CM4: Experimental Methodology, Profiling, and Performance/Energy Optimization

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Master Calcul Haute Performance et Simulation - GLHPC | UVSQ

1. Scientific visualization
2. Experimental Methodology
3. Plotting Tools
4. Profiling

Scientific visualization

Plot Example - Intro

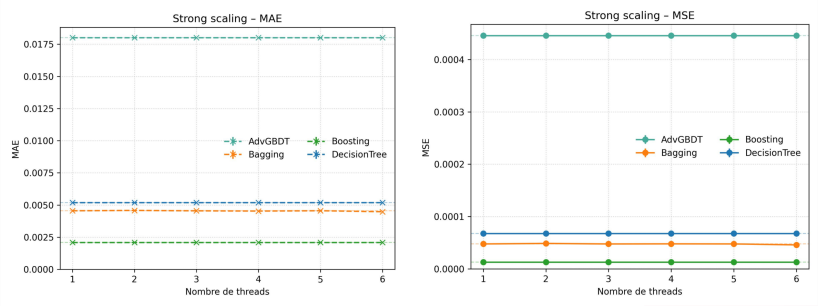
In the following slides, you will be shown a series of plots; mainly taken from the PPN course reports of previous students.

For each plot:

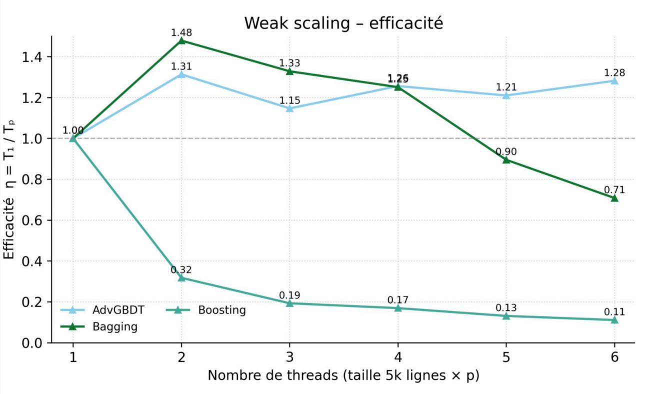
- Try to understand what is represented
- Explain what you observe
- Give a **definitive** conclusion from the data shown

Raise your hands when ready to propose an explanation.

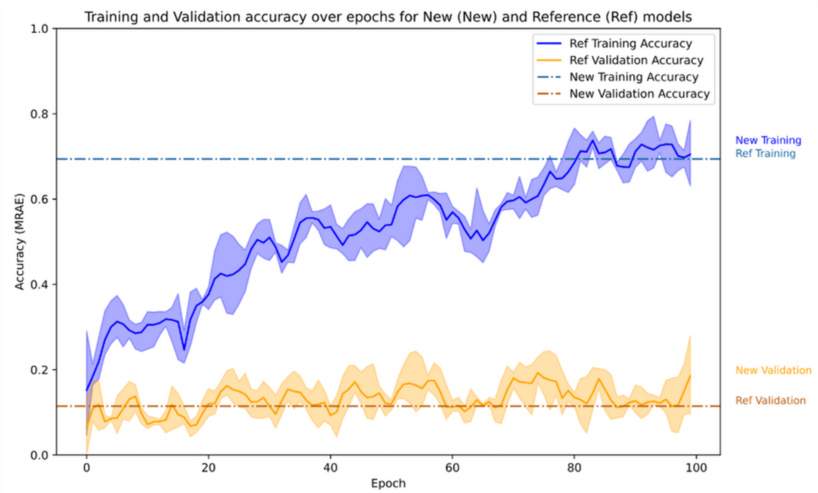
Plot Example (1)



PPN Example - (No Caption)

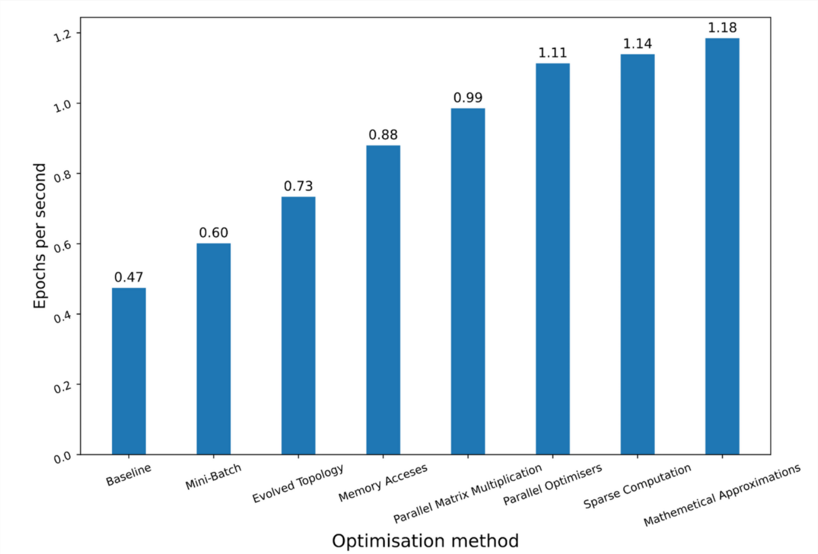


PPN Example - (No Caption)

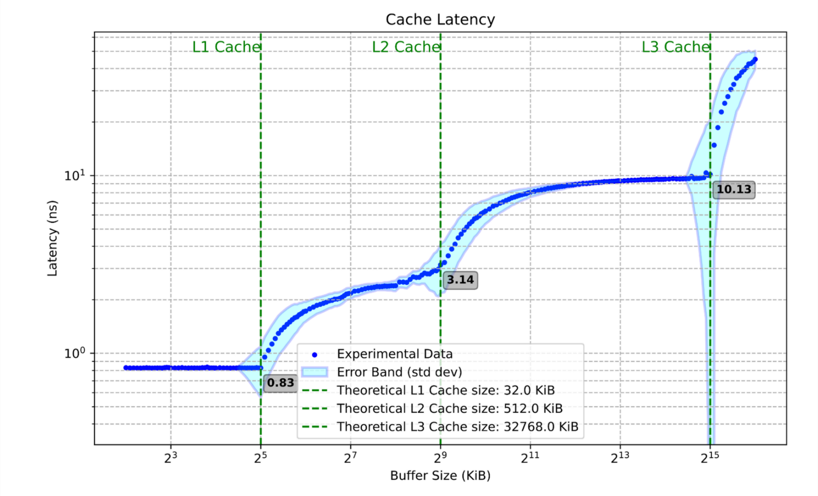


PPN Example - (No Caption)

Plot Example (4)

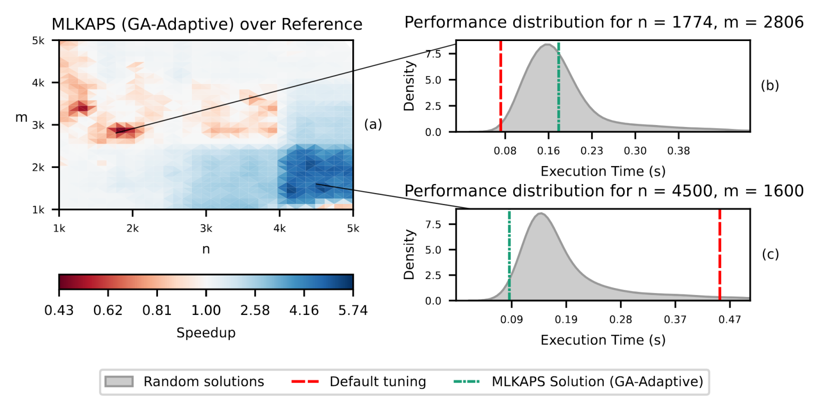


PPN Example - “Récapitulatif des optimisations faites”



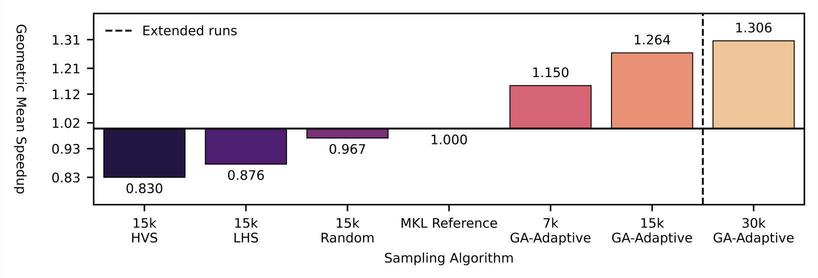
PPN Example - "Nouveau tracé de la latence cache"

Plot Example (6)



Prof Example - (KNM): (a) Speedup map of GA-Adaptive (7k samples) over the Intel MKL hand-tuning for `dgetrf` (LU), higher is better. (b) Analysis of the slowdown region (performance regression). (c) Analysis of the high speedup region. $3,000$ random solutions were evaluated for each distribution.

Plot Example (7)



Prof Example - (SPR): Geometric mean Speedup (higher is better) against the MKL reference configuration on `dgetrf` (LU), depending on the sampling algorithm. 46x46 validation grid. 7k/15k/30k denotes the samples count. GA-Adaptive outperforms all other sampling strategies for auto-tuning. With 30k samples it achieves a mean speedup of $\times 1.3$ of the MKL dgetrf kernel.

Plot Example - What makes a good plot

Ask yourself:

- What do I want to communicate ?
- What data do I need ?
- **Is my plot understandable in ~10 seconds ?**
- Is my plot self-contained ?
- Is the context, environment, and methodology clear ?

Plot Example - Summary

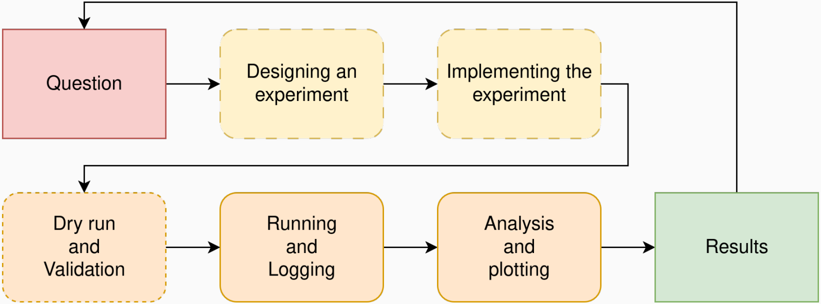
HPC is a scientific endeavour; data analysis and plotting are essential.

- Plots drive decisions
- Plots make results trustworthy
- Plots explain complex behaviors

Datasets are large, multi-disciplinary, and often hard to reproduce.

Experimental Methodology

Experimental Methodology - Workflow



Statistical significance - Introduction

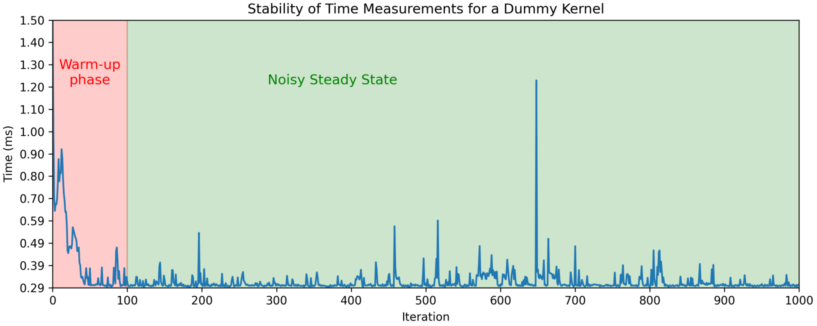
Computers are noisy, complex systems:

- Thread scheduling is non deterministic -> runtime varies between runs.
- Dynamic CPU frequency (Turbo/Boost)
- Systems are heterogeneous (CPU/GPU, dual socket, numa effects, E/P cores)
- Temperature/thermal throttling can alter runtime

How can we make sure our experimental measurements are reliable and conclusive?

Statistical significance - Warm-up effects

Systems need time to reach steady-state:



On a laptop: $\mathrm{Mean} = 0.315\,\mathrm{ms},\ \mathrm{CV} = 13.55\%$

We need “warm-up” iterations to measure stable performance and skip cold caches, page faults, frequency scaling.

Statistical significance - Noise mitigation

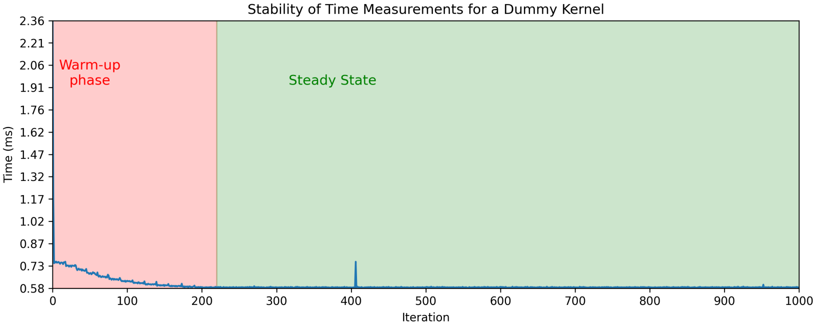
Noise can only be mitigated:

- Stop all other background processes (other users)
- Stabilize CPU Frequency (`sudo cpupower -g performance`)
    - Make sure laptops are plugged to avoid powersaving policies
- Pin threads via `taskset`, `OMP_PLACES` and `OMP_PROC_BIND`
- Consider hyperthreading
- Use stable compute nodes

Meta-repetitions are essential to mitigate noisy measurements.

Statistical significance - Example

Same experiment on a stabilized benchmarking server:



On a laptop: $\text{Mean} = 0.315\,\text{ms},\ \text{CV} = 13.55\%$
Stabilized node: $\text{Mean} = 0.582\,\text{ms},\ \text{CV} = 1.14\%$

Note

Timing on a laptop is always subpar

Statistical significance - Mean, Median, Variance

Single-run measurements are misleading; we need statistics.

- Mean runtime $\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$
- Median: less sensitive to outliers than the mean
- Variance/standard deviation: Measure of uncertainty
- Relative metrics are useful: Coefficient of variation ($CV = \frac{\sigma}{\bar{x}} \times 100\%$)

We usually give both the mean and standard deviation when giving performance results. Plots usually show $\bar{x} \pm 1\sigma$ as a shaded region around the mean to represent uncertainty.

Note

Distribution plots can be useful: stable measurements are often close to Gaussian, even if systematic noise may lead to skewed or heavy-tailed distributions.

Statistical significance - Confidence Intervals

How to decide how many repetitions we should perform ?

- Usually, the costlier the kernels, the less meta-repetitions are expected
- Short or really short kernels should have more metas to reduce the influence of noise

Remember that:

$$CI_{0.95} \approx \bar{x} \pm 1.96 \cdot \frac{\sigma}{\sqrt{n}}$$

More repetitions increase confidence, but returns diminish:
CI width $\propto \frac{1}{\sqrt{n}}$

Note

Confidence intervals are a bit less common in plots than $\pm 1\sigma$ but can also be used !

Statistical significance - p-score & Hypothesis testing

In HPC, mean/median and variance often suffice, but hypothesis testing can become handy in some contexts.

- Null hypothesis (H_0): GPU and CPU have the same performance for small matrixes
  - Differences in measurements are **only** due to noise
- Alternative hypothesis: CPU is faster for small matrixes
- **p-value** is the probability that H_0 explains a phenomenon.
- If $p < 0.05$, we can safely reject H_0 (Statistically significant difference)

Example: $\bar{x}_{GPU} = 5.0\text{s}$, $\sigma_{GPU} = 0.20$, $\bar{x}_{CPU} = 4.8\text{s}$, $\sigma_{CPU} = 0.4$, Two-sample t-test with 10 samples $p = 0.02$.

The measured differences between CPU and GPU execution time are **statistically significant**.

Experimental Methodology – Reproducibility

Reproducibility is a very hot topic (Reproducibility crisis in science):

- **Data and protocols are first-class citizens**: as important as the plots themselves
- **Transparency** matters: make data, scripts, and parameters accessible
- Enables others to **verify, build on, and trust your results**

Note

Beware of your mindset: your results should be credible and honest before being "good".

"Our results are unstable, we have yet to understand why, this is what we tried" is a completely valid answer

Plotting Tools

Plotting tools - Cheetsheet

Plotting tools - Matplotlib

Plotting tools - Seaborn

Profiling

Profiling - Time

gprof

Perf - Introduction

Perf - Performance counters

Profiling - Energy

Perf - Energy

Vtune