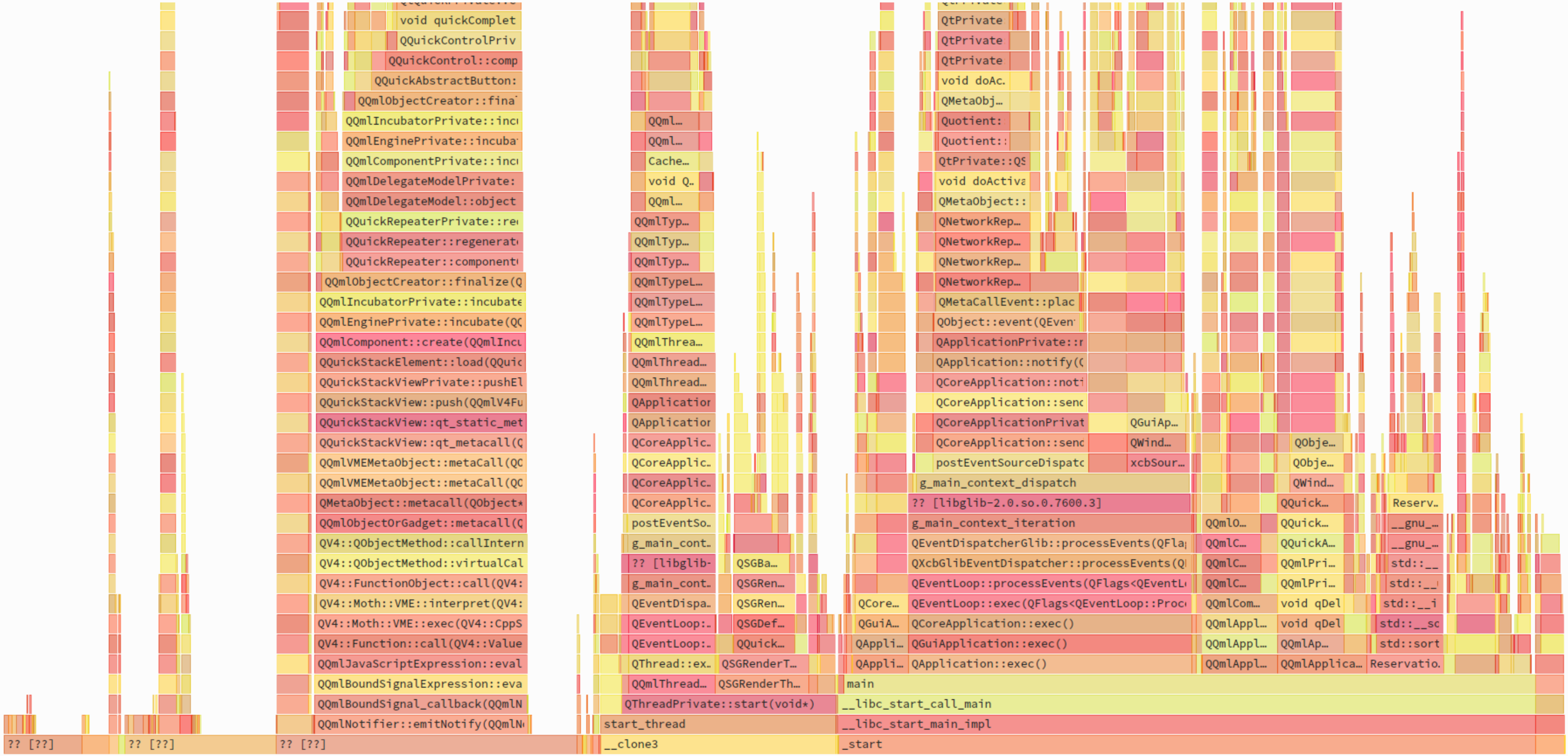
# Does this make a difference?

- Physics isn’t linear
  - Gains can be higher than intuitively assumed
- Scaling effects
  - Optimizations multiply over time and by number of users

# Understanding what our software does

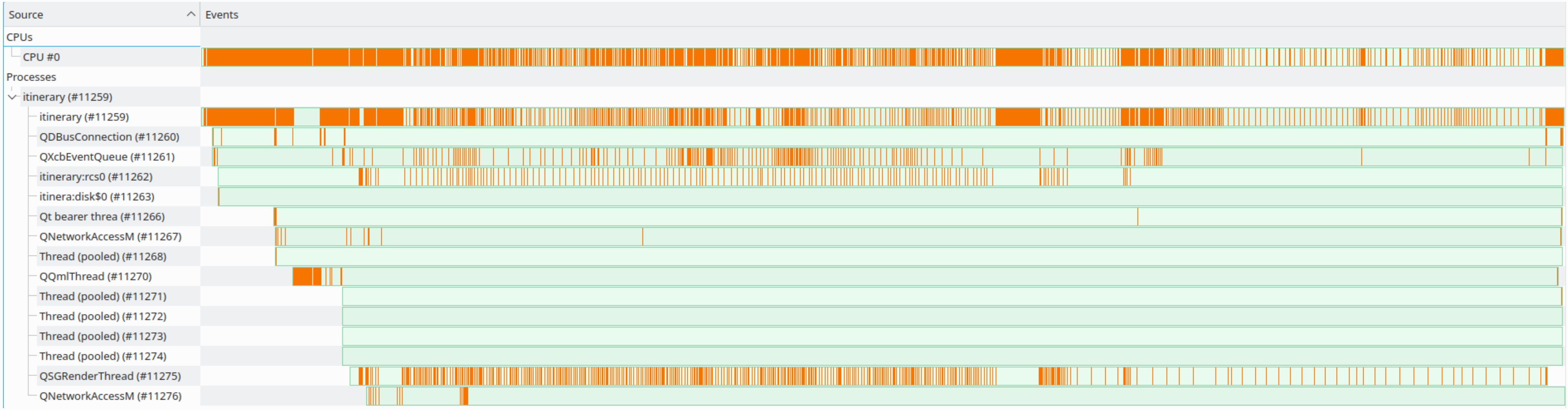
- General purpose profilers
  - `perf record --call-graph=dwarf <app>`
  - Hotspot flamegraph for workloads
  - Hotspot timeline for idle behavior
- Specialized tools
  - powertop for idle behavior

# perf Flamegraph



9.206E+09 aggregated cycles:u cost in total

# perf Timeline



Source

Events

CPUs

CPU #0

Processes

itinerary (#11259)

itinerary (#11259)

QDBusConnection (#11260)

QXcbEventQueue (#11261)

itinerary:rcs0 (#11262)

itinera:disk$0 (#11263)

Qt bearer threa (#11266)

QNetworkAccessM (#11267)

Thread (pooled) (#11268)

QQmlThread (#11270)

Thread (pooled) (#11271)

Thread (pooled) (#11272)

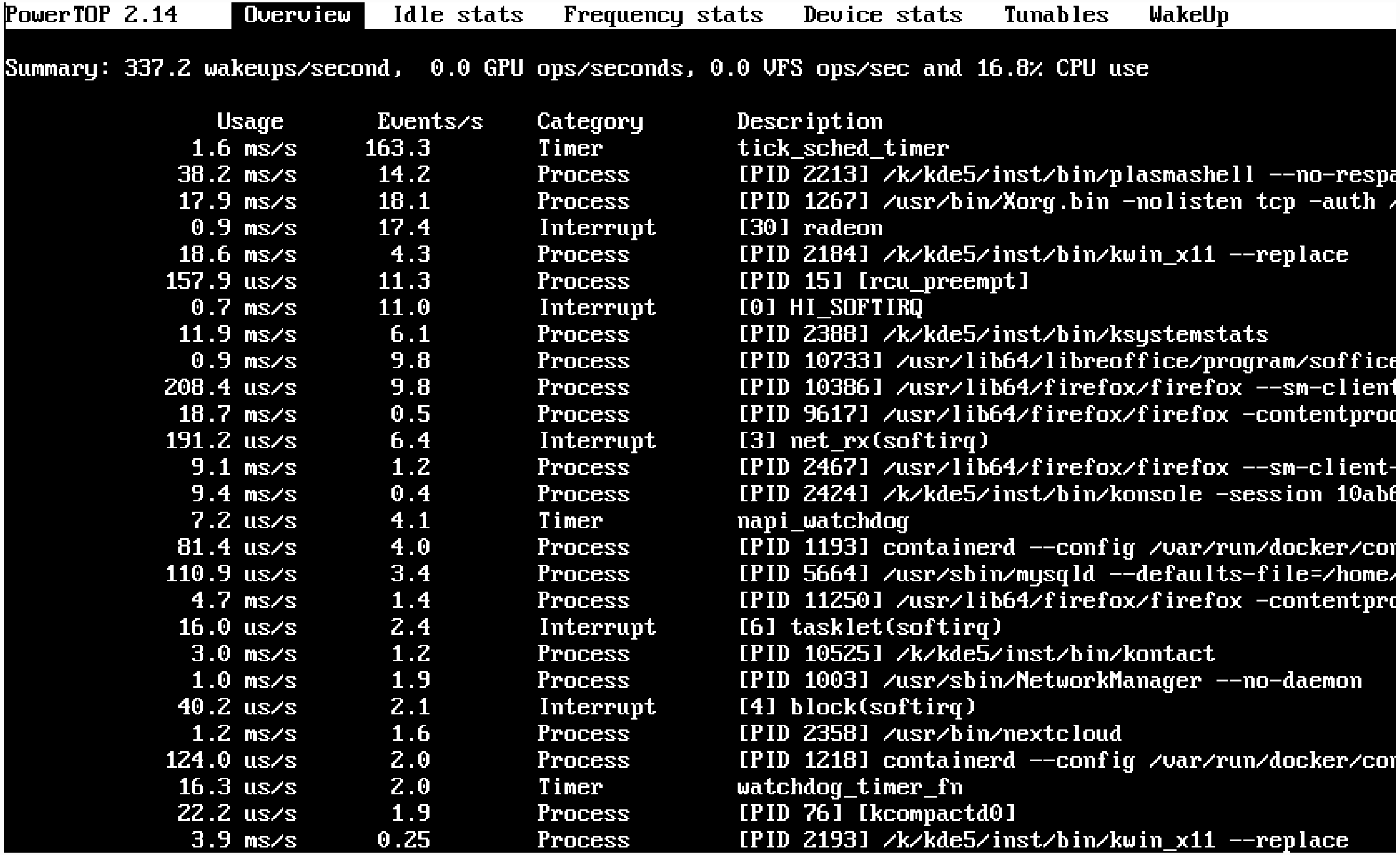
Thread (pooled) (#11273)

Thread (pooled) (#11274)

QSGRenderThread (#11275)

QNetworkAccessM (#11276)

# Powertop



```
PowerTOP 2.14    Overview   Idle stats   Frequency stats   Device stats   Tunables   WakeUp

Summary: 337.2 wakeups/second,  0.0 GPU ops/seconds, 0.0 VFS ops/sec and 16.8% CPU use

                Usage       Events/s     Category       Description
              1.6 ms/s     163.3        Timer          tick_sched_timer
             38.2 ms/s      14.2        Process        [PID 2213] /k/kde5/inst/bin/plasmashell --no-respa
             17.9 ms/s      18.1        Process        [PID 1267] /usr/bin/Xorg.bin -nolisten tcp -auth /
              0.9 ms/s      17.4        Interrupt      [30] radeon
             18.6 ms/s       4.3        Process        [PID 2184] /k/kde5/inst/bin/kwin_x11 --replace
            157.9 us/s      11.3        Process        [PID 15] [rcu_preempt]
              0.7 ms/s      11.0        Interrupt      [0] HI_SOFTIRQ
             11.9 ms/s       6.1        Process        [PID 2388] /k/kde5/inst/bin/ksystemstats
              0.9 ms/s       9.8        Process        [PID 10733] /usr/lib64/libreoffice/program/soffice
            208.4 us/s       9.8        Process        [PID 10386] /usr/lib64/firefox/firefox --sm-client
             18.7 ms/s       0.5        Process        [PID 9617] /usr/lib64/firefox/firefox -contentproc
            191.2 us/s       6.4        Interrupt      [3] net_rx(softirq)
              9.1 ms/s       1.2        Process        [PID 2467] /usr/lib64/firefox/firefox --sm-client-
              9.4 ms/s       0.4        Process        [PID 2424] /k/kde5/inst/bin/konsole -session 10ab6
              7.2 us/s       4.1        Timer          napi_watchdog
             81.4 us/s       4.0        Process        [PID 1193] containerd --config /var/run/docker/con
            110.9 us/s       3.4        Process        [PID 5664] /usr/sbin/mysqld --defaults-file=/home/
              4.7 ms/s       1.4        Process        [PID 11250] /usr/lib64/firefox/firefox -contentpro
             16.0 us/s       2.4        Interrupt      [6] tasklet(softirq)
              3.0 ms/s       1.2        Process        [PID 10525] /k/kde5/inst/bin/kontact
              1.0 ms/s       1.9        Process        [PID 1003] /usr/sbin/NetworkManager --no-daemon
             40.2 us/s       2.1        Interrupt      [4] block(softirq)
              1.2 ms/s       1.6        Process        [PID 2358] /usr/bin/nextcloud
            124.0 us/s       2.0        Process        [PID 1218] containerd --config /var/run/docker/con
             16.3 us/s       2.0        Timer          watchdog_timer_fn
             22.2 us/s       1.9        Process        [PID 76] [kcompactd0]
              3.9 ms/s       0.25       Process        [PID 2193] /k/kde5/inst/bin/kwin_x11 --replace
```

# Optimizing software

- Doing less is always good
  - Rare to find such cases though
- Tradeoffs
  - Doing the same thing faster
  - Doing the same thing using different types of hardware
  - Can be hard to predict, can depend on specific hardware

# Evaluating tradeoffs

- Few established guidelines for energy consumption
- Non-linear behavior vs intuition
- Measure and compare!

# Measuring energy consumption

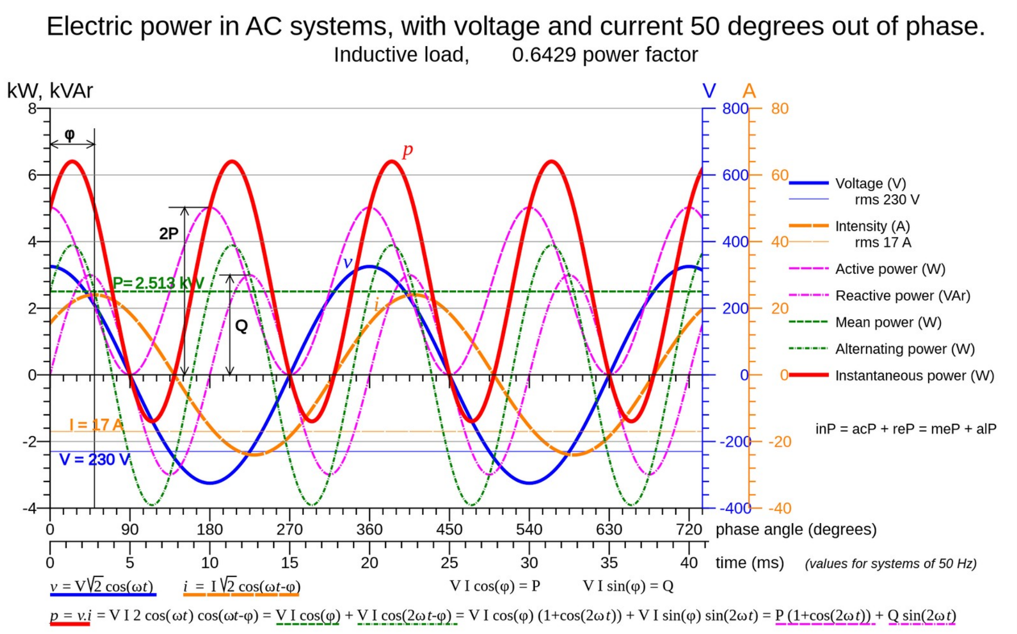
- Primary side (AC)
  - (+) complete (-) tricky for battery powered devices, safety
- Secondary side (DC)
  - (+) safety (o) misses power supply loss (-) difficult to access
- Built-in sensors
  - (+) availability, resolution (-) partial view, in-situ measurement

# Physics – The Good - DC

- Power (P), measured in Watt
  - P = Voltage (U) x Current (I)
- Energy: power over time
  - Measured in Ws, kWh or J/MJ

# Physics – The Bad - AC

- Power is now a complex number
  - Active power/real power (P), measured in Watt
  - Reactive power (Q), in VAr
  - Complex power (S), in VA
  - Apparent power (|S|), in VA
  - Power factor (α): P/Q



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# Physics – The Ugly – Switched-mode Power Supplies

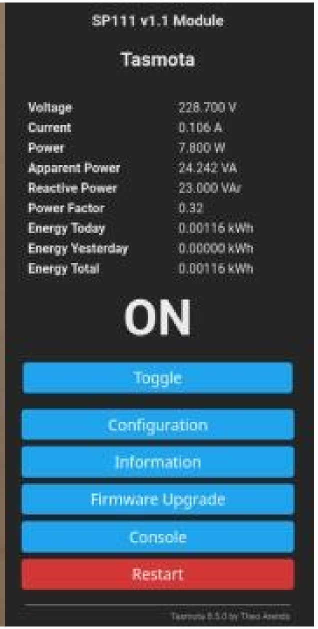
- Operating at ~100kHz - 2MHz
- Distort the AC sine wave
- Highly dynamic loads
- Results in noisy measurements when using a lower sampling rate

# AC Measurements – Household/IT devices

- Standalone devices: ~10€, no machine readable output
- IT server management devices: 300+€, Ethernet access
- Sample rate: <= 1Hz

# AC Measurements – Tasmota-based Wi-Fi plugs

- Switchable Wi-Fi power plugs with power meter
- ~8-20€ a piece
- Tasmota firmware (FOSS)
- Up to 5Hz sample rate
- Potential for more with modified firmware


SP111 v1.1 Module

Tasmota

| | |
|---|---|
| Voltage | 228.700 V |
| Current | 0.106 A |
| Power | 7.800 W |
| Apparent Power | 24.242 VA |
| Reactive Power | 23.000 VAr |
| Power Factor | 0.32 |
| Energy Today | 0.00116 kWh |
| Energy Yesterday | 0.00000 kWh |
| Energy Total | 0.00116 kWh |

ON

Tasmota 8.5.0 by Theo Arends

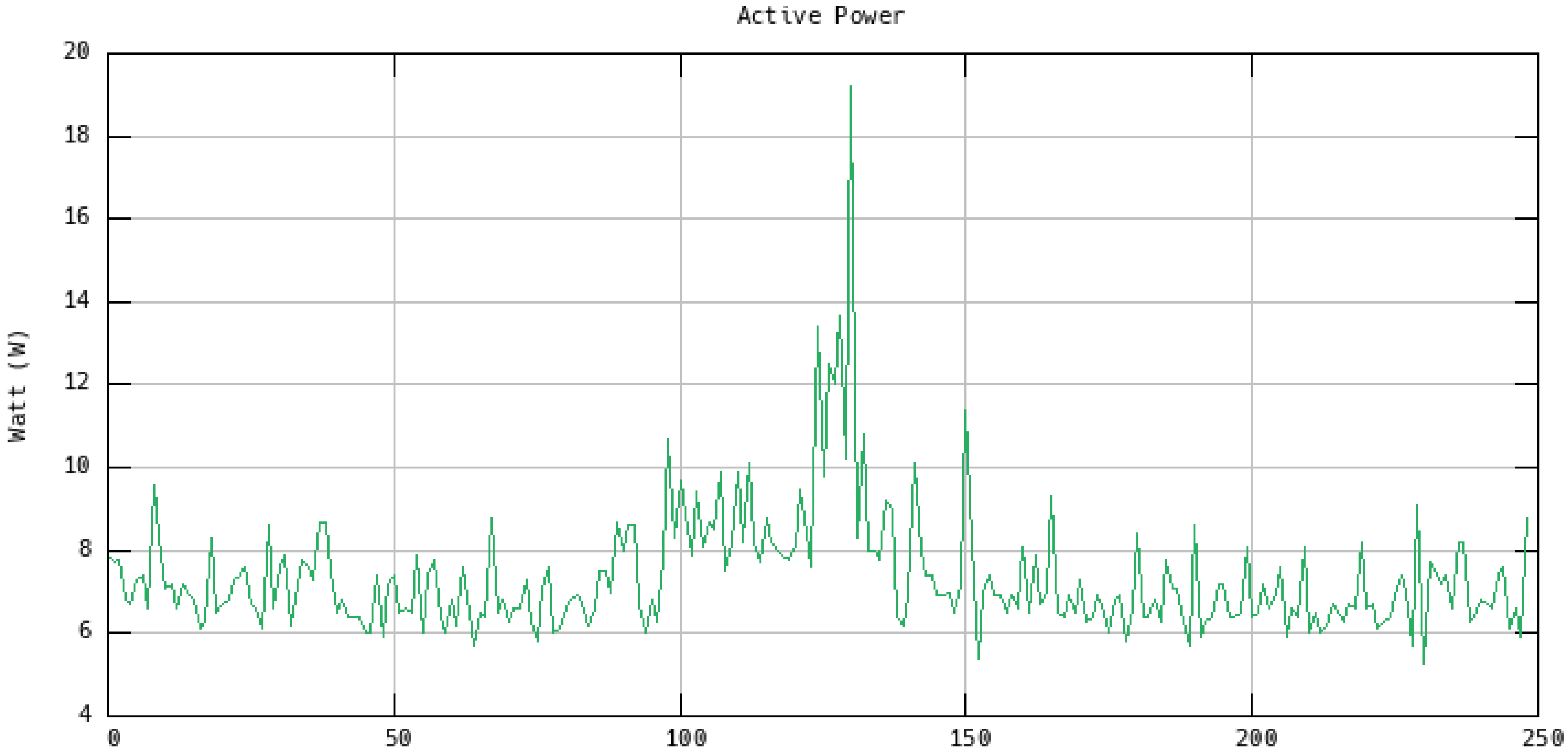
# AC Measurements – ALCIOM PowerSpy2

- Specialized device
- Serial over Bluetooth access
- Up to 50Hz sample rate
- Live data and recording
- ~300€
- Only partial protocol implementation

# AC Measurements - DIY

- Sensors only cost ~2$
- Development boards ~200-250$
- Sampling rate up to 1kHz
- Safety...

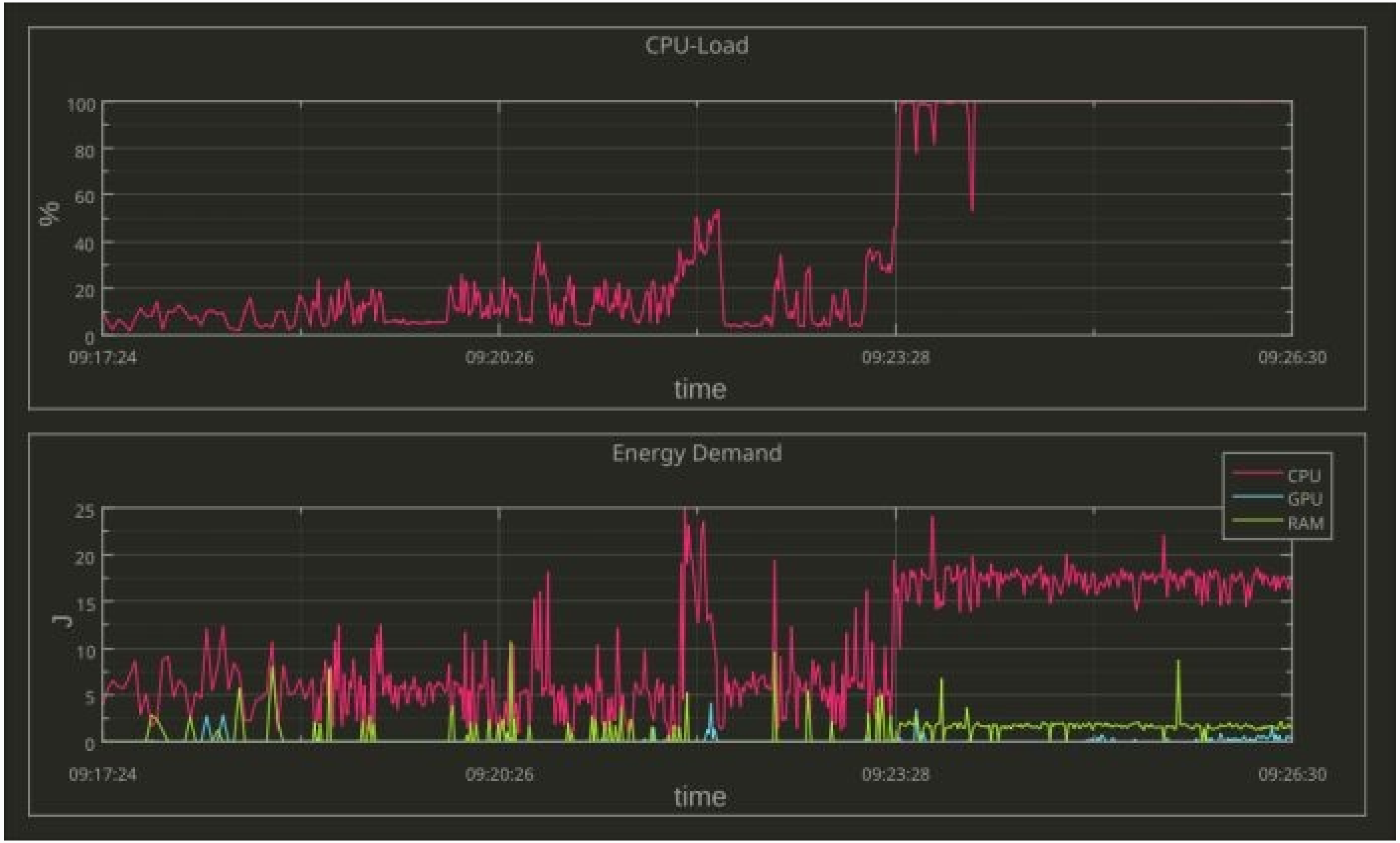
# AC Measurements - Example



# Internal power sensors

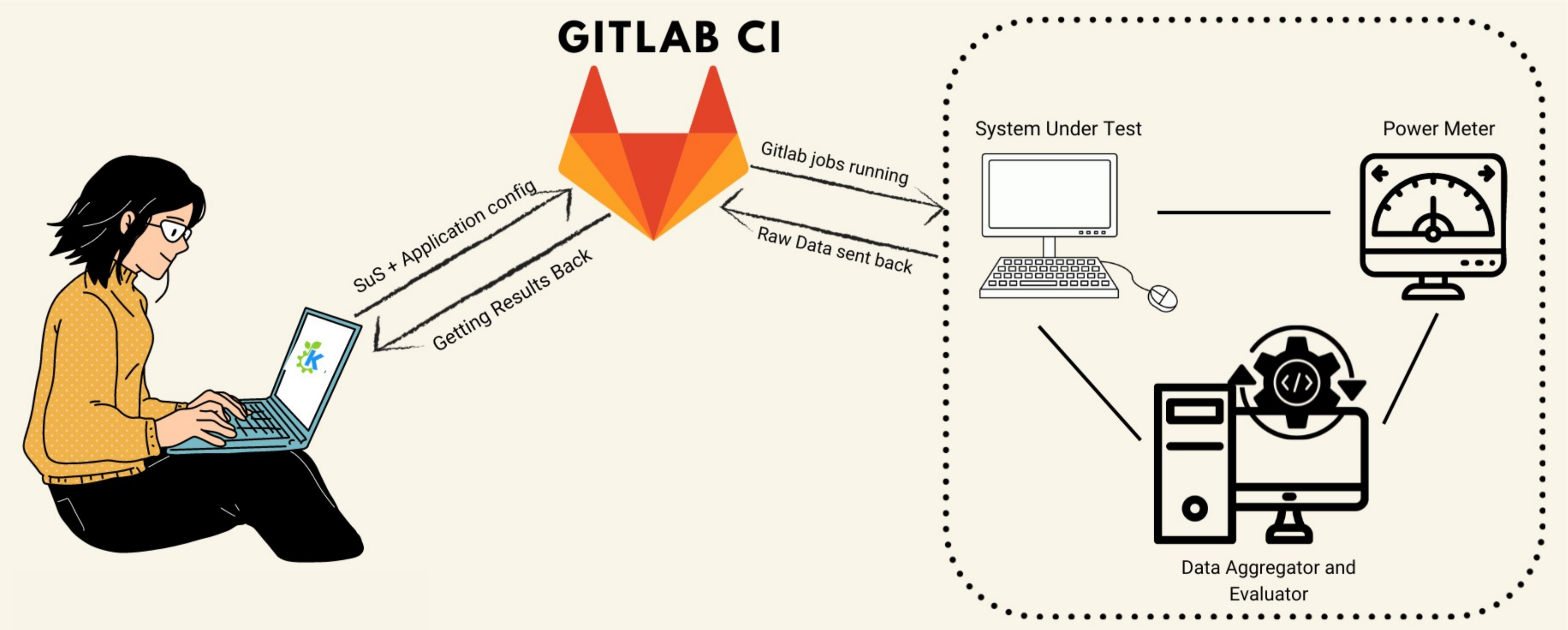
- e.g. Intel RAPL
- Available sensors depend on hardware/hardware version
  - `perf list | grep energy`
- Data accessible via perf or specialized tools
  - `perf stat -e "power/energy-pkg/,power/energy-cores/" <app>`
  - `pinpoint --header -c <app>`
- Needs root access

# Internal power sensors - Example



# There is no cloud, just other people’s power meters…

- GSoC “KEcoLab” by Karanjot Singh



# What do we do with all that?

- Do general profiling and optimizing first
- Focus on long-running processes
  - Continuous/frequent workloads
  - Idle behavior
- Research
  - Tooling and best practices are still very basic

# Thank you!

Questions?

BoF
Monday 10:00 Room 1

# References

- https://volkerkrause.eu/2020/10/17/kde-cheap-power-measurement-tools.html
- https://tasmota.github.io/docs
- https://invent.kde.org/vkrause/powerspy2-tools
- https://github.com/osmhpi/pinpoint/
- https://eco.kde.org/blog/2023-06-13-gsoc23-energy-measurement-lab/