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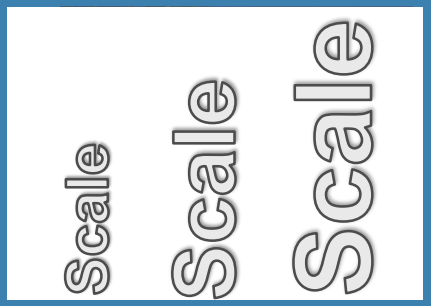
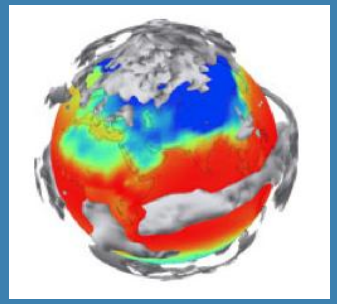
Using Automated Performance Modeling to Find Scalability Bugs in Complex Codes



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2) ETH Zurich

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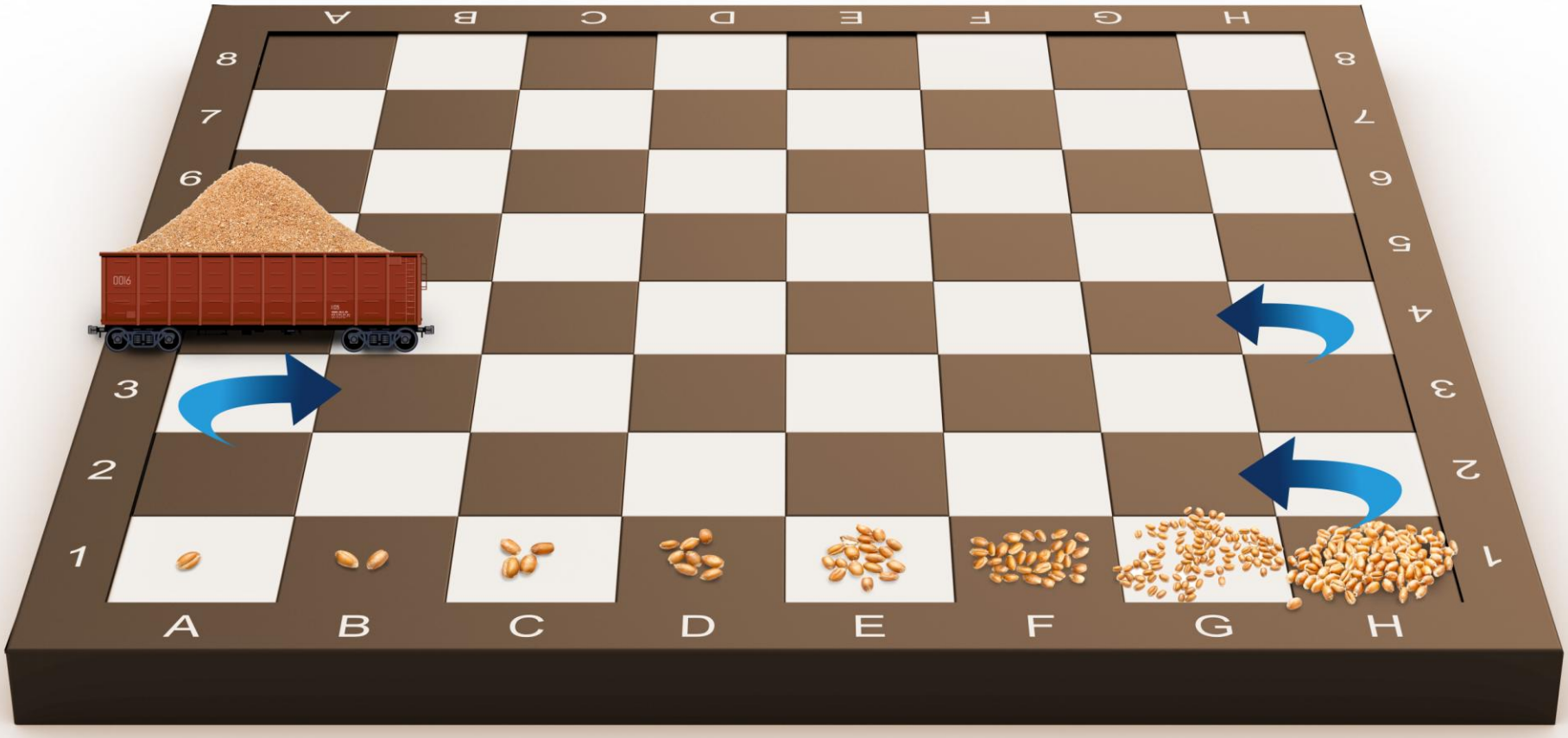
JÜLICH FORSCHUNGSZENTRUM

RWTH AACHEN UNIVERSITY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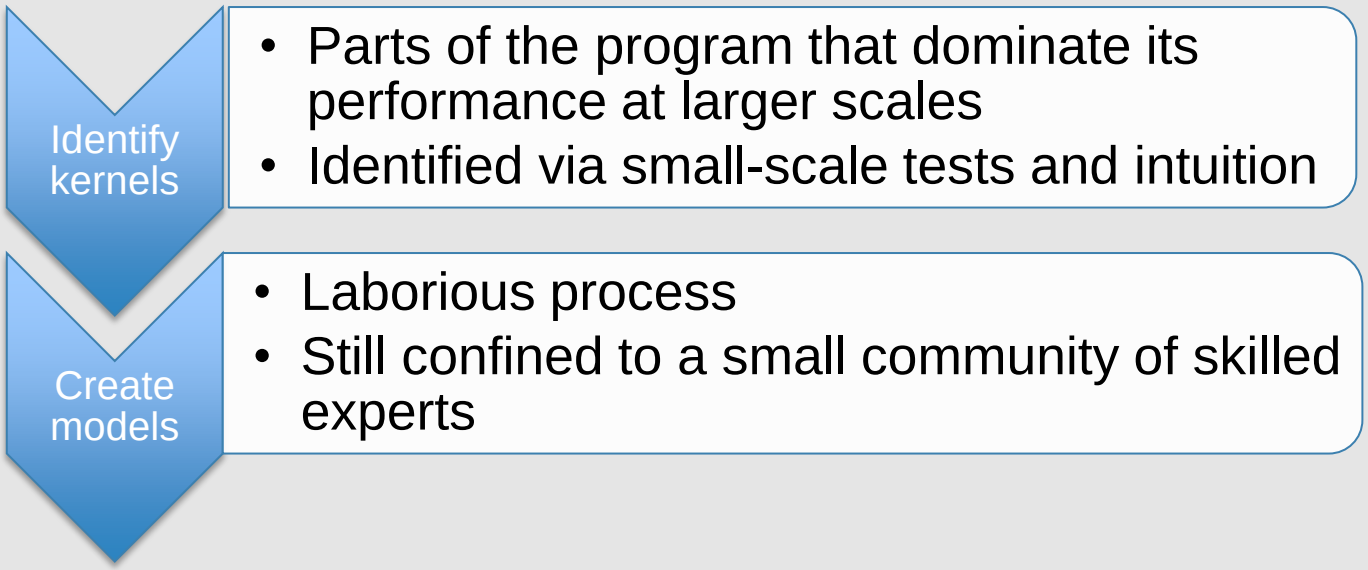
Analytical performance modeling



Disadvantages

- Time consuming
- Danger of overlooking unscalable code

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Our approach

Generate an empirical model for each part of the program automatically

- Run a manageable number of small-scale performance experiments
- Launch our tool
- Compare extrapolated performance to expectations

Key ideas

- Exploit that space of function classes underlying such model is small enough to be searched by a computer program
- Abandon model accuracy as the primary success metric and rather focus on the binary notion of scalability bugs
- Create requirements models alongside execution models

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SPPEXA project Catwalk

- German Research School for Simulation Sciences, Laboratory for Parallel Programming (Prof. Dr. Felix Wolf)
- Technische Universität Darmstadt, Institute for Scientific Computing (Prof. Dr. Christian Bischof)

- Swiss Federal Institute of Technology Zurich, Institute of Computer Systems, (Prof. Dr. Torsten Hoefler)

- Forschungszentrum Jülich, Jülich Supercomputing Centre (Dr.-Ing. Bernd Mohr)

- Goethe University Frankfurt, Goethe Center for Scientific Computing (Prof. Dr. Gabriel Wittum)

DFG FNSNF

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Outline

Overview
Detailed approach
Evaluation
Conclusion

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Scalability bug detector

Input
- Set of performance measurements (profiles) on different processor counts $\{p_1, \ldots, p_{max}\}$ w/ weak scaling
- Individual measurement broken down by program region (call path)

Output
- List of program regions (kernels) ranked by their predicted execution time at target scale $p_t > p_{max}$
- Or ranked by growth function ($p_t \rightarrow \infty$)

- Not 100% accurate but good enough to draw attention to right kernels
- False negatives when phenomenon at scale is not captured in data
- False positives possible but unlikely

- Can also model parameters other than p

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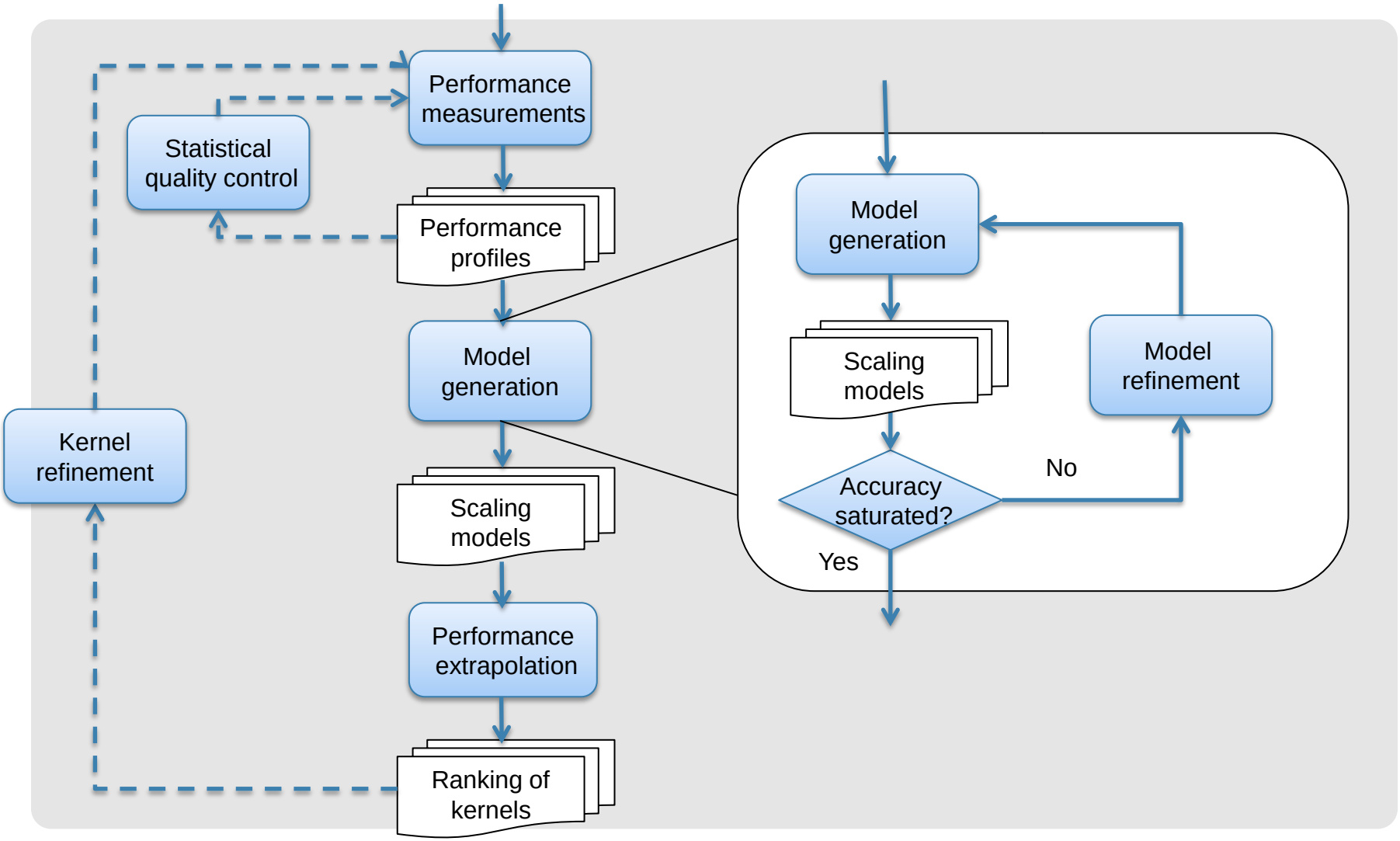
Workflow



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Model generation

Performance Model Normal Form (PMNF)

$$f(p) = \sum_{k=1}^{n} c_k \times p^{i_k} \times \log_2^{j_k}(p)$$

- Not exhaustive but works in most practical scenarios
- An assignment of n, i_k and j_k is called model hypothesis
- i_k and j_k are chosen from sets $I,J \subset \mathbf{Q}$
- n, $|I|$, $|J|$ don't have to be arbitrarily large to achieve good fit

Instead of deriving model through reasoning, make reasonable choices for n, I, J and try all assignment options one by one

- Select winner through **cross-validation**

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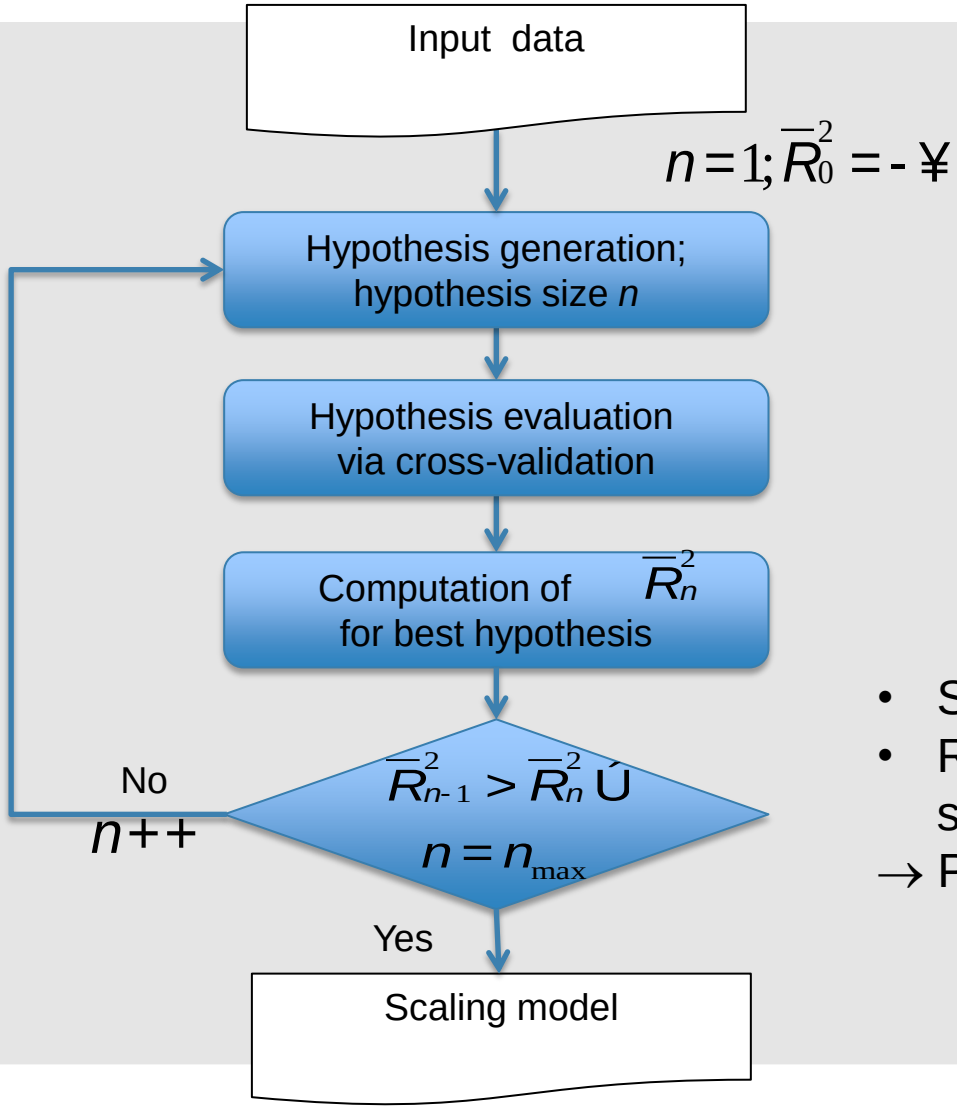
Model refinement



- Start with coarse approximation
- Refine to the point of statistical shrinkage

→ Protection against over-fitting

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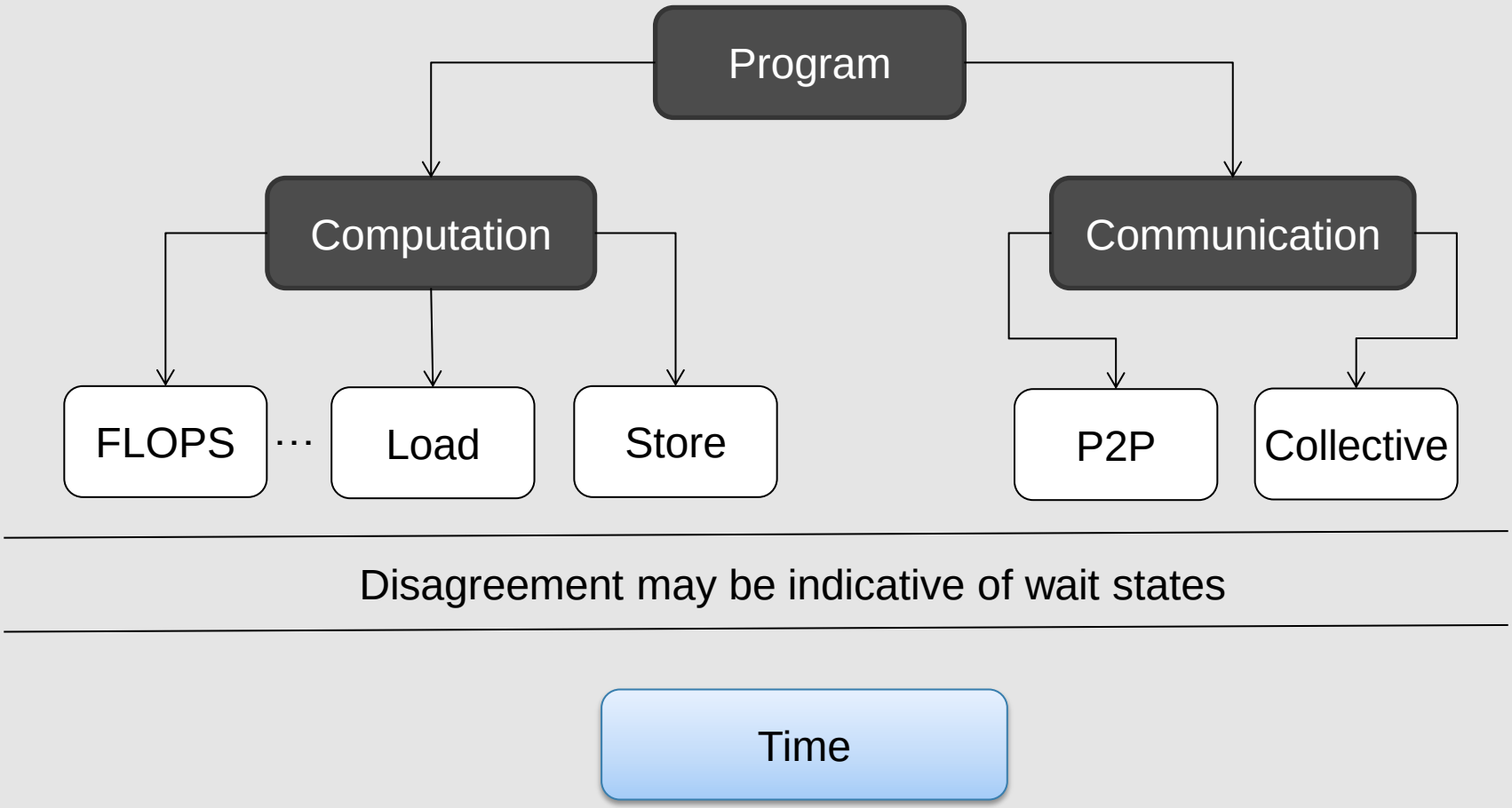
Requirements modeling



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Evaluation

We demonstrate that our tool

- identifies a scalability issue in a code that is known to have one
- does not identify a scalability issue in a code that is known to have none
- identifies two scalability issues in a code that was thought to have only one

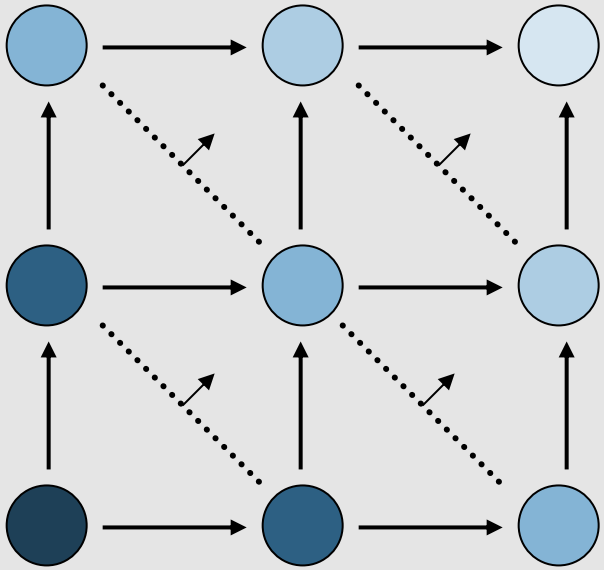
Test platform:
IBM Blue Gene/Q
Juqueen in Jülich

$$I = \{\tfrac{0}{2}, \tfrac{1}{2}, \tfrac{2}{2}, \tfrac{3}{2}, \tfrac{4}{2}, \tfrac{5}{2}, \tfrac{6}{2}\}$$
$$J = \{0,1,2\}$$
$$n = 5$$

Sweep3D

Solves neutron transport problem

- 3D domain mapped onto 2D process grid
- Parallelism achieved through pipelined wave-front process



LogGP model for communication developed by Hoisie et al.

$$t^{comm} = [2(p_x + p_y - 2) + 4(n_{sweep} - 1)] \times t_{msg}$$

$$t^{comm} = c \times \sqrt{p}$$

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Sweep3D (2)

Kernel	Runtime[%] p_t=262k	Increase $\frac{t(p=262k)}{t(p=64)}$	Model [s] t = f(p)	Predictive error [%] p_t=262k
sweep->MPI_Recv	65.35	16.54	$4.03\sqrt{p}$	5.10
sweep	20.87	0.23	582.19	0.01
global_int_sum-> MPI_Allreduce	12.89	18.68	$1.06\sqrt{p}+ 0.03\sqrt{p}*\log(p)$	13.60
sweep->MPI_Send	0.40	0.23	$11.49+0.09\sqrt{p}*\log(p)$	15.40
source	0.25	0.04	$6.86+9.13*10^{-5}\log(p)$	0.01

$p_i \leq 8k$

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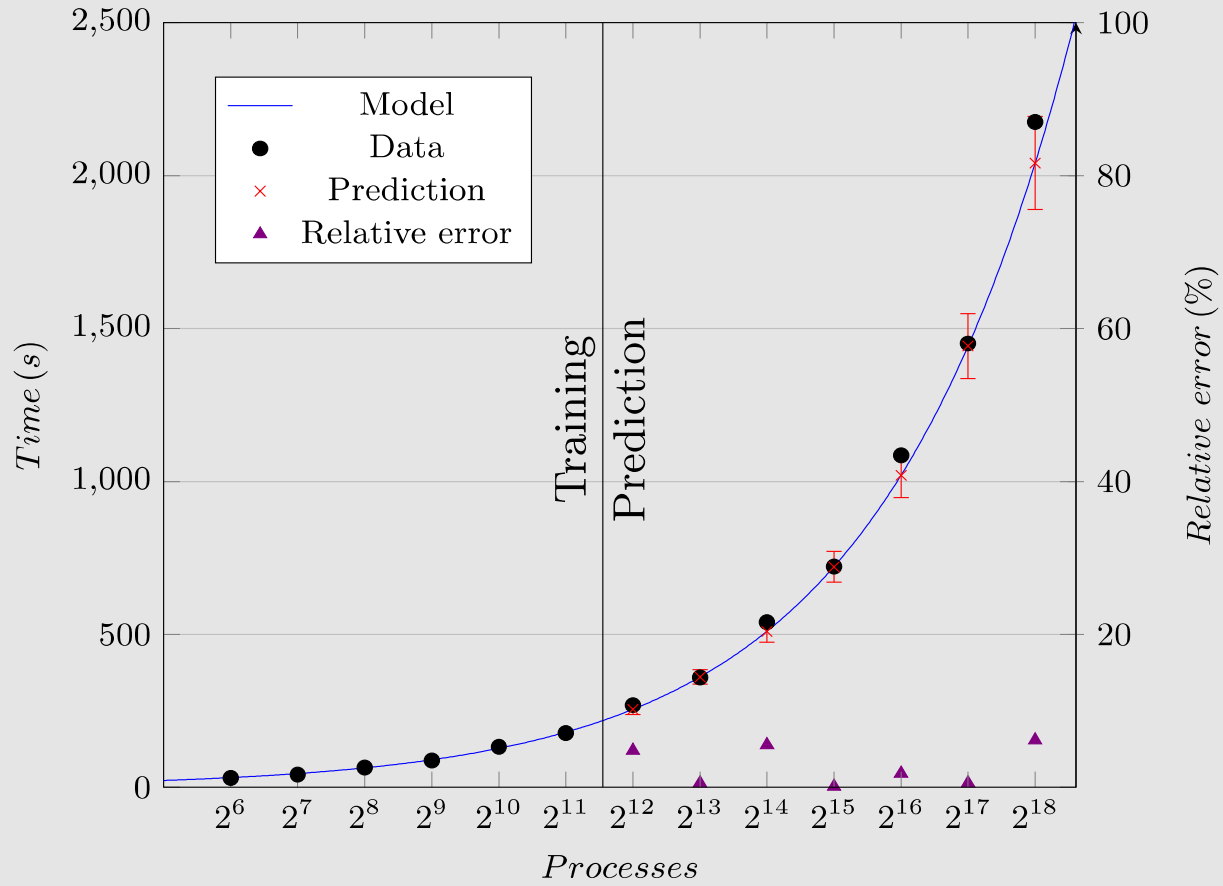
Sweep3D (3)



MILC

MILC/su3_rmd – code from MILC suite of QCD codes with performance model manually created by Hoefler et al.

- Time per process should remain constant except for a rather small logarithmic term caused by global convergence checks

Kernel	Model [s] t=f(p)	Predictive Error [%] p_t=64k
compute_gen_staple_field	$2.40*10^{-2}$	0.43
g_vecdoublesum>MPI_Allreduce	$6.30*10^{-6}*\log^2 p$	0.01
mult_adj_su3_fieldlink_lathwec	$3.80*10^{-3}$	0.04

$p_i \leq 16k$

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MILC – Varying grid points per process

Kernel	Flops Model[s] flops=f(V)	$\overline{R^2}$ [*10^{-3}]	Visits Model visits=f(V)	$\overline{R^2}$ [*10^{-3}]	Flops/Visit Model	$\overline{R^2}$ [*10^{-3}]
load_lnglinks	$5.64*10^4*V$	0.030	$2.31*10^3$	0.000	24.42*V	0.030
load_fatlinks_cpu	$1.95*10^6*V$	0.210	$7.14*10^4$	0.000	27.36*V	0.210
ks_congrad	$1.16*10^8+ 3.24*10^5*V^{5/4}$	0.292	$5.11*10^4+ 1.38*10^4*V^{1/4}$	4.000	15.94*V	0.143
imp_gauge_force_cpu	$1.65*10^6*V$	0.015	$7.40*10^4$	0.000	22.28*V	0.015
eo_fermion_force_two_terms_site	$4.02*10^6*V$	0.002	$1.27*10^5$	0.000	31.61*V	0.002

Test platform: Juropa in Jülich (Intel Nehalem cluster)
p = 32= constant

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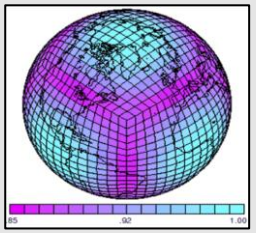
HOMME

Core of the Community Atmospheric Model (CAM)

- Spectral element dynamical core on a cubed sphere grid



Kernel	$p_i \leq 15k$ Model [s] t = f(p)	$p_i \leq 15k$ Predictive error [%] $p_t = 130k$	$p_i \leq 43k$ Model [s] t = f(p)	$p_i \leq 43k$ Predictive error [%] $p_t = 130k$
Box_rearrange->MPI_Reduce	$0.03+2.53*10^{-6}p*\sqrt{p}+1.24*10^{-12}p^3$	57.02	$3.63*10^{-6}p*\sqrt{p}+7.21*10^{-13}p^3$	30.34
Vlaplace_sphere_vk	49.53	99.32	$24.44+2.26*10^{-7}p^2$	4.28
…				
Compute_and_apply_rhs	48.68	1.65	49.09	0.83

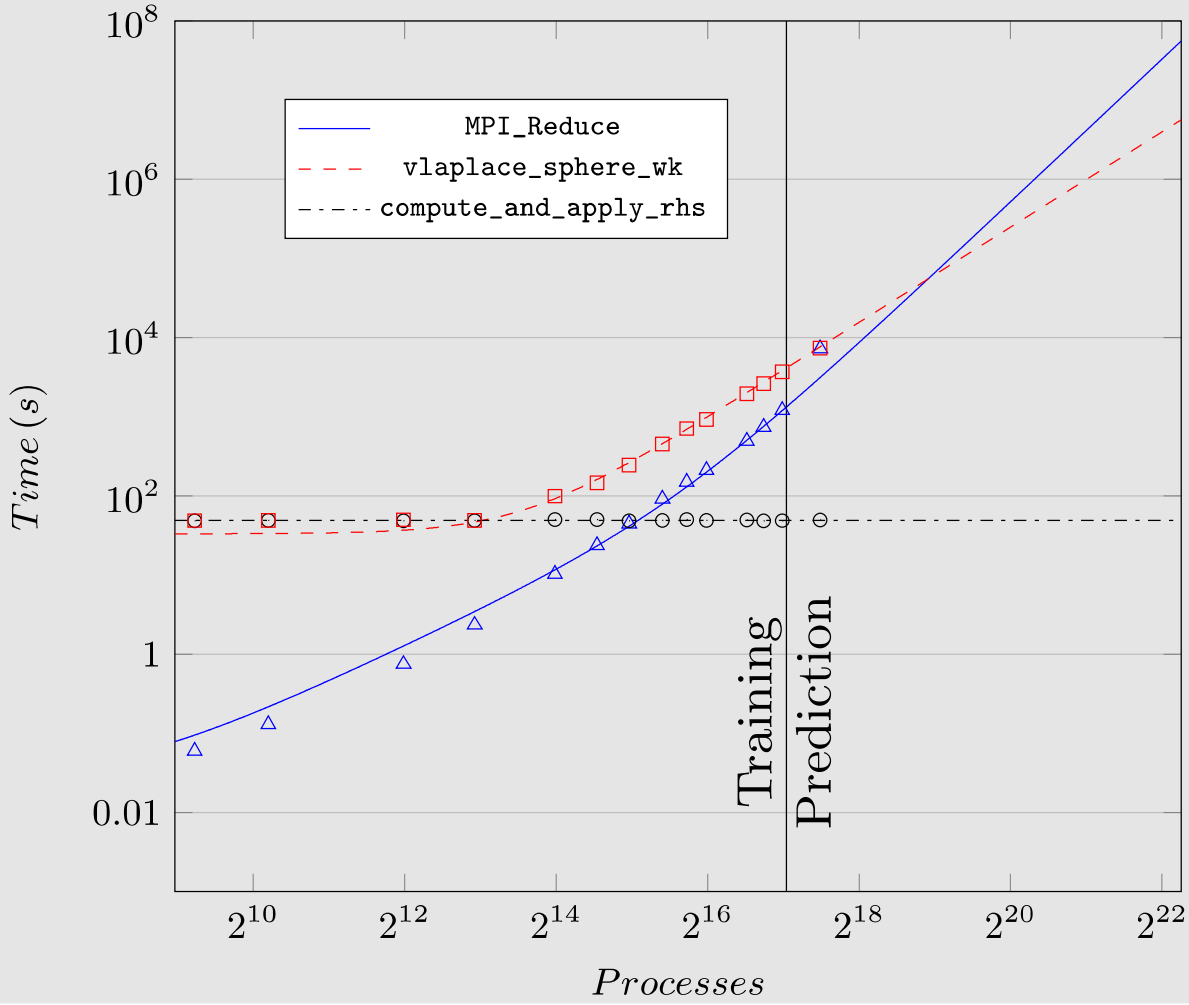
HOMME (2)

Two issues

Number of iterations inside a subroutine grows with p^2
- Ceiling for up to and including 15k
- Developers were aware of this issue and had developed work-around

Growth of time spent in reduce function grows with p^3
- Previously unknown
- Function invoked during initialization to funnel data to dedicated I/O processes
- Execution time at 183k ~ 2h, predictive error ~40%

HOMME (3)


MPI_Reduce
vlaplace_sphere_wk
compute_and_apply_rhs
Training
Prediction
Time (s)
Processes
10^8
10^6
10^4
10^2
1
0.01
2^10
2^12
2^14
2^16
2^18
2^20
2^22

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Conclusion

Automated performance modeling is feasible

Generated models accurate enough to identify scalability bugs and in good agreement with hand-crafted models

Advantages of mass production also performance models

- Approximate models are acceptable as long as the effort to create them is low and they do not mislead the user
- Code coverage is as important as model accuracy

Future work

- Study influence of further hardware parameters
- More efficient traversal of search space (allows increase of modeling parameters)
- Integration into Scalasca