

HIGH PERFORMANCE COMPUTING: TOWARDS BETTER PERFORMANCE PREDICTIONS AND EXPERIMENTS

Tom Cornebize

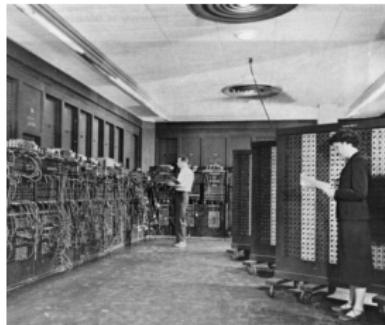
2 June 2021, PhD defense



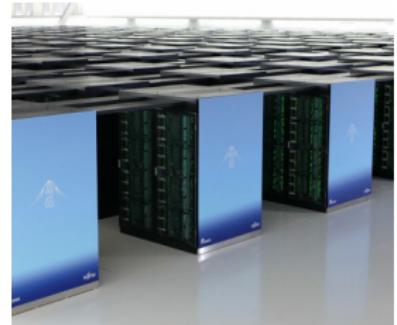
No SCIENCE WITHOUT COMPUTING



Arithmomètre (1851)



ENIAC (1945)

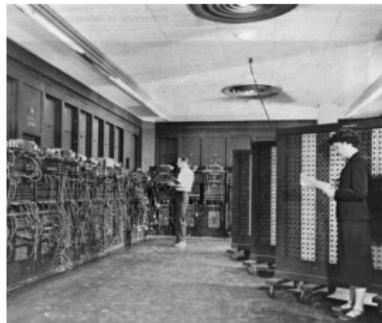


Fugaku (2021)

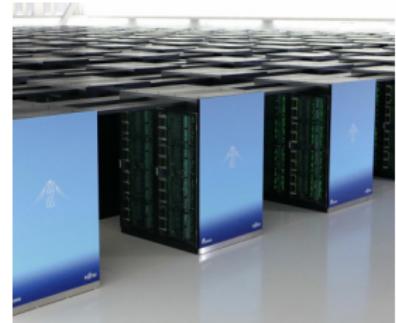
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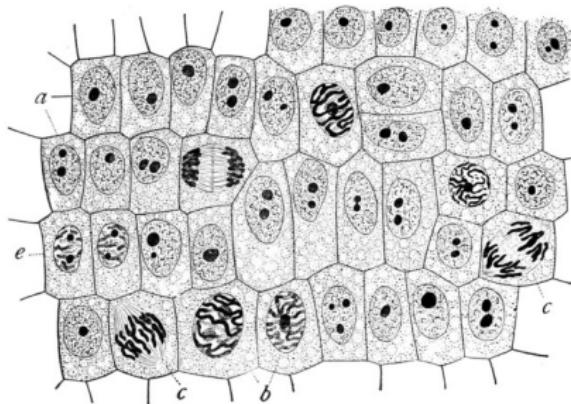


Fugaku (2021)

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



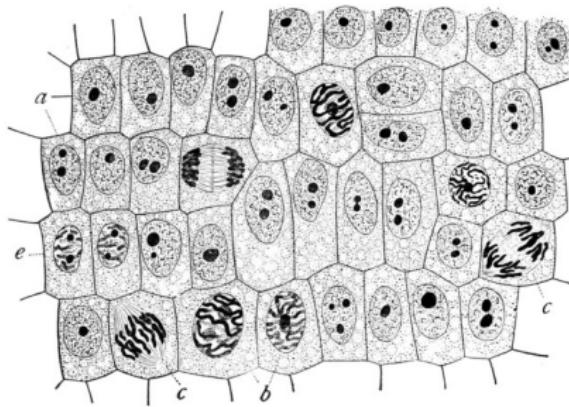
Similar to natural sciences

Complexity ⇒ Variability and Opacity

⇒ No perfect model

⇒ Need for [experiments](#)

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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?
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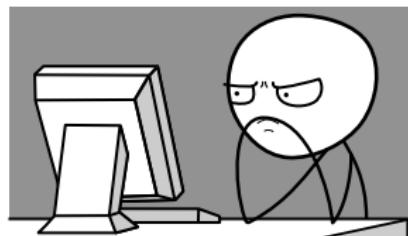
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Holy Grail: Predictive Simulation on a “Laptop”

Capture the whole application and platform complexity

Initial goal: **predict** the performance of a parallel application

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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
- Modeling correctly the platform variability is key

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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?



- Application runs for real on a laptop
- Communications are faked, good fluid network models
- **Performance model** for the target platform



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

QUICK WORD ON HPL



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

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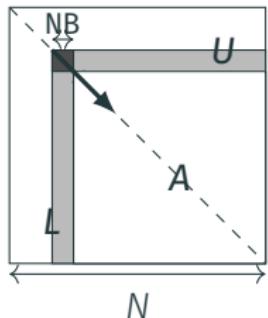


```
Allocate and initialize A  
for  $k = N$  to 0 step NB do  
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    Factor the panel  
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    Update the sub-matrix
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Tuning parameters

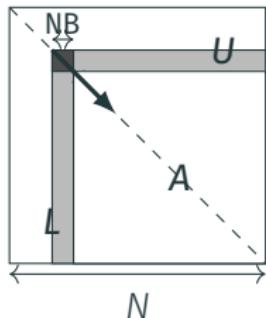
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- Block size
- Broadcast algorithm
- etc.

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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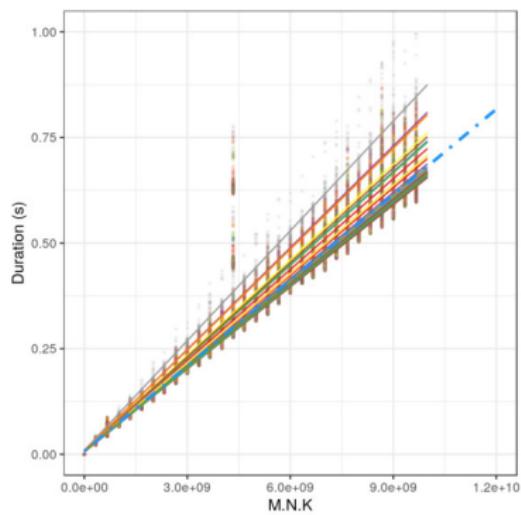
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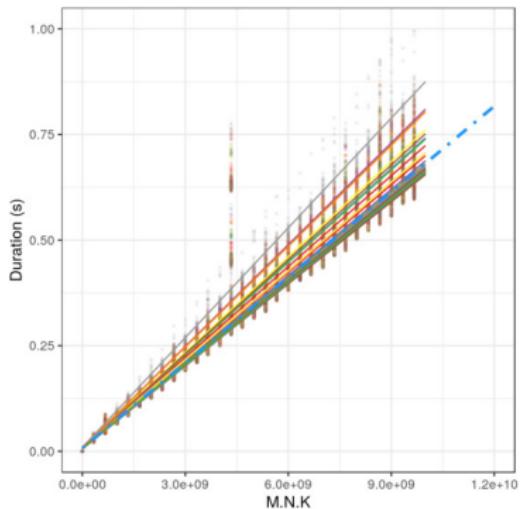
For a particular host



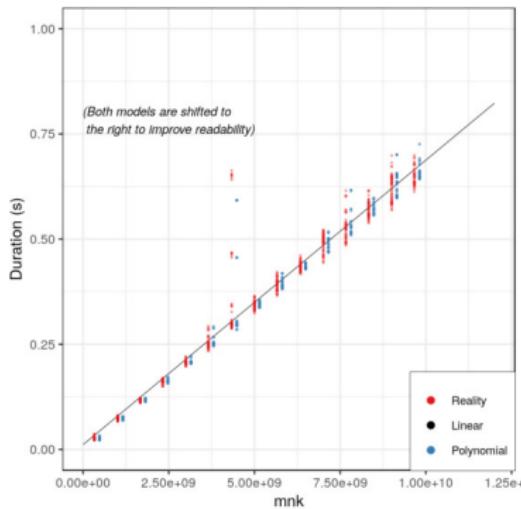
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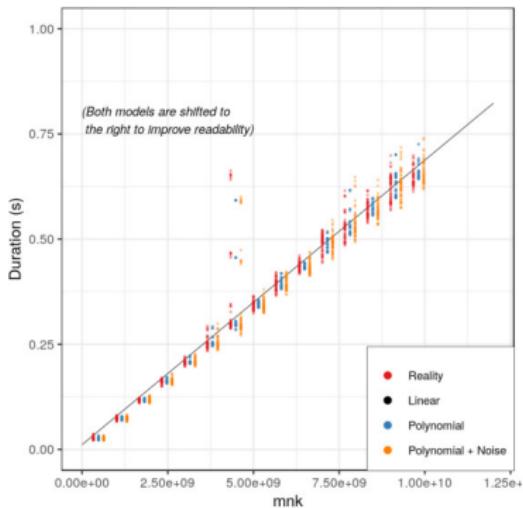
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MODELING COMMUNICATIONS

Hand-crafted non-blocking collective operations intertwined with computations

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VALIDATING THE PREDICTIONS

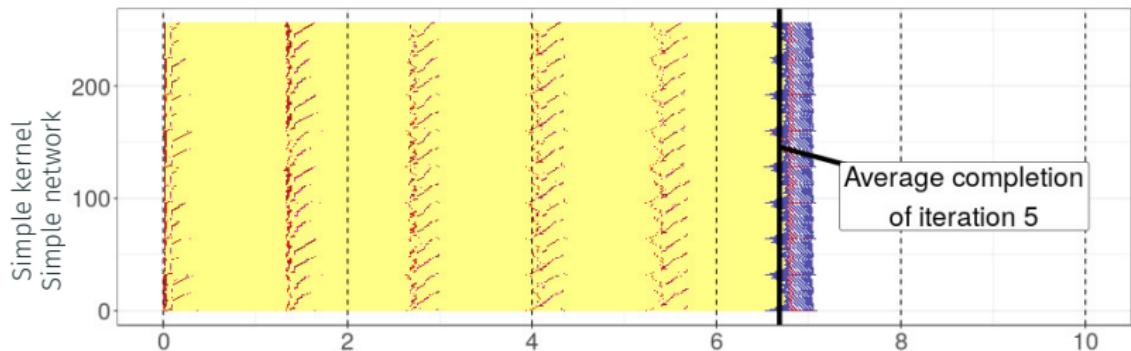
INTERNAL BEHAVIOR OF THE APPLICATION

256 MPI ranks, interrupted after the 5th iteration



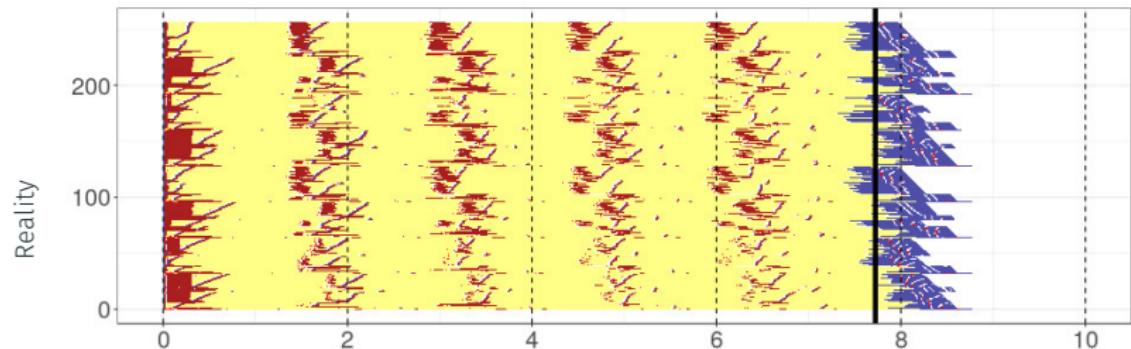
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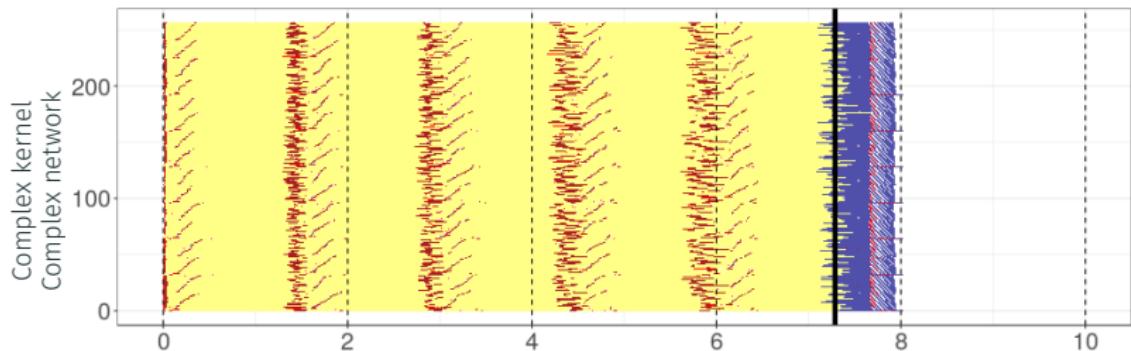
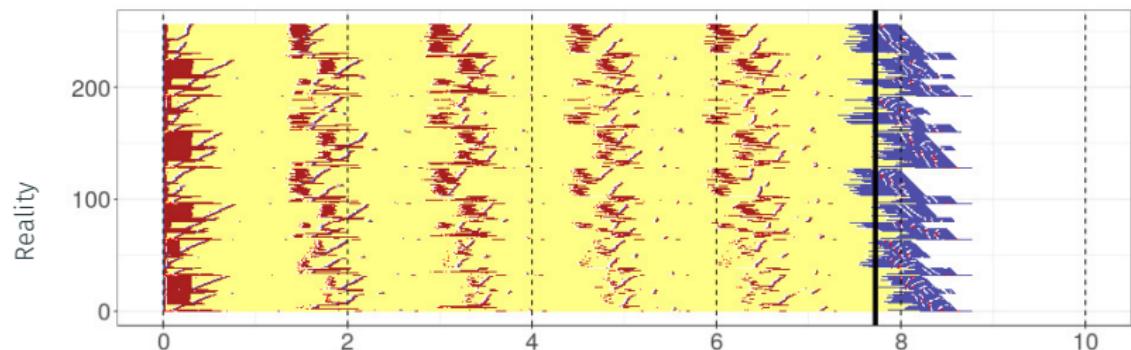
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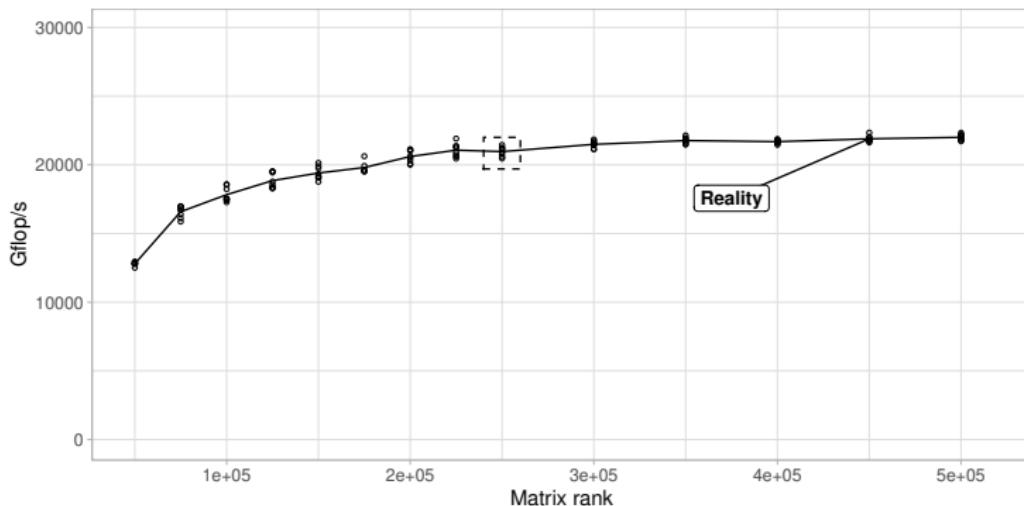
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INFLUENCE OF THE PROBLEM SIZE

Now the complete run, with 1024 MPI ranks



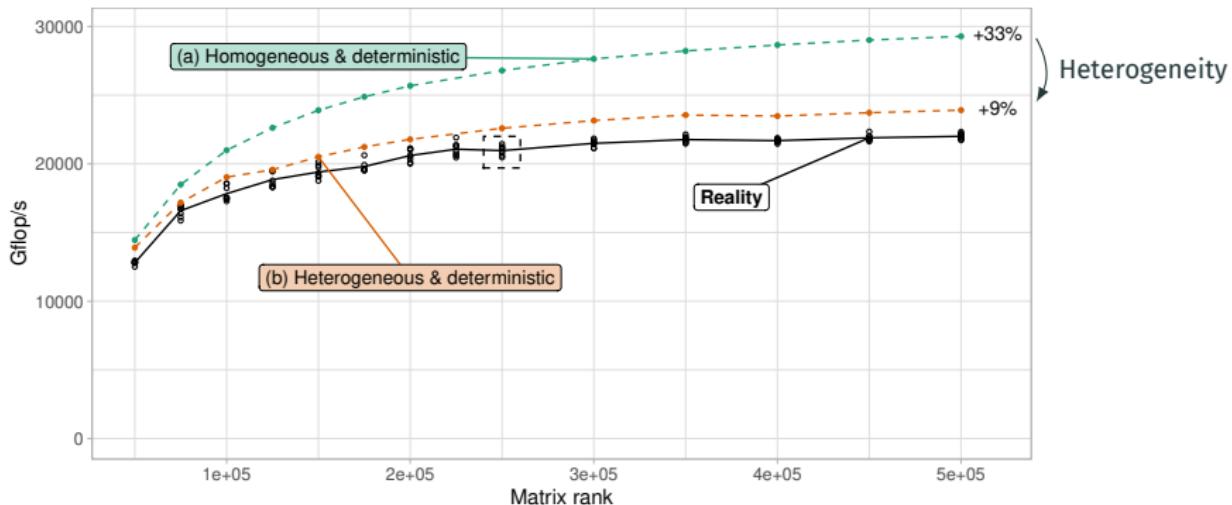
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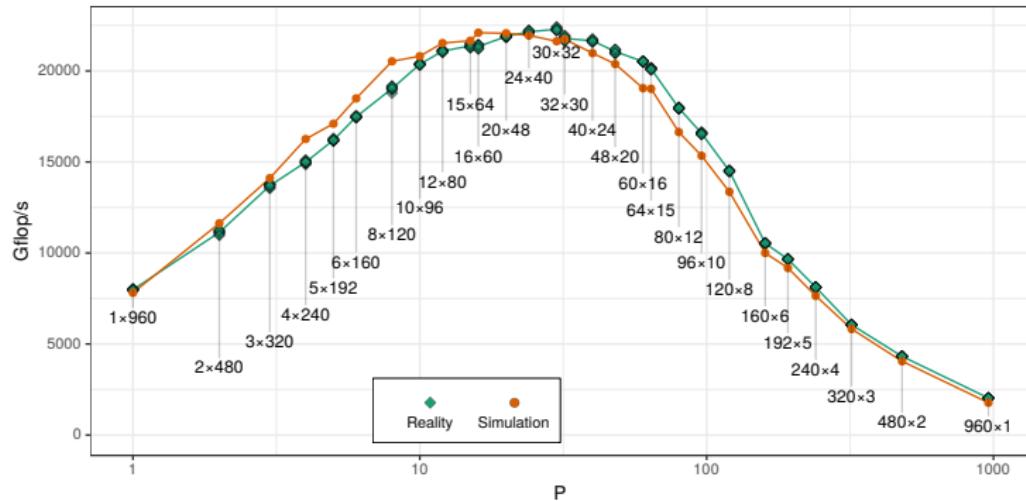


Take-Away Message: accurate prediction

Modeling both **spatial** and **temporal** computation variability is essential

INFLUENCE OF THE GEOMETRY

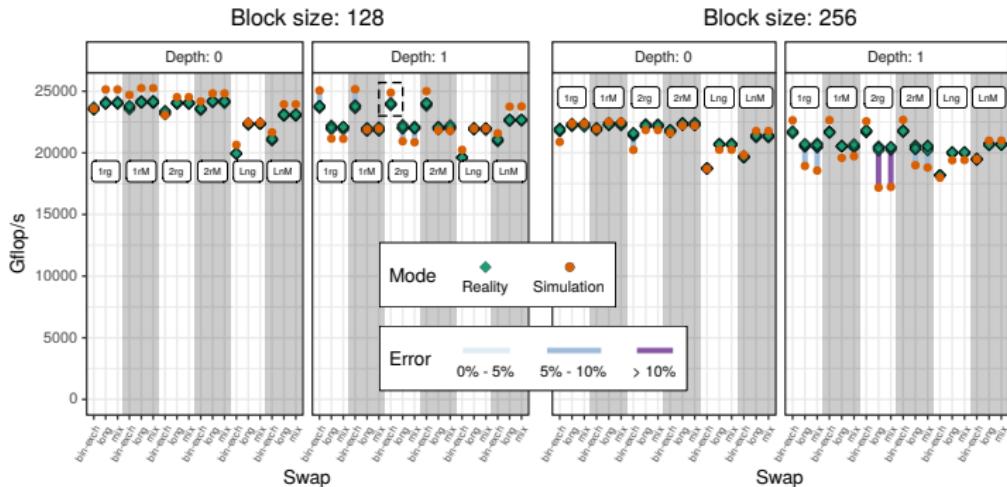
$P \times Q$ MPI processes, organized in a 2D grid



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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On four nodes, the cooling system malfunctionned for several weeks

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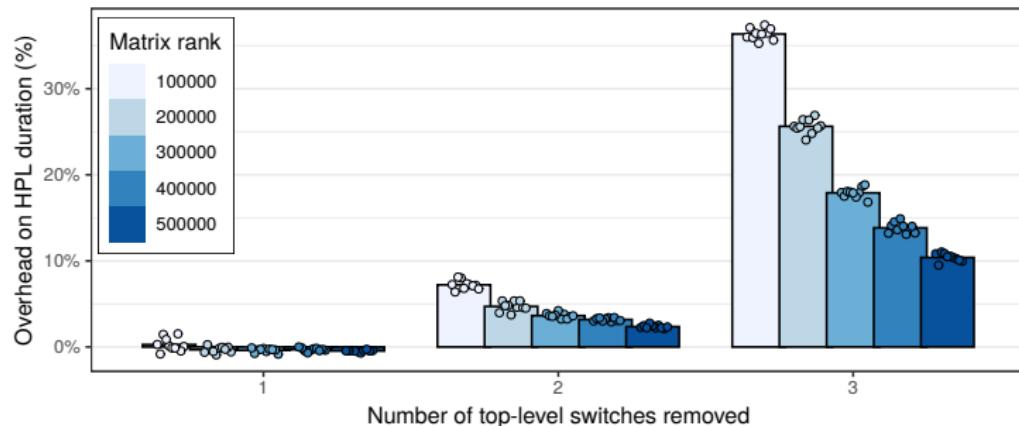


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Take-Away Message: Re-measuring `dgemm` durations to generate a new model was enough to account for the platform change

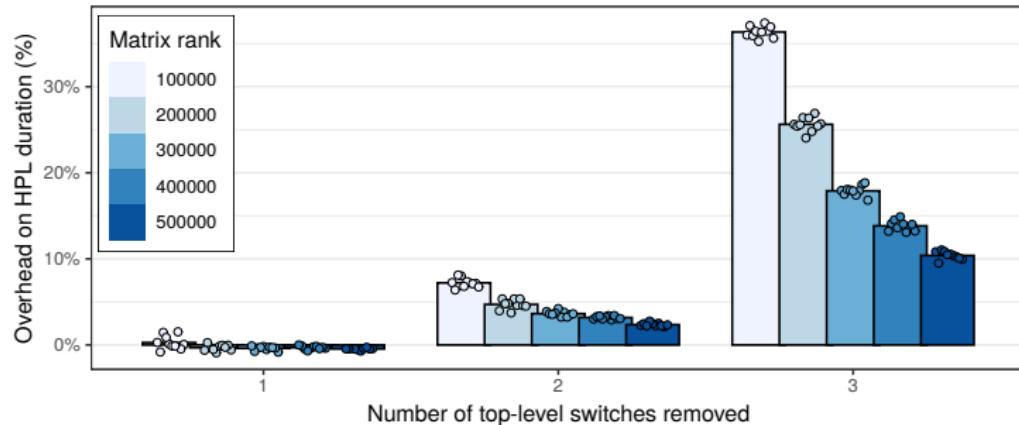
USE CASE: SENSIBILITY ANALYSIS

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

Goal: performance prediction ✓

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Main difficulties:

- Experimentation/calibration
- 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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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

PERFORMANCE TESTS

REGULAR MEASURES

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



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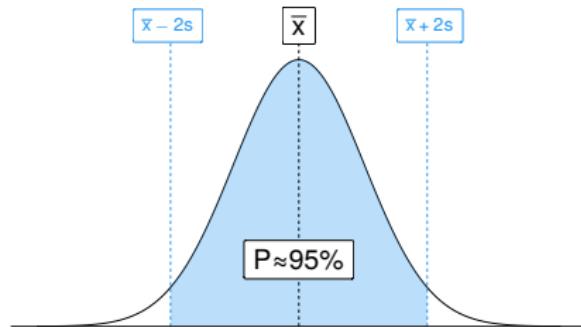
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If the platform did not change, then each parameter is
[normally distributed](#) (thanks to CLT)

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} ?

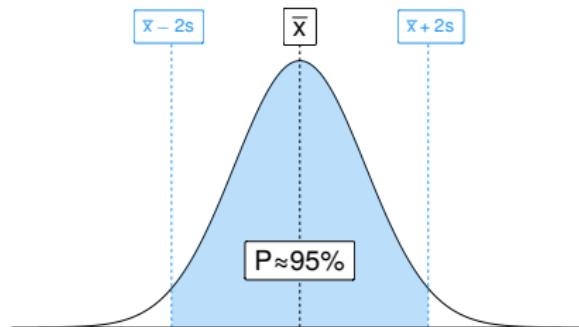


Take the sample mean \bar{x} and standard deviation s of the old observations

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

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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 $\mathbb{P}(x_{n+1} \in \text{interval}) \approx 99.5\%$



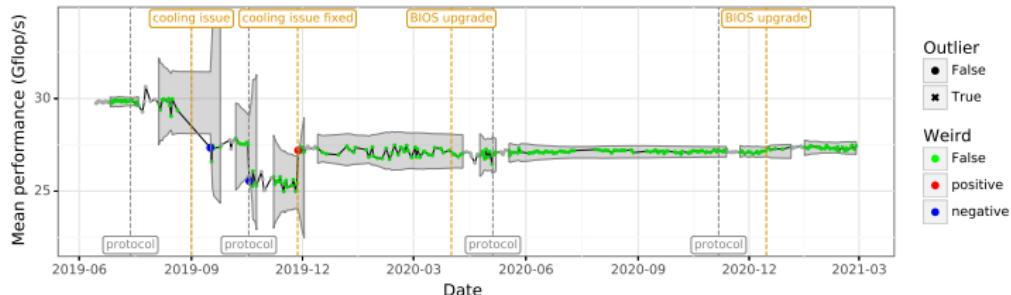
RESULT: PERFORMANCE FLUCTUATION

Performance fluctuation of the node dahu-14

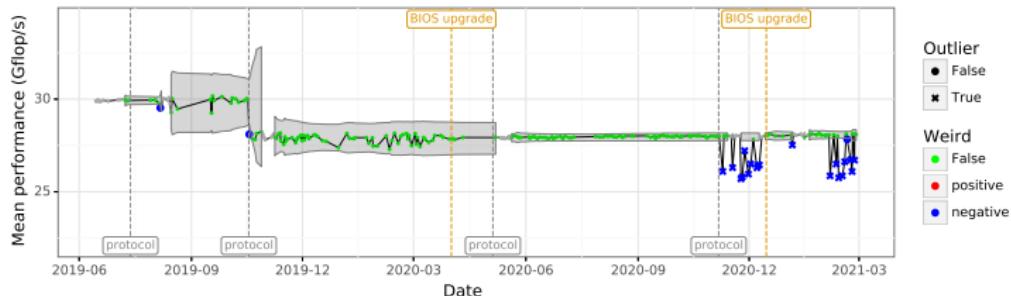


RESULT: PERFORMANCE FLUCTUATION

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Performance fluctuation of the node dahu-32



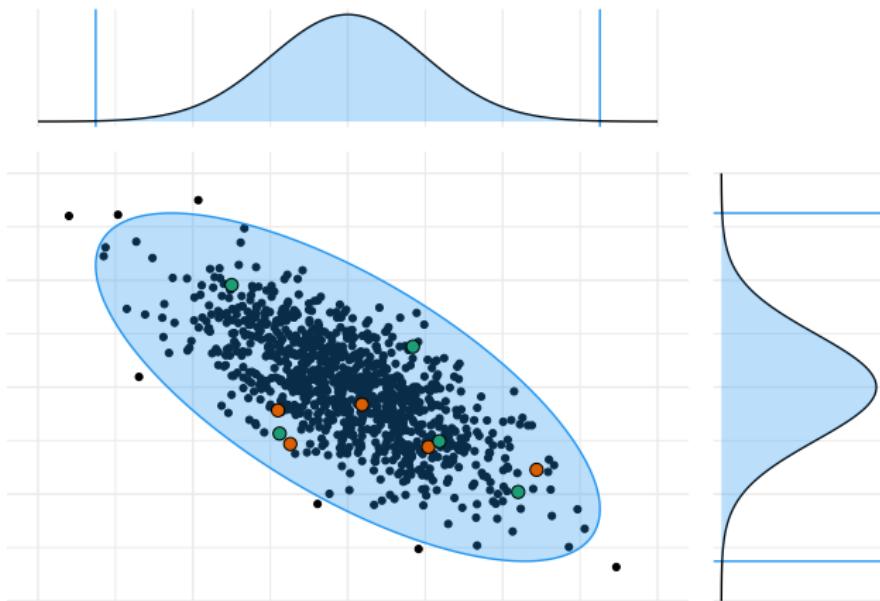
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Example with 5 measures



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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)

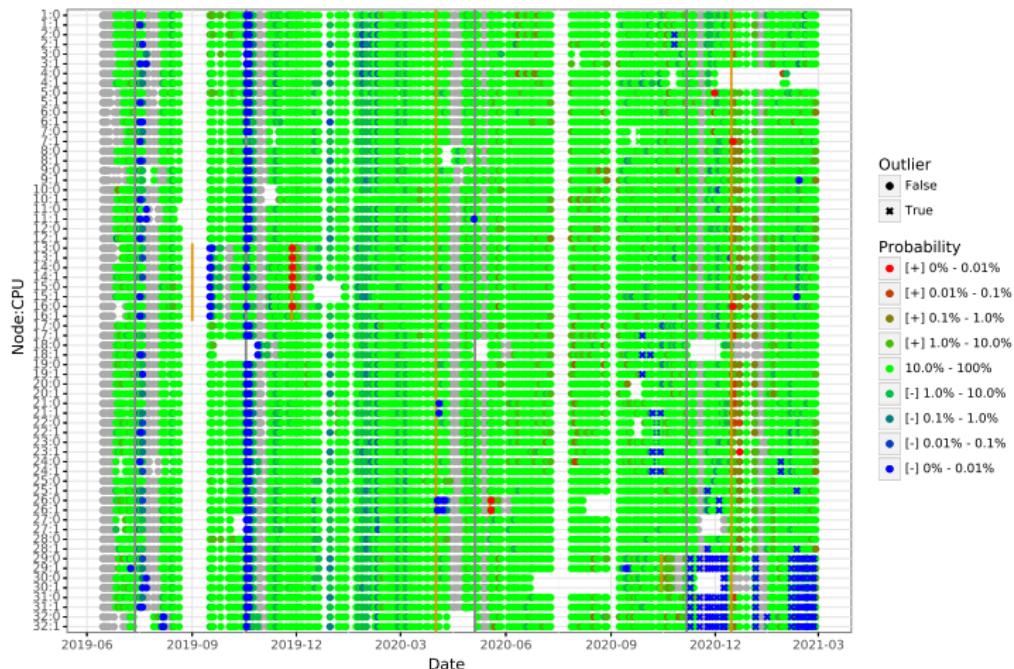


Performance fluctuation of the node dahu-32 (5-day window)



RESULT: PERFORMANCE OVERVIEW

Overview of the performance on cluster dahu



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PERFORMANCE TESTS: WRAPING UP

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

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Results available at https://cornebize.net/g5k_test

| Cluster | Performance | Performance _{GPU} | Frequency | Power _{CPU} | Power _{GPU} | Temperature | Model |
|----------|-------------|----------------------------|-----------|----------------------|----------------------|-------------|-------|
| chetteri | | | | | | | |
| chiclet | | | | | | | |
| dehu | | | | | | | |
| ecotype | | | | | | | |
| grassu | | | | | | | |
| gras | | | | | | | |
| grvingt | | | | | | | |
| parasito | | | | | | | |
| panchine | | | | | | | |
| pynix | | | | | | | |
| troll | | | | | | | |
| yeti | | | | | | | |

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| Cluster | Performance | Performance _{DMB} | Frequency | Power _{CPU} | Power _{DRAM} | Temperature | Model |
|----------|-------------|----------------------------|-----------|----------------------|-----------------------|-------------|-------|
| chetteri | | | | | | | |
| chiclet | | | | | | | |
| dehu | | | | | | | |
| ecotype | | | | | | | |
| grisou | | | | | | | |
| gross | | | | | | | |
| gringst | | | | | | | |
| parasito | | | | | | | |
| pantheon | | | | | | | |
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Detected events

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

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

⇒ Great help potential

CONCLUDING THOUGHTS

CAN WE TRUST OUR PREDICTIONS?

How to know if our predictions are faithful?

There is no *correctness proof*, a model can be validated only by
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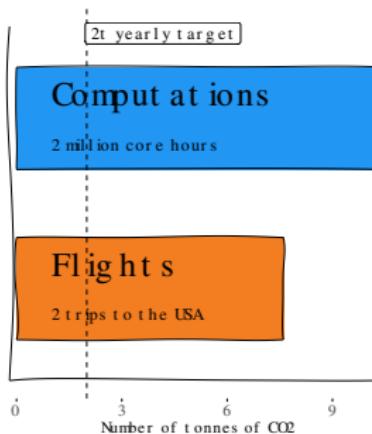
Repeated the whole study **from scratch** on a new cluster:



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

THERE IS NO PLANET B

About 18t of CO₂eq 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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- Change the experiment procedure (e.g. no full node reinstallation)
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- Use a cheaper test (e.g. shorter warmup, less extensive coverage)

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Who should be responsible of tests?

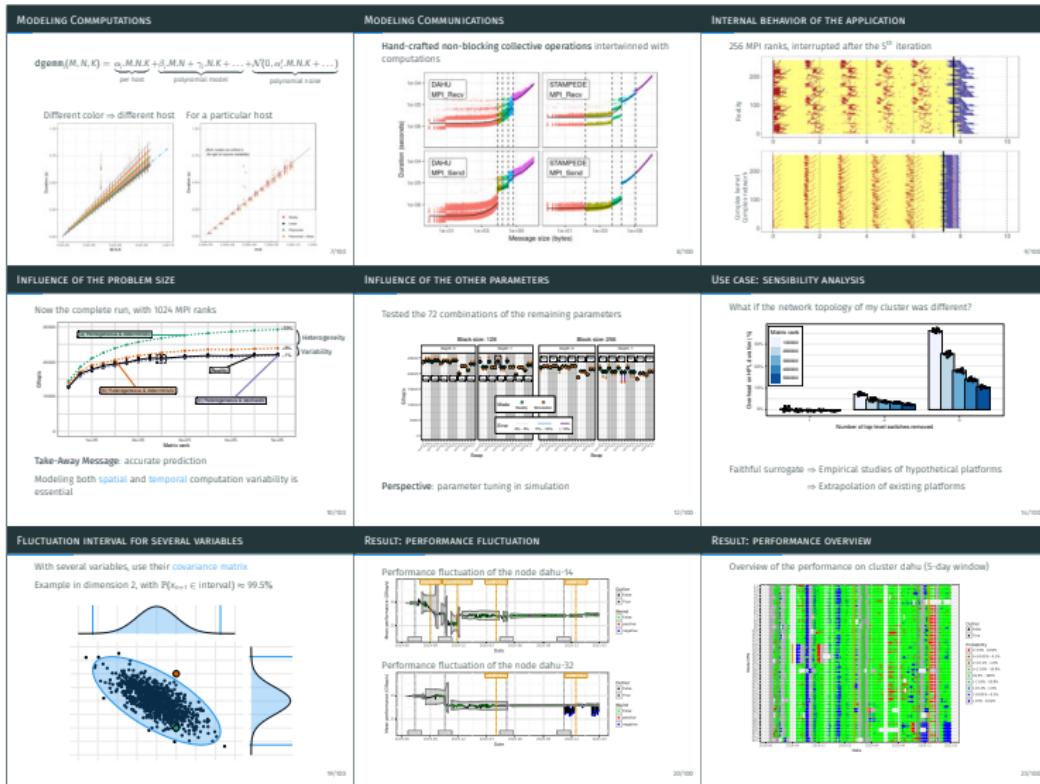
- Platform staff? But what should they test?
- Researchers? Isn't it redundant?

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!