

HIGH PERFORMANCE COMPUTING: TOWARDS BETTER PERFORMANCE PREDICTIONS AND EXPERIMENTS

Tom Cornebize

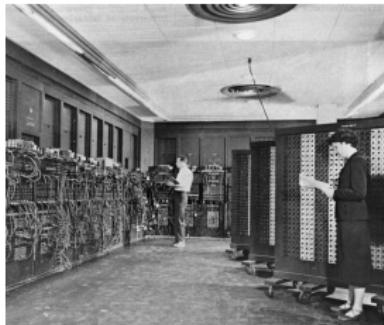
2 June 2021, PhD defense



No SCIENCE WITHOUT COMPUTING



Arithmomètre (1851)



ENIAC (1945)

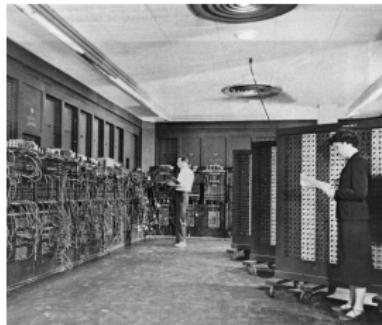


Fugaku (2021)

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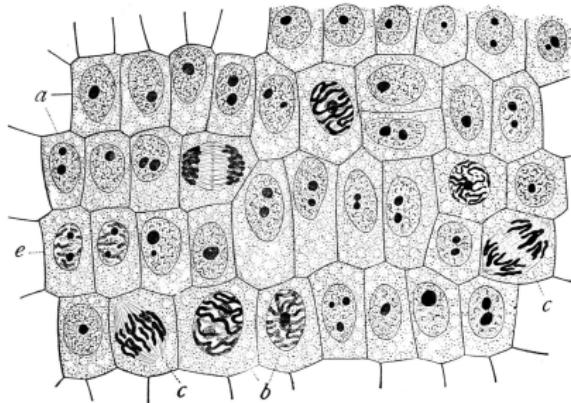


Fugaku (2021)

Last decades:

- Exponential **performance** improvements (e.g. sequencing an entire human genome costed \$100,000,000 in 2001, \$1000 now)
- At the price of **complexity** (both software and hardware)

EXPERIMENTAL STUDY OF COMPUTER PERFORMANCE



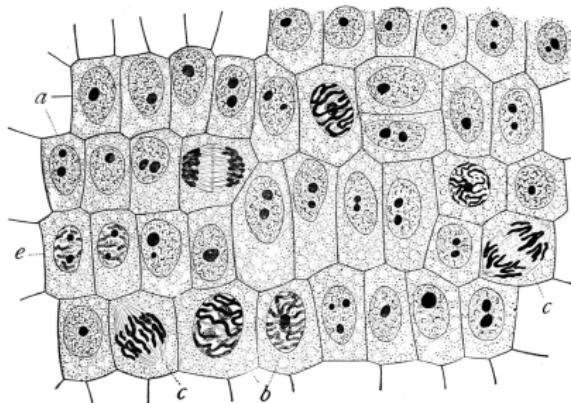
Similar to natural sciences

Complexity ⇒ Variability and Opacity

⇒ No perfect model

⇒ Need for [experiments](#)

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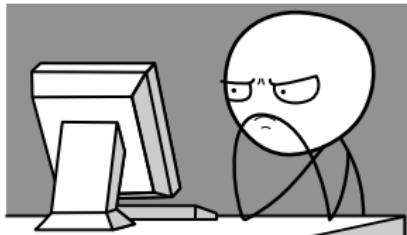
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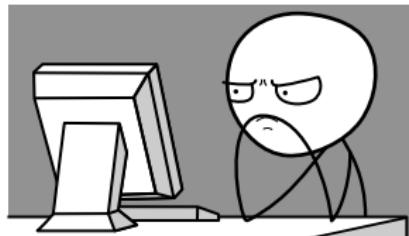
Empirical studies can be carried in reality or in simulation

Typical Performance Evaluation Questions (Given my application and a supercomputer)

- Before running
 - How many nodes?
 - For how long?
 - Which parameters?

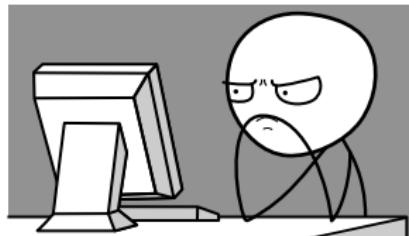


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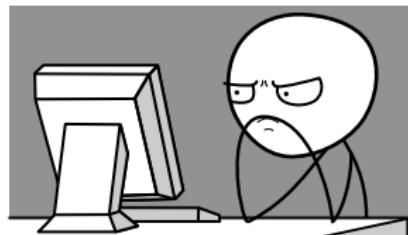
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Holy Grail: Predictive Simulation on a “Laptop”

Capture the whole application and platform complexity

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Thesis contributions (towards this goal)

- Case study: High Performance Linpack (HPL)
- Extensive (in)validation, comparing simulations with reality
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- Experiment methodology, to bias or not to bias
- Performance tests, to detect eventual platform changes

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PERFORMANCE PREDICTION THROUGH SIMULATION

SIM(EM)ULATION: THE SMPI APPROACH



Full reimplementation of MPI on top of



- C/C++/F77/F90 codes run [unmodified out of the box](#)
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Emulation: how?



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- Communications are faked, good fluid network models
- [Performance model](#) for the target platform

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Contribution: Skip the expensive computations (mostly `dgemm`) and replace them by performance models

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Validations of SMPI before this thesis: simple applications without any high performance tricks

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Contribution: predict accurately the performance of HPL



- Computations and communication overlap
- More representative of some HPC workloads
- Well established, used for the Top500

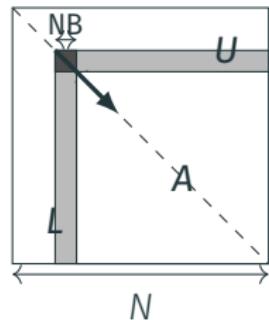
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for k = N to 0 step NB do  
    Allocate the panel  
    Factor the panel  
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    Update the sub-matrix
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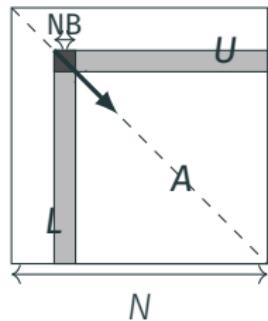
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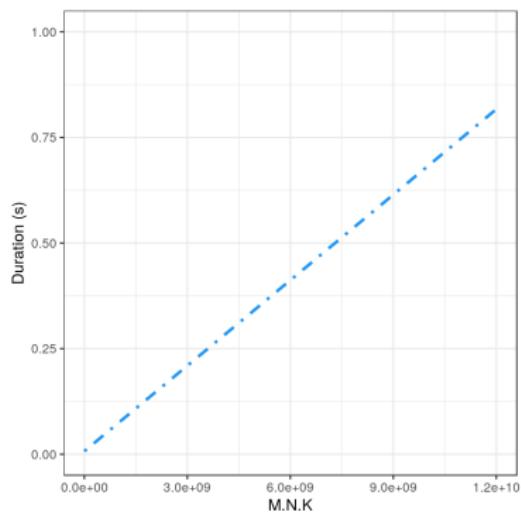
Tuning parameters

- Broadcast algorithm
- Block size
- Process grid
- etc.

Hundreds of combinations

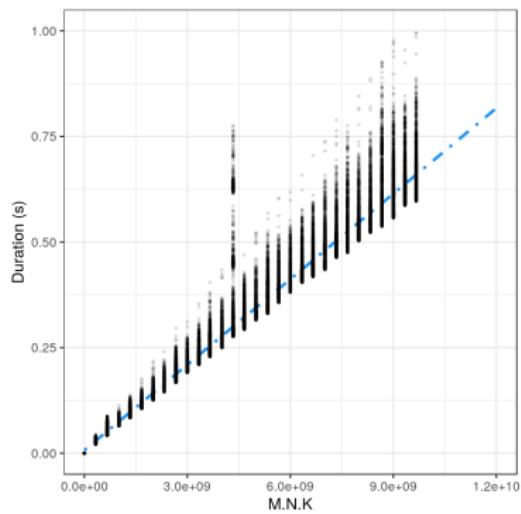
MODELING COMPUTATIONS

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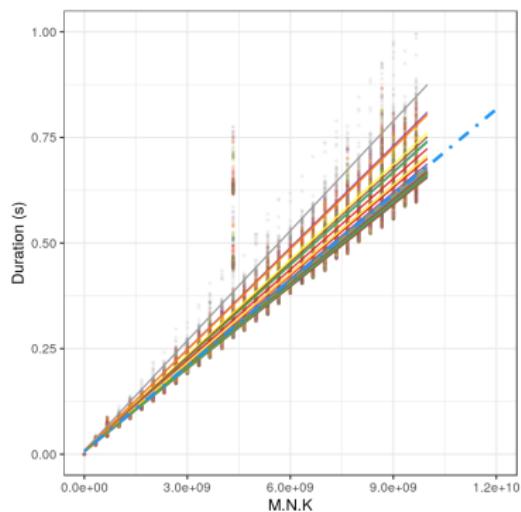
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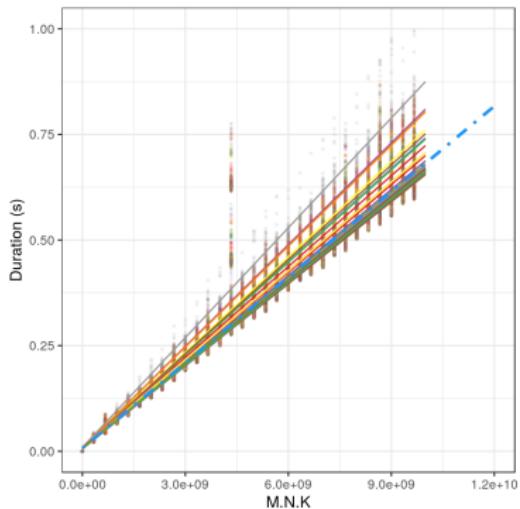
Different color \Rightarrow different host



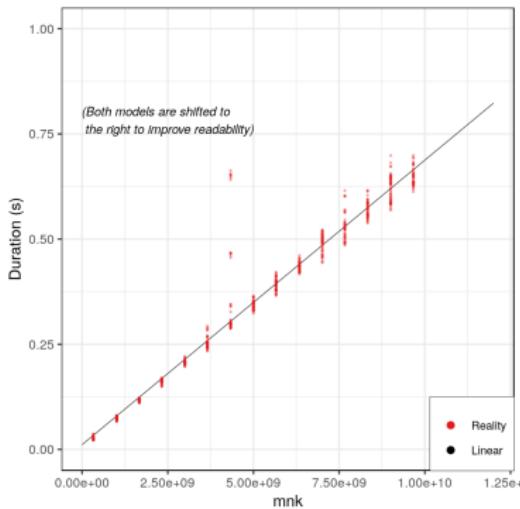
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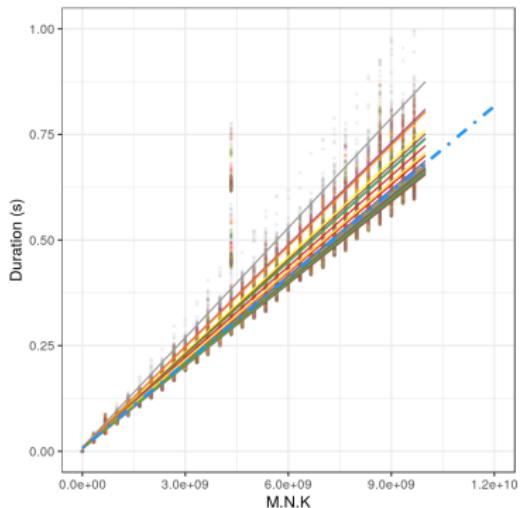
For a particular host



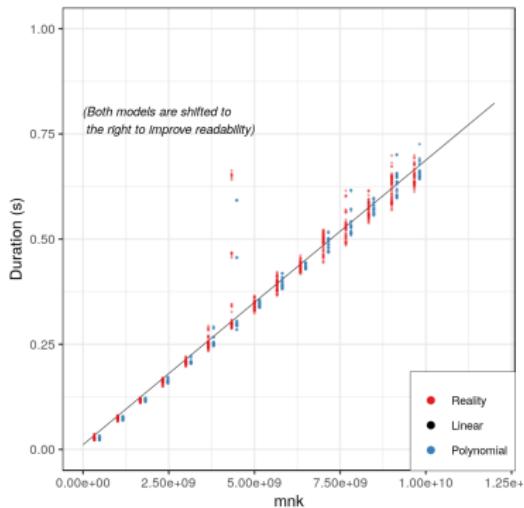
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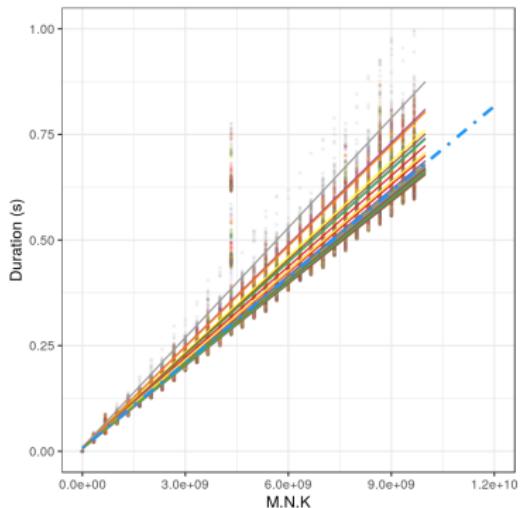
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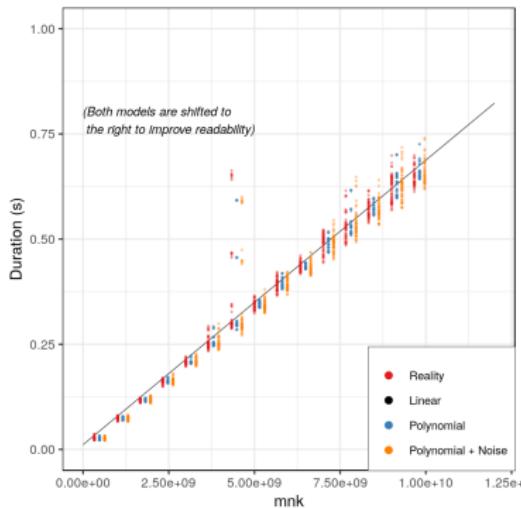
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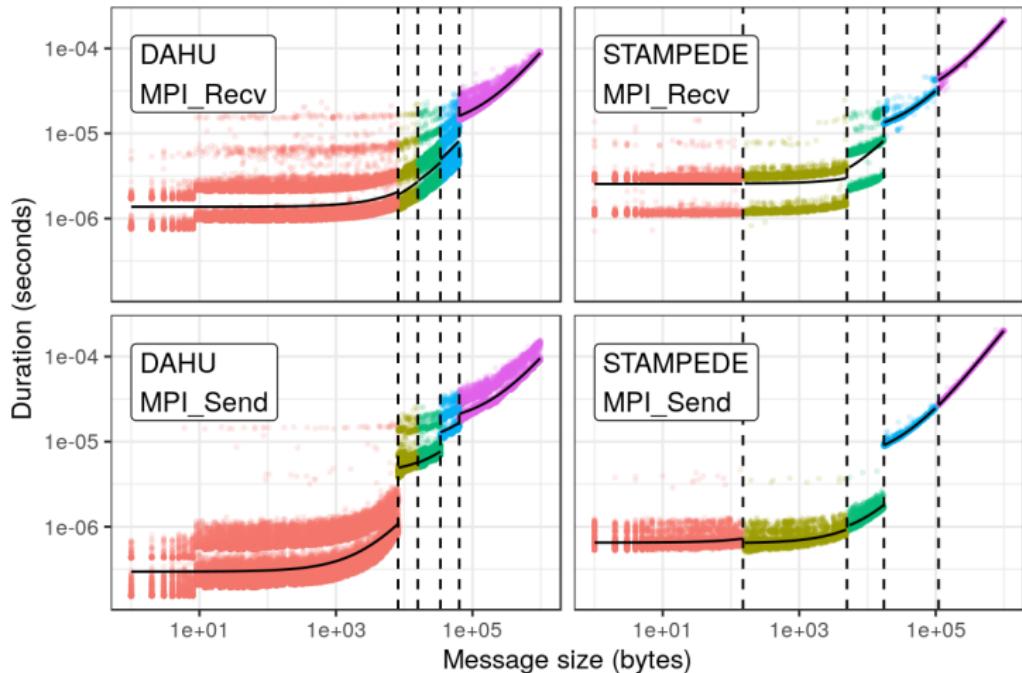


MODELING COMMUNICATIONS

Hand-crafted non-blocking collective operations intertwined with computations

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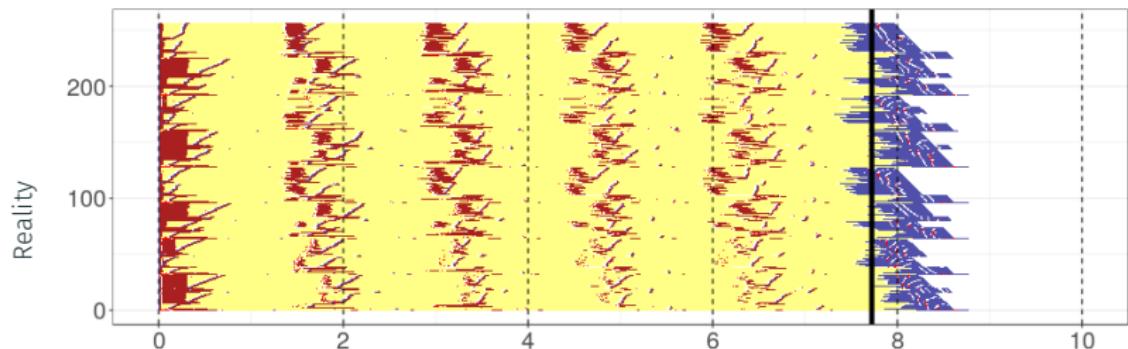
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VALIDATING THE PREDICTIONS

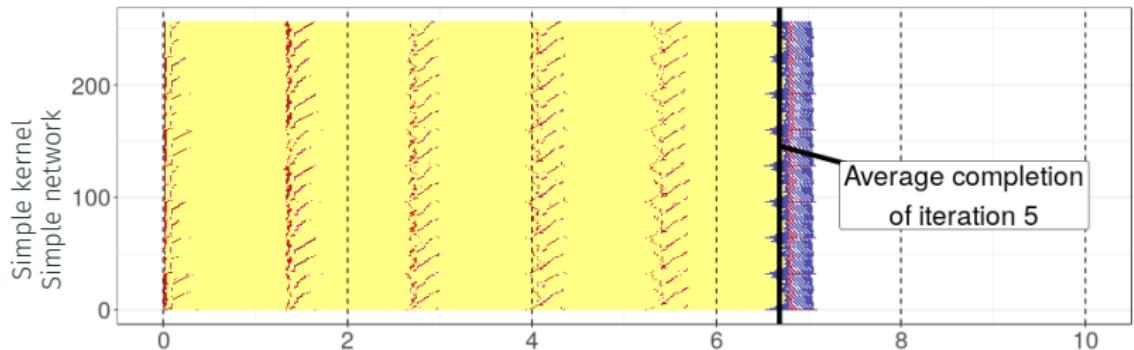
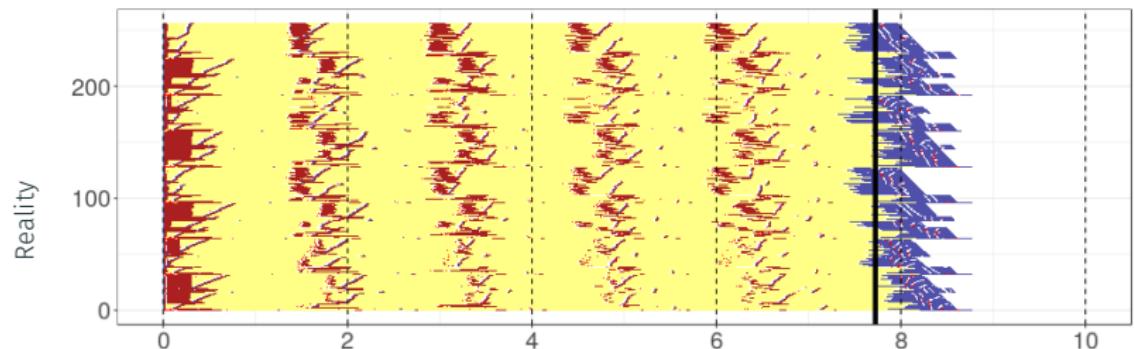
INTERNAL BEHAVIOR OF THE APPLICATION

256 MPI ranks, interrupted after the 5th iteration



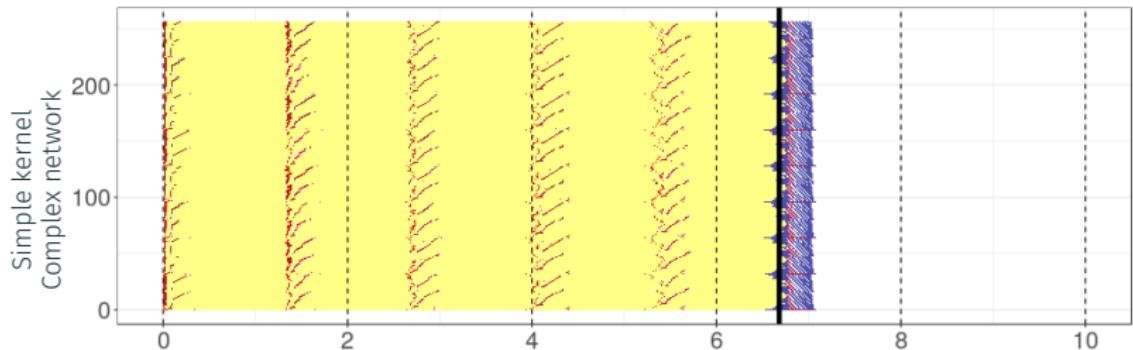
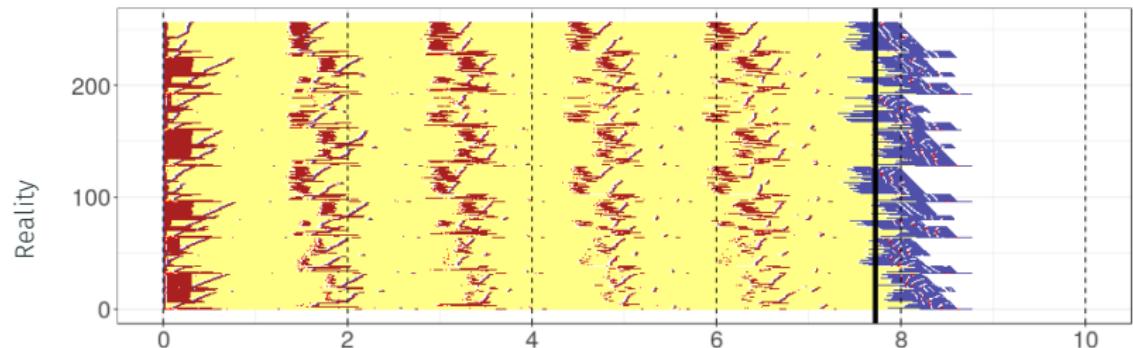
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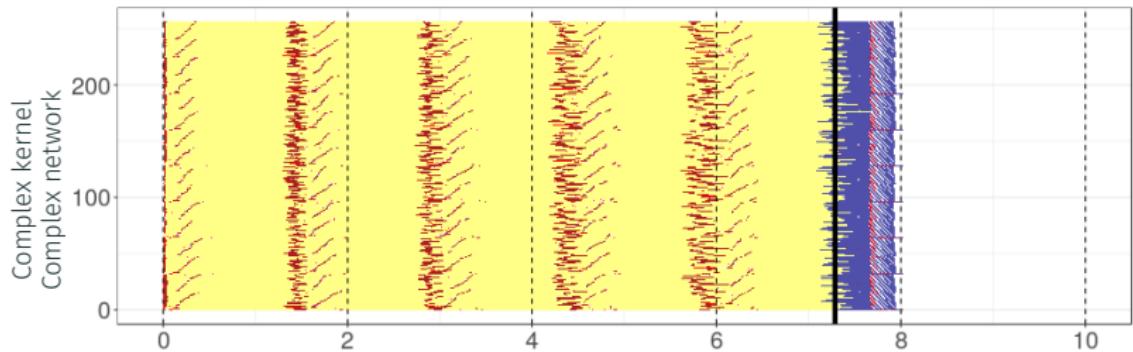
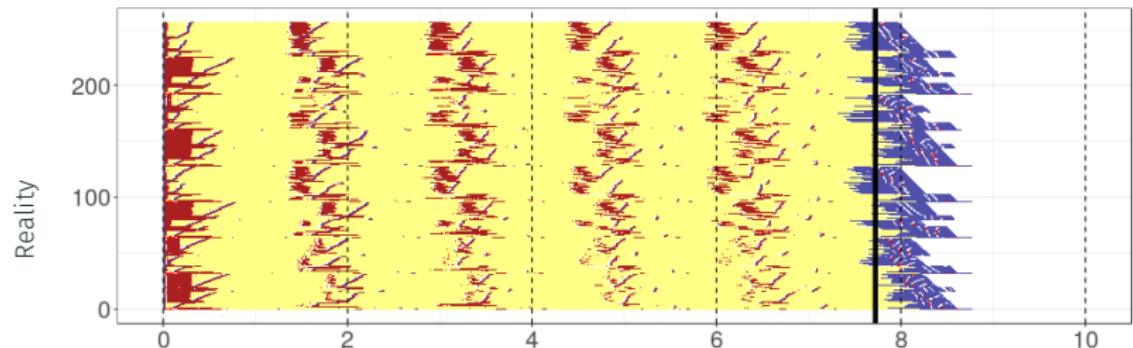
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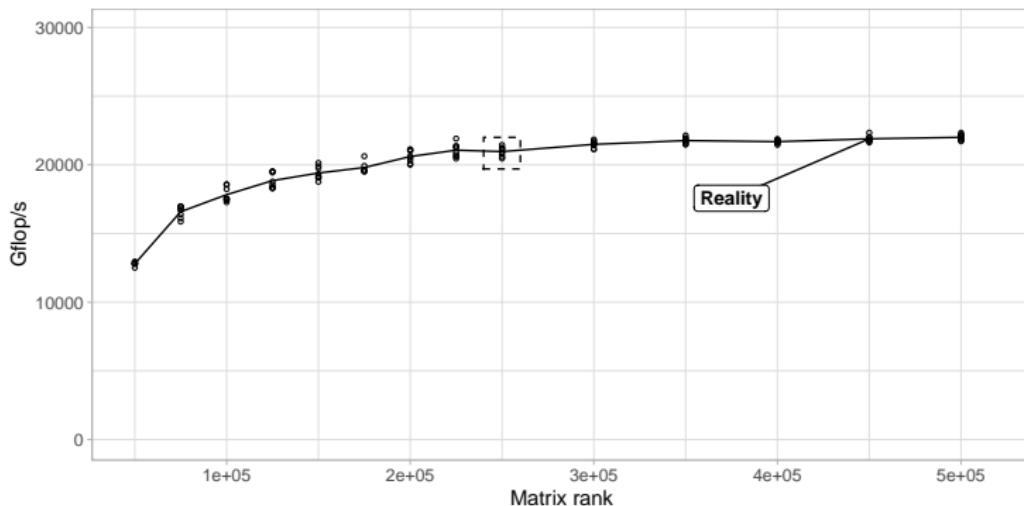
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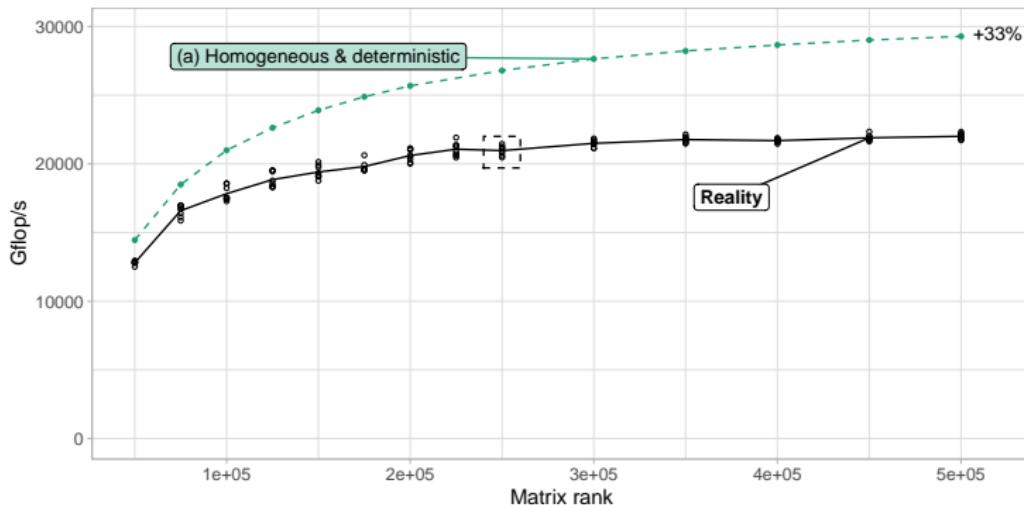
INFLUENCE OF THE PROBLEM SIZE

Now the complete run, with 1024 MPI ranks



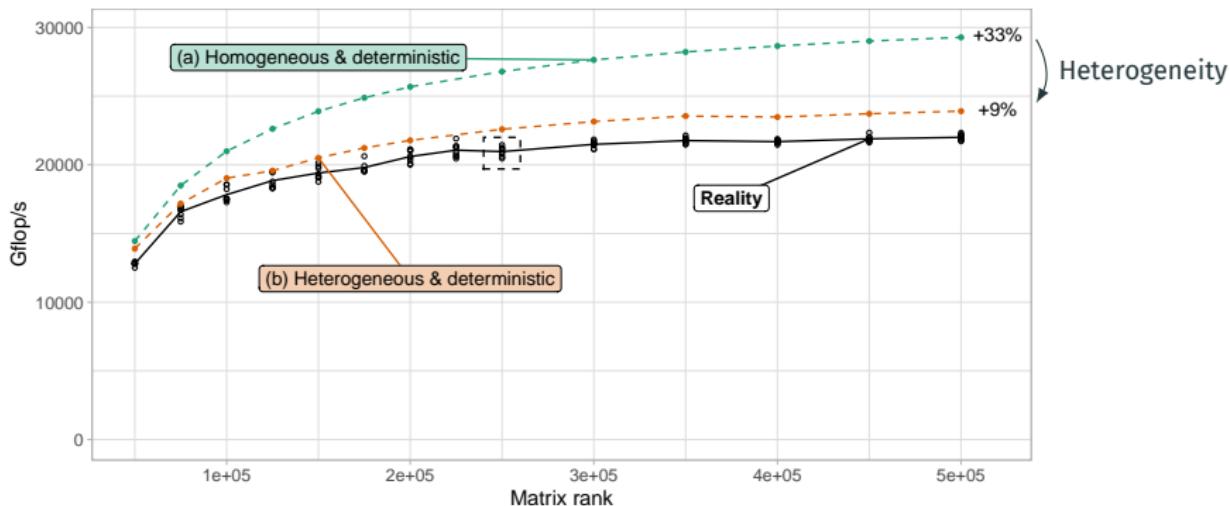
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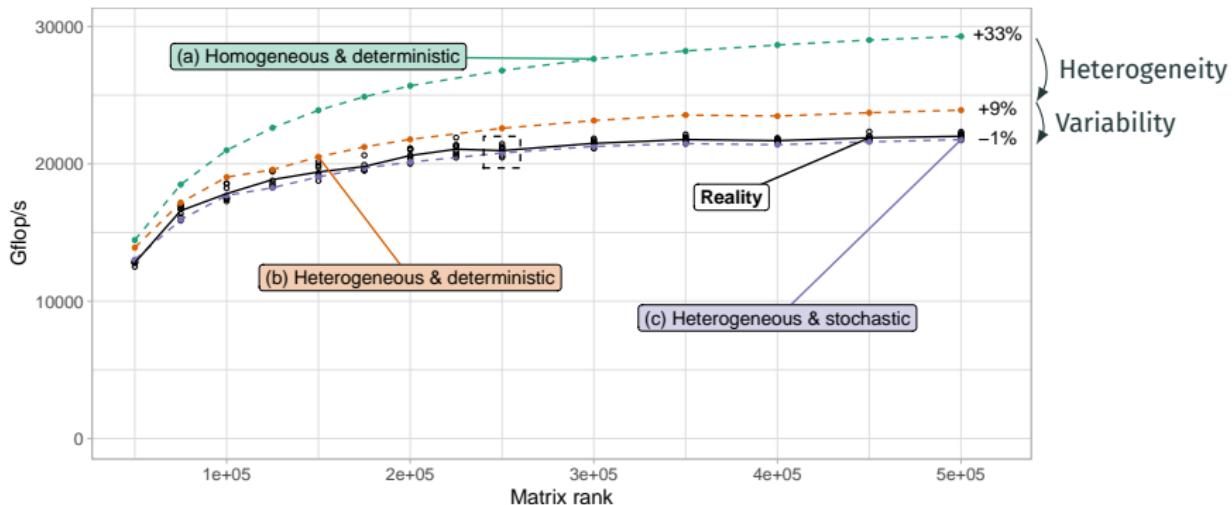
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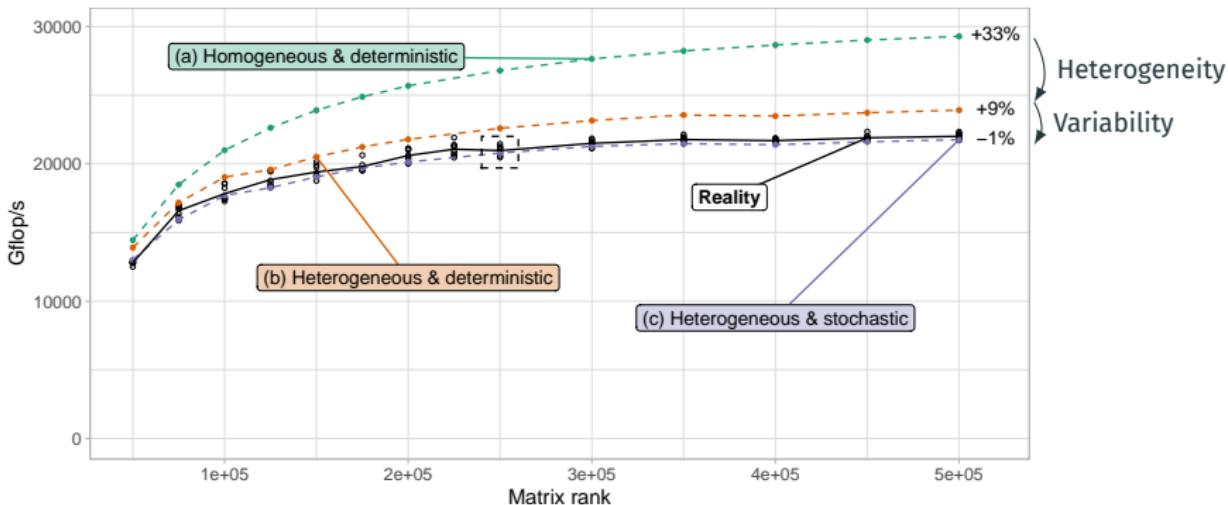
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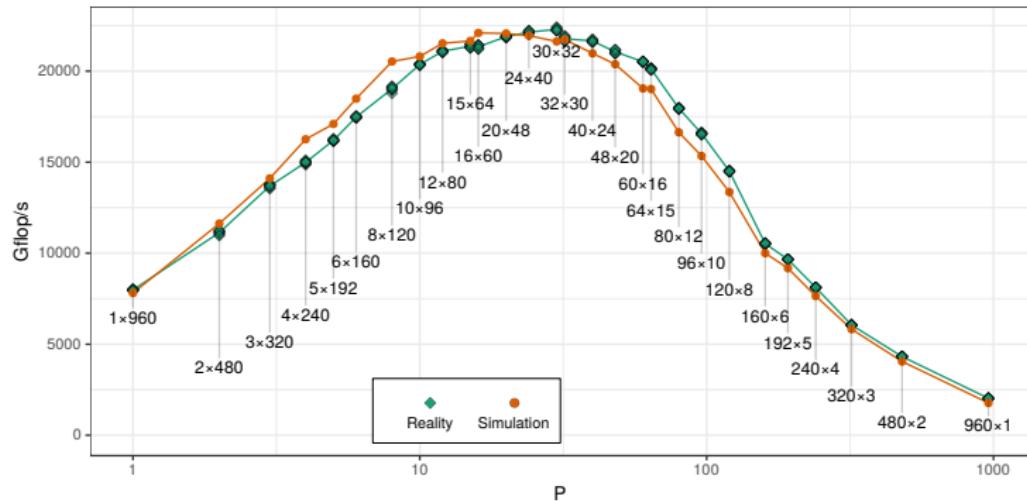


Take-Away Message: accurate prediction

Modeling both spatial and temporal computation variability is essential

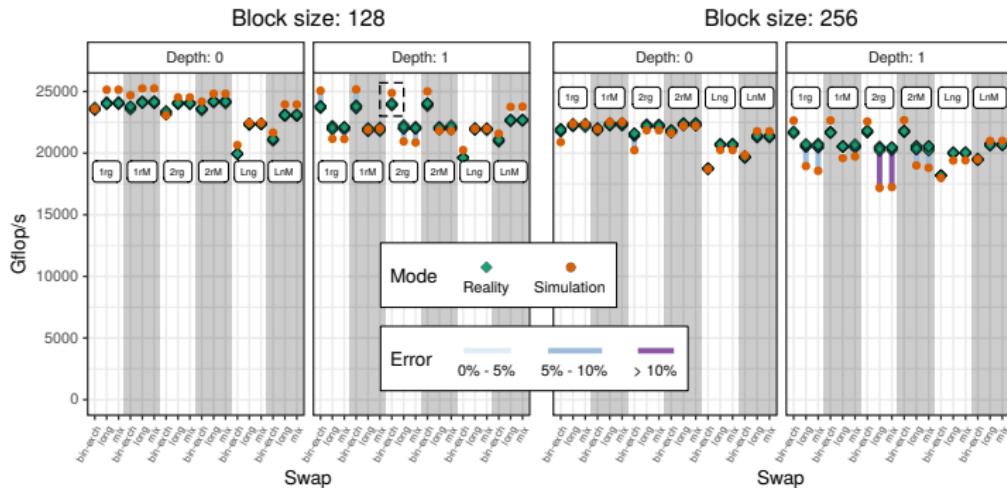
INFLUENCE OF THE GEOMETRY

$P \times Q$ MPI processes, organized in a 2D grid

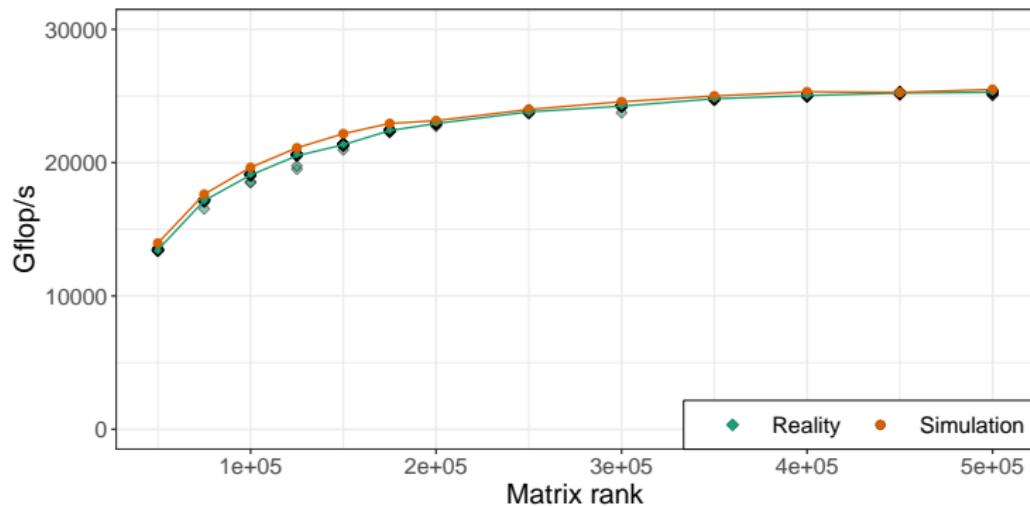


INFLUENCE OF THE OTHER PARAMETERS

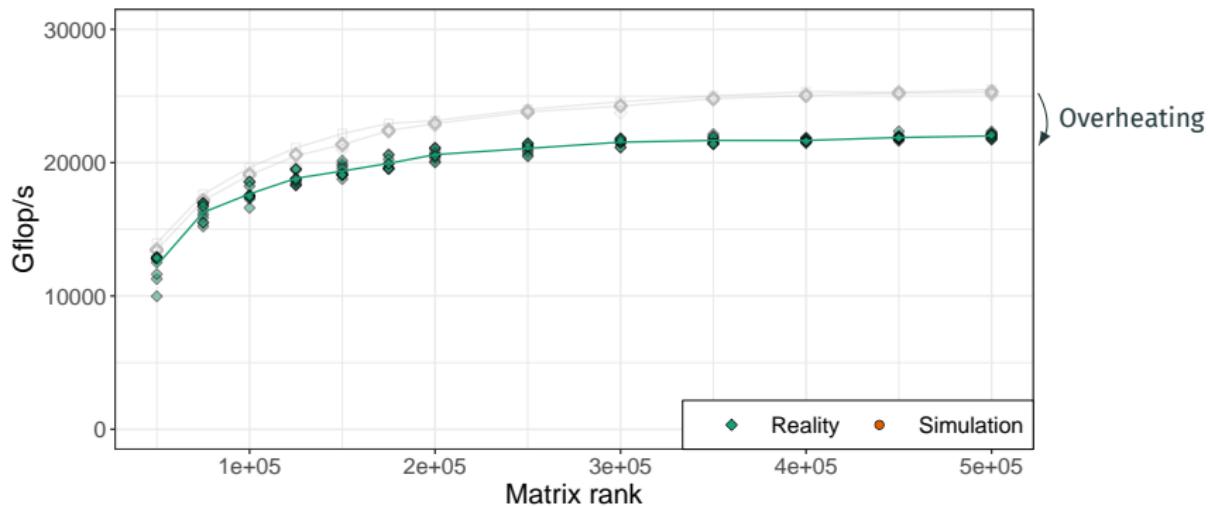
Tested the 72 combinations of the remaining parameters



INFLUENCE OF A PLATFORM CHANGE

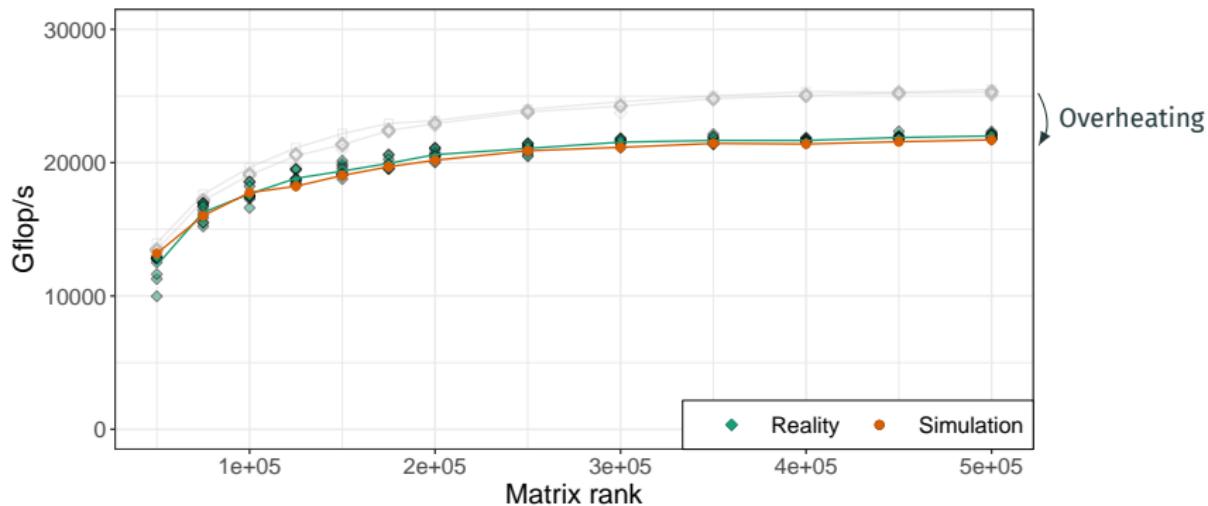


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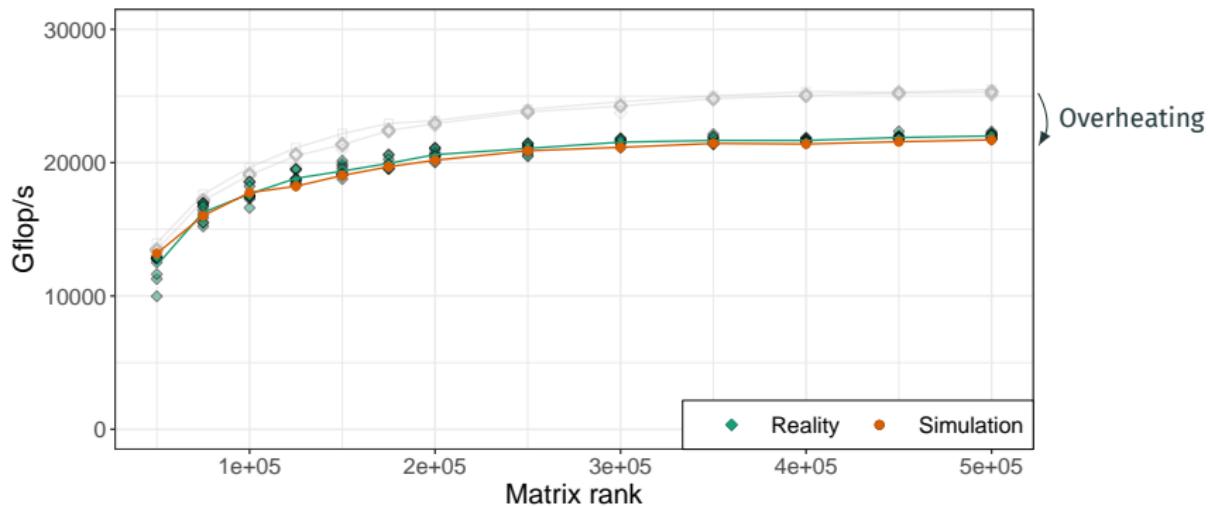
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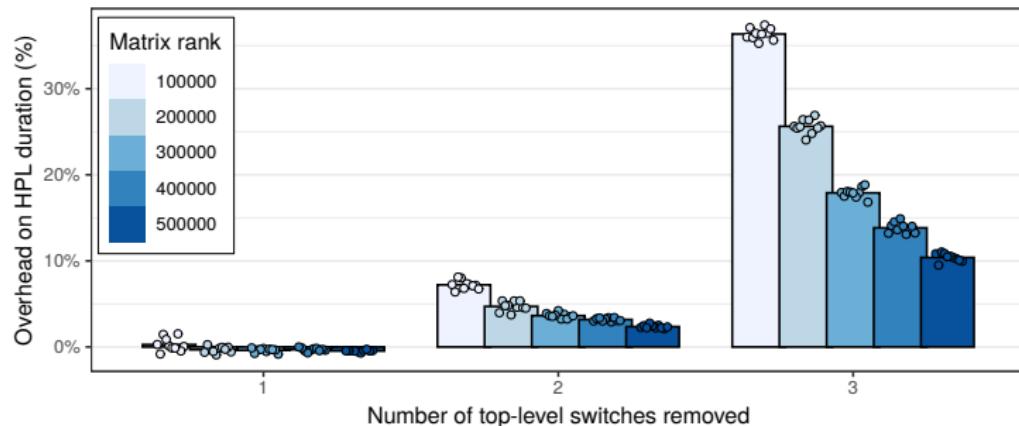


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Take-Away Message: Re-measuring `dgemm` durations to generate a new model was enough to account for the platform change

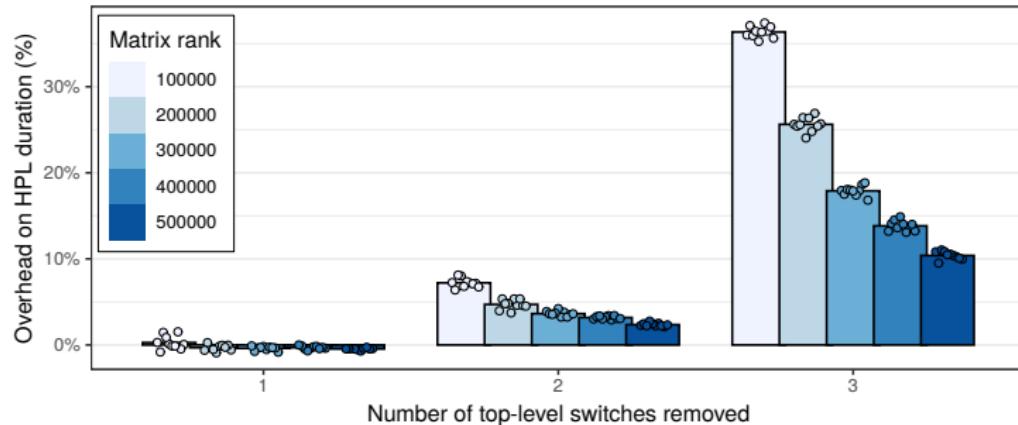
USE CASE: SENSIBILITY ANALYSIS

What if the network topology of my cluster was different?



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Faithful surrogate \Rightarrow Empirical studies of hypothetical platforms
 \Rightarrow Extrapolation of existing platforms
 \Rightarrow Accounting for spatial and temporal variability

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Main difficulties:

- Realistic experimental conditions
- Platform changes (e.g., the cooling issue)

PARENTHESIS: ON THE DIFFICULTIES OF EXPERIMENTATION

Experimental biases when measuring `dgemm` or MPI durations

Effect on durations, but also other metrics (e.g. CPU frequency)

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Bias may be desirable in some situations

PERFORMANCE TESTS

REGULAR MEASURES

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454 nodes (792 CPU) from 12 clusters



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For each CPU, collect:

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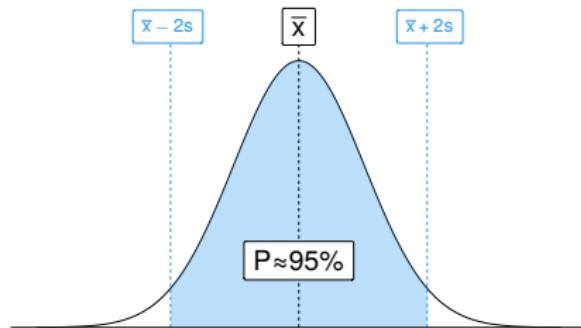
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Each parameter is **normally distributed** (thanks to CLT)

FLUCTUATION INTERVAL

Given a sequence of old observations x_1, \dots, x_n and a new observation x_{n+1} , how likely was it to observe x_{n+1} ?

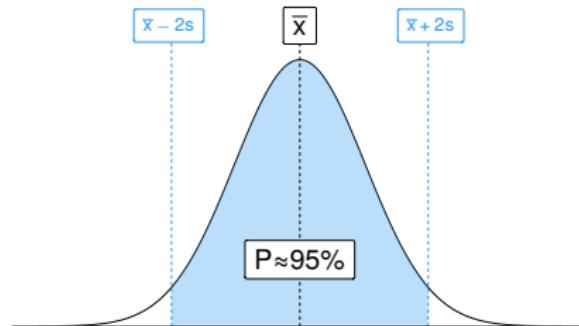


Take the sample mean \bar{x} and standard deviation s of the old observations

$$\mathbb{P}(x_{n+1} \in [\bar{x} - 2s; \bar{x} + 2s]) \approx 95\%$$

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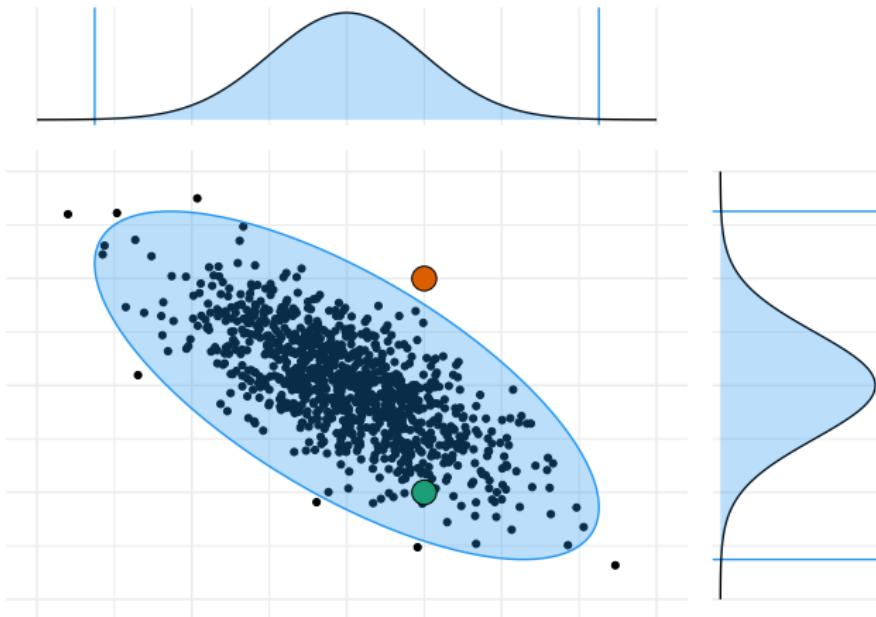
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Note: using the F distribution instead of the normal distribution (the true mean and standard deviation are unknown)

FLUCTUATION INTERVAL FOR SEVERAL VARIABLES

With several variables, using their [covariance matrix](#)

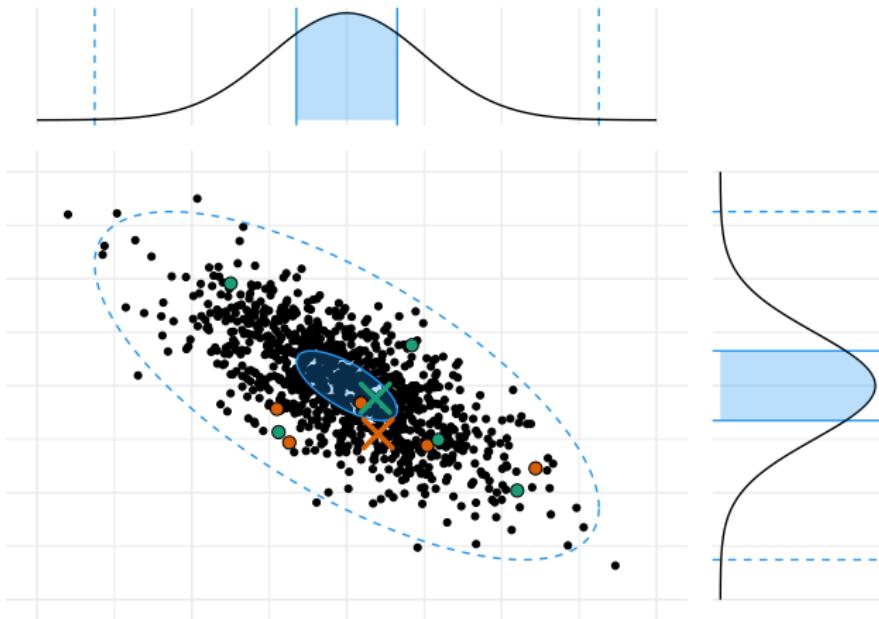
Example in dimension 2, with $\mathbb{P}(x_{n+1} \in \text{interval}) \approx 99.5\%$



FLUCTUATION INTERVAL FOR SEVERAL MEASURES

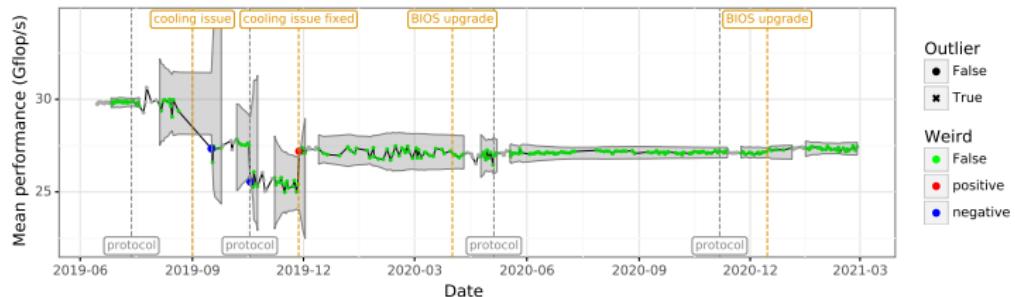
With several measures, using their **average** and shrinking the interval

Example with 5 measures (averages represented by crosses)



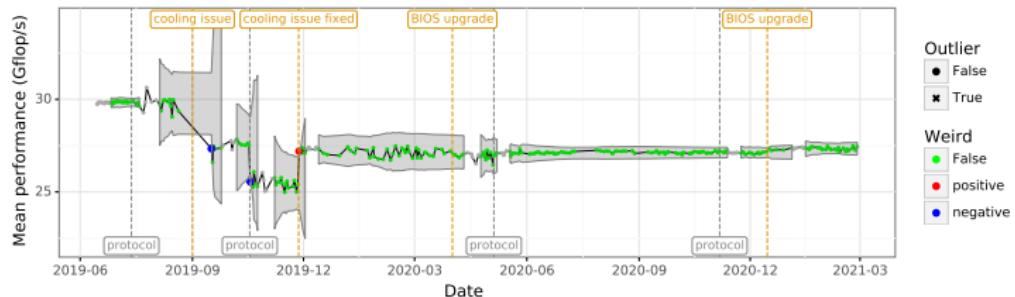
RESULT: PERFORMANCE FLUCTUATION

Performance fluctuation of the node dahu-14

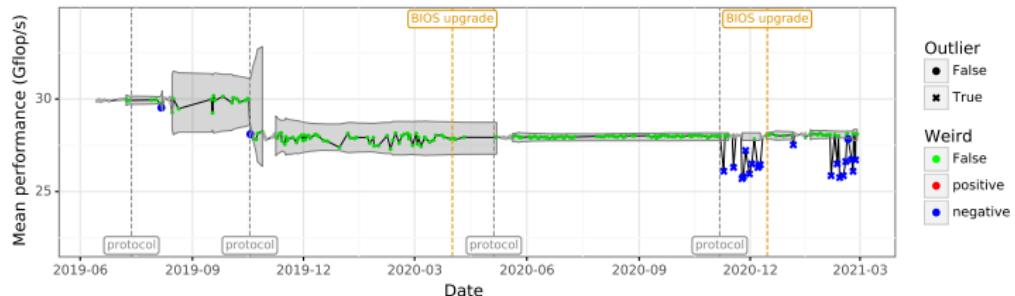


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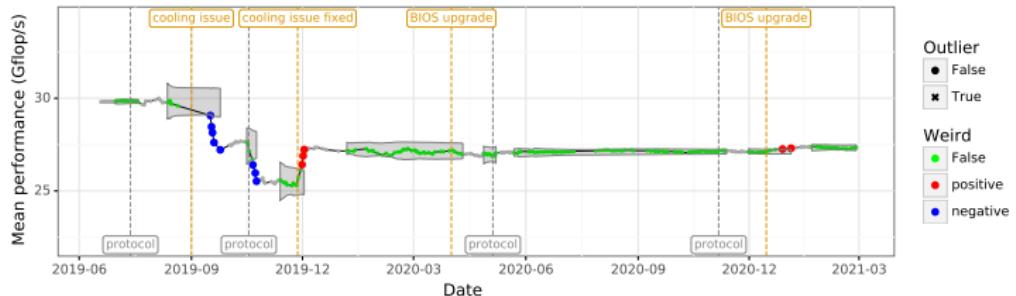


Performance fluctuation of the node dahu-32

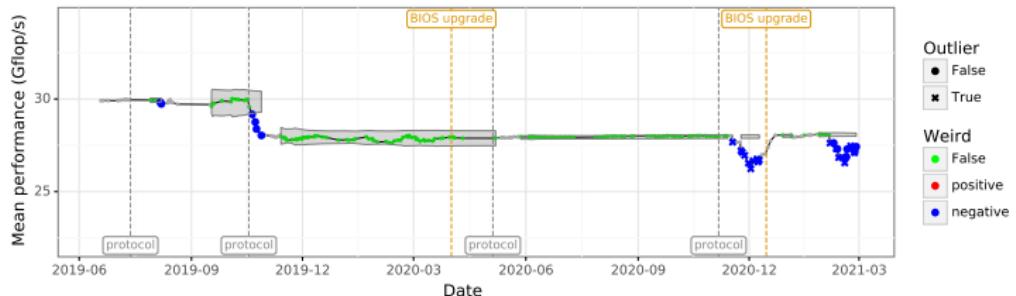


RESULT: PERFORMANCE FLUCTUATION

Performance fluctuation of the node dahu-14 (5-day window)

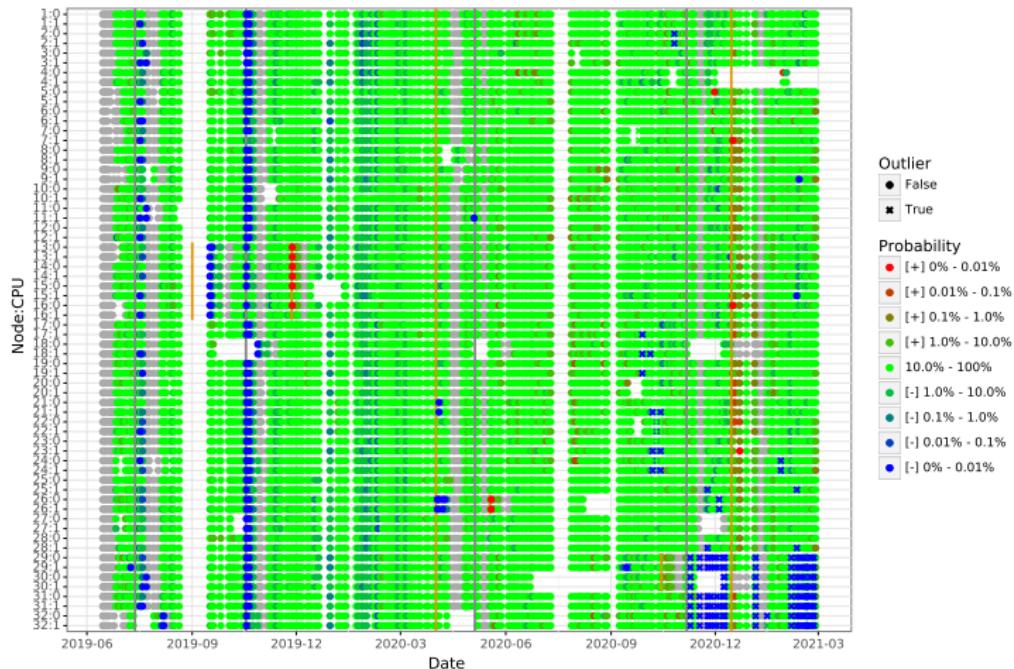


Performance fluctuation of the node dahu-32 (5-day window)



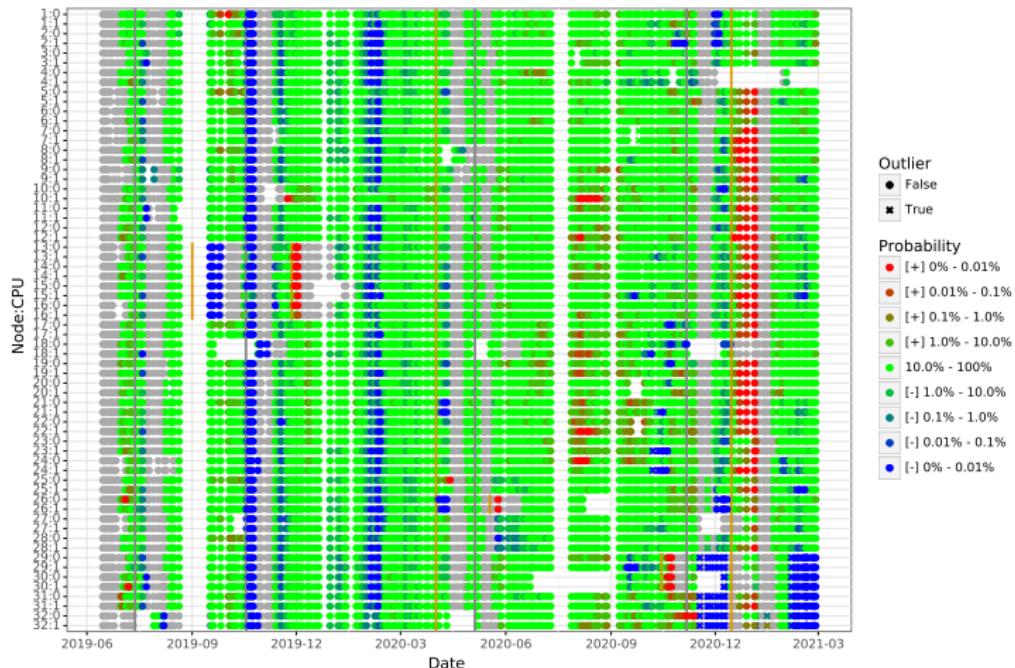
RESULT: PERFORMANCE OVERVIEW

Overview of the performance on cluster dahu



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PERFORMANCE TESTS: WRAPING UP

Multi-variable test also implemented

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Cluster	Performance	Performance _{PS4}	Frequency	Power _{CPU}	Power _{DRAM}	Temperature	Model
chezeli							
chidet							
dahu							
ecotype							
grossu							
gras							
gringst							
parasito							
panitanice							
pyxis							
troll							
yeti							

Detected events

- BIOS upgrades
- Cooling issue
- Faulty memory
- Power instability

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troll							
yeti							

Legend:

- Intercept: MNK
- MN
- MK
- NK
- M
- N
- K
- Intercept_residual: MNK_residual
- MN_residual
- MK_residual
- NK_residual
- M_residual
- N_residual
- K_residual

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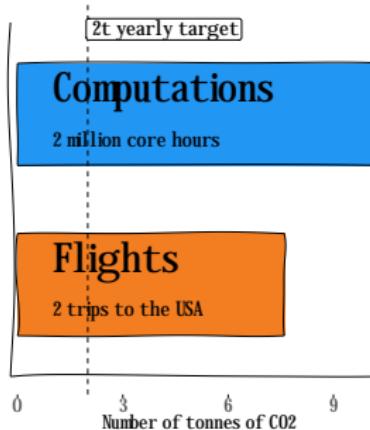
All went unnoticed by both Grid'5000 staff and users, despite significant effects

⇒ Great help potential

CONCLUDING THOUGHTS

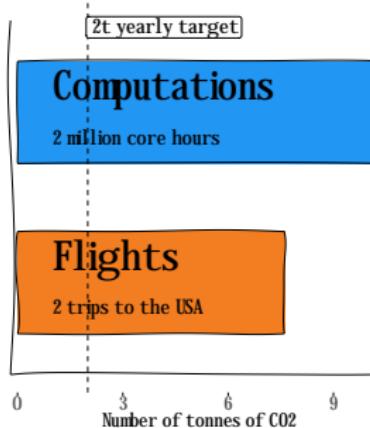
THERE IS NO PLANET B

About 18t of CO₂eq were emitted for this thesis



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Do we really *need* to attend conferences in person?

What about computations?

WHY SO MANY COMPUTATIONS?

More than half the total core hours were used for performance tests

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Who should be responsible of tests?

- Platform staff? But what should they test?
- Researchers? Isn't it redundant?

MODELING COMPUTATIONS

$$\text{dgemm}(M, N, K) = \frac{\alpha_1 M, N, K + (\beta_1 M, N + \gamma_1 N, K + \dots + N[0, \alpha'_1] M, N, K + \dots)}{\text{per host}} + \frac{\text{polynomial model}}{\text{polynomial size}}$$

