

# HIGH PERFORMANCE COMPUTING: TOWARDS BETTER PERFORMANCE PREDICTIONS AND EXPERIMENTS

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Tom Cornebize

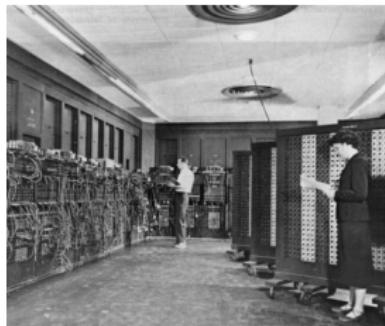
2 June 2021, PhD defense



# No SCIENCE WITHOUT COMPUTING



Arithmomètre (1851)



ENIAC (1945)

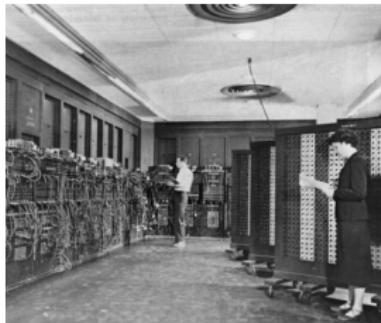


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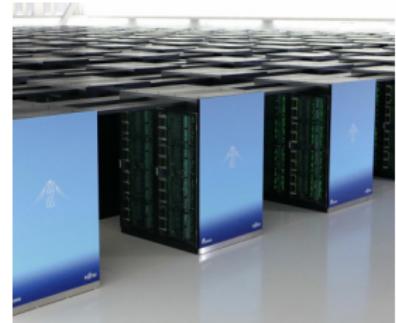
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Last decades:

- 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
- ⇒ No perfect model
- ⇒ Need for [experiments](#)

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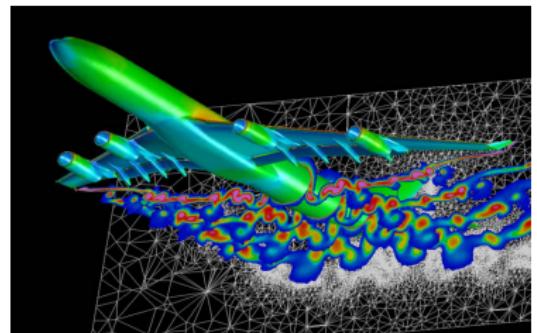


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Empirical studies can be carried in [reality](#) or in [simulation](#)



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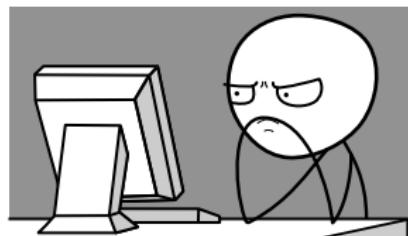
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## Holy Grail: Predictive Simulation on a “Laptop”

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
- Demonstrate it is possible to **predict faithfully** the behavior of complex parallel applications
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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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- Communications are faked, good fluid network models
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Validations of SMPI before this thesis: simple applications without any high performance tricks

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- Computations and communication overlap (custom collectives)
- More representative of some HPC applications
- Well established, used for the Top500

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## Tuning parameters

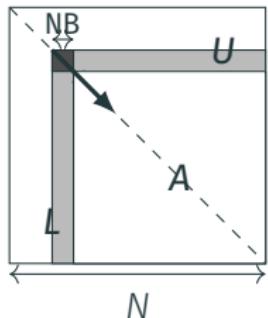
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- Block size
- Broadcast algorithm
- etc.

Hundreds of combinations

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

# MODELING COMPUTATIONS

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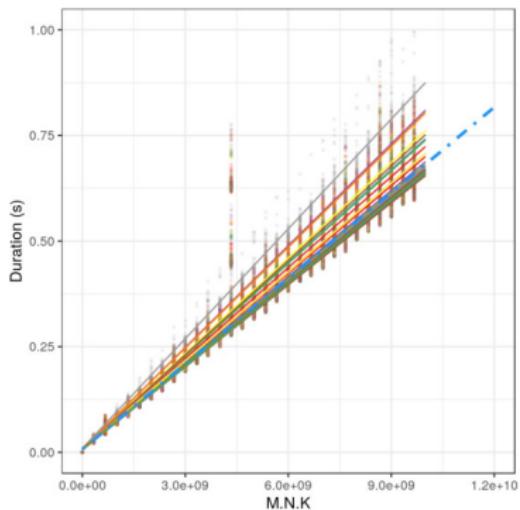
Different color  $\Rightarrow$  different host



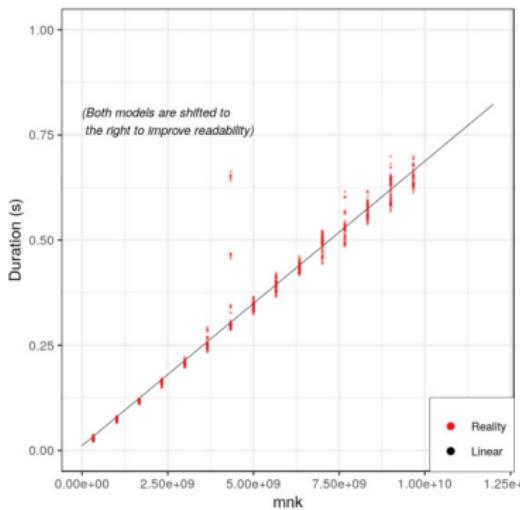
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For a particular host



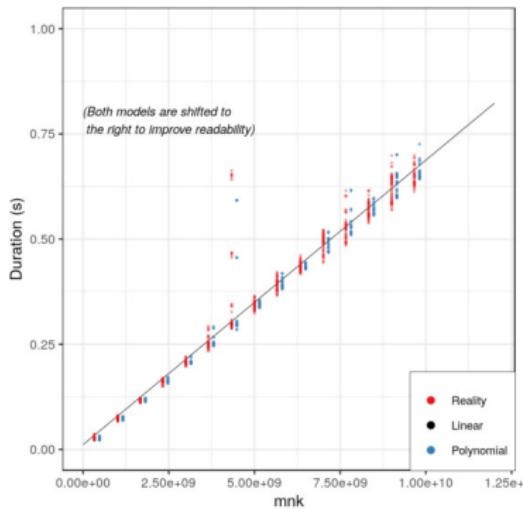
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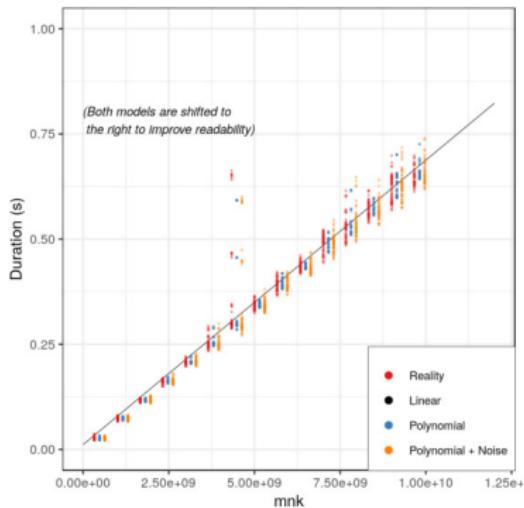
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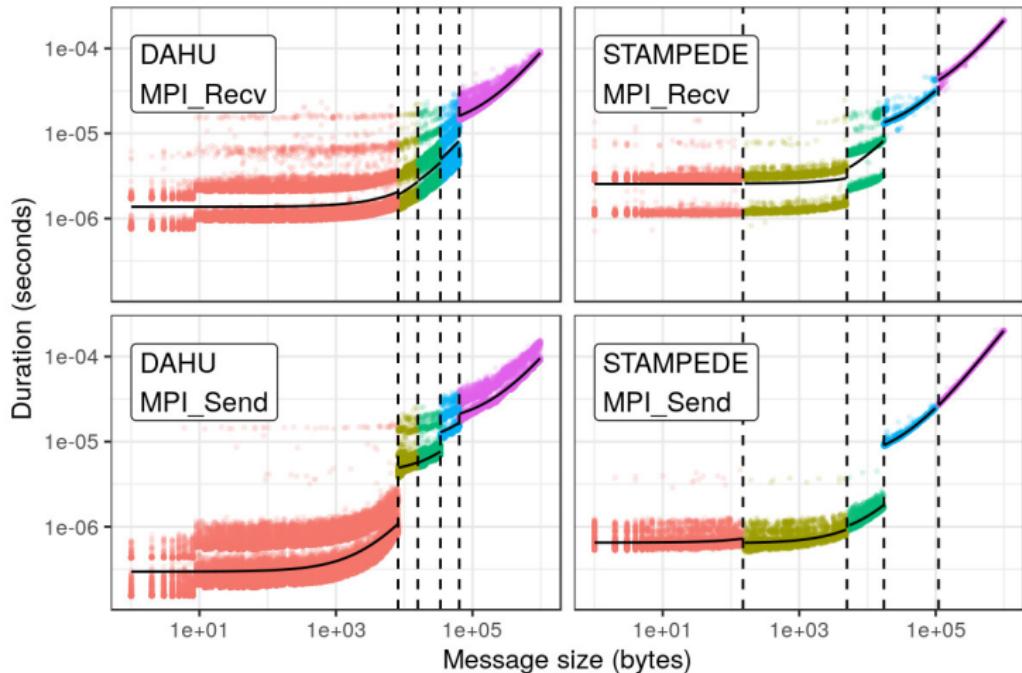
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Hand-crafted non-blocking collective operations intertwined with computations

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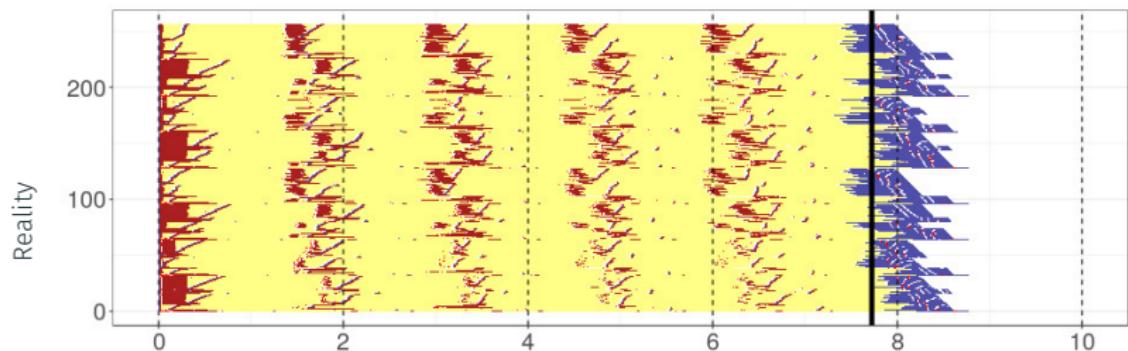


## VALIDATING THE PREDICTIONS

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# INTERNAL BEHAVIOR OF THE APPLICATION

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



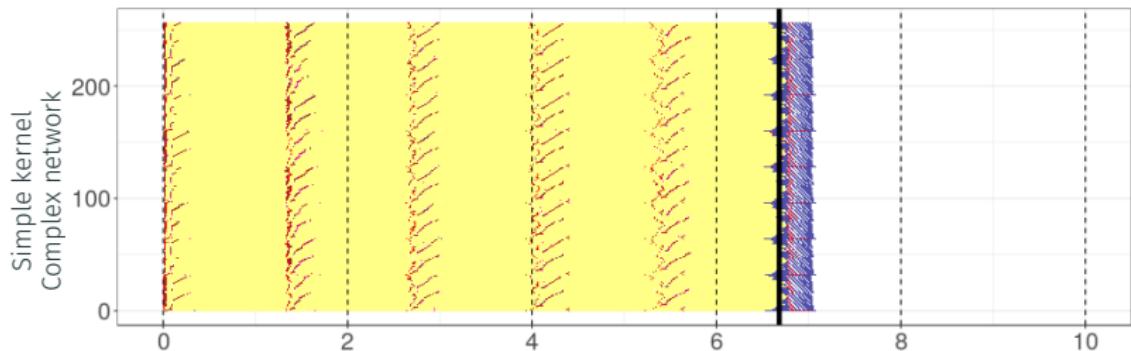
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Now the complete run, with 1024 MPI processes



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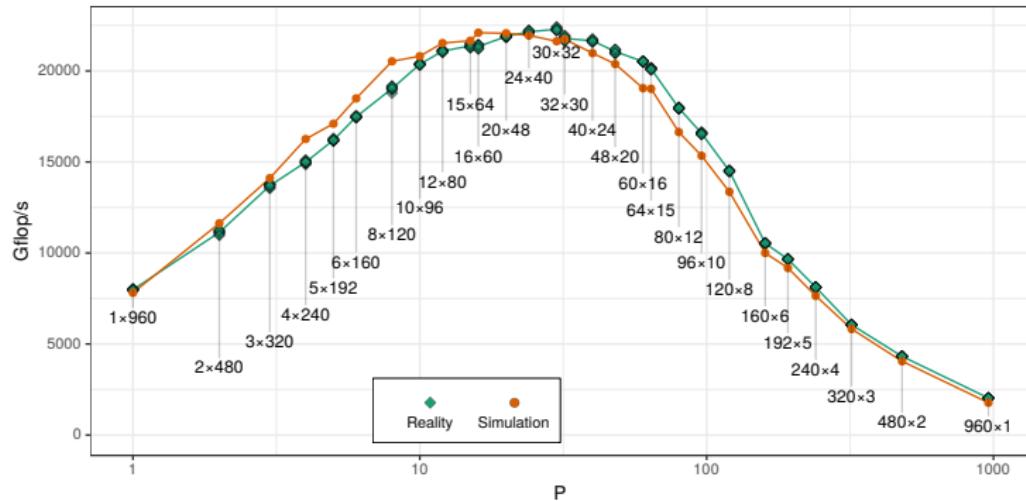


Take-Away Message: accurate prediction

Modeling both spatial and temporal computation variability is essential

# INFLUENCE OF THE GEOMETRY

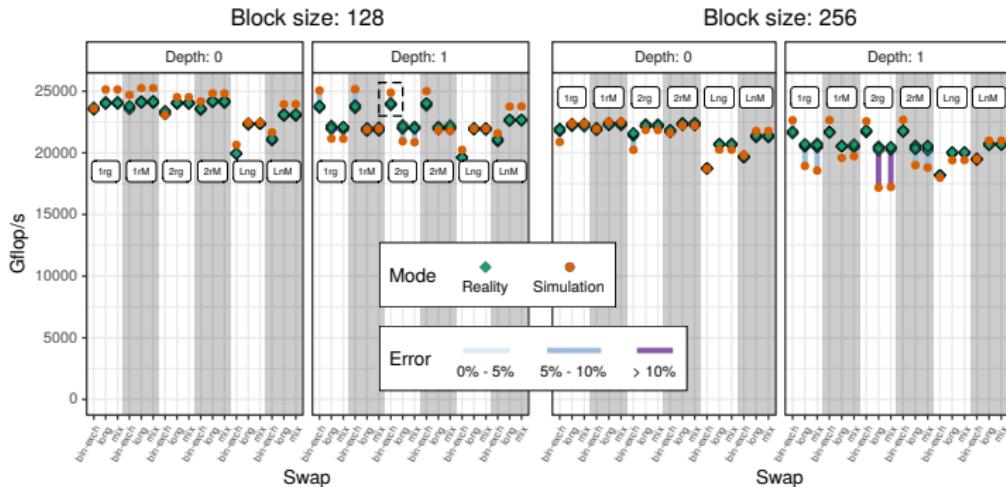
$P \times Q$  MPI processes, organized in a 2D grid



Perspective: geometry tuning in simulation

# INFLUENCE OF THE OTHER PARAMETERS

Tested the 72 combinations of the remaining parameters



Perspective: parameter tuning in simulation

# INFLUENCE OF A PLATFORM CHANGE



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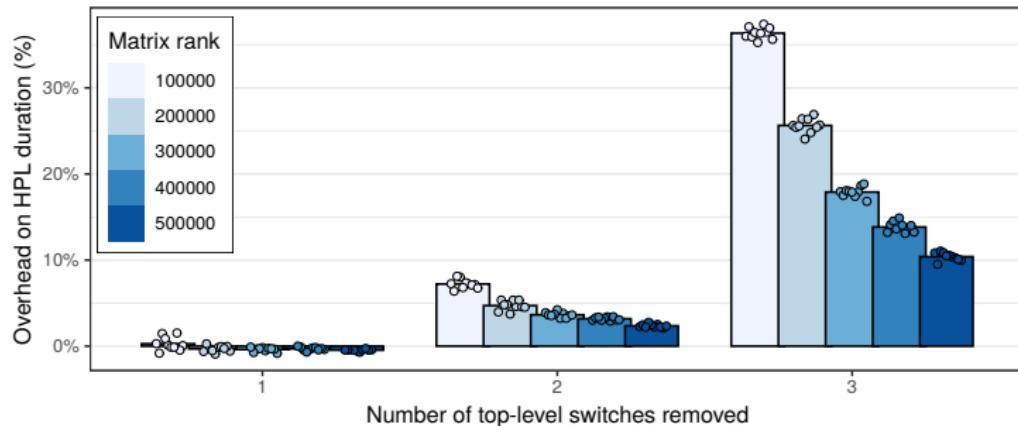
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**Take-Away Message:** Re-measuring `dgemm` durations to generate a new model was enough to account for the platform change

## USE CASE: SENSIBILITY ANALYSIS

What if the network topology of my cluster was different?

Study: take a 2-level fat tree with 4 top-level switches,  
remove them one by one



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Faithful surrogate  $\Rightarrow$  Empirical studies of hypothetical platforms  
 $\Rightarrow$  Extrapolation of existing platforms

Goal: performance prediction ✓

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Main difficulties:

- Experimentation/calibration
- Platform changes (e.g., the cooling issue)

## ON THE DIFFICULTIES OF EXPERIMENTATION

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Experimental biases when measuring `dgemm` or MPI durations

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

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## Take-Away Message:

- These biases could only be identified with a solid experimental methodology with heavy use of randomization
- Bias may be desirable, to increase prediction accuracy

## CONTINUOUS PLATFORM MODELING

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## REGULAR MEASURES

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454 nodes (792 CPU) from 12 clusters, ~30 min. jobs



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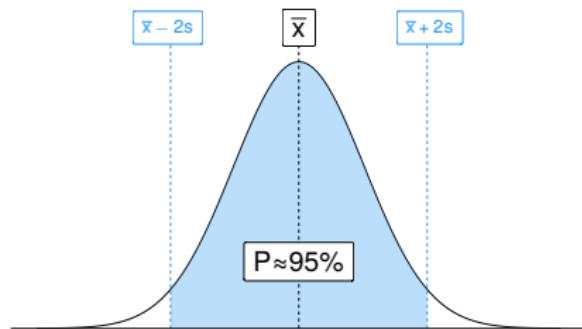
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If the platform did not change, then each parameter is  
[normally distributed](#) (thanks to CLT)

# 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 sample 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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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, use their [covariance matrix](#)

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



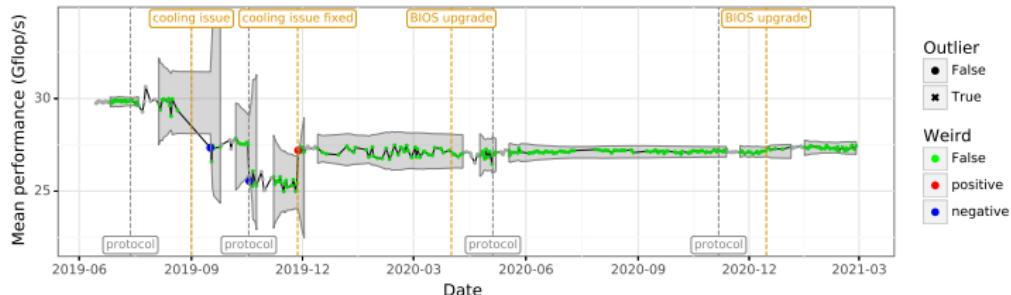
# RESULT: PERFORMANCE FLUCTUATION

## Performance fluctuation of the node dahu-14

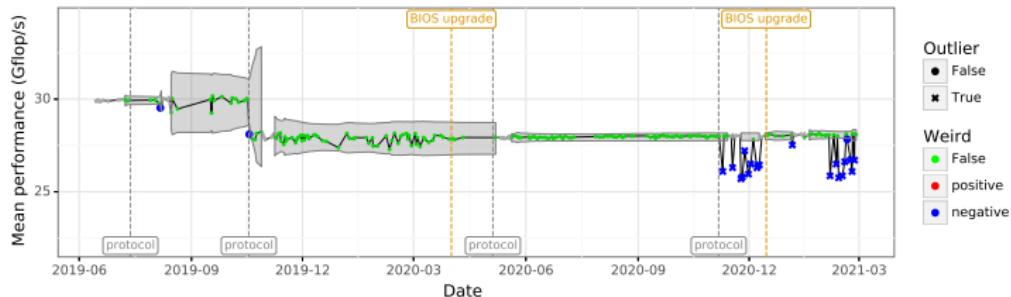


# RESULT: PERFORMANCE FLUCTUATION

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## Performance fluctuation of the node dahu-32



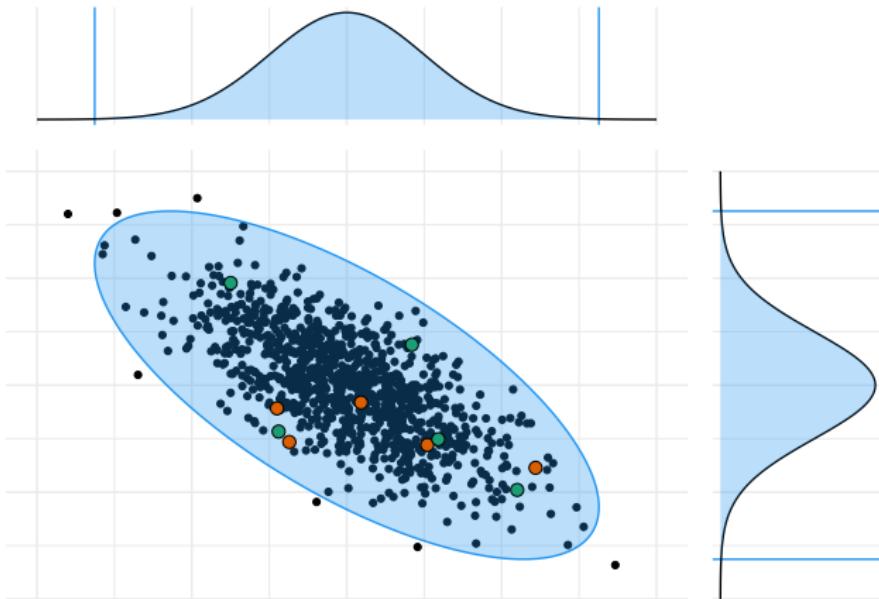
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How to detect more subtle changes? Take several consecutive measures  $x_{n+1}, \dots, x_{n+k}$ , use their **average** and shrink the interval accordingly

Example with 5 measures (averages represented by crosses)



# RESULT: PERFORMANCE FLUCTUATION

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

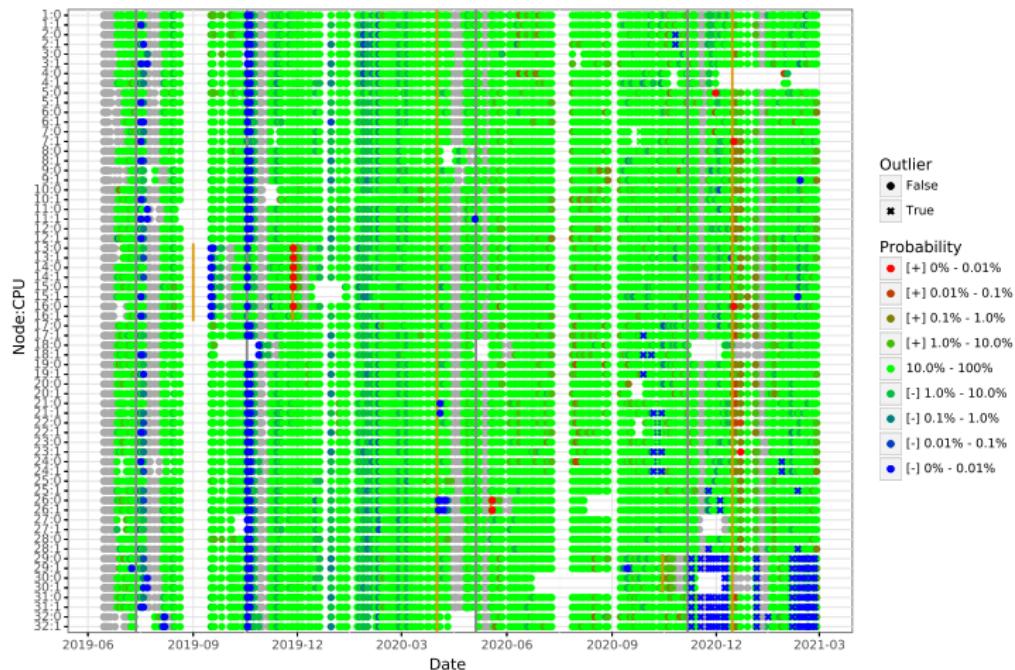


Performance fluctuation of the node dahu-32 (5-day window)



# RESULT: PERFORMANCE OVERVIEW

Overview of the performance on cluster dahu



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## PERFORMANCE TESTS: WRAPING UP

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Multi-variable test also implemented, on all the model coefficients

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

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chetteri							
chiclet							
dehu							
ecotype							
grassu							
gras							
grvingt							
parasito							
panchine							
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yeti							

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

⇒ Great help potential

## CONCLUDING THOUGHTS

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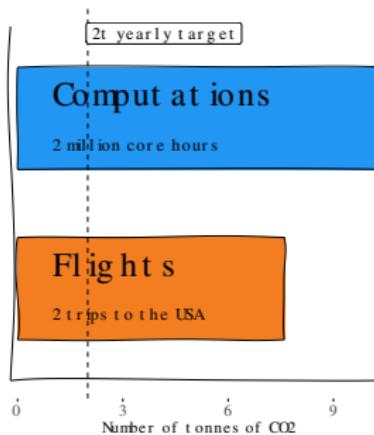
**Repeated** the whole study **from scratch** on a new cluster:



Where to stop? Try all the Grid'5000 clusters? Other applications?

# 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?

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## Who should be responsible of tests?

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

Applying our approach on the whole life cycle of supercomputers:

**Design** Constructing the best machine for a given budget,  
using co-design

**Development** Debugging and improving software performance

**Maintenance** Ensuring that routine upgrades keep the performance  
as expected



Thank you all!