

# HIGH PERFORMANCE COMPUTING: TOWARDS BETTER PERFORMANCE PREDICTIONS AND EXPERIMENTS

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Tom Cornebize

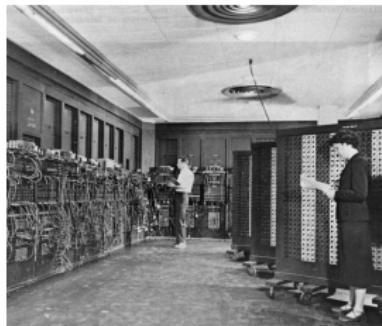
2 June 2021, PhD defense



# No SCIENCE WITHOUT COMPUTING



Arithmomètre (1851)



ENIAC (1945)

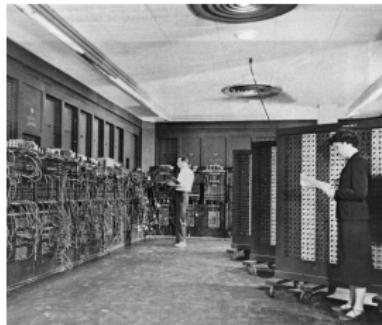


Fugaku (2021)

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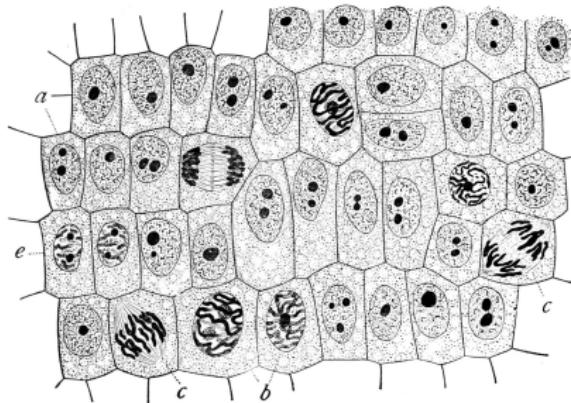


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Last decades:

- 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



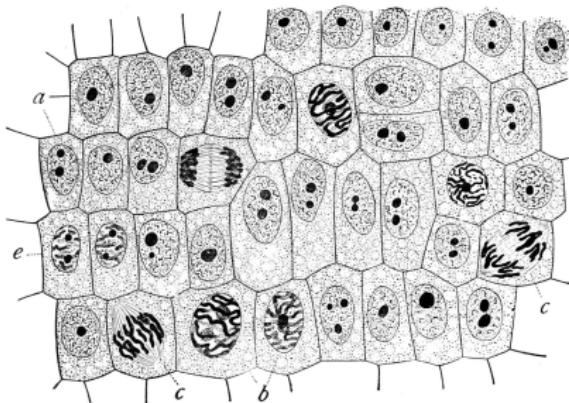
Similar to natural sciences

Complexity ⇒ Variability and Opacity

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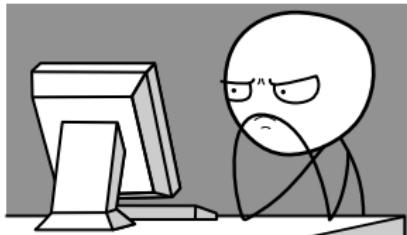
⇒ Need for experiments

Empirical studies can be carried in reality or in simulation

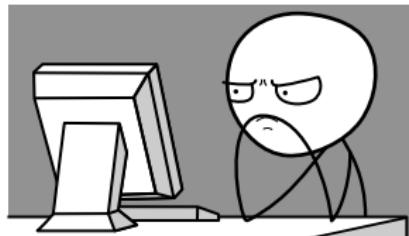
## Typical Performance Evaluation Questions (Given my application and a supercomputer)

- **Before** running

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

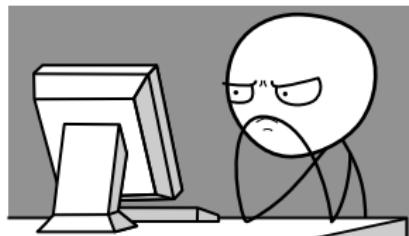


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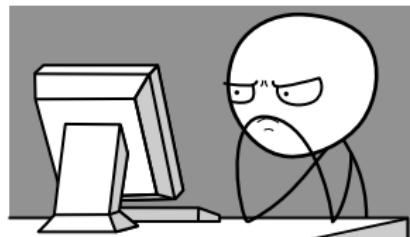
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## Holy Grail: Predictive Simulation on a “Laptop”

Capture the whole application and platform complexity

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# PERFORMANCE PREDICTION THROUGH SIMULATION

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

## QUICK WORD ON HPL

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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

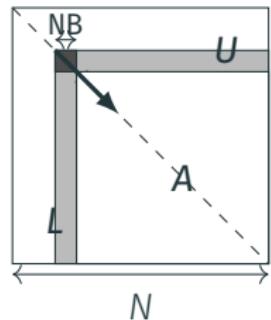
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Allocate and initialize A  
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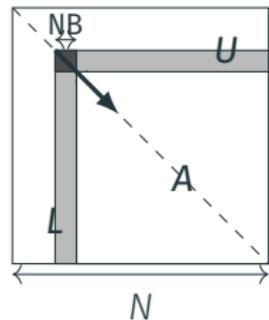
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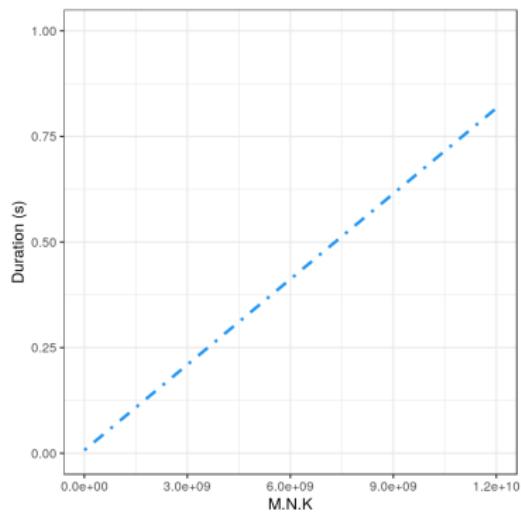
## Tuning parameters

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

Hundreds of combinations

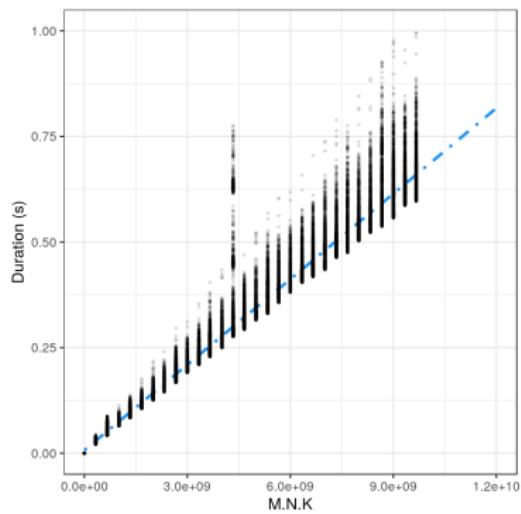
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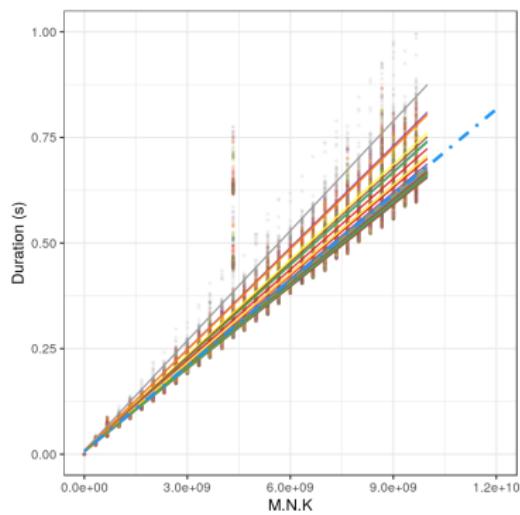
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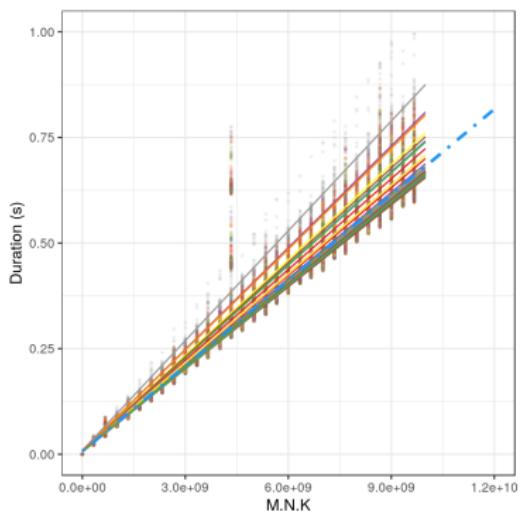
Different color  $\Rightarrow$  different host



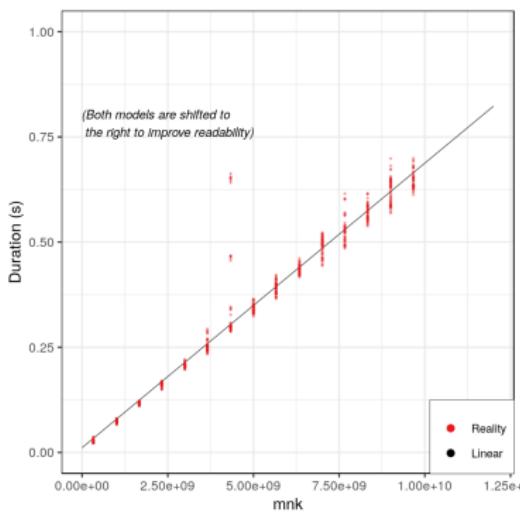
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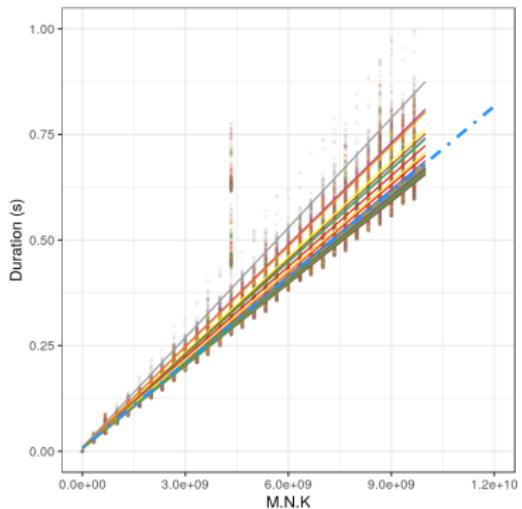
For a particular host



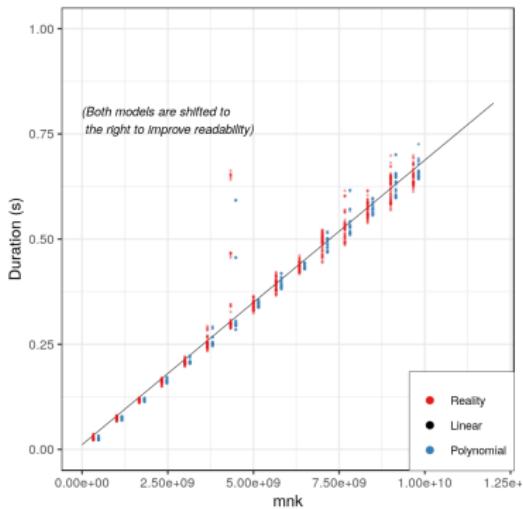
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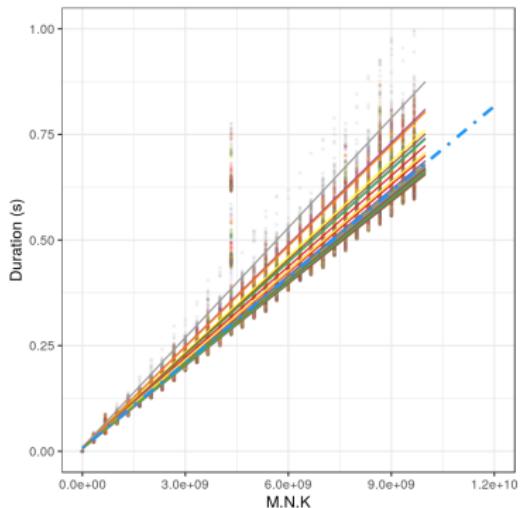
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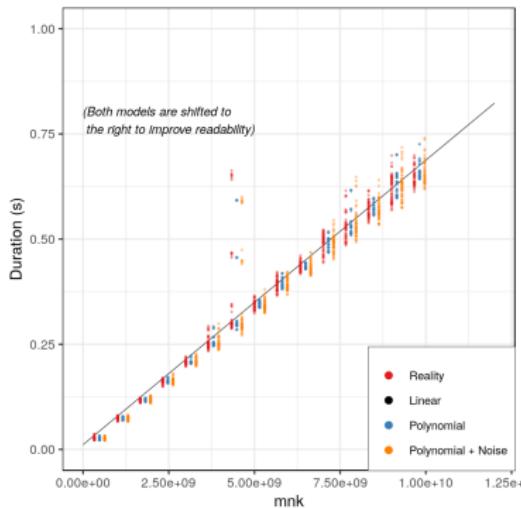
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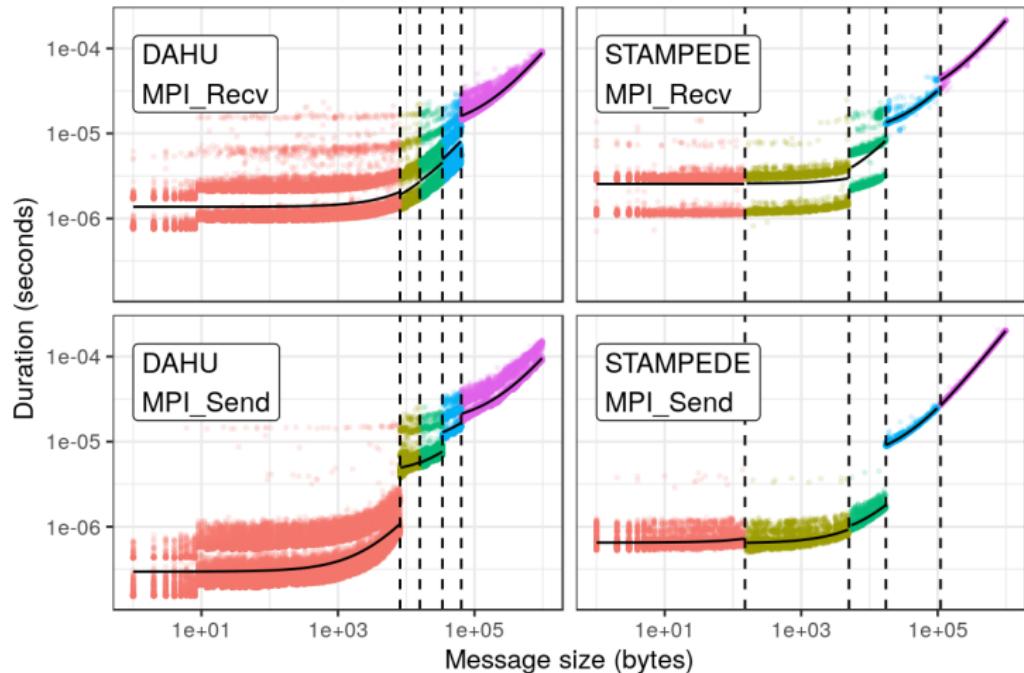
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Hand-crafted non-blocking collective operations intertwined with computations

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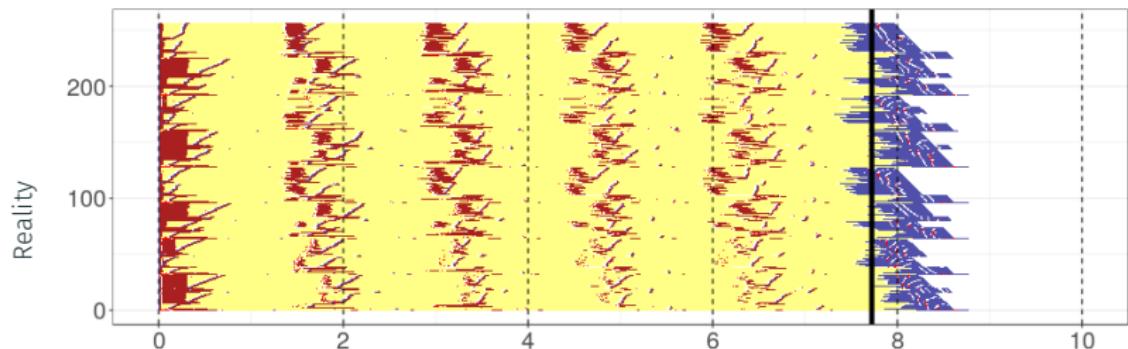


## VALIDATING THE PREDICTIONS

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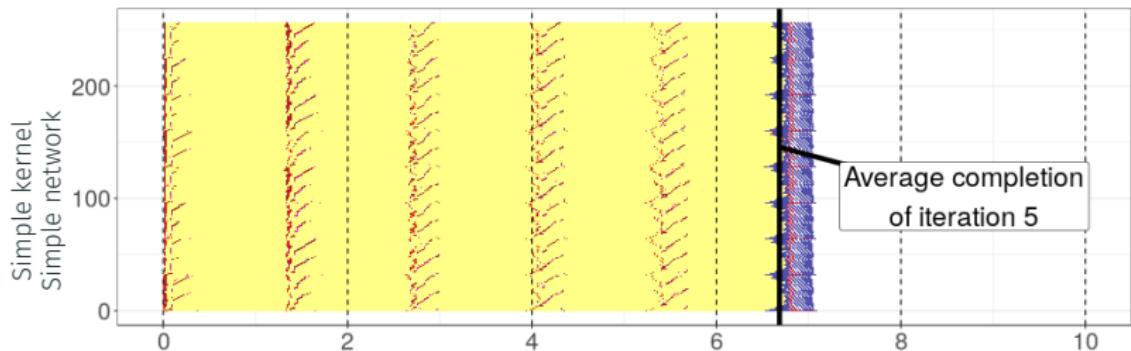
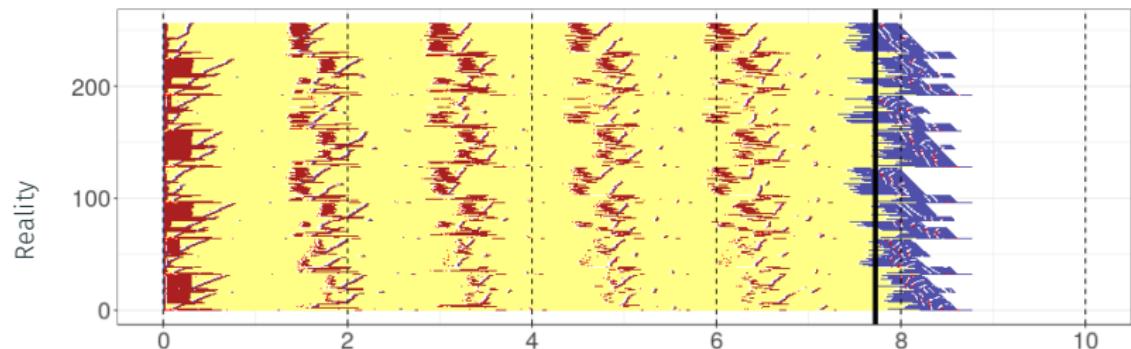
# INTERNAL BEHAVIOR OF THE APPLICATION

256 MPI ranks, interrupted after the 5<sup>th</sup> iteration



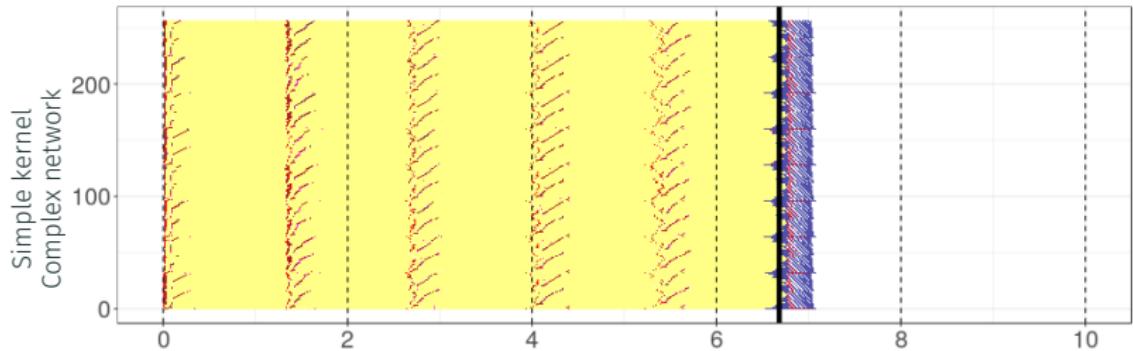
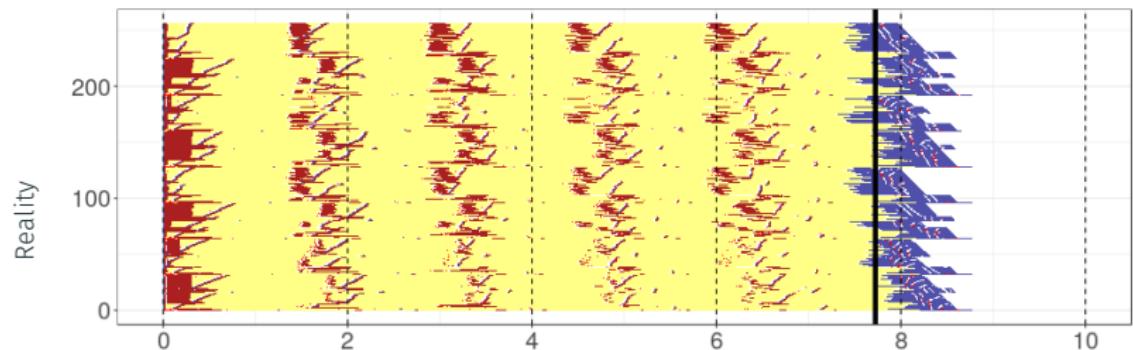
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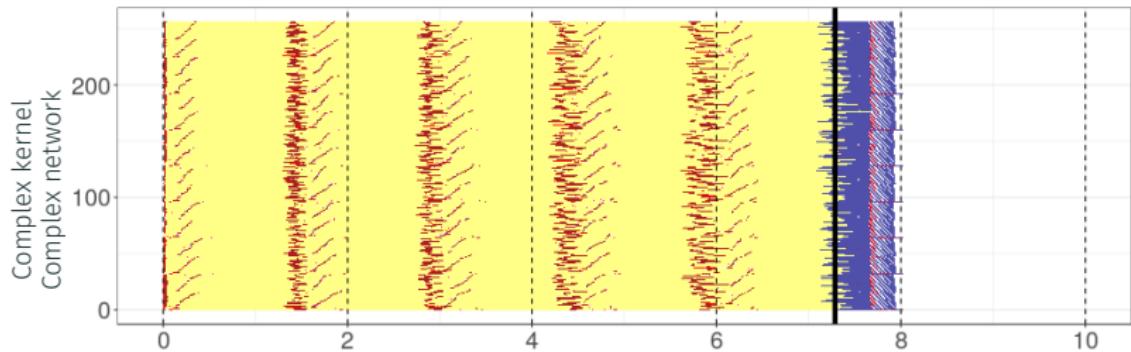
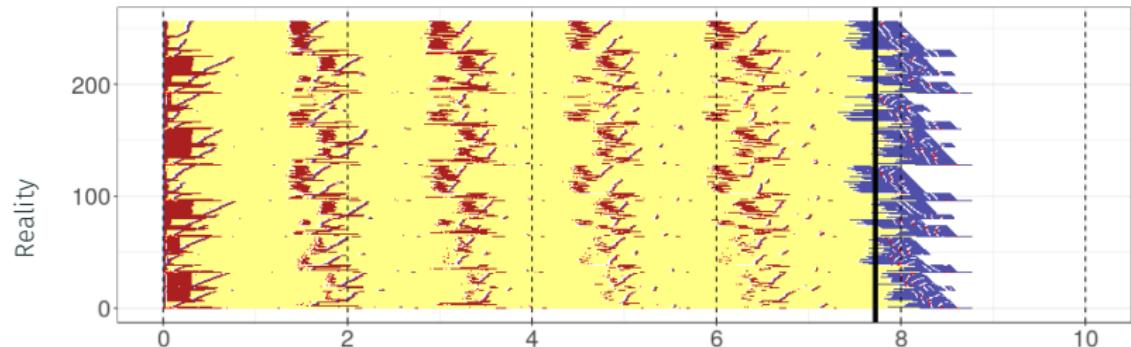
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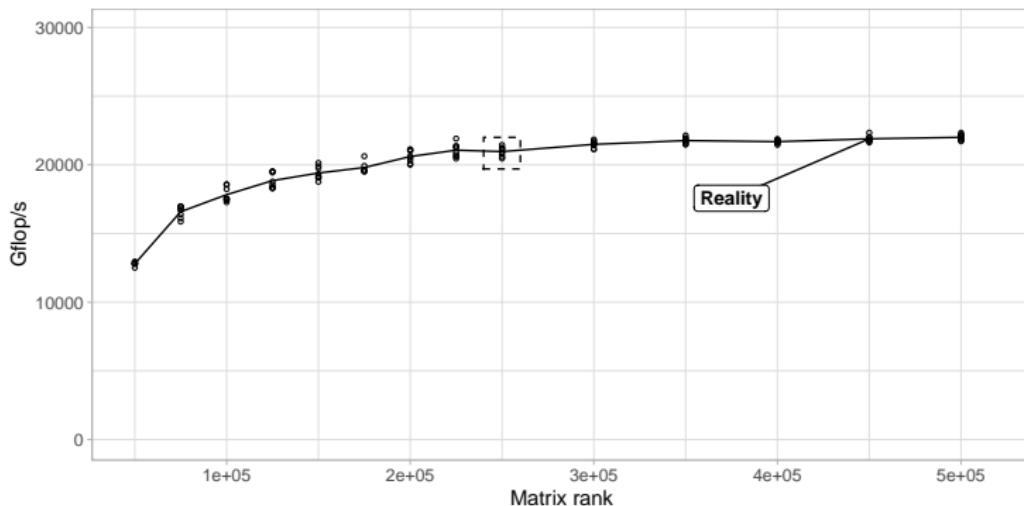
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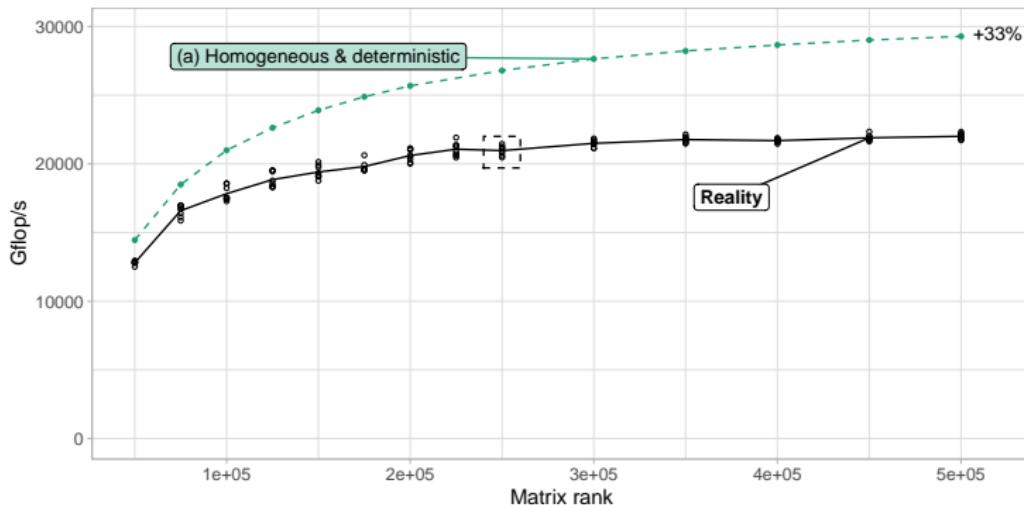
# INFLUENCE OF THE PROBLEM SIZE

Now the complete run, with 1024 MPI ranks



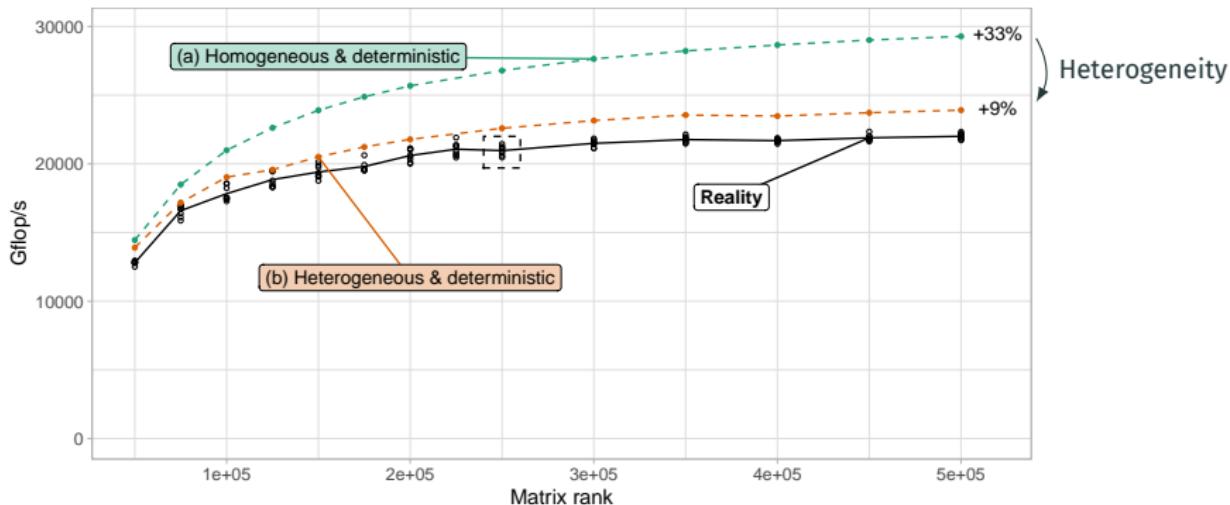
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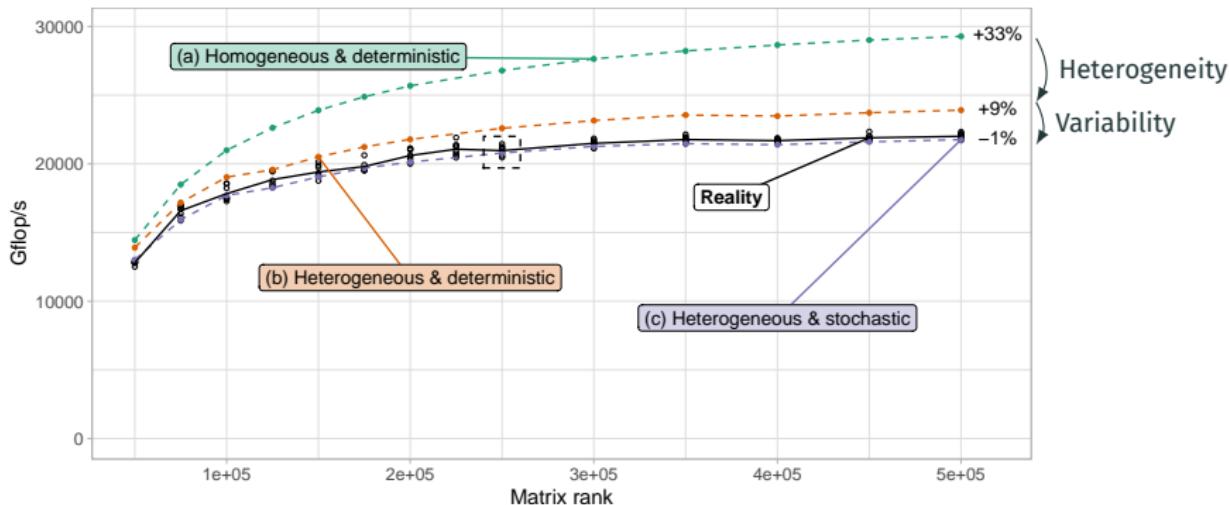
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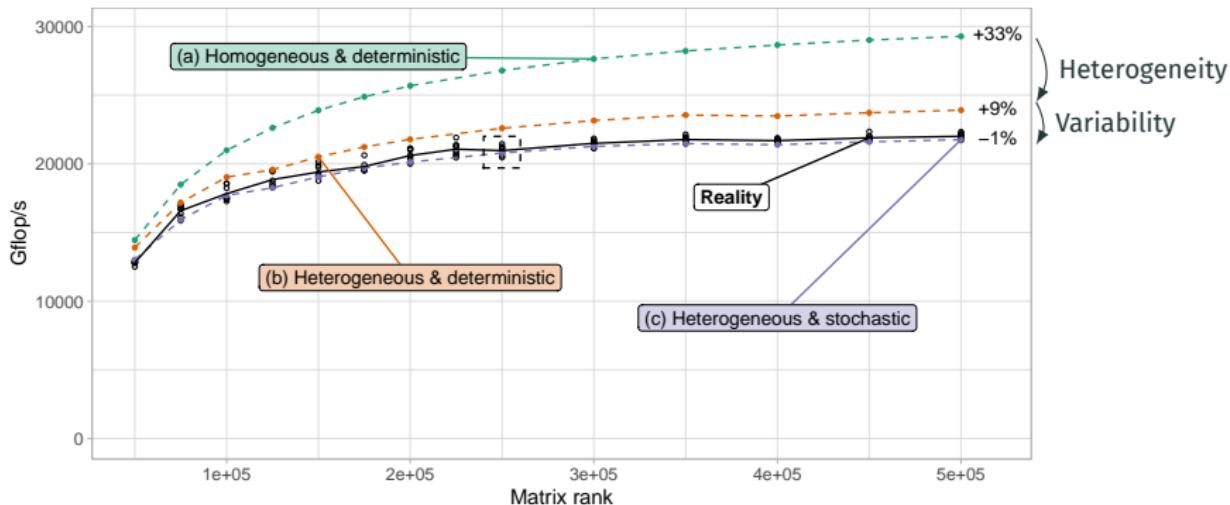
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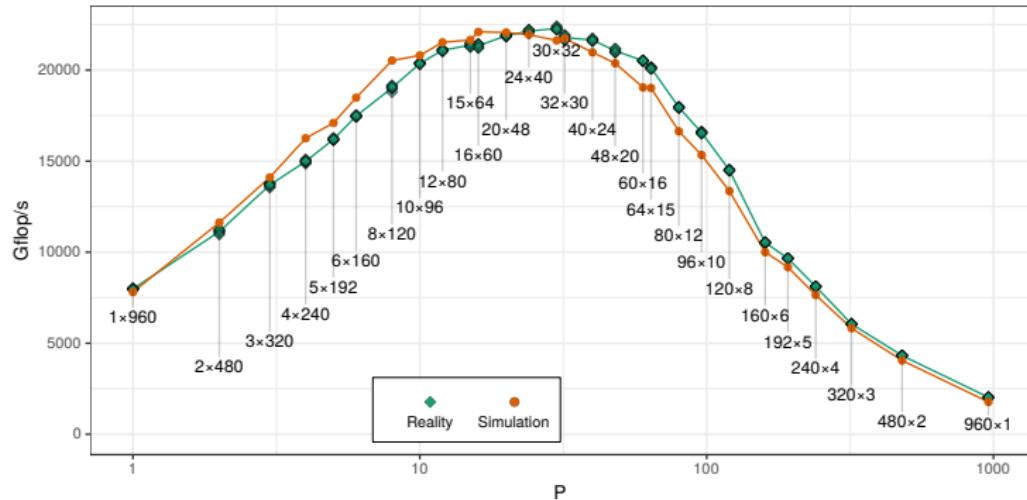


Take-Away Message: accurate prediction

Modeling both spatial and temporal computation variability is essential

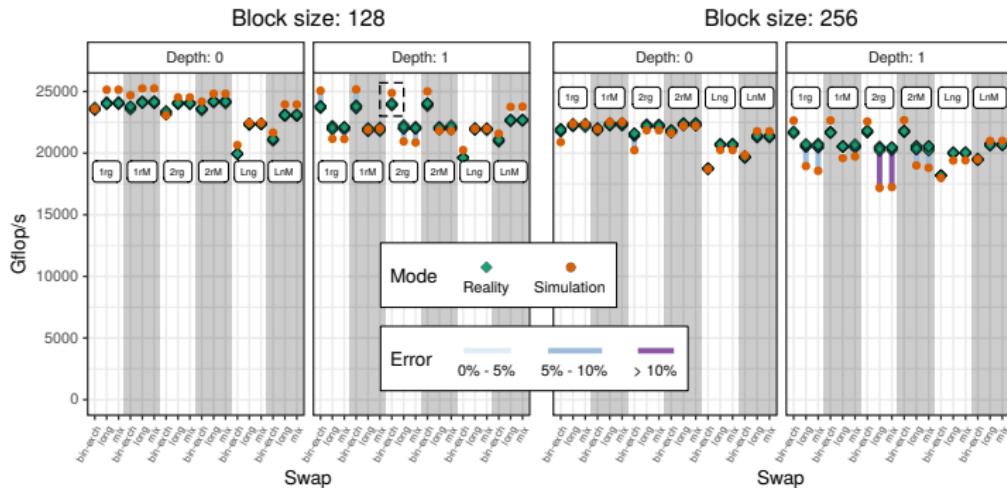
# INFLUENCE OF THE GEOMETRY

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

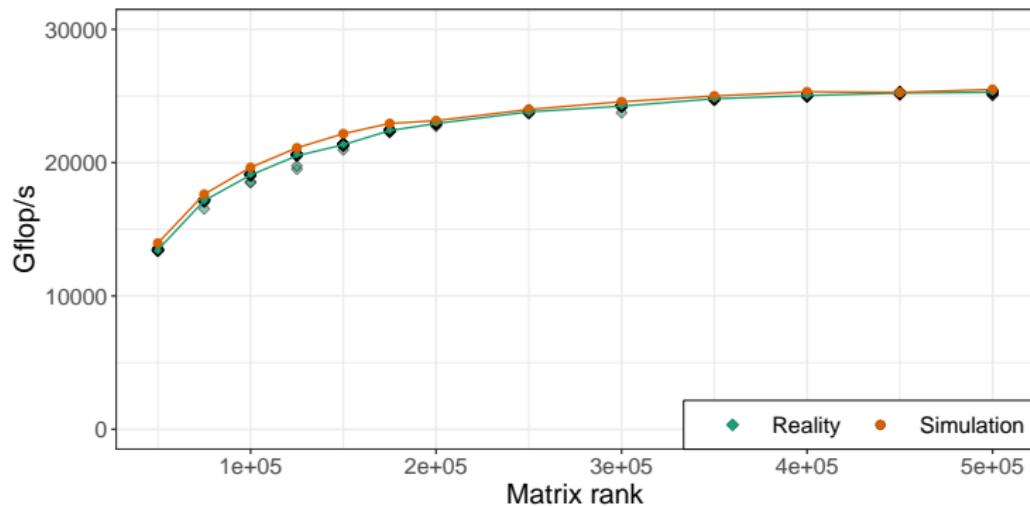


## **INFLUENCE OF THE OTHER PARAMETERS**

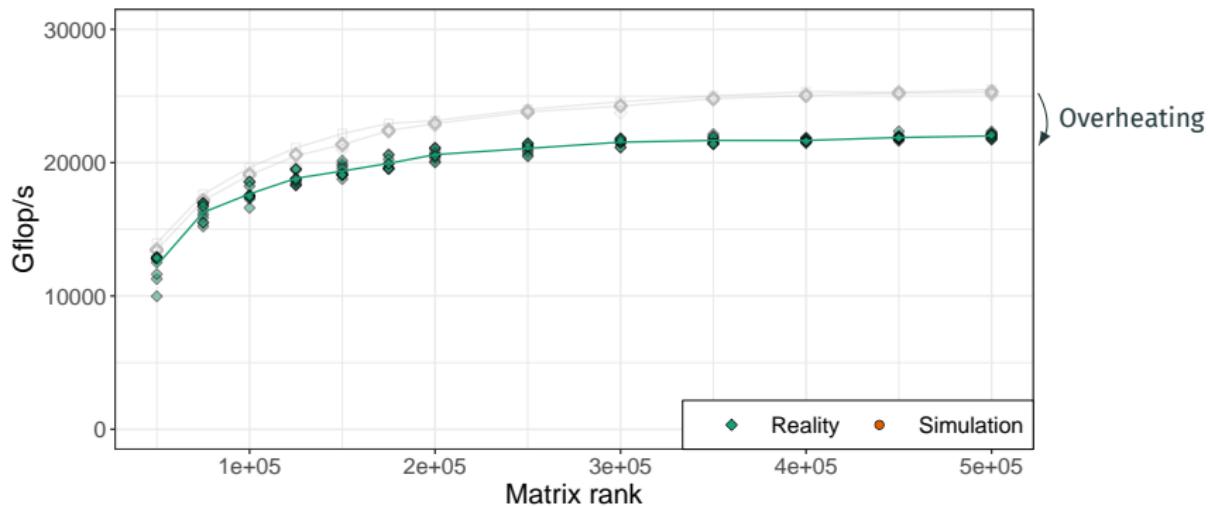
Tested the 72 combinations of the remaining parameters



# INFLUENCE OF A PLATFORM CHANGE

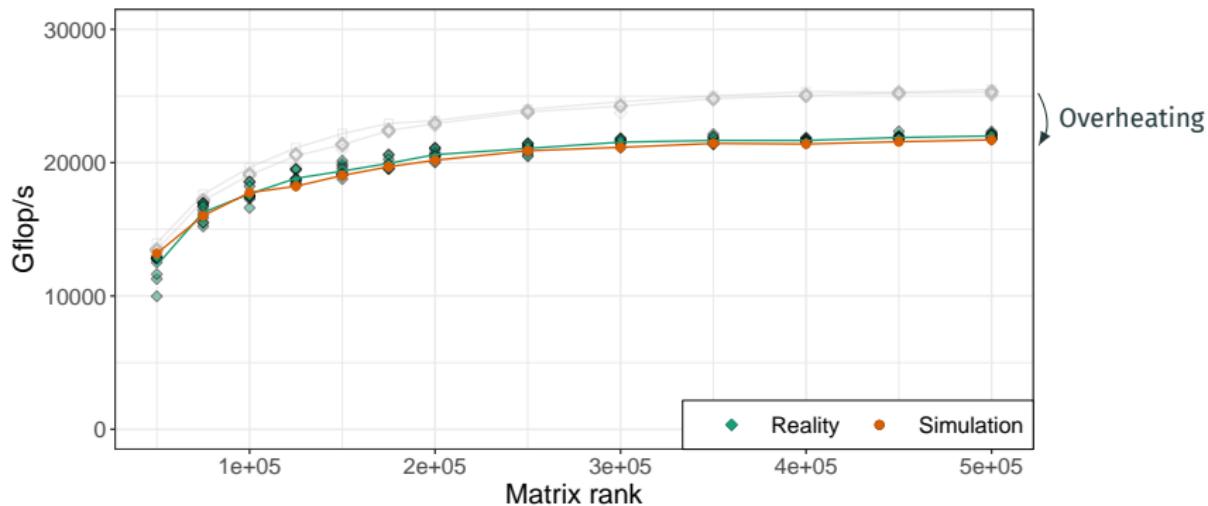


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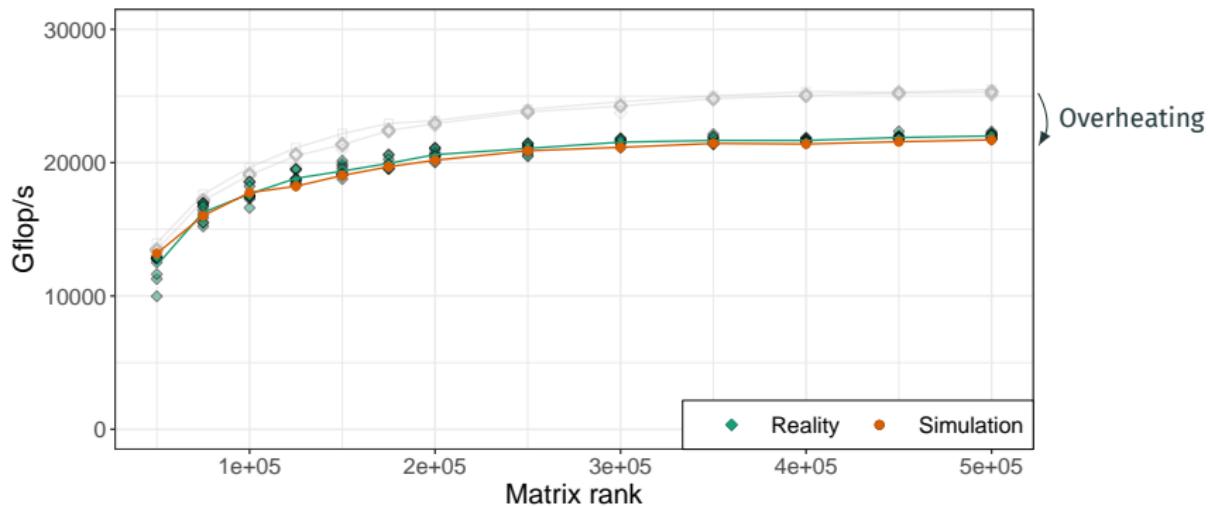
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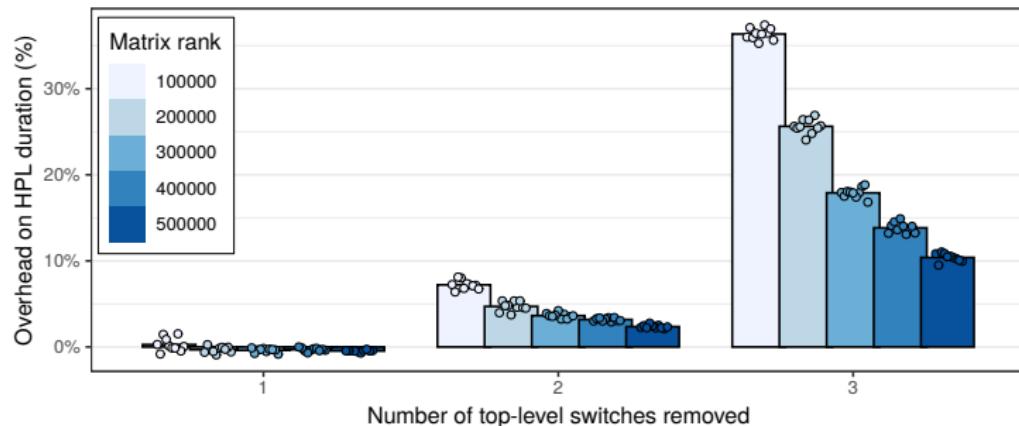


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**Take-Away Message:** Re-measuring `dgemm` durations to generate a new model was enough to account for the platform change

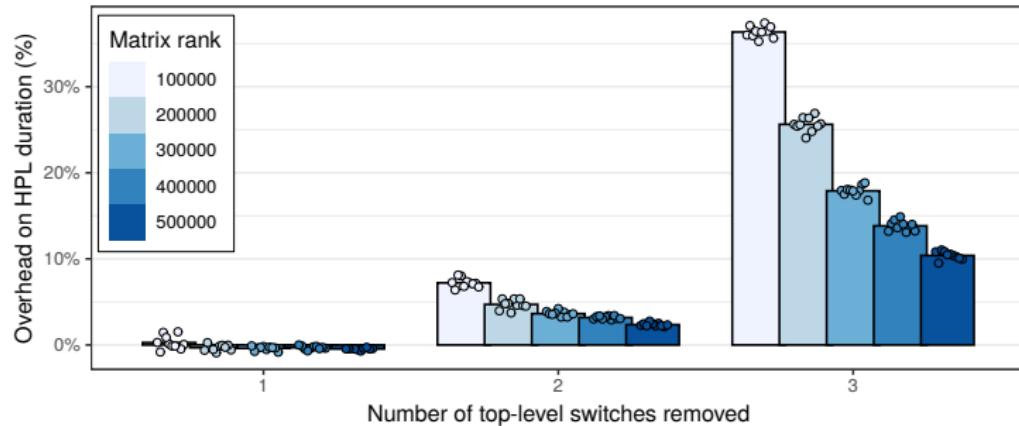
## USE CASE: SENSIBILITY ANALYSIS

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

Goal: performance prediction ✓

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Main difficulties:

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

## PARENTHESIS: ON THE DIFFICULTIES OF EXPERIMENTATION

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Bias may be desirable in some situations

## PERFORMANCE TESTS

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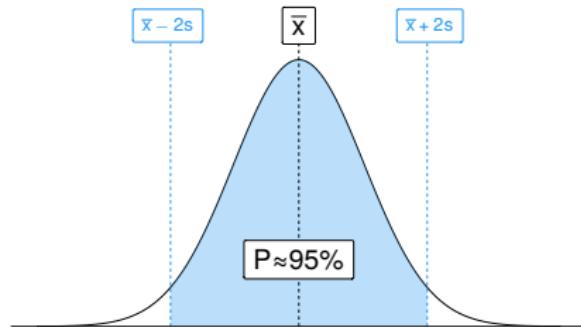
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Each parameter is **normally distributed** (thanks to CLT)

# 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  $x_{n+1}$ ?

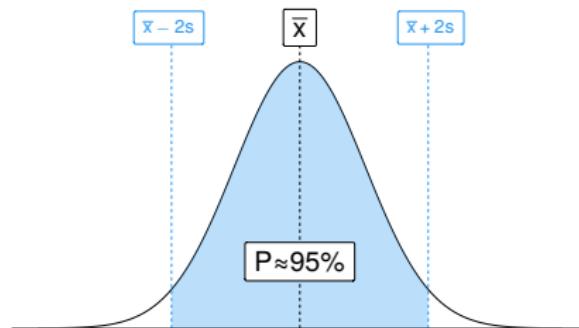


Take the sample mean  $\bar{x}$  and standard deviation  $s$  of the old observations

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

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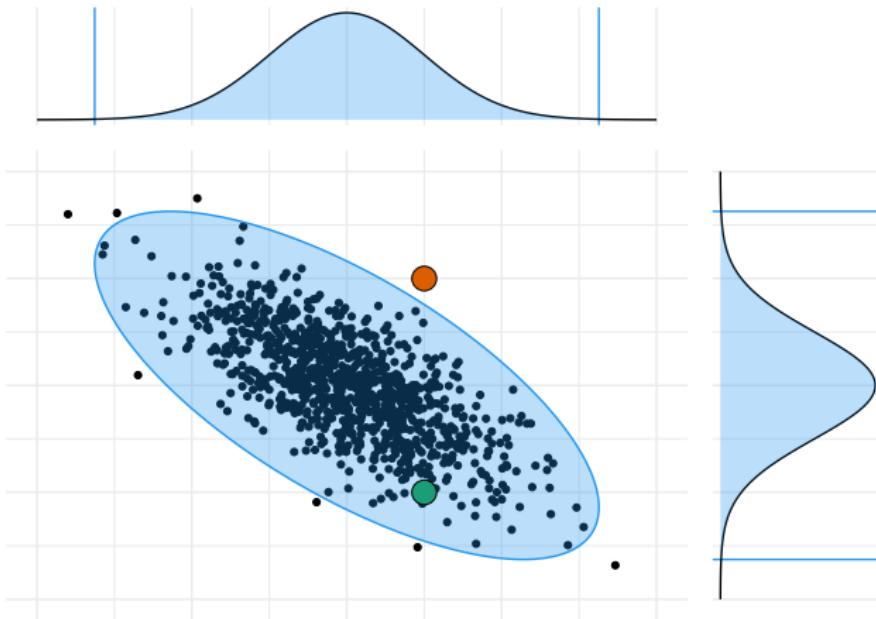
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Note: using the F distribution instead of the normal distribution (the true mean and standard deviation are unknown)

## FLUCTUATION INTERVAL FOR SEVERAL VARIABLES

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

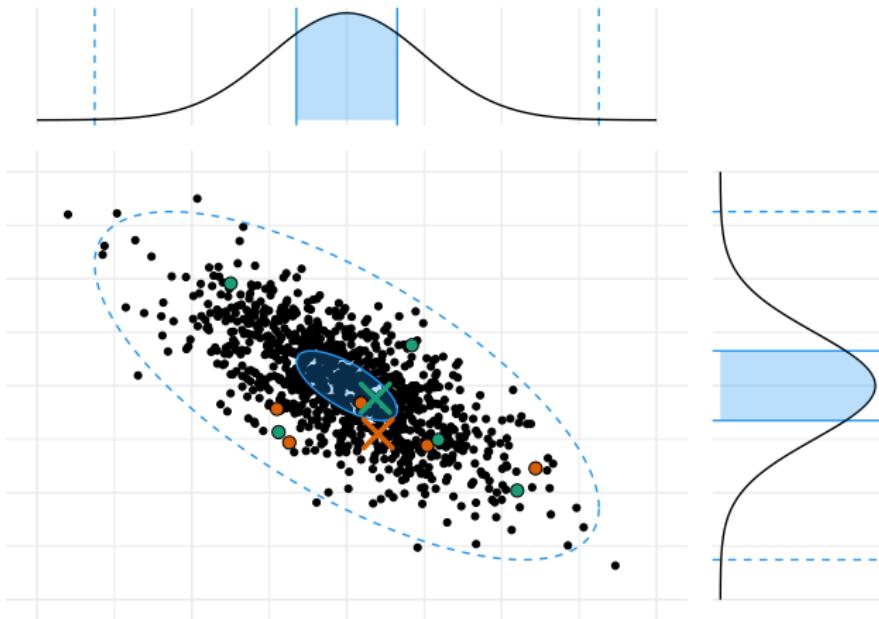
Example in dimension 2, with  $\mathbb{P}(x_{n+1} \in \text{interval}) \approx 99.5\%$



## FLUCTUATION INTERVAL FOR SEVERAL MEASURES

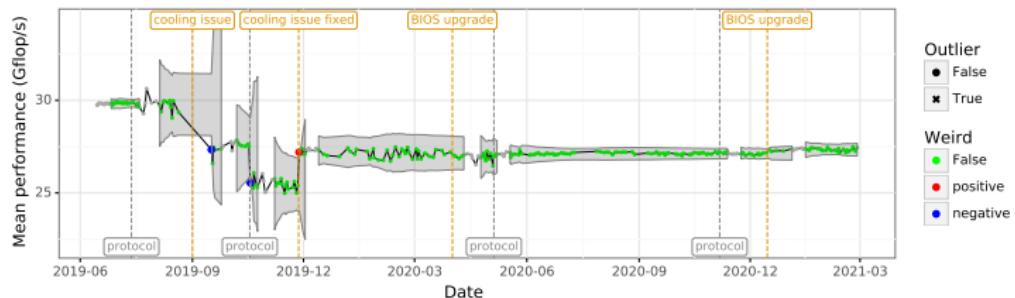
With several measures, using their **average** and shrinking the interval

Example with 5 measures (averages represented by crosses)



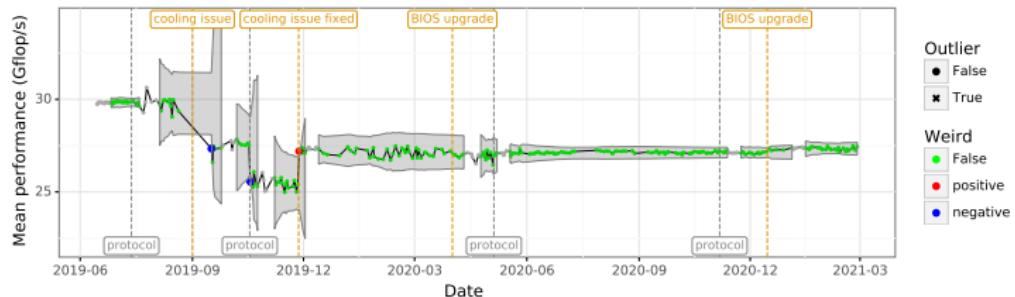
# RESULT: PERFORMANCE FLUCTUATION

## Performance fluctuation of the node dahu-14

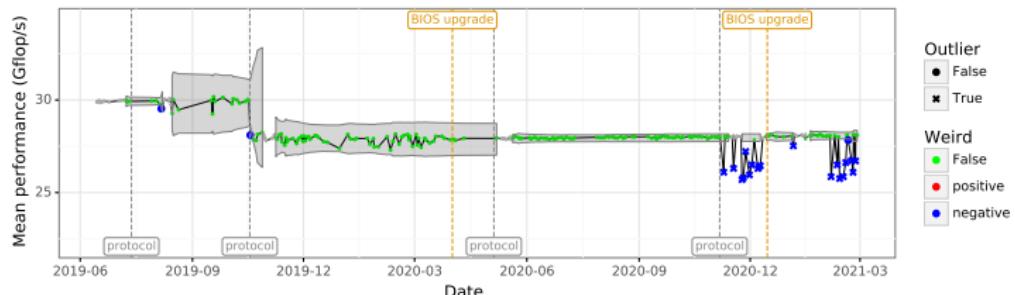


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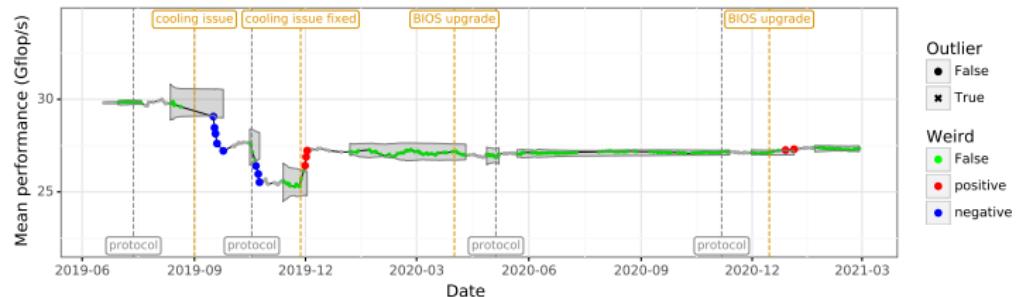


Performance fluctuation of the node dahu-32

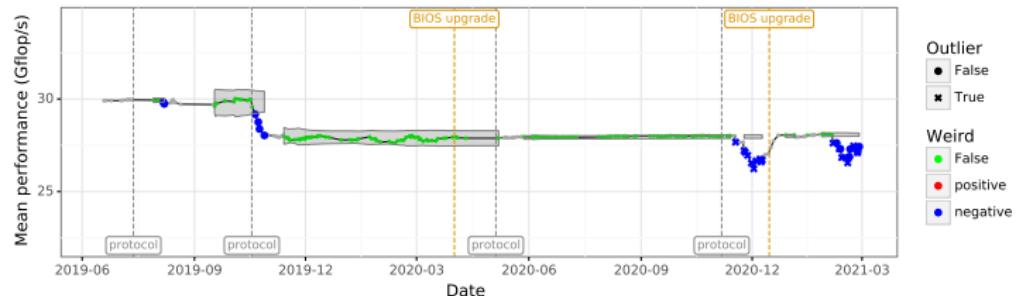


# RESULT: PERFORMANCE FLUCTUATION

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

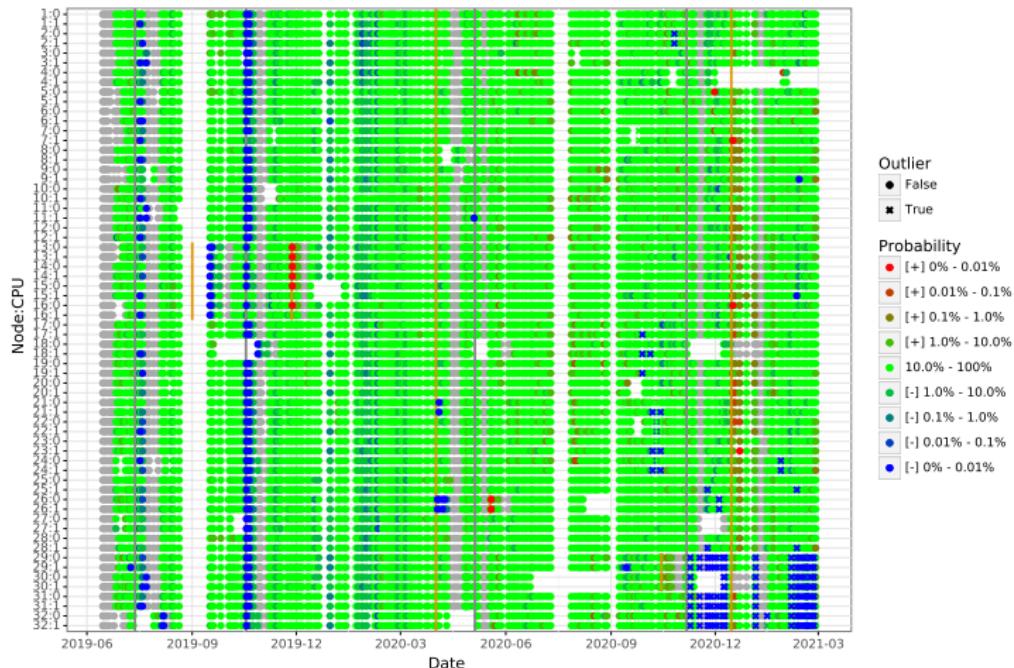


Performance fluctuation of the node dahu-32 (5-day window)



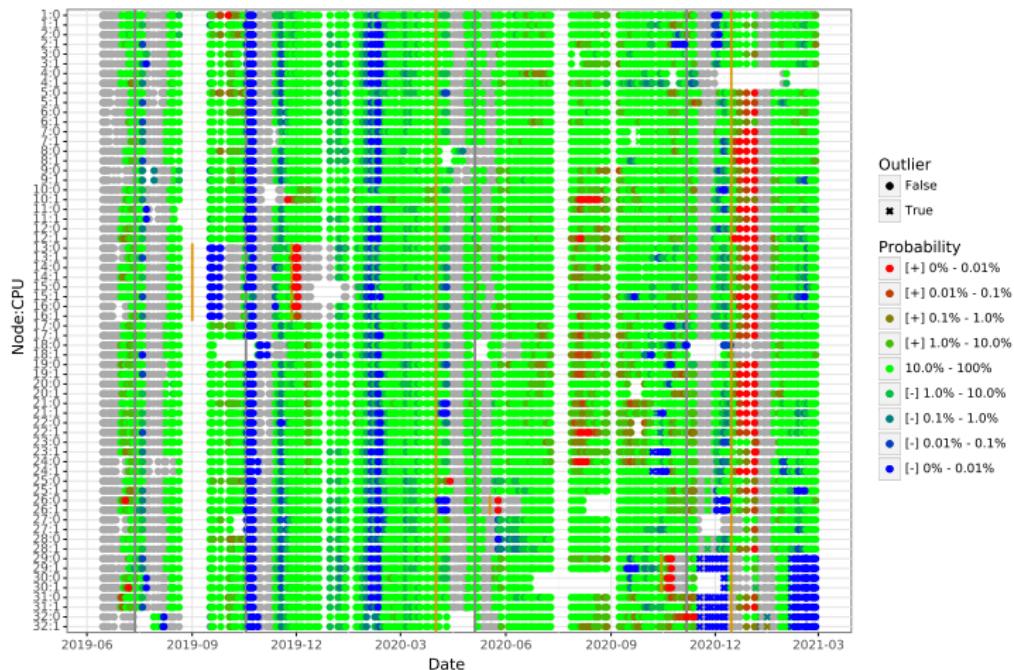
# RESULT: PERFORMANCE OVERVIEW

Overview of the performance on cluster dahu



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Overview of the performance on cluster dahu (5-day window)



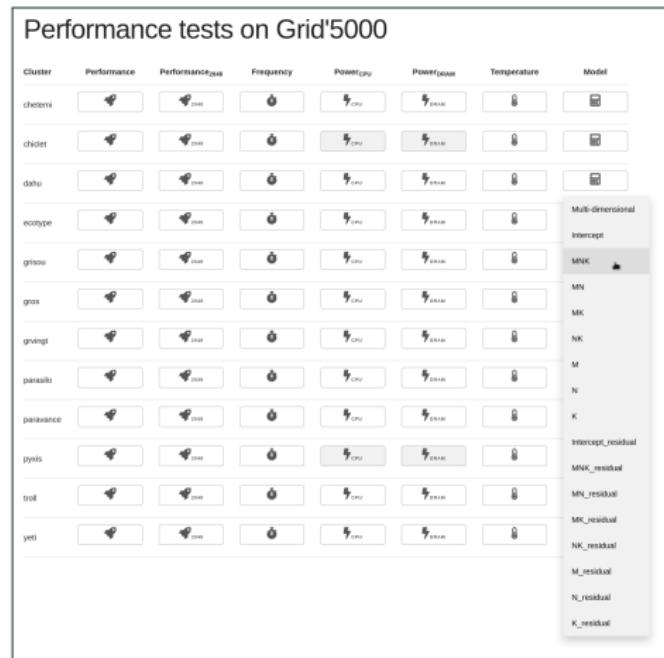
## PERFORMANCE TESTS: WRAPING UP

Multi-variable test also implemented

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Multi-variable test also implemented

Results available on [https://cornebize.net/g5k\\_test](https://cornebize.net/g5k_test)

Cluster	Performance	Performance <sub>PS48</sub>	Frequency	Power <sub>CPU</sub>	Power <sub>DRAM</sub>	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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Multi-variable test also implemented

Results available on [https://cornebize.net/g5k\\_test](https://cornebize.net/g5k_test)

Cluster	Performance	Performance <sub>PSM</sub>	Frequency	Power <sub>CPU</sub>	Power <sub>DRAM</sub>	Temperature	Model
chezeli							
chidet							
dahu							
ecotype							
grisou							
gris							
gringst							
parasilo							
panthaea							
pyxis							
troll							
yeti							

Legend (dropdown menu):

- Intercept
- MNK \*
- MN
- MK
- NK
- M
- N
- K
- Intercept\_residual
- MNK\_residual
- MN\_residual
- MK\_residual
- NK\_residual
- M\_residual
- N\_residual
- K\_residual

## Detected events

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

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

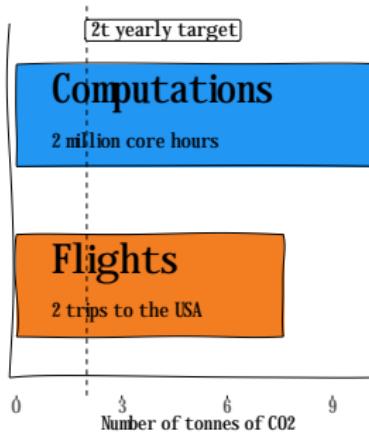
⇒ Great help potential

## CONCLUDING THOUGHTS

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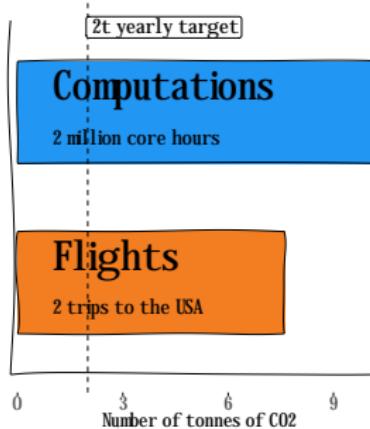
# THERE IS NO PLANET B

About 18t of CO<sub>2</sub>eq were emitted for this thesis



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

What about computations?