# Noise-Resilient Performance Modeling of HPC Applications

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**Scalable Tools Workshop 2022**

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Photo: Alex Becker / TU Darmstadt

# Acknowledgement


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- Bernd Mohr
- […]

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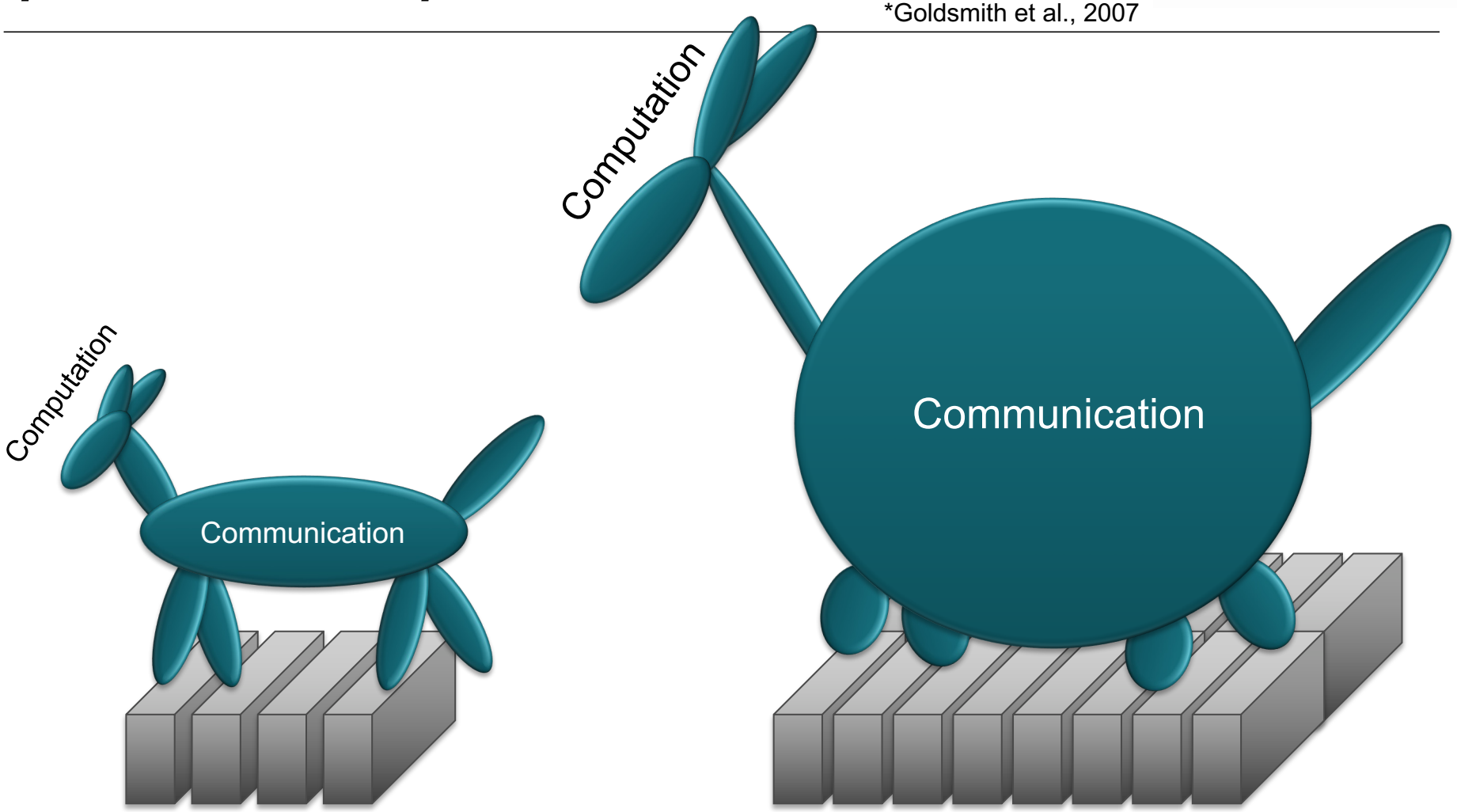
- Larissa Schmidt
- […]

# Scaling your code can harbor *performance surprises**…

*Goldsmith et al., 2007



# Performance model

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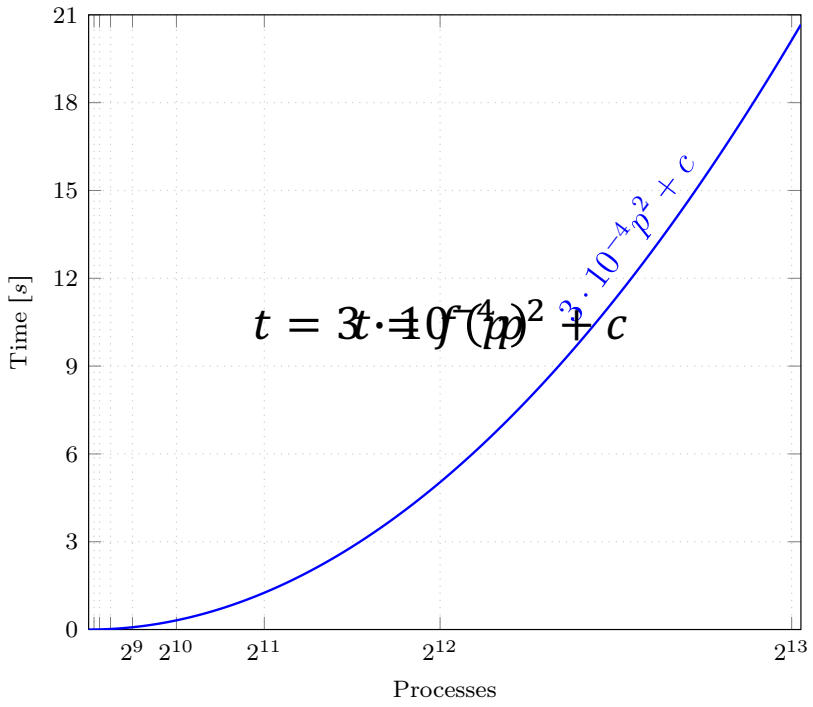
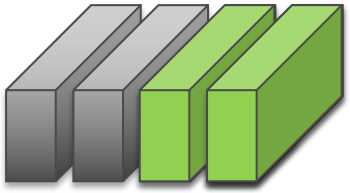
Formula that expresses a relevant performance metric as a function of one or more execution parameters



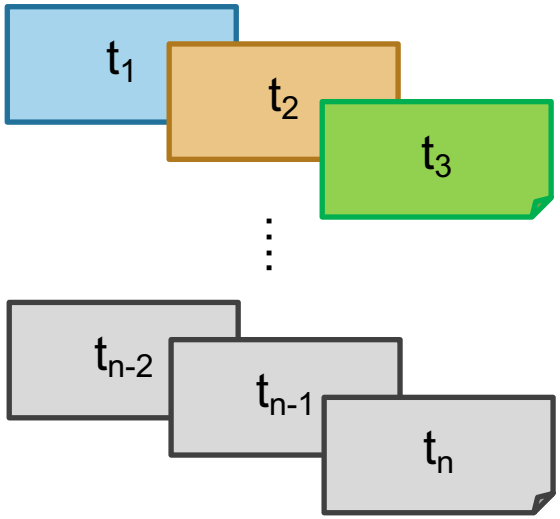

Analytical (i.e., manual) creation challenging for entire programs

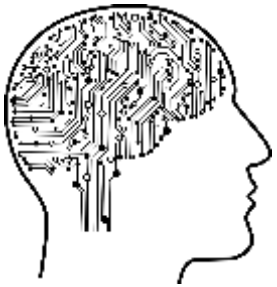
- Identify kernels
  - Incomplete coverage
- Create models
  - Laborious, difficult

# Empirical performance modeling



Performance measurements with different execution parameters $\mathbf{x_1,\ldots,x_n}$



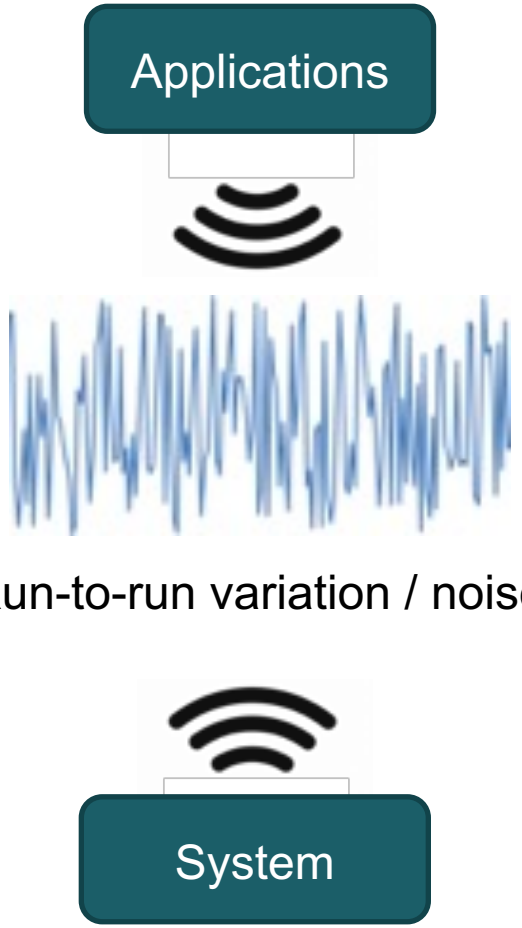



Machine learning

$$t = f(x_1, \ldots, x_n)$$

Alternative metrics: FLOPs, data volume…

# Challenges




Run-to-run variation / noise

Cost of the required experiments

# How to deal with noisy data

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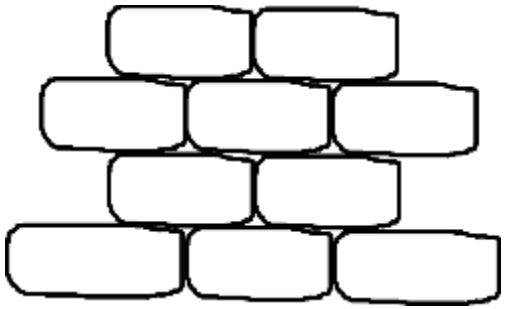
- Introduce **prior** into learning process
  - Assumption about the probability distribution generating the data

Time

~



Effort

- Computation
- Memory access
- Communication
- I/O

# Performance model normal form (PMNF)

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

Single parameter
[Calotoiu et al., SC13]

Parameter selection → Search space configuration → Linear regression + cross-validation → Quality assurance

$$f(x_1, \ldots, x_m) = \sum_{k=1}^{n} c_k \prod_{l=1}^{m} x_l^{i_{kl}} \cdot log_2^{j_{kl}}(x_l)$$

Multiple parameters [Calotoiu et al., Cluster'16]

Heuristics to reduce search space

# Extra-P 4.0

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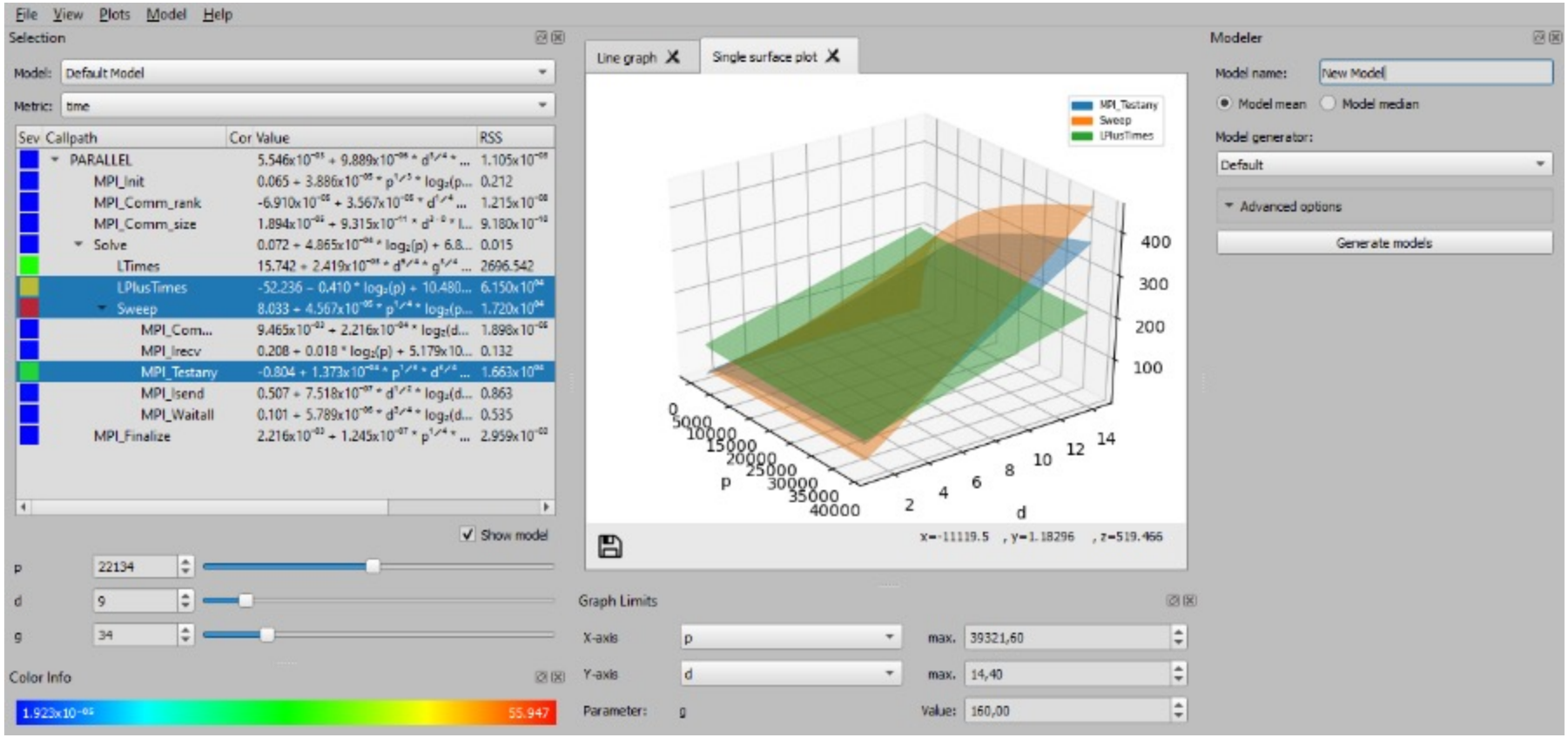


Available at: https://github.com/extra-p/extrap

# Noise-resilient performance modeling

[Ritter et al., IPDPS'21]

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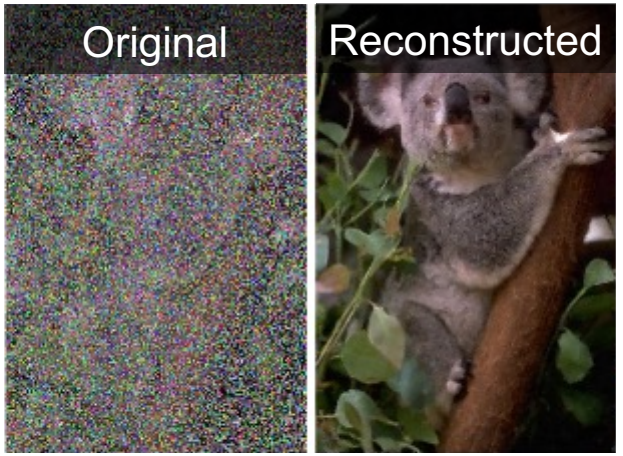
- Performance measurements frequently affected by noise
- Regression struggles with increased amounts of noise – especially w/ more parameters

- Neural networks are resilient to noise – **when noise is part of their training**

**1 Parameter:**


**3 Parameter:**


Adapted from: https://developer.nvidia.com/blog/ai-can-now-fix-your-grainy-photos-by-only-looking-at-grainy-photos/

# Noise-resilient adaptive modeling

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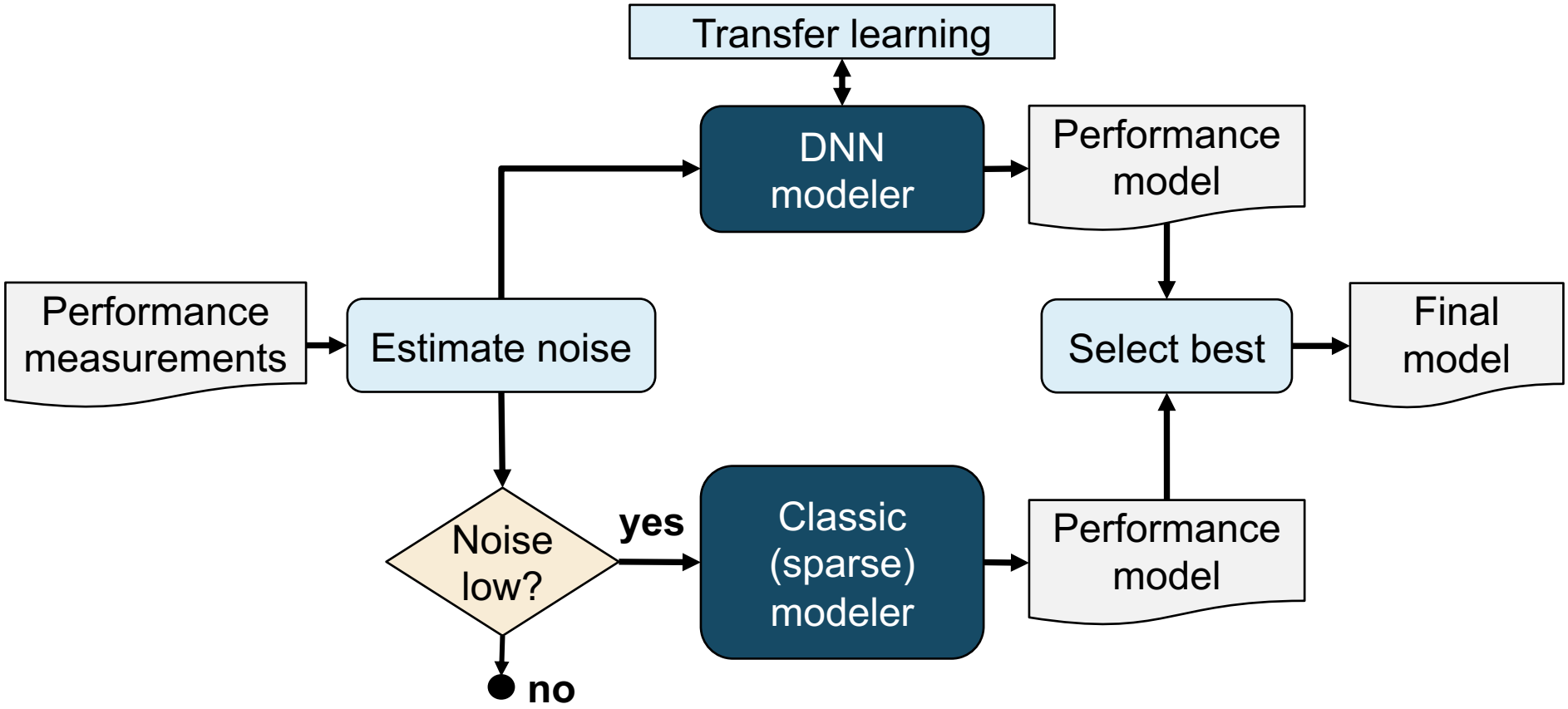
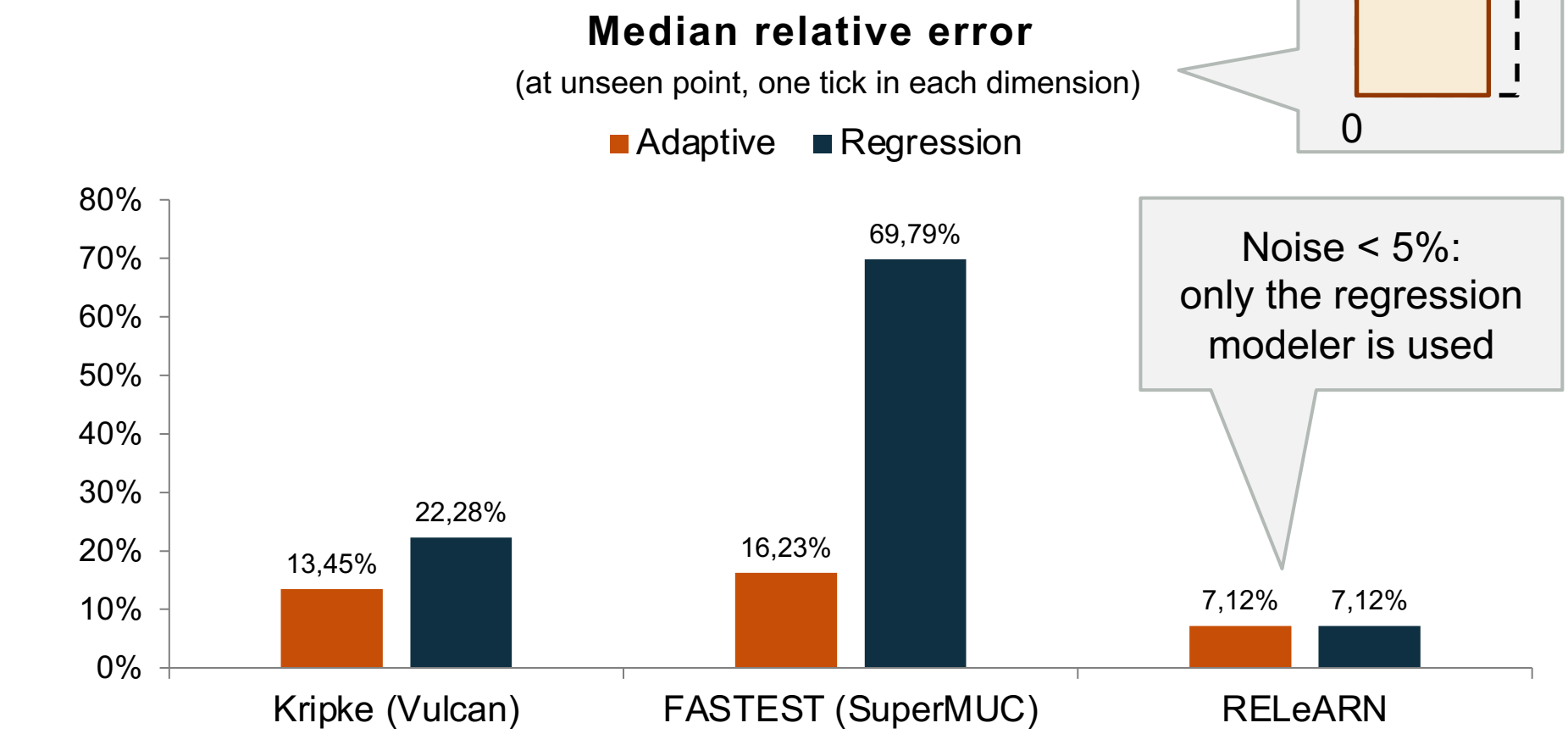
DNNs often better at guessing models in the presence of noise



# Noise-resilient performance modeling

## Case studies – Results



# Parameter selection
[Copik et al, PPoPP'21]

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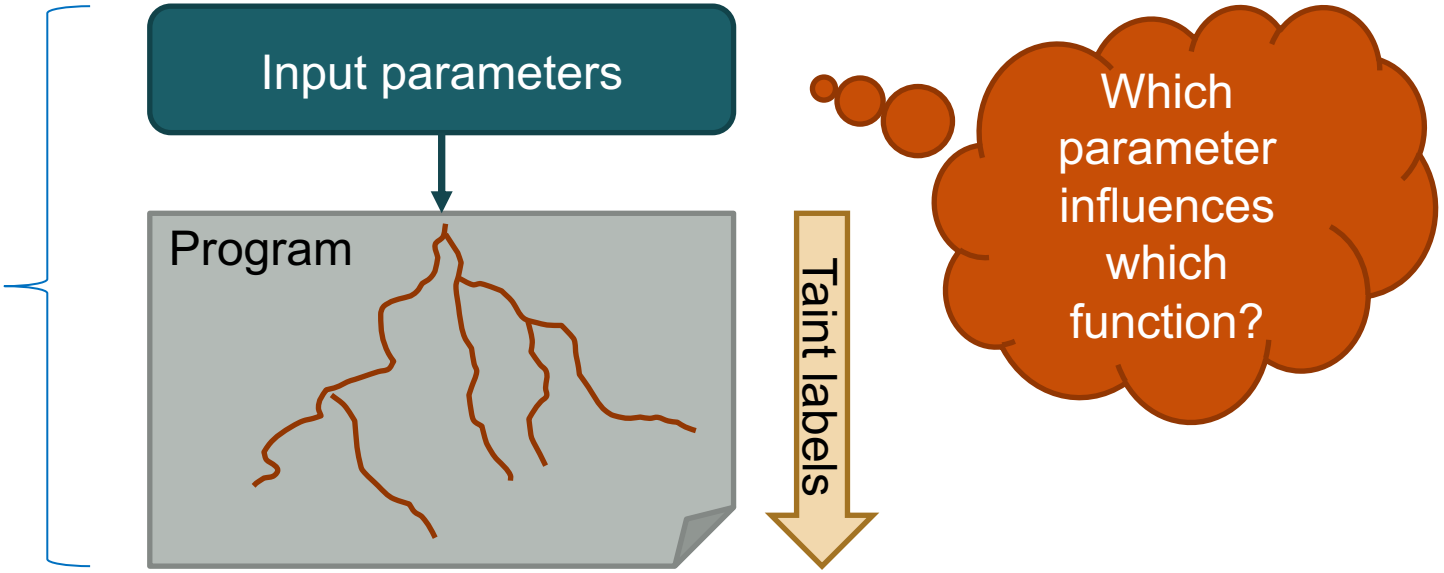
- The more paramters the more experiments
- Modeling parameters without performance impact is harmful

**Taint analysis**



# Case study – LULESH & MILC
## Influence of program parameters

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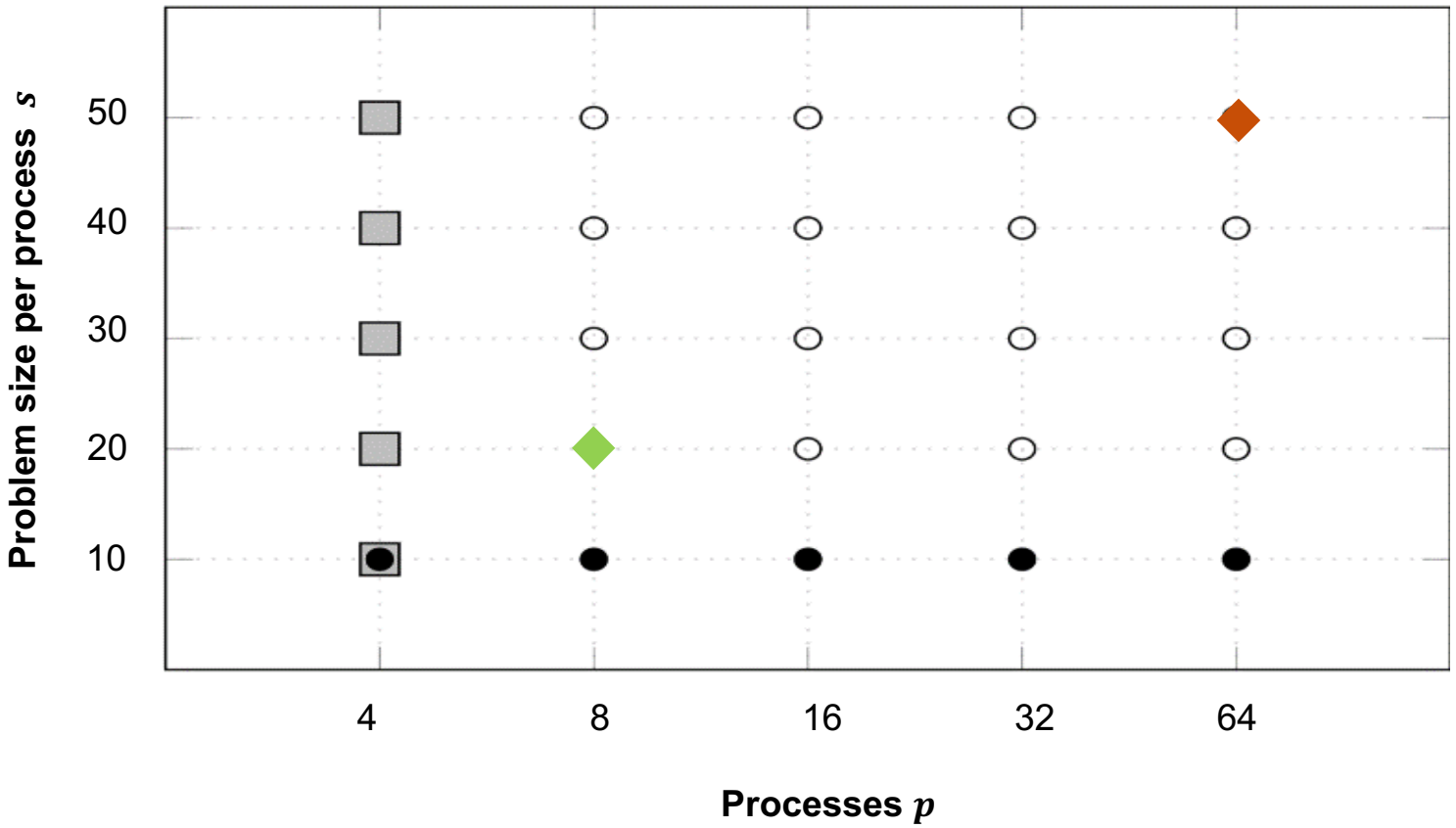
| LULESH | Total | p | size | regions | iters | balance | cost | p, size |
|---|---|---|---|---|---|---|---|---|
| Functions | 349 | 2 | 40 | 15 | 1 | 1 | 2 | 40 |
| Loops | 275 | 2 | 78 | 29 | 1 | 1 | 2 | 78 |

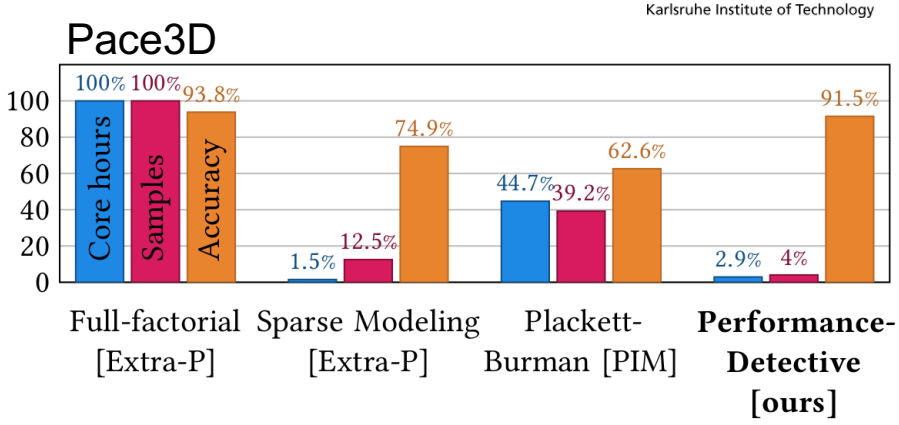
| MILC | Total | p | size | trajecs | warms steps | nrest. niter | mass, beta nfl. | u0 | p, size |
|---|---|---|---|---|---|---|---|---|---|
| Functions | 621 | 54 | 53 | 12 | 9 | 6 | 1 | 4 | 56 |
| Loops | 874 | 187 | 161 | 39 | 31 | 15 | 1 | 7 | 196 |

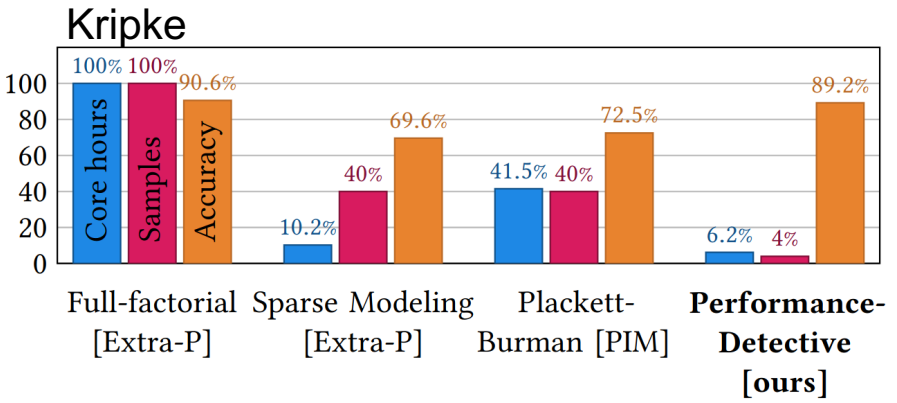
# How many data points do we really need?



# Performance Detective –
## Automatic deduction of cheap and accurate performance models
## [Schmidt et al, ICS 2022]

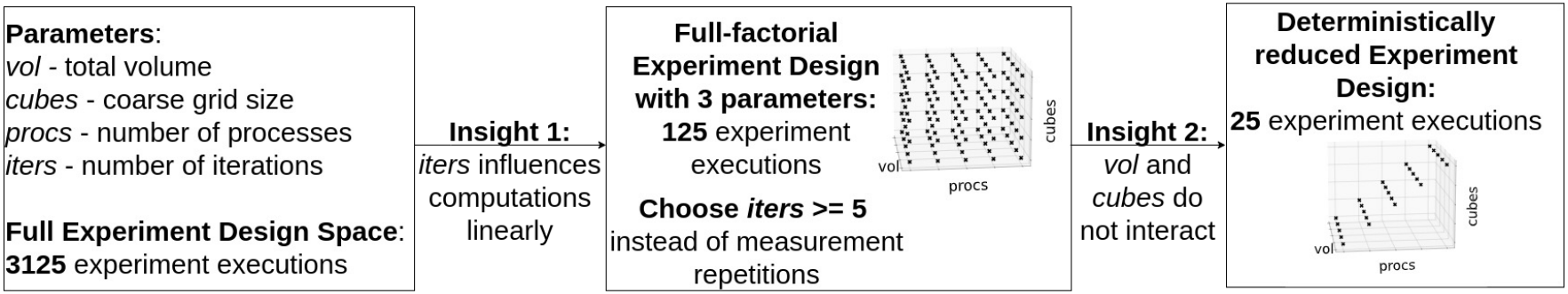
- **Problem** – Current heuristic sampling strategy too expensive
- **Contribution** – Use PerfTaint to deduce minimum set of experiments
- Case studies show same model accuracy at reduced cost



# Performance Detective (2)

- Parameters that influence computation linearly
  - Instead of repeating measurements, set parameter influencing the computation linearly to >= 5
- Strike out configurations aimed at finding interactions between parameters that do not interact



# Refine prior based on noise-resilient metrics

[de Morais et al., work in progress]

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## Single parameter

$$f_{\text{bb}}(x) = \sum_{k=1}^{n_1} c_k \cdot p^{i_k} \cdot log_2^{j_k}(x)$$

(basic block based model)

**Search space to (i, j)**

$$f(x) = \sum_{k=1}^{n_2} c_k \cdot p^{i_k} \cdot log_2^{j_k}(x)$$

(time based model)

## Multiple parameters

$$f_{\text{bb}}(x_1, \ldots, x_m) = \sum_{k=1}^{n_3} c_k \prod_{l=1}^{m_3} x_l^{i_{kl}} \cdot log_2^{j_{kl}}(x_l)$$

(basic block based model)

**Search space to (i, j)**

$$f(x_1, \ldots, x_m) = \sum_{k=1}^{n_4} c_k \prod_{l=1}^{m_4} x_l^{i_{kl}} \cdot log_2^{j_{kl}}(x_l)$$

(time based model)

# Basic block

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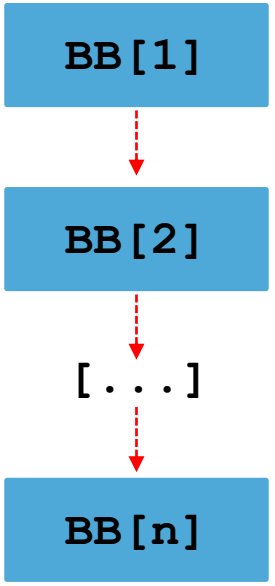
- Code sequence with no branches (except input and output) where all the instructions are executed sequentially
- Roughly constant execution time modulo noise
  - Good unit of effort
  - Number of basic blocks executed is reproducible



# LLVM

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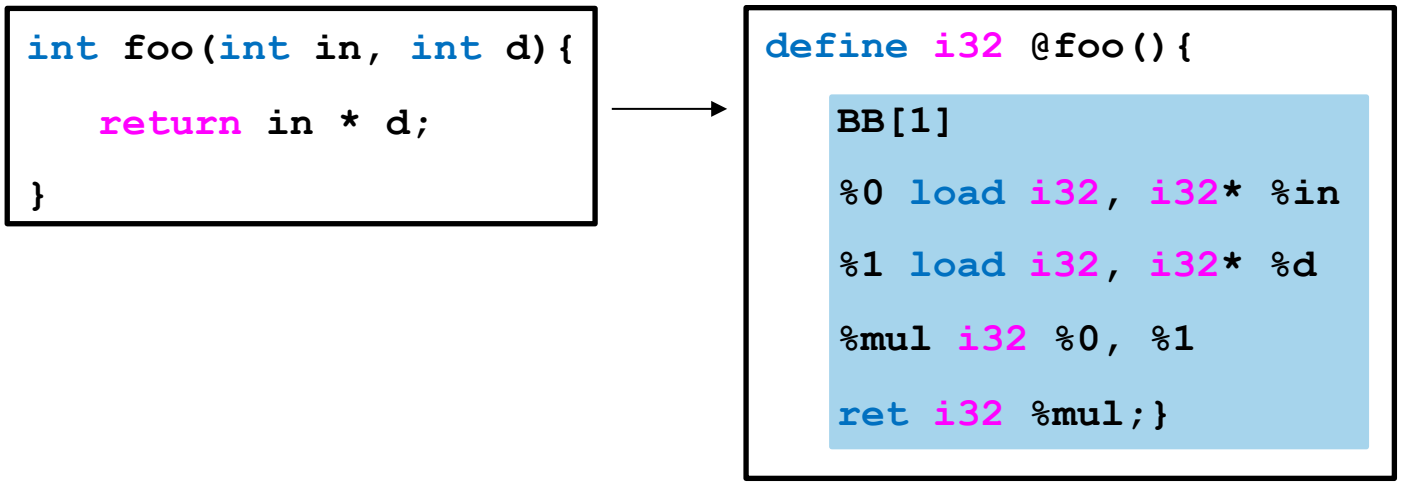
- Converts C/C++ source code to Intermediate Representation (IR)
- Allows automatic instrumentation, analyses, and optimizations of source codes on the IR level

C/C++ code to IR representation:



# Basic block instrumentation w/ Score-P

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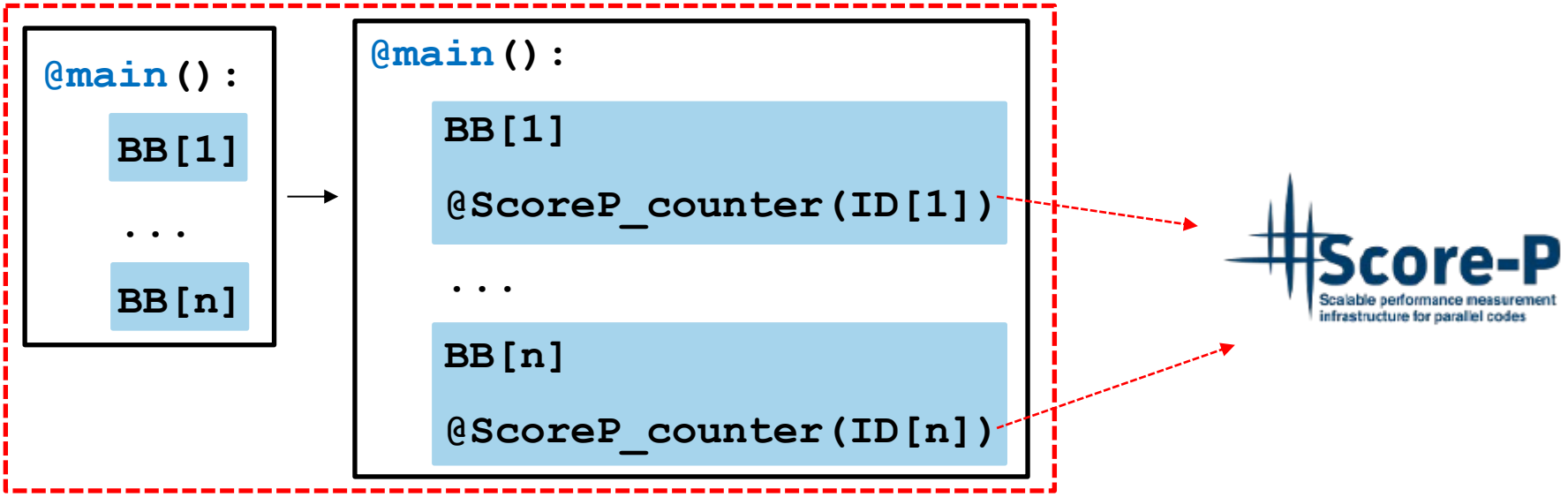
## IR instrumentation




- Static analysis: shows the number of functions, basic blocks and instructions present in the code
- Dynamic analysis: runs the code and counts the basic blocks as they are executed

# Selected papers

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| Topic | Bibliography |
|---|---|
| Foundation (single model paramter) | Alexandru Calotoiu, Torsten Hoefler, Marius Poke, Felix Wolf: Using Automated Performance Modeling to Find Scalability Bugs in Complex Codes. **SC13**. |
| Foundation (multipler model paramters) | Alexandru Calotoiu, David Beckingsale, Christopher W. Earl, Torsten Hoefler, Ian Karlin, Martin Schulz, Felix Wolf: Fast Multi-Parameter Performance Modeling. **IEEE Cluster 2016**. |
| Noise resilience | Marcus Ritter, Alexander Geiß, Johannes Wehrstein, Alexandru Calotoiu, Thorsten Reimann, Torsten Hoefler, Felix Wolf: Noise-Resilient Empirical Performance Modeling with Deep Neural Networks. **IPDPS 2021**. |
| Taint-based performance modeling | Marcin Copik, Alexandru Calotoiu, Tobias Grosser, Nicolas Wicki, Felix Wolf, Torsten Hoefler: Extracting Clean Performance Models from Tainted Programs. **PPoPP 2021**. |
| Performance detective | Larissa Schmid, Marcin Copik, Alexandru Calotoiu, Dominik Werle, Andreas Reiter, Michael Selzer, Anne Koziolek, Torsten Hoefler: Performance-Detective: Automatic Deduction of Cheap and Accurate Performance Models. **ICS 2022**. |

# Thank you!

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Q&A