Testing thermal-aware scheduling for avionics applications

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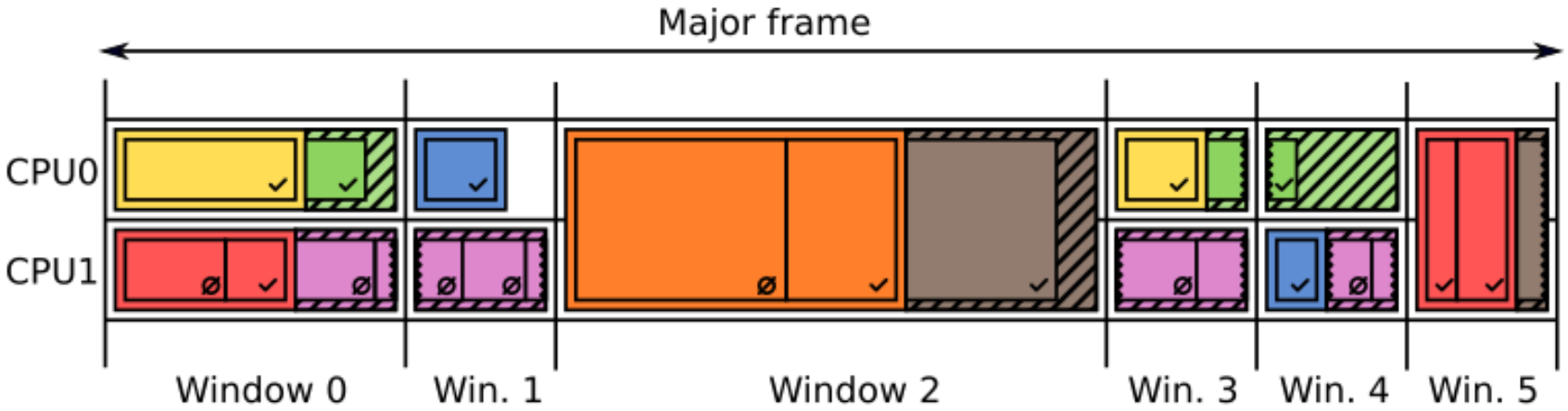
THERMAC project overview

- Collaboration with avionics company
- Their requirements
  - **embedded** systems
  - no **fans**, no heavy **heat sinks**
  - as much **performance** as **thermal** constrains allow
  - no deadline misses for **safety critical** workload
  - **best effort** workload runs when **temperature** and **time** allows

Operating system & scheduling

- Safety-critical avionics applications **cannot use Linux**
- Special-purpose OSes with time-partitioned scheduling
- We simulate such scheduling on Linux via cgroups
- Safety-critical workload is **well known** in advance



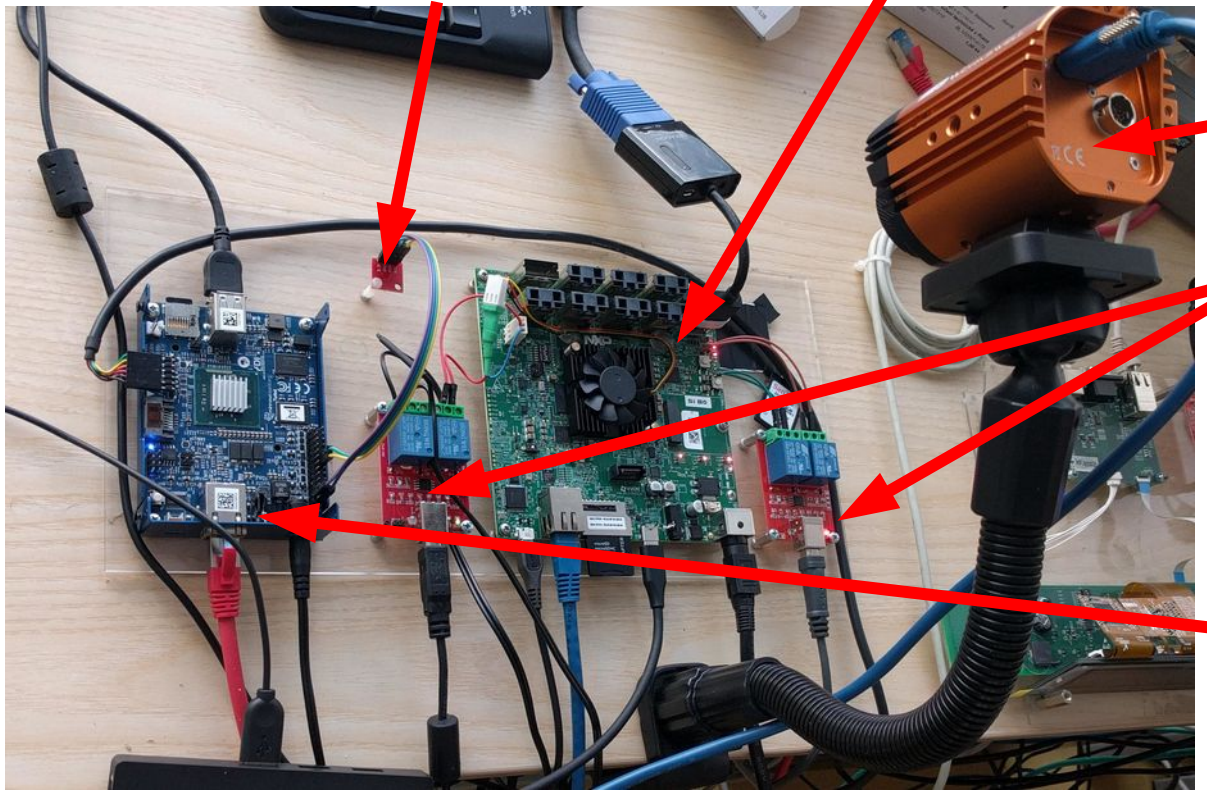
Goals

- Prepare methods and benchmarks to evaluate thermal-aware scheduling strategies
- Measure thermal properties of the HW
  - **NXP i.MX8 QuadMax**, NVIDIA Tegra X2/Xavier
- Come up with thermal-aware scheduling strategies to control the peak temperature
- Evaluate the scheduling strategies

Testbed

Board under test
NXP i.MX8 QuadMax MEK
4× Cortex A53, 2× A72, 2× GPU

Ambient temperature sensor

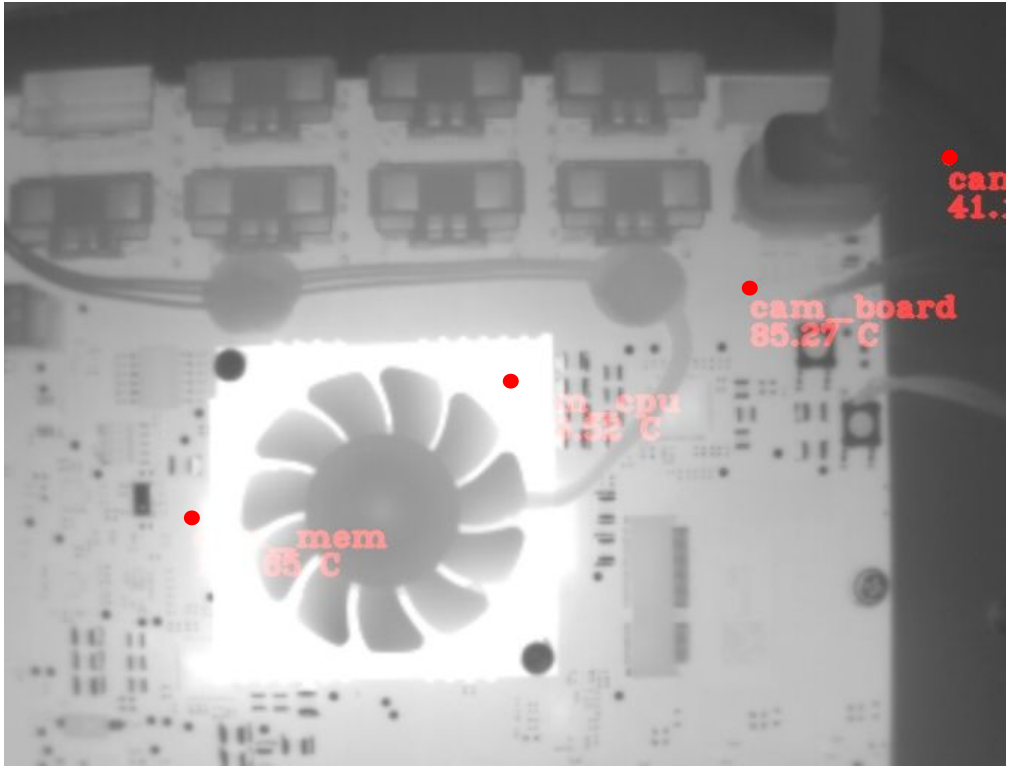


Thermal camera

Relays for remote control and automation

MinnowBoard – management

Thermo camera

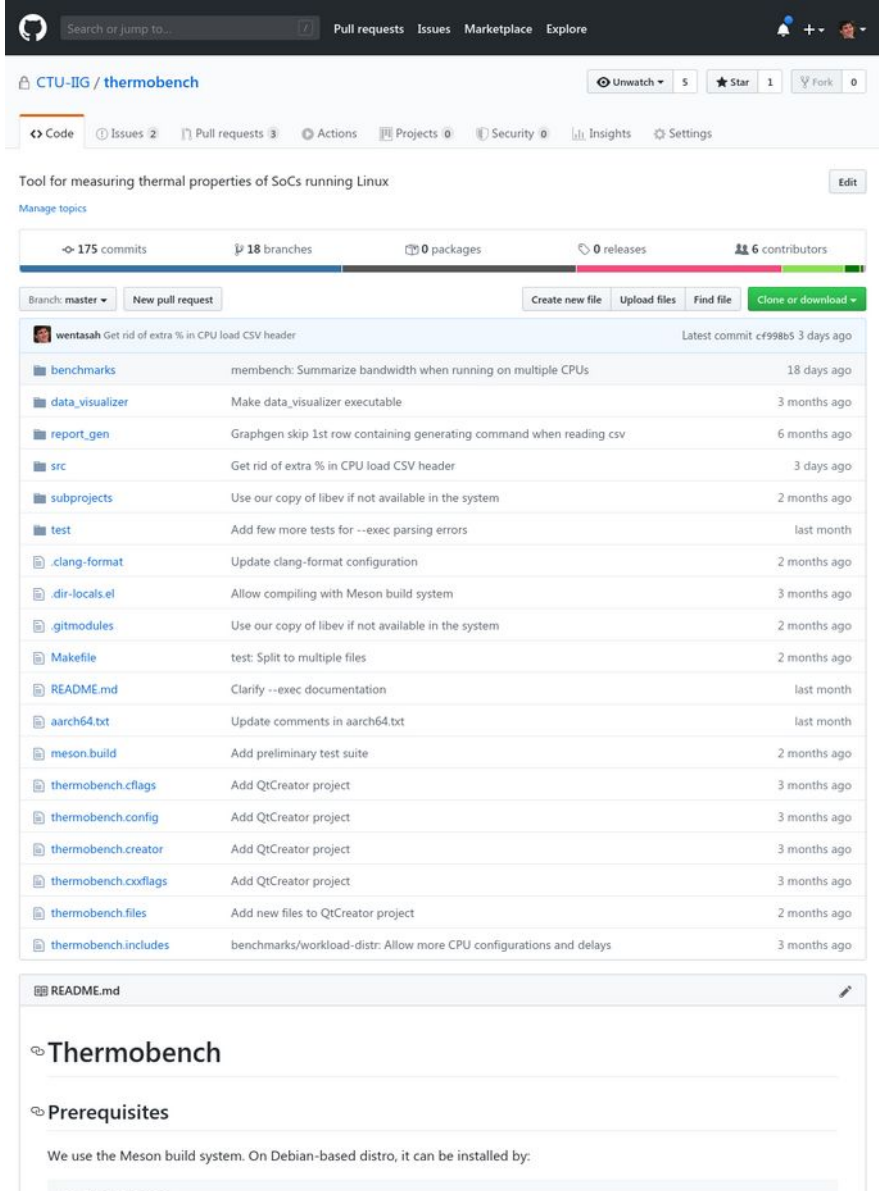


- Measures temperature of various points on the board
- 336×256px, 9 Hz
- Results over HTTP

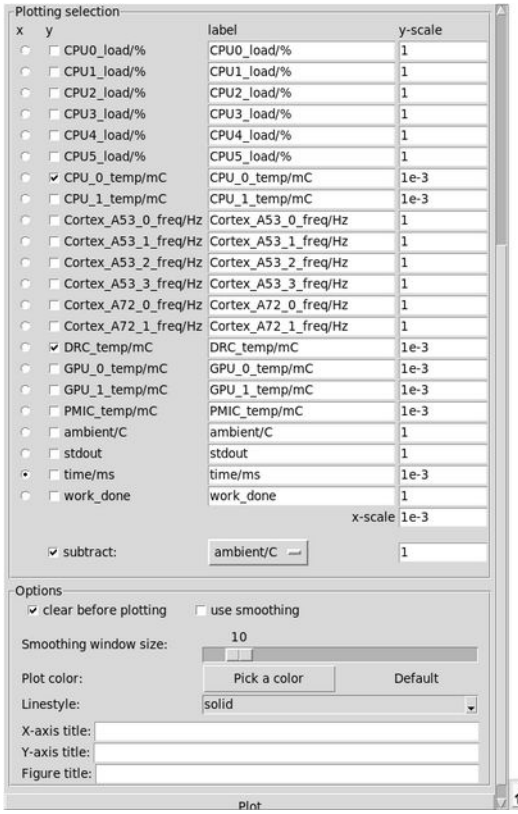
Thermobench tool

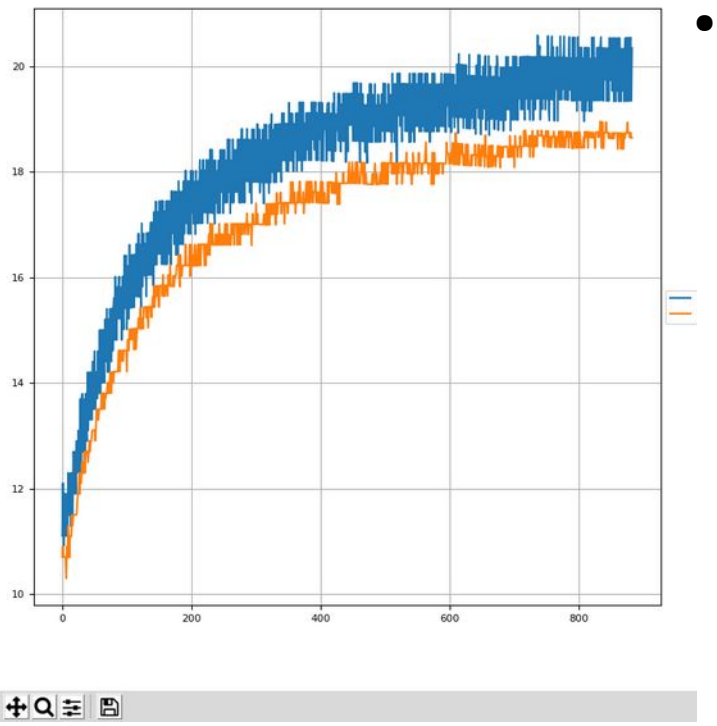
https://github.com/CTU-IIG/thermobench

- Fancy .csv file generator (C++)
- Controls cooling devices (fan)
- Runs a benchmark
- Periodically captures
  - thermal-zone temperatures
  - CPU frequency
  - CPU load
  - benchmark stdout
  - other commands stdout (thermocam, ambient temp.)
  - etc.
- GPL



Interactive data visualizer (Python)

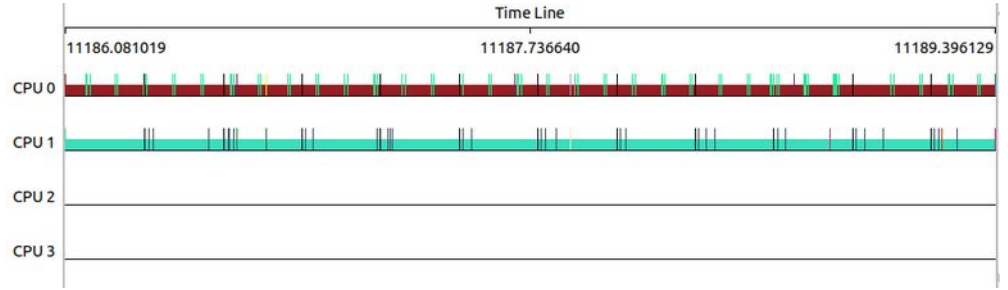


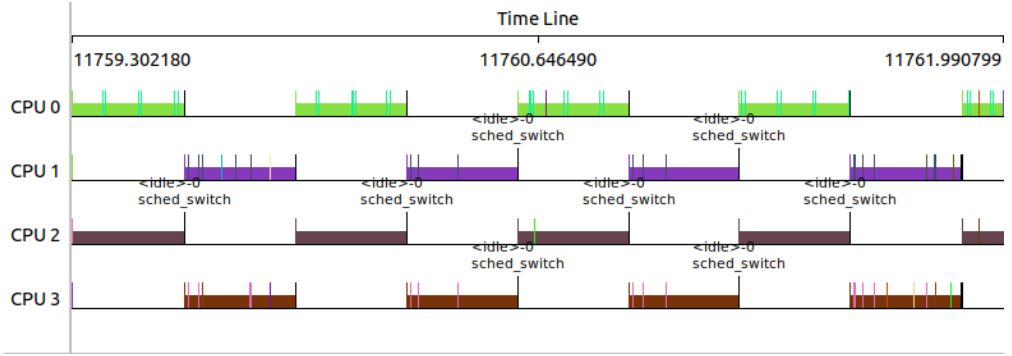


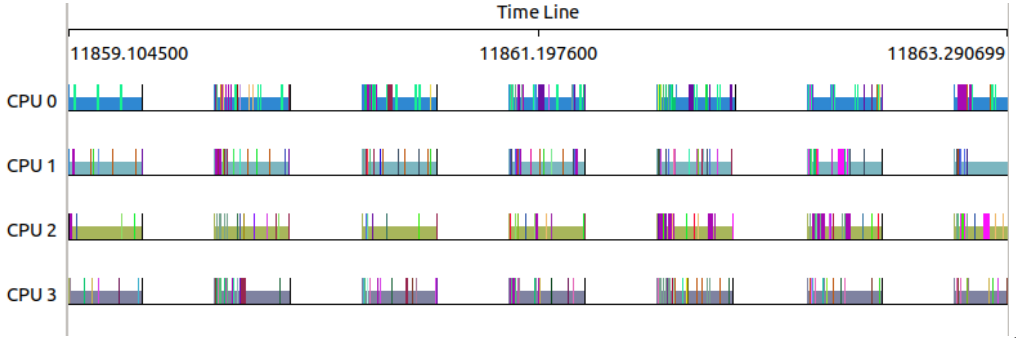
- Easily plot data produced by Thermobend
  - temp. vs. time
  - temp. vs. work_done
  - subtract ambient temperature
  - and more...

Benchmarks

- Instruction µ-benchmarks
- Various sleep patterns
- Memory-/CPU-bound
- etc.

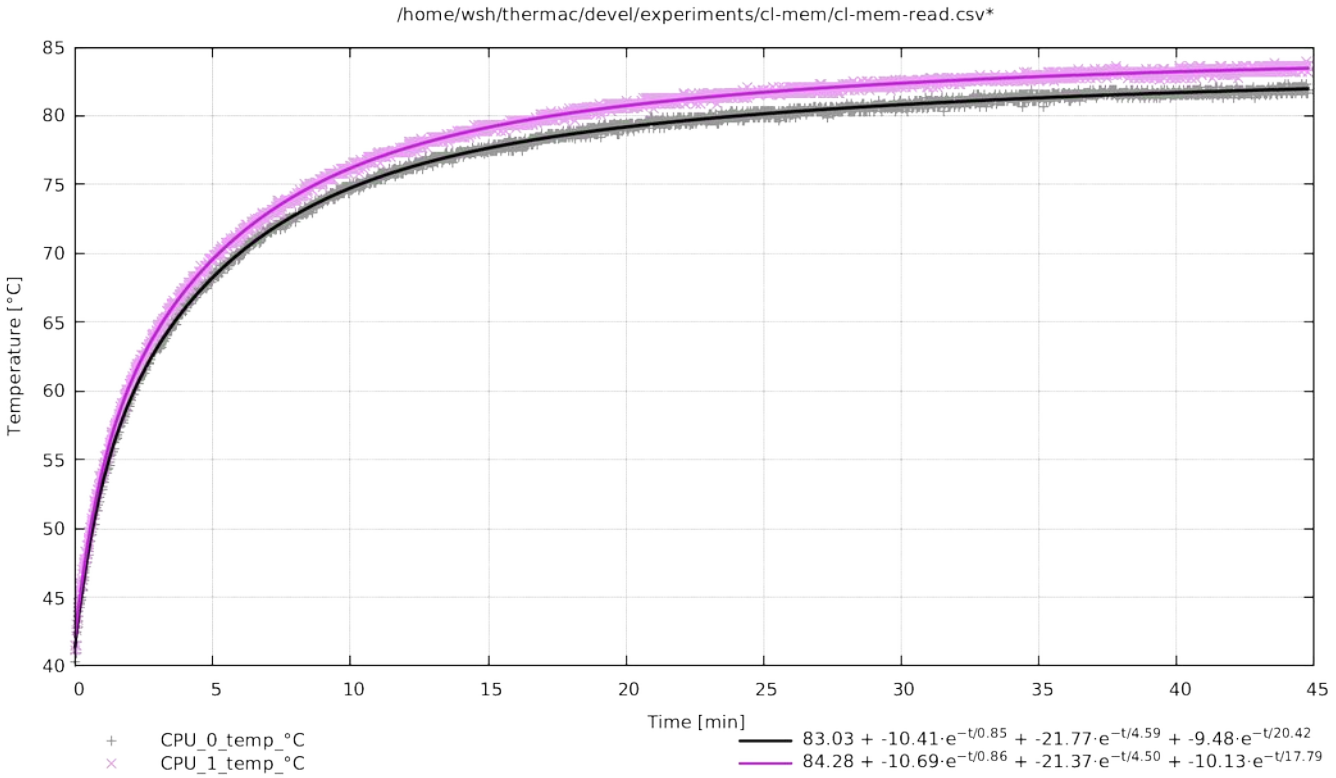






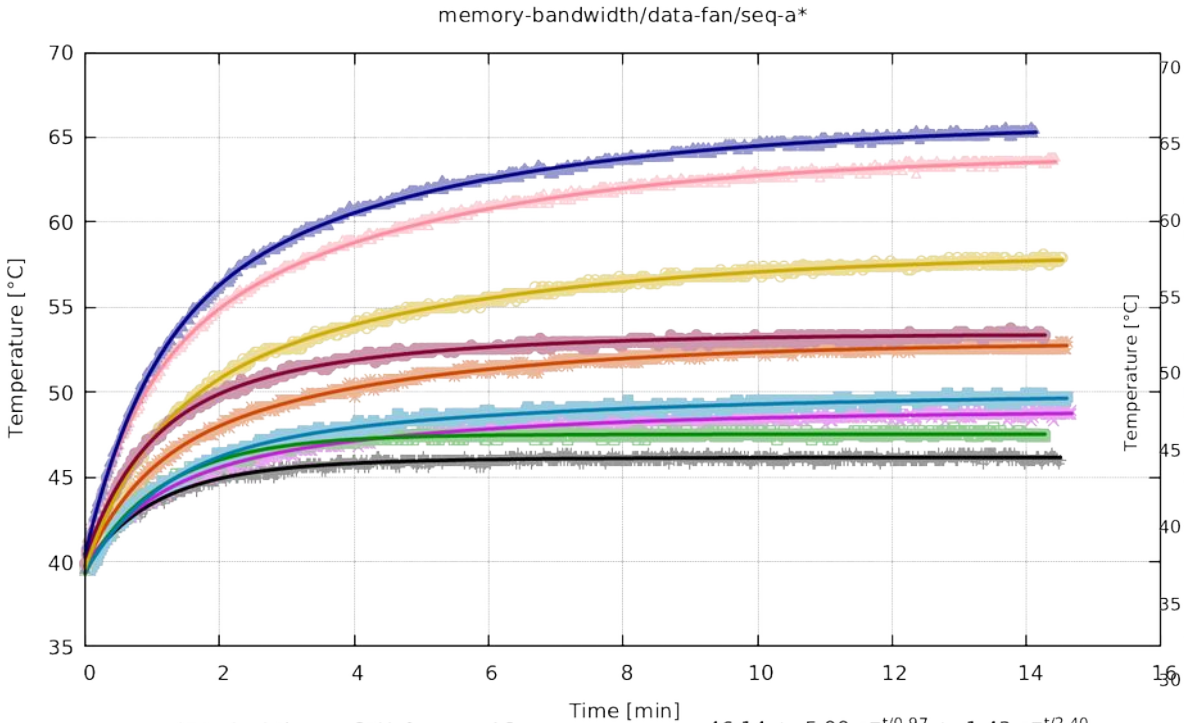
Thermal model fitting in Julia

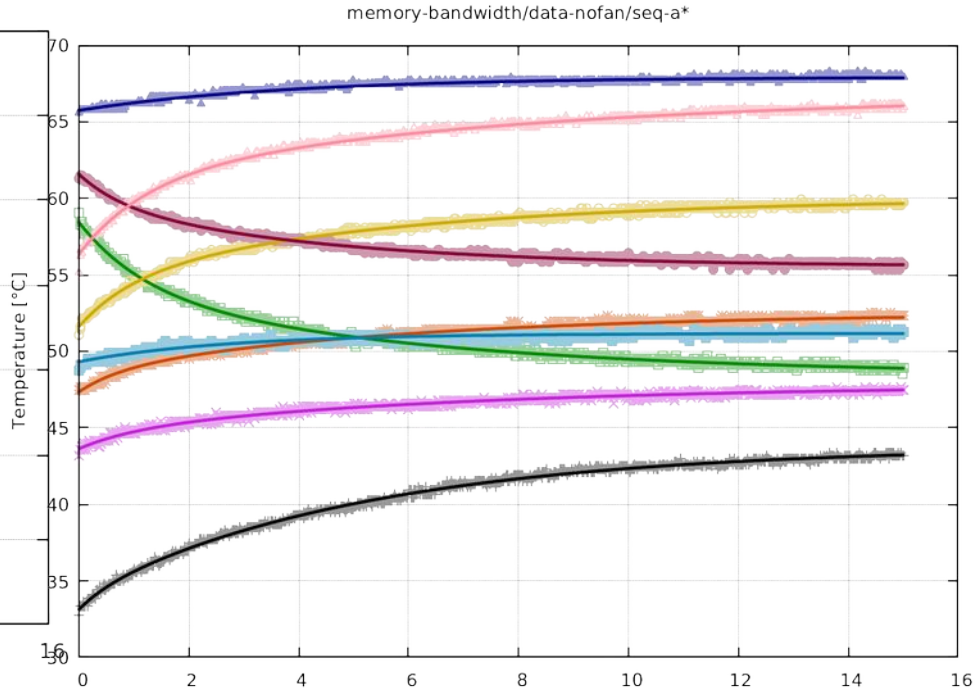
$$84.28 - 10.69 \cdot e^{-\frac{t}{0.86}} - 21.37 \cdot e^{-\frac{t}{4.50}} - 10.13 \cdot e^{-\frac{t}{17.79}}$$



- Fits n-th order dynamic system model to data from Thermobench
- n=1,**2**,3
- 1st coeff. = T(∞)
- Coefficients in exponents = “time constant”
  - How long to run experiments?

Comparison of various experiments





Feedback/Discussion

- Can this be useful for something else?
  - Linux PM/scheduler work?
- Preliminary results:
  - Execute on all CPUs in parallel + sleep
  - Execute on a small part of GPU continuously, let the rest of the GPU sleep
- What other benchmarks would you find useful?
- Power measurements vs. temperature measurements
- Experience with oil-based cooling