Extracting Clean Performance Models from Tainted Programs

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THE UNIVERSITY OF EDINBURGH
TECHNISCHE UNIVERSITÄT DARMSTADT

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C, C++, Fortran

MPI, OpenMP

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bar: $1.3\log_2 p$

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Scalability bugs [1]

[1] A. Calotoiu, *"Using Automated Performance Modeling to Find Scalability Bugs in Complex Codes"*, **SC '13**

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Performance validation [2]

[2] S. Shudler, "*Exascaling Your Library: Will Your Implementation Meet Your Expectations?*", **ICS '15**

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Scalability bugs [1]

Performance validation [2]

Exascale system design [3]

[3] A. Calotoiu, *"Lightweight Requirements Engineering for Exascale Co-design"*, **CLUSTER '18**

Challenges in Automatic Performance Modeling

Parameters Identification

Select problem size **s** and ranks **p** as model parameters.

Challenges in Automatic Performance Modeling

Parameters Identification → **Experiment Design**

Select problem size **s** and ranks **p** as model parameters.

Decide to use
- **5** values per parameter
- **5** samples per experiment

25 combinations of **p** and **s**

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Parameters Identification → Experiment Design → Experiment Execution

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Experiment Execution

Score-P
Scalable performance measurement infrastructure for parallel codes

25 parameter values
5 repetitions per sample
125 instrumented executions

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Create performance model for **each function**.
Example result:

$$2.3\, s^3 + 1.71 \log_2 p - 0.1329$$

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#1: Which parameters are relevant? [1]

```
int nx, ny, nz, nt;
int node_geometry[4];
int nflavors, propinterval;
int warms, trajecs, steps;
int niter, nrestart, prec_pbp;
```

A **subset** of all *su3_rmd* parameters.

[1] T. Hoefler *"Performance Modeling for Systematic Performance Tuning"*, **SC '11**

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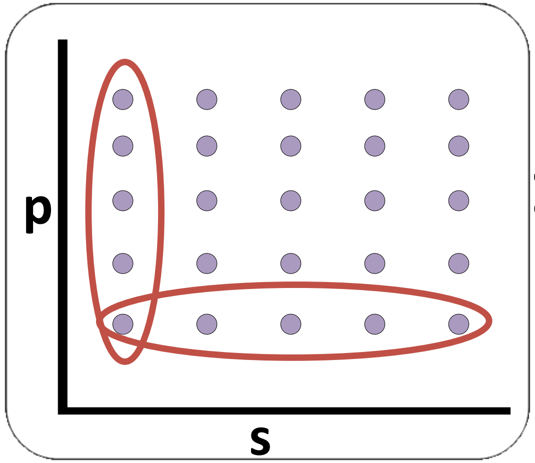
#2: How do parameters interact with each other? [2]



$p \times s$
10+ experiments
$p + s$
9 experiments

[2] M. Ritter, *"Performance Modeling at a Discount"*, **IPDPS '20**

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#3: Which functions are worth being instrumented?

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```
int p = MPI_ranks();
for(int i = 0; i < p - 1; ++i)
  MPI_Send(…);
```

$$-10^{-5} s^2 + 1.3\, p + 0.7$$

#4: Which functions and parameters affect performance?

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#1: Which parameters are relevant? [1]

other? [2]

We need a **white-box approach.**

#4: Which functions and parameters affect performance?

#5: Does the model represent application behavior or hardware effects?

What is important in our program?

```c
void main(int s, int p) {
  g(s, p); h(s, p); i(s, p);
}
```

```c
void g(int s) {
  MPI_Send(&s, 1, MPI_INT);
}
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```c
void h(int s, int p) {
  j(s);
}
```

```c
void i(int s, int p) {
  printf("%d %d\n", s, p);
}
```

```c
void j(int x) {
  for(int j = 0; j < x; ++j)
    // compute
}
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What is important in our program?

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Which functions are performance-critical?

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void i( ... p) {
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Which parameters affect performance?

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- …require minor code changes.

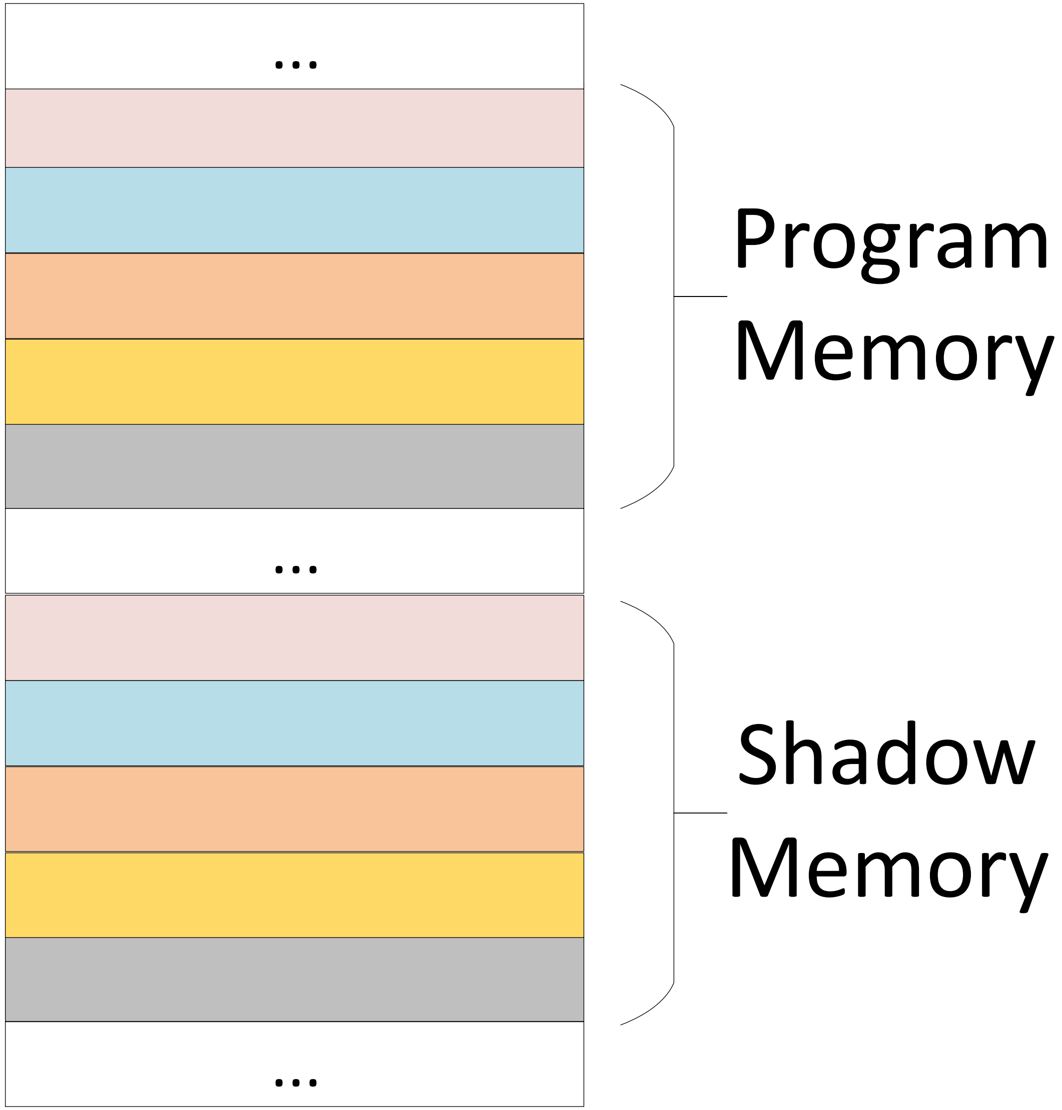
Answer? Taint Analysis.

Taint Analysis: track parameters propagation

```
int a = 42;
int b; MPI_Comm_size(&b, comm);
taint_variable(a);

// Data-flow propagation
int x = 2 * a;
int y = modulo(a, b);

// Control-flow propagation
int z = 10;
if(a != 43)
  z = 6;
```



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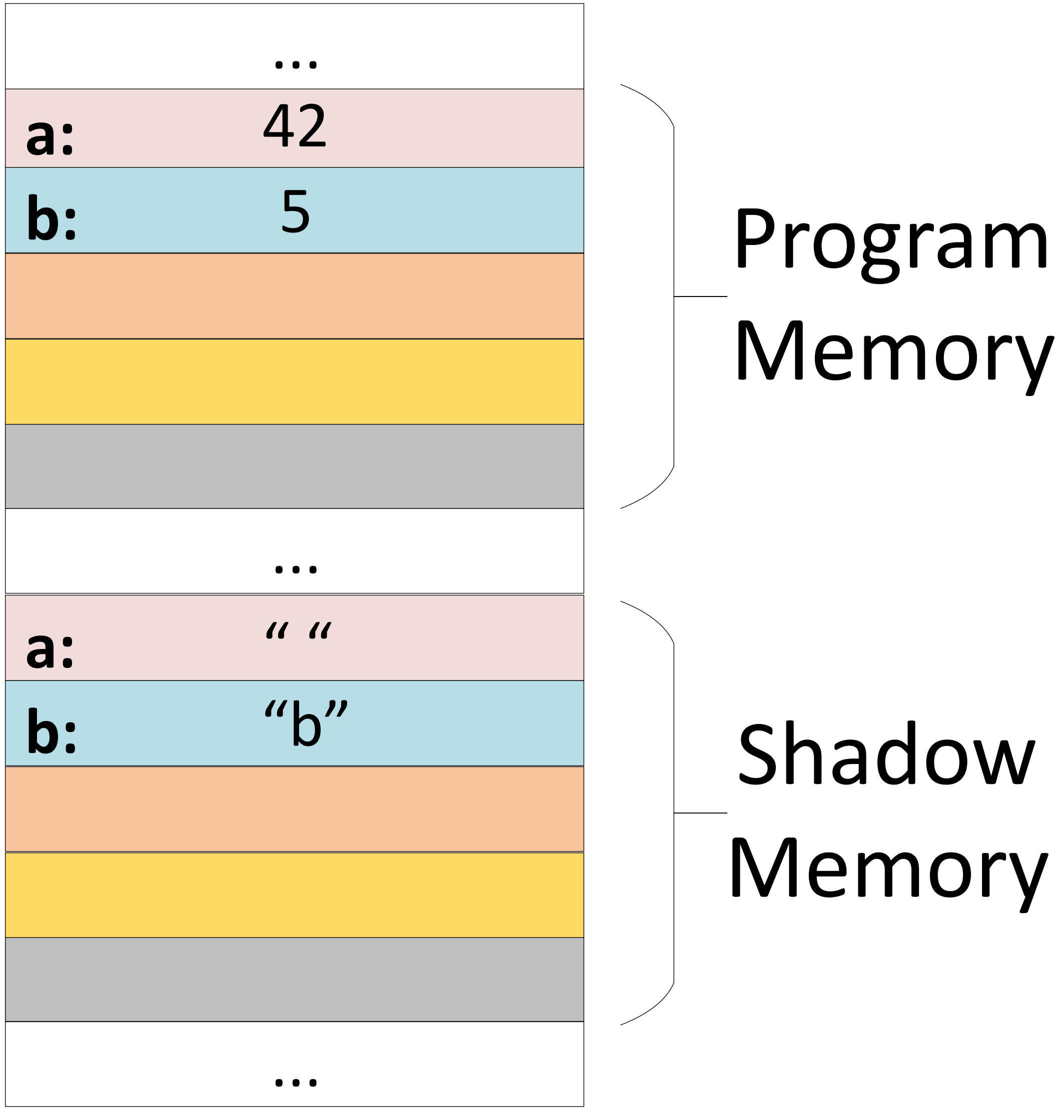

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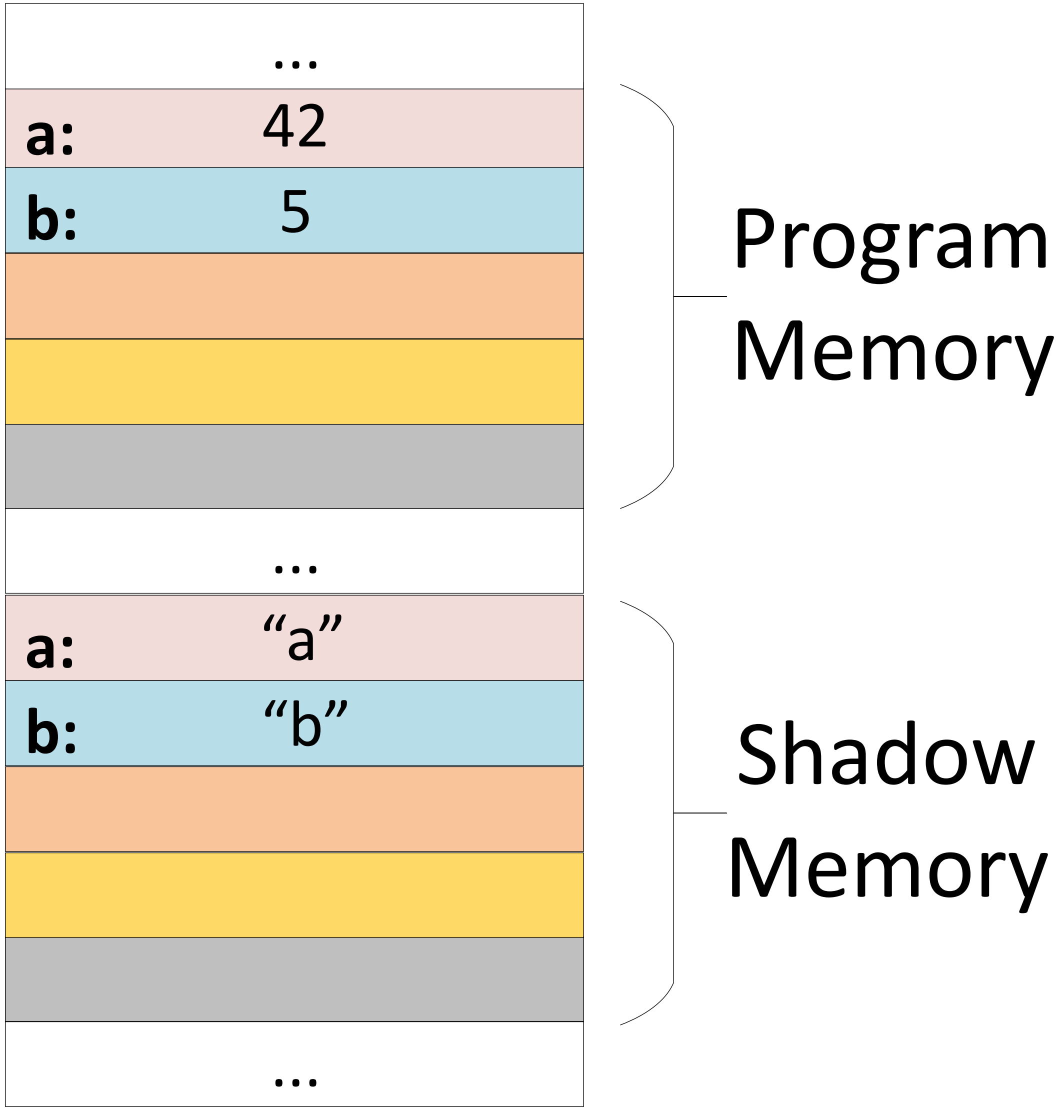

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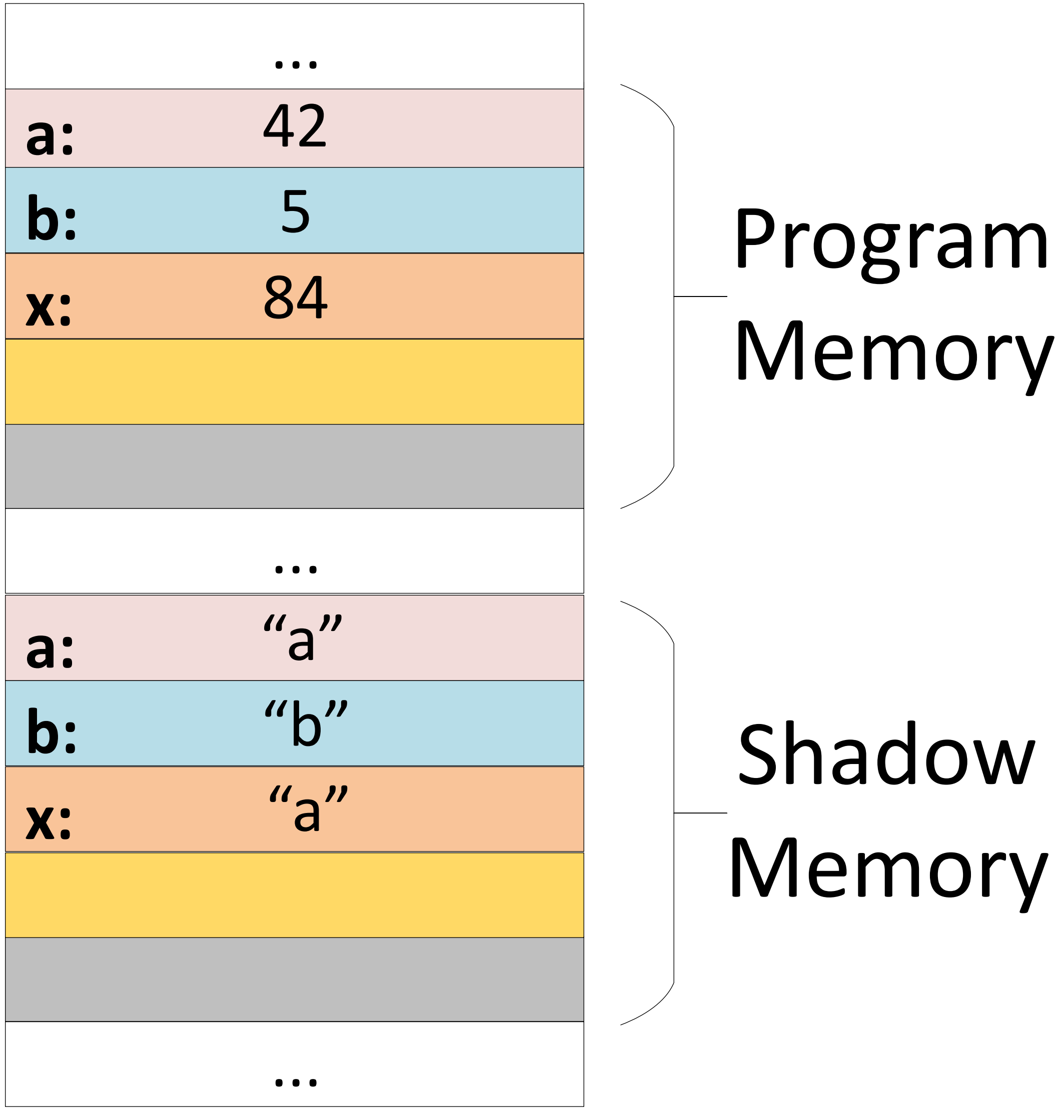

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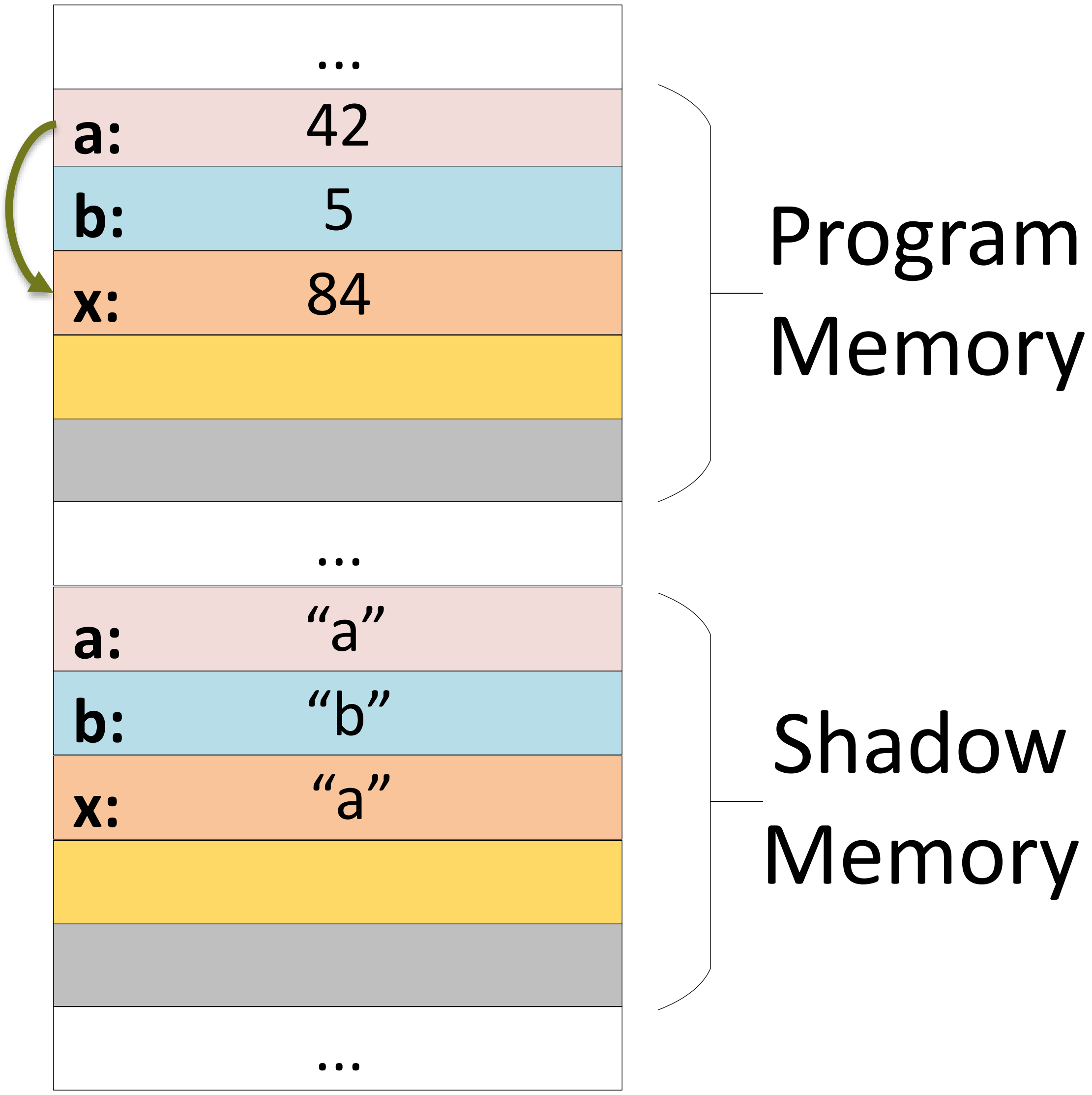

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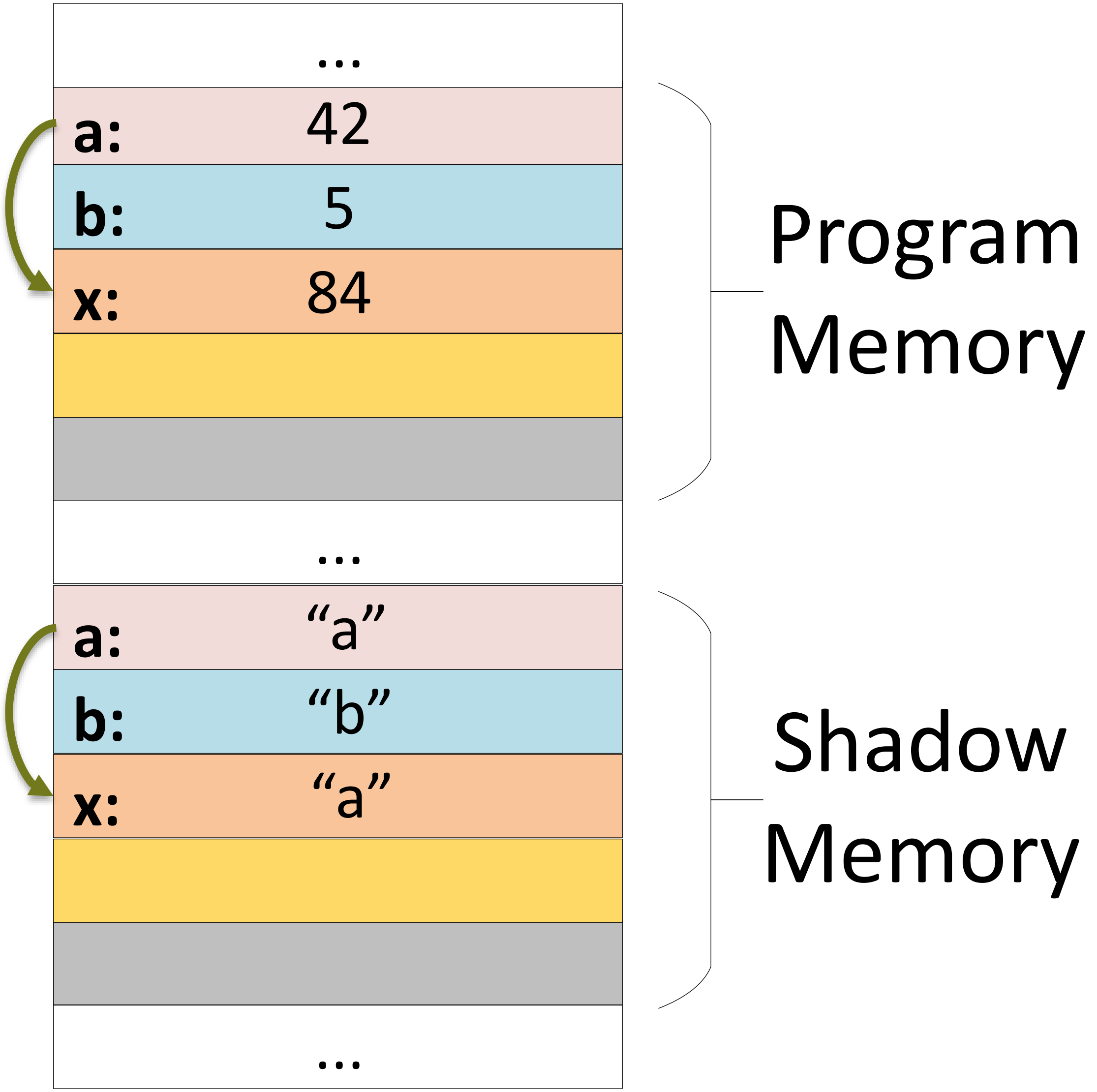

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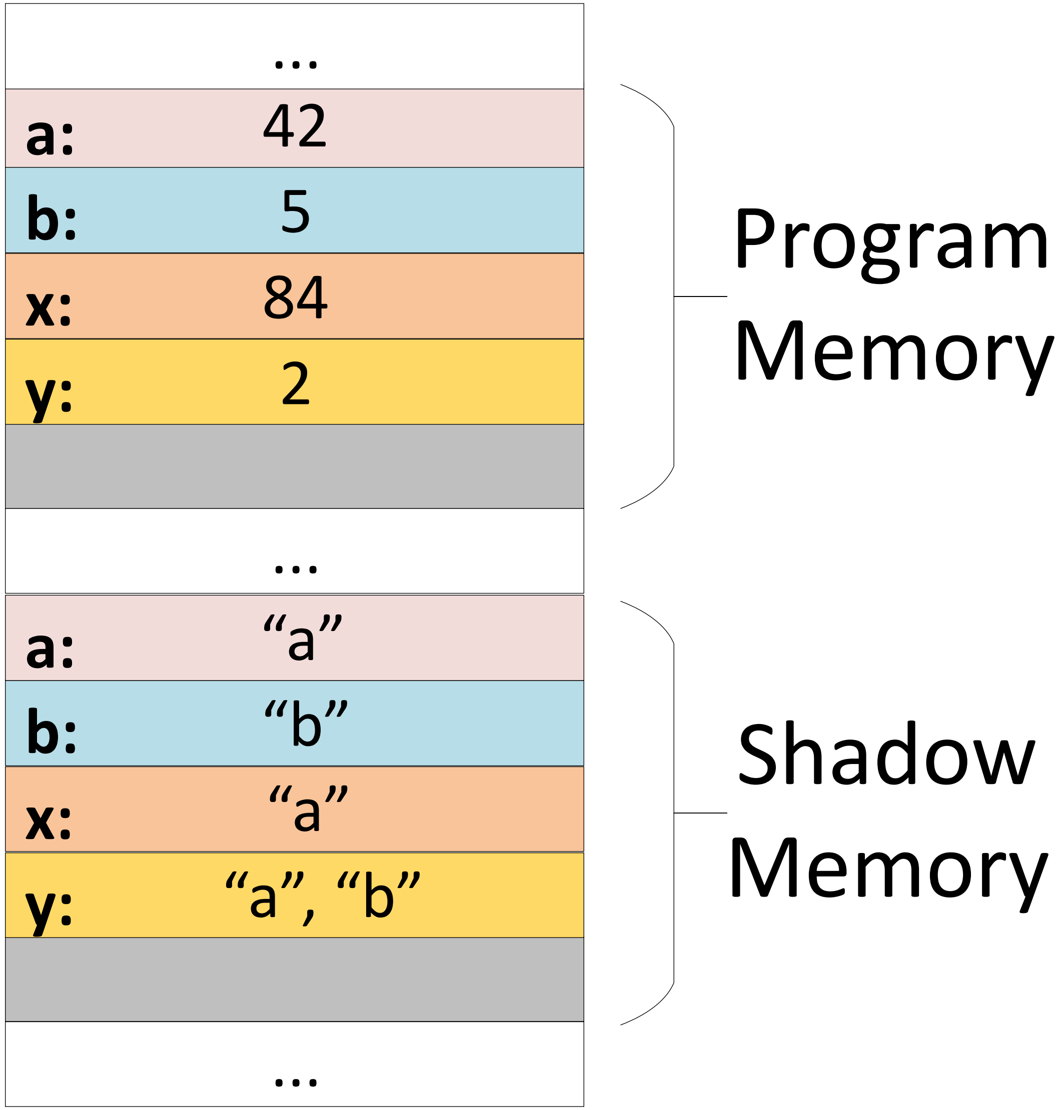

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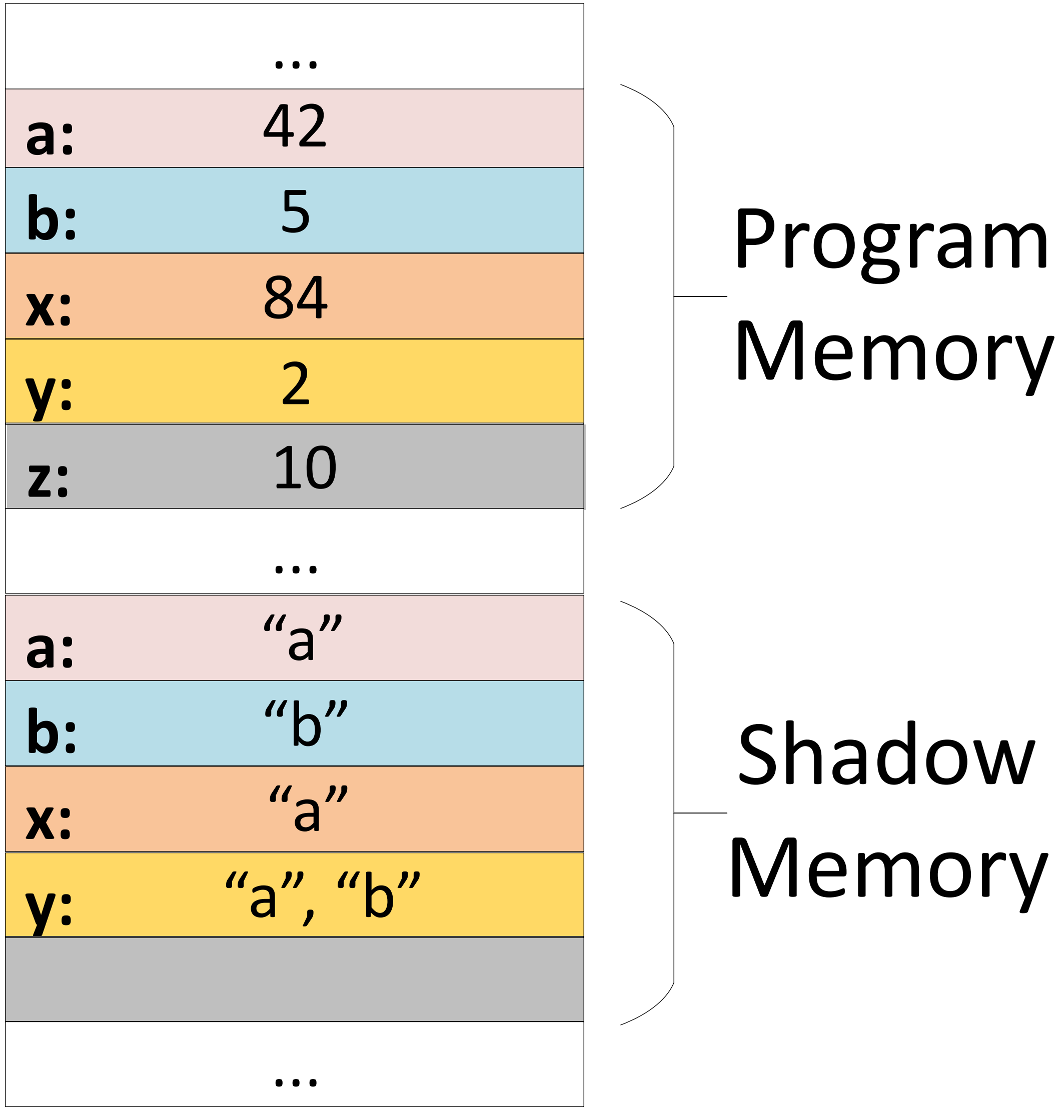

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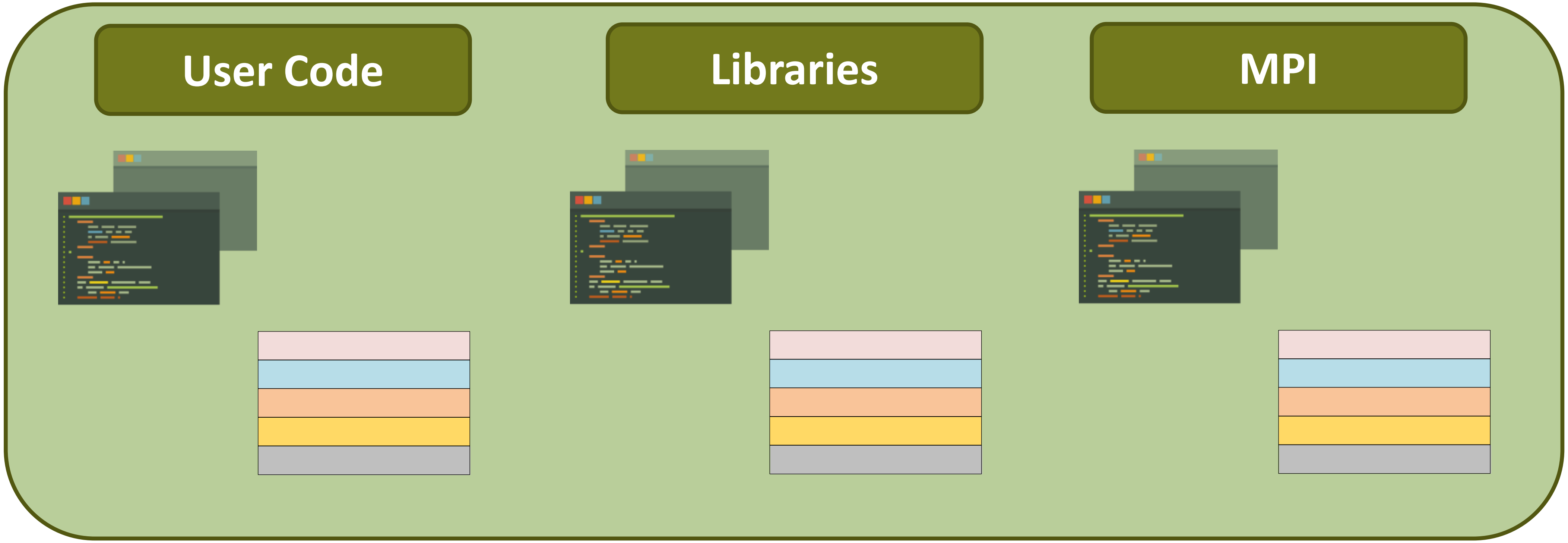
Program Memory

	…
a:	42
b:	5
x:	84
y:	2
z:	6
	…

Shadow Memory

a:	“a”
b:	“b”
x:	“a”
y:	“a”, “b”
z:	“a”
	…

Support for MPI



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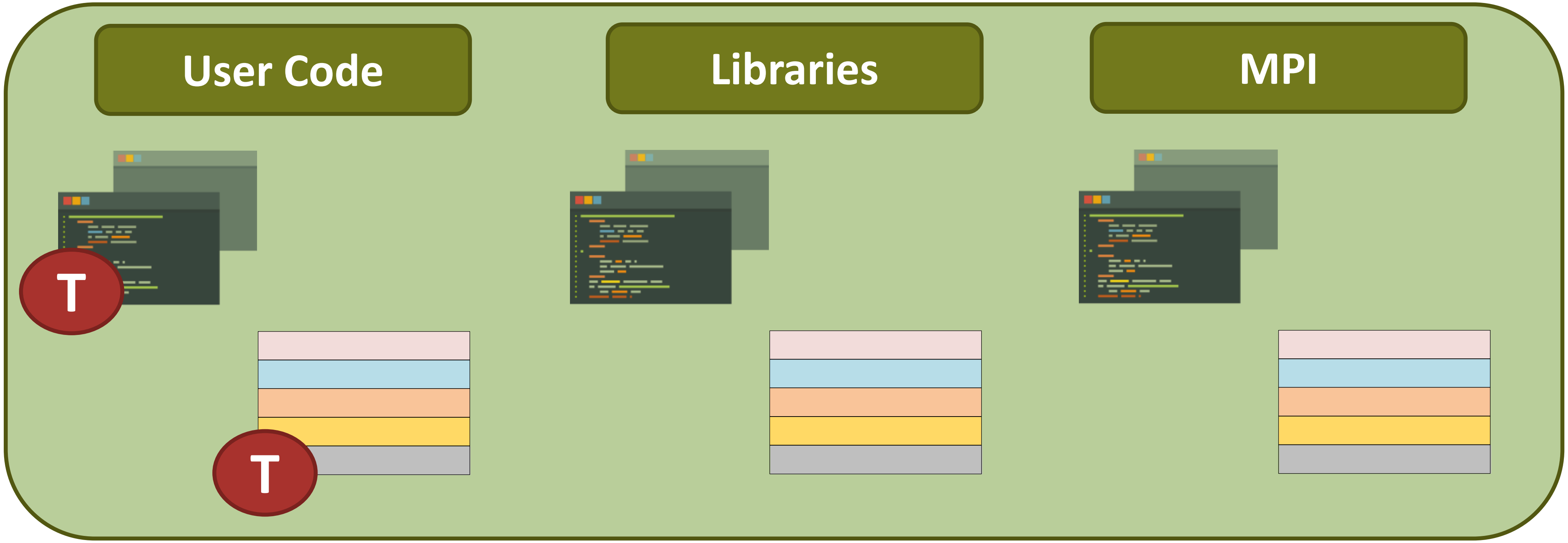

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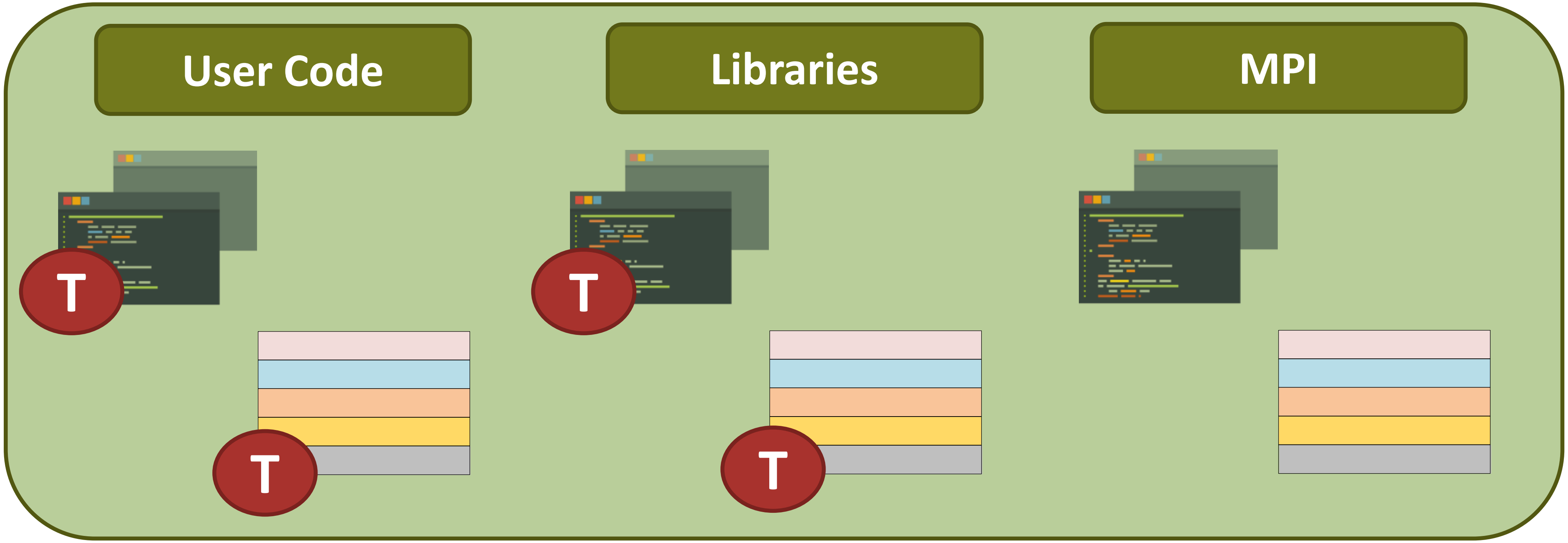

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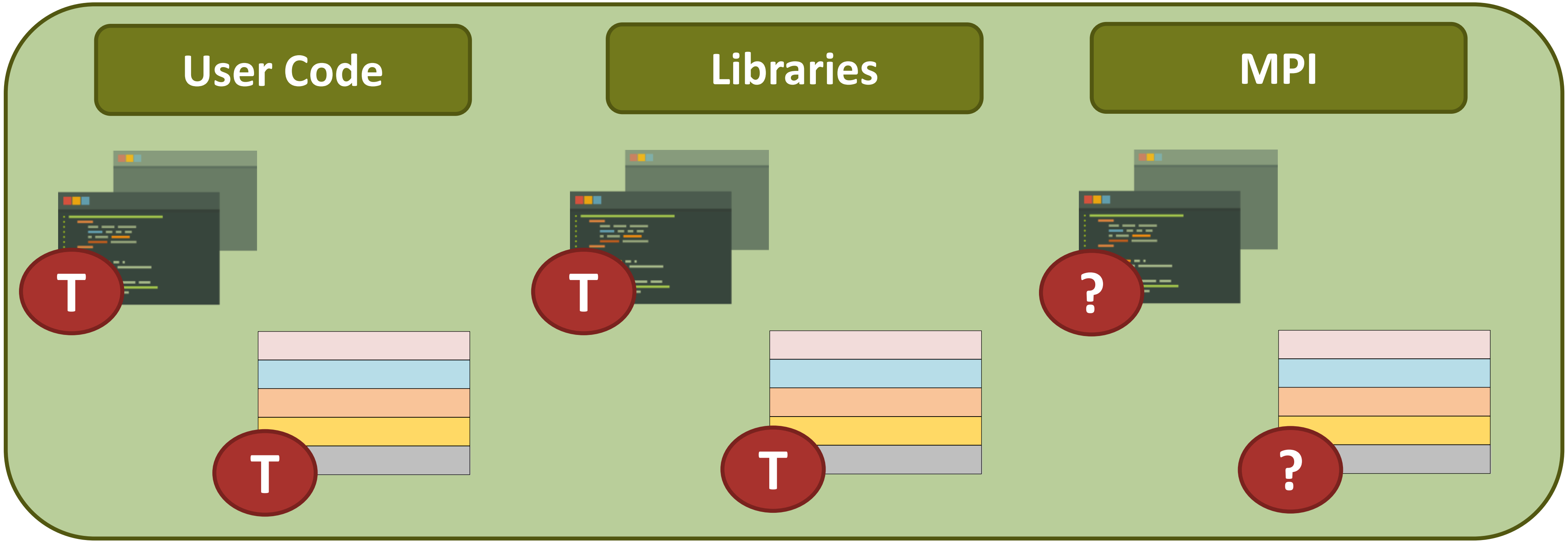

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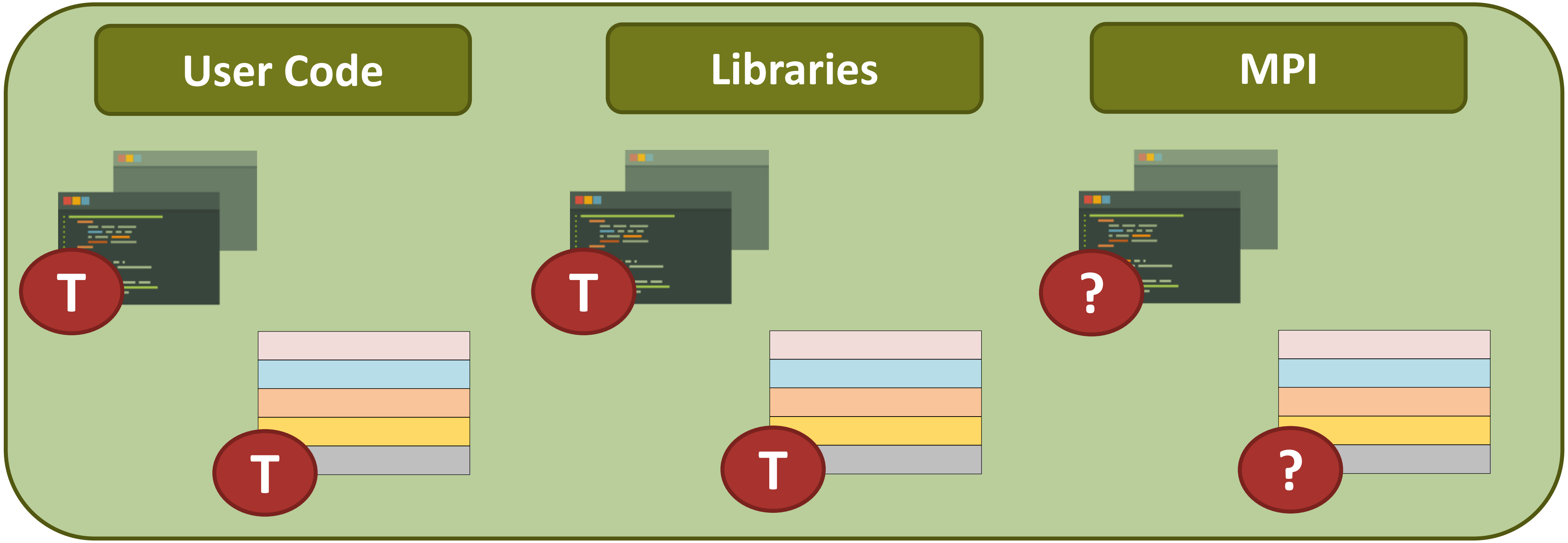

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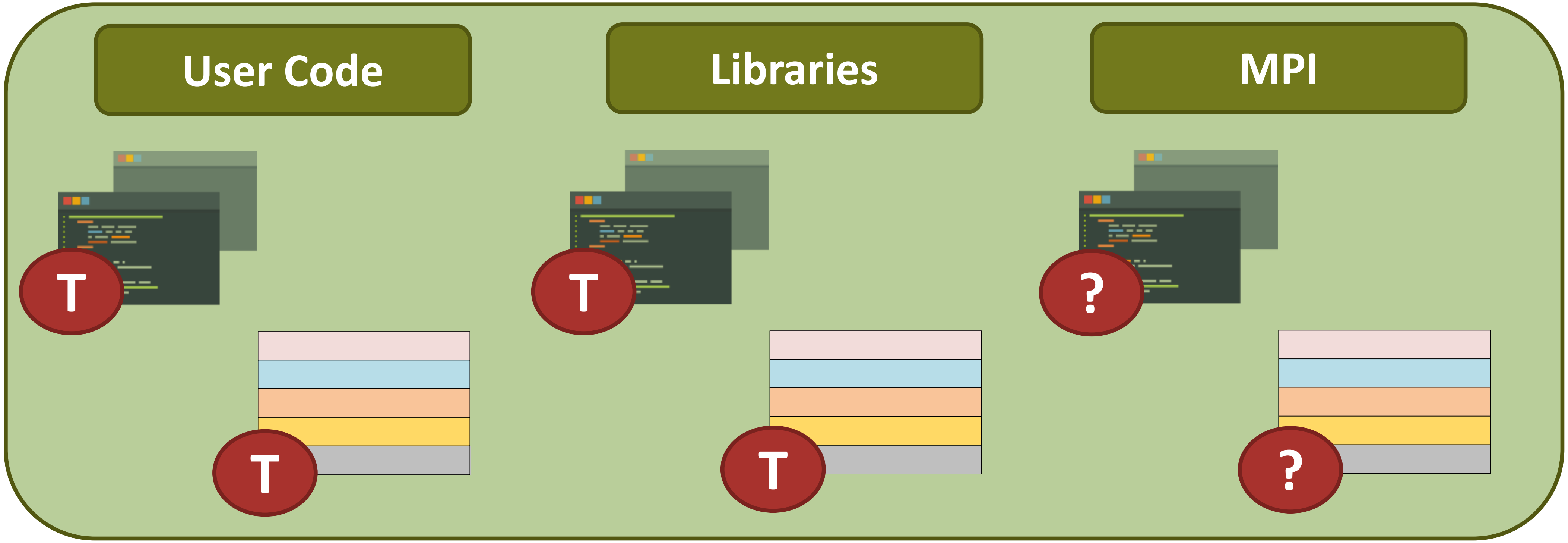

Compile MPI with taint support?

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Define taint characteristics of MP

- ✓ No recompilation needed.
- ✓ Works with every implementation.

perf-taint: Hybrid Taint Analysis

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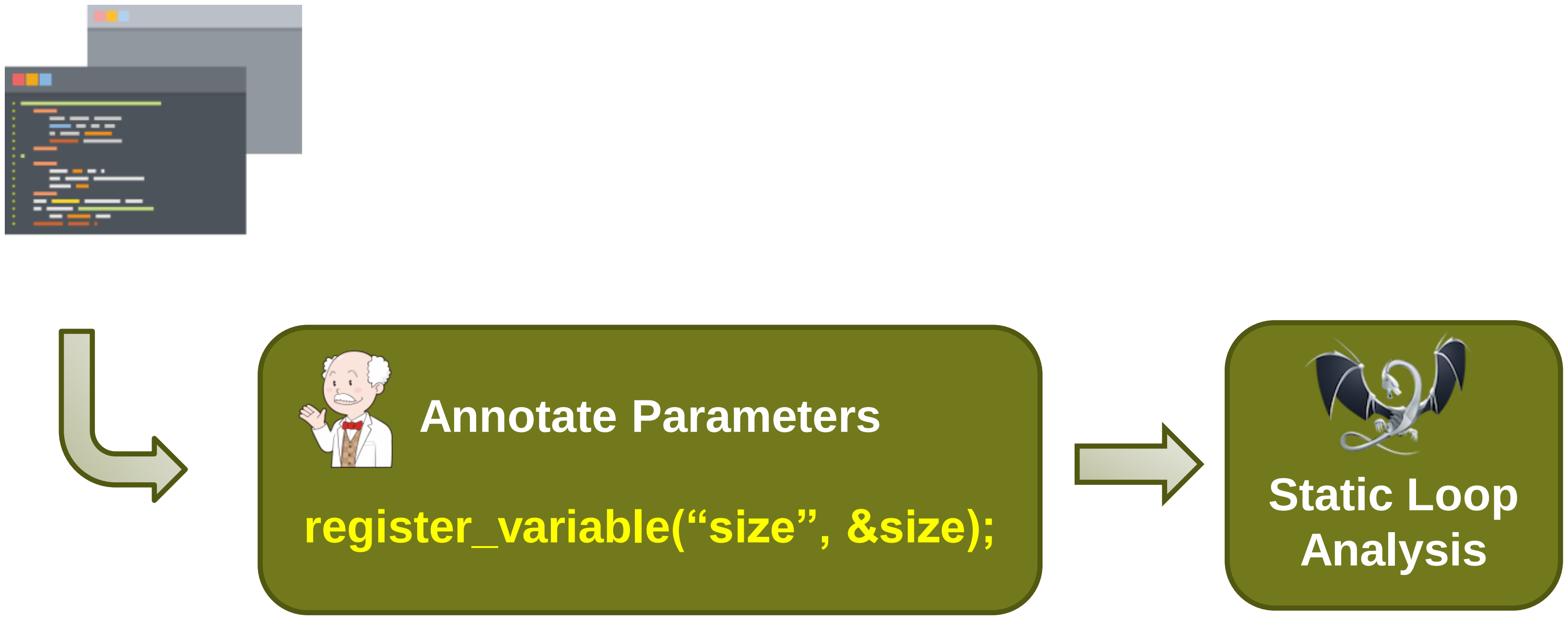
Annotate Parameters

`register_variable(“size”, &size);`

perf-taint: Hybrid Taint Analysis



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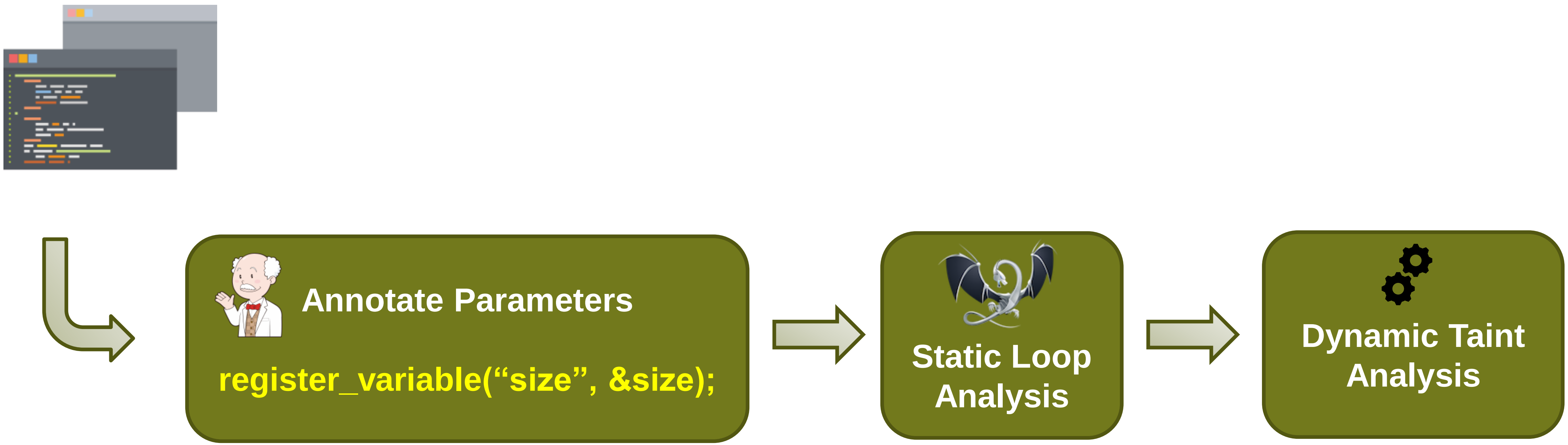

perf-taint: Hybrid Taint Analysis

Annotate Parameters

register_variable("size", &size);

→ Static Loop Analysis

→ Dynamic Taint Analysis

↓

(1) Parametric Dependencies
(2) Constant Functions

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Experiment Execution

Score-P: Scalable performance measurement infrastructure for parallel codes

25 parameter values
5 repetitions per sample
125 instrumented executions

Expert selects parameters.

Use complex heuristics.

Instrument all functions.

Taint-based coverage selects parameters.

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How do we apply this knowledge?

Parameters Identification → Experiment Design → Experiment Execution

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Expert selects parameters.	**Use complex heuristics.**	**Instrument all functions.**	**Model all functions.**
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Case Studies

Cost

Fewer Experiments

Cheaper Experiments

Case Studies

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Quality

Less Intrusion

More Noise Resilience

Case Studies

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Validity
Experiment Design
Hardware Contention

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- Intel Xeon E5-2695 v4 2.1 GHz
- 2 sockets, 18 cores each
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LULESH

- p: 27, 64, 81, 125, 343, 729
- *size*: 25, 30, 35, 40, 45
- Taint run: $p = 8$, *size* = 5
- Taint overhead: < 5 mins

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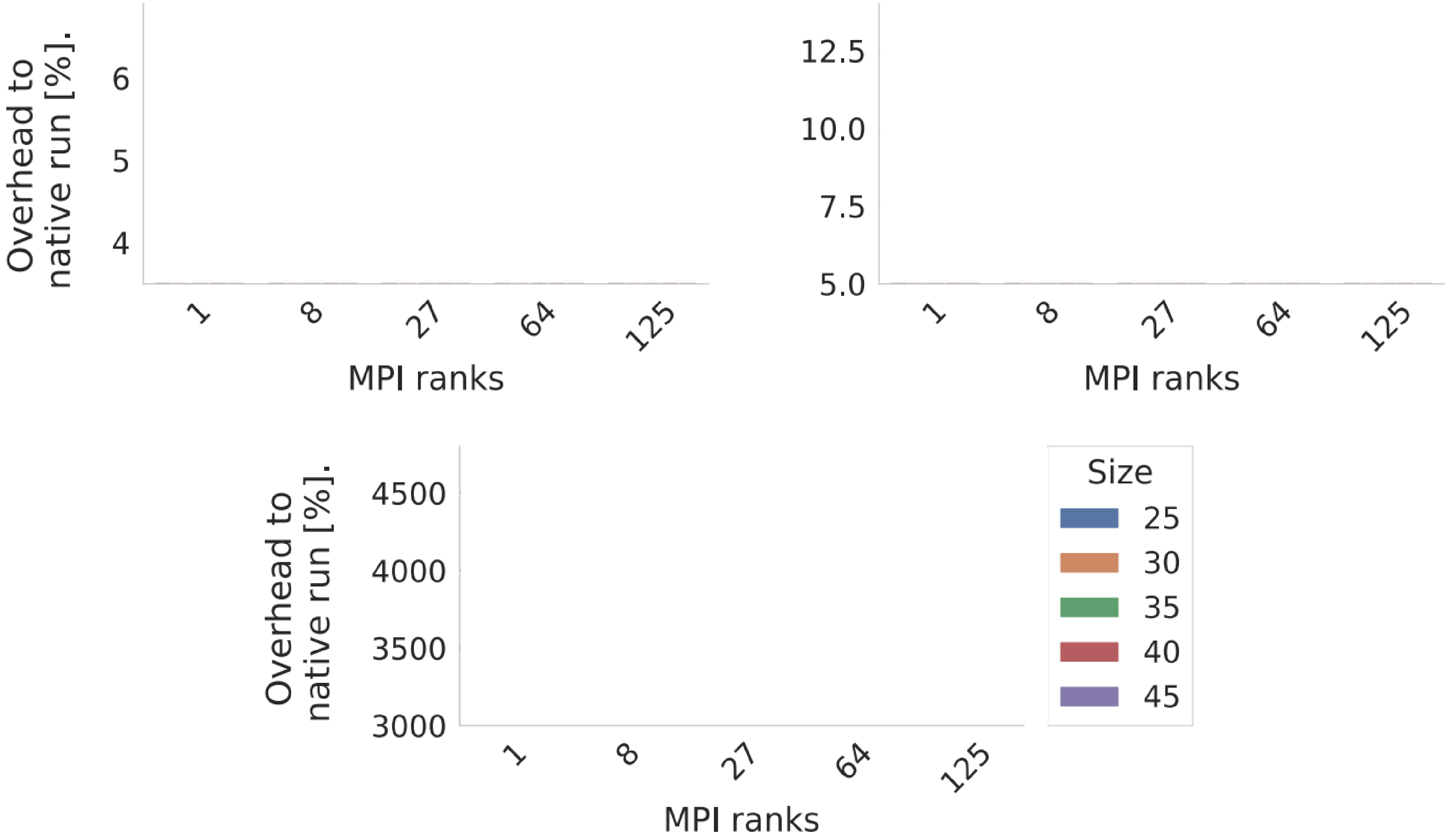
MILC su3_rmd
- *p*: 4, 8, 16, 32, 64
- *size*: 32, 64, 128, 256, 512
- Taint run: *p* = 32, *size* = 128
- Taint overhead: ~1 hr

Parameter Pruning

LULESH	Total	Comm	p	size	regions	iters	balance	cost	p, size
Functions [count]	349	2 + 7	2	40	13	4	9	2	40
Loops [count]	275	-	2	78	27	4	20	2	78

MILC	Total	Comm	p	size	trajecs	warms steps	nrest. niter	mass, beta, nfl.	u0	p, size
Functions [count]	629	13 + 8	54	53	12	9	6	1	4	56
Loops [count]	874	-	187	161	39	31	15	1	7	196

Instrumentation Overhead



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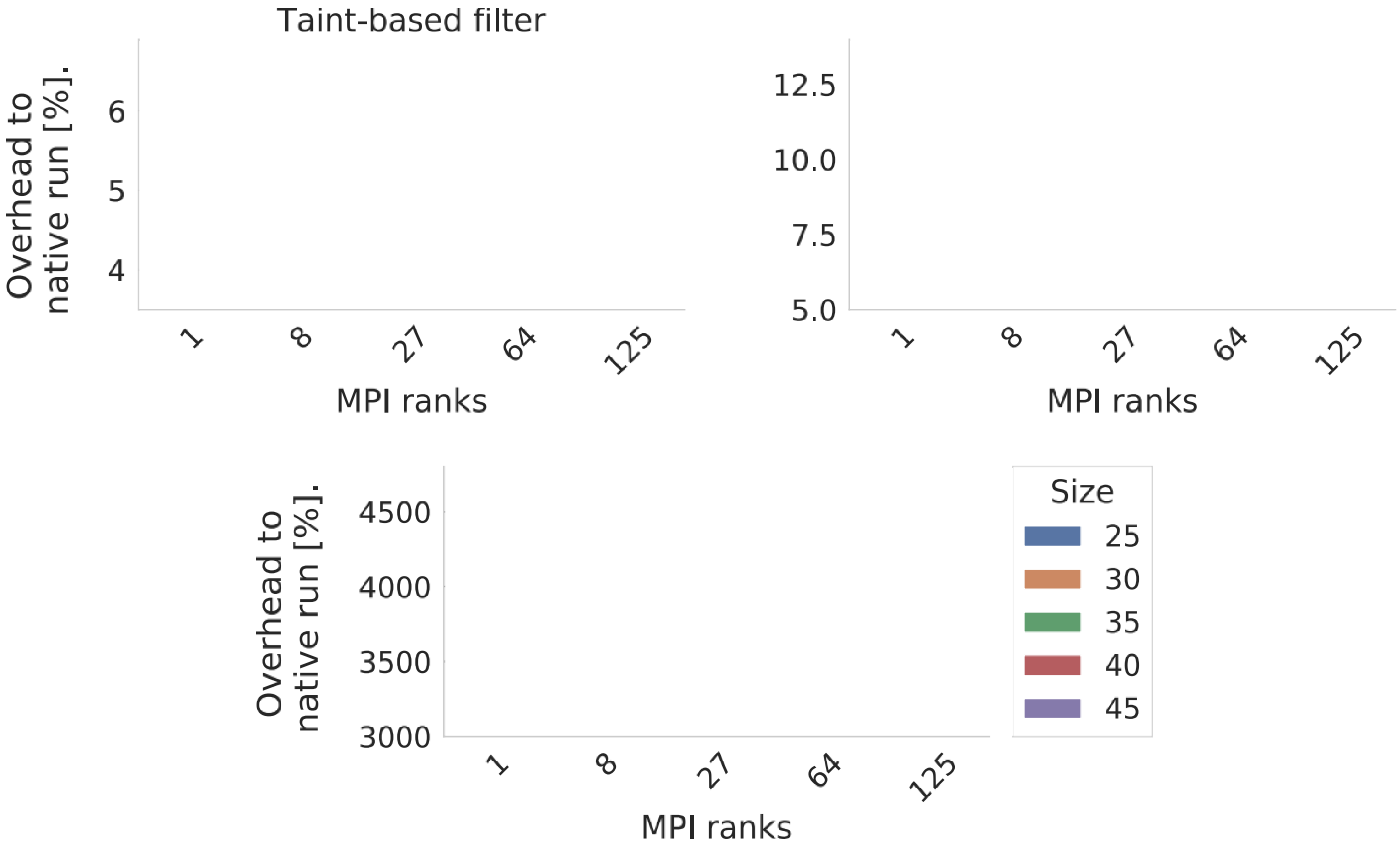

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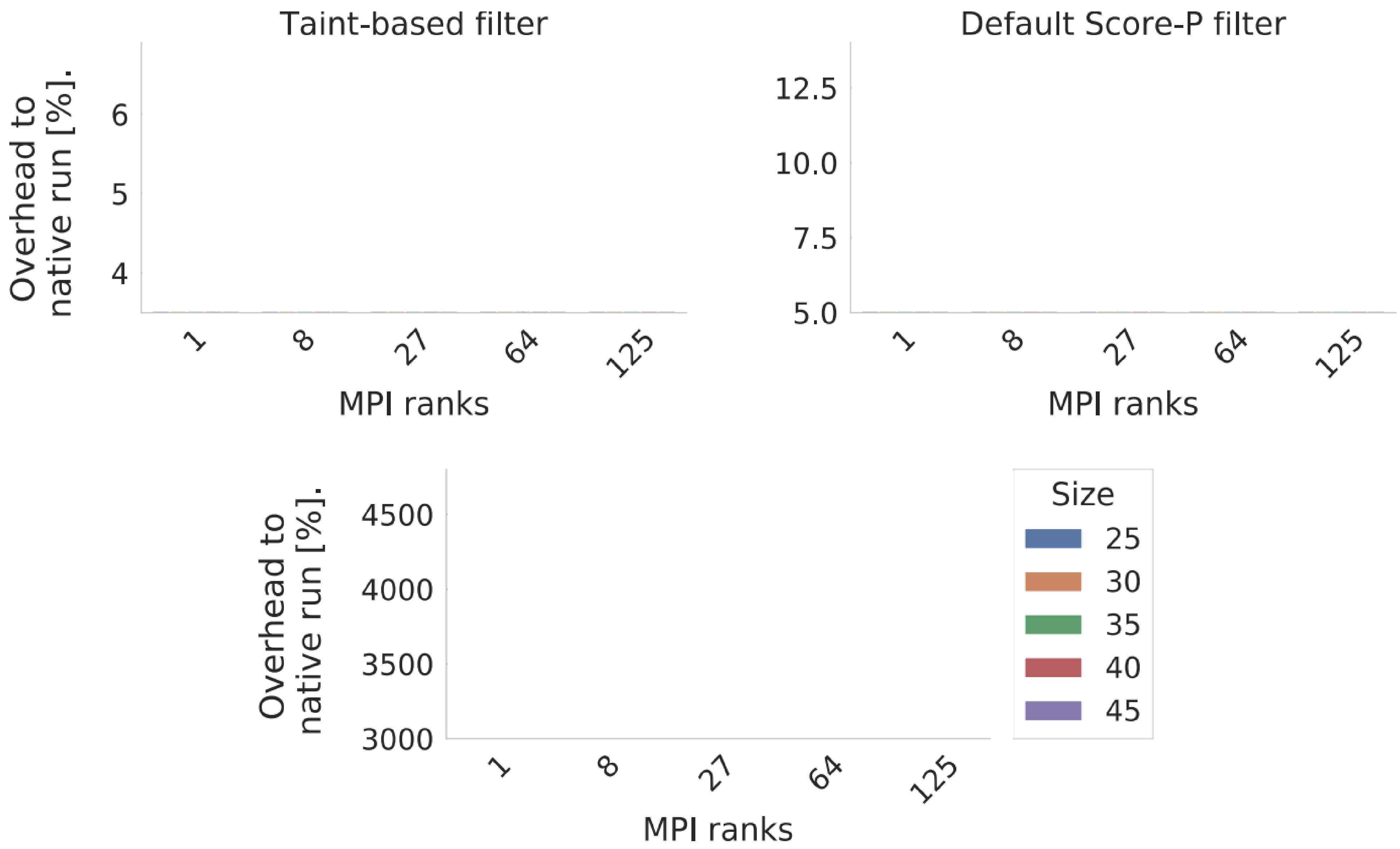

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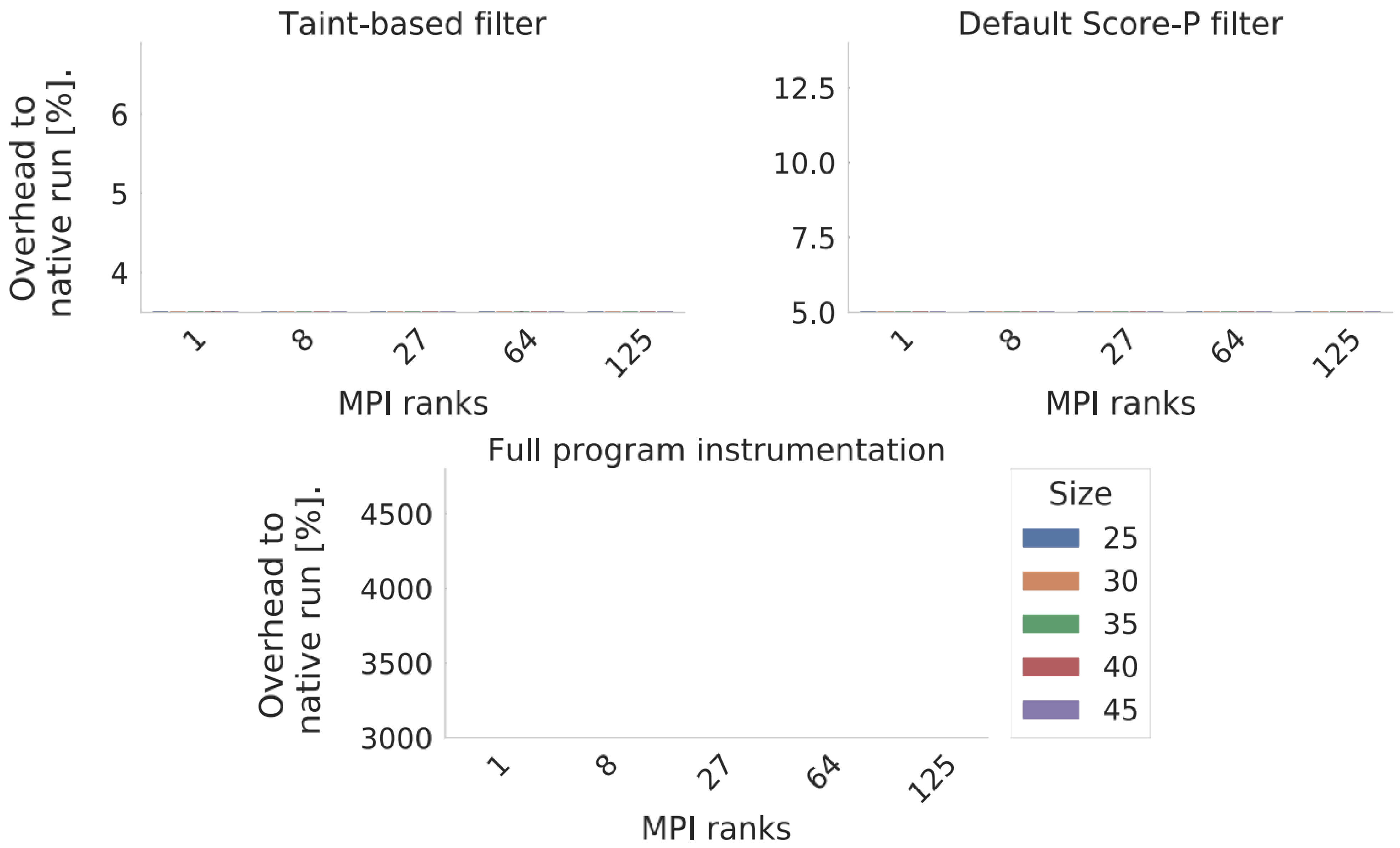

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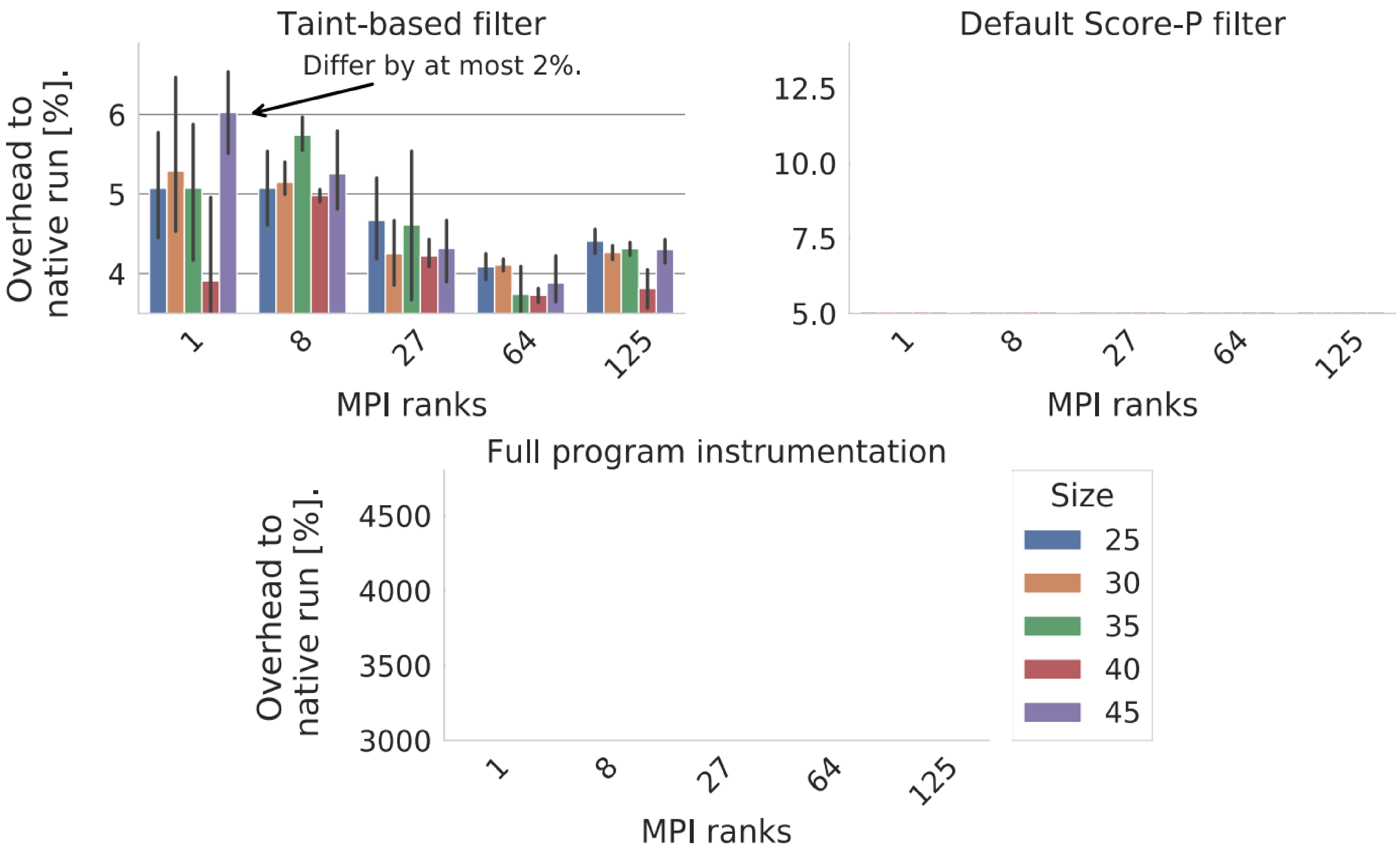

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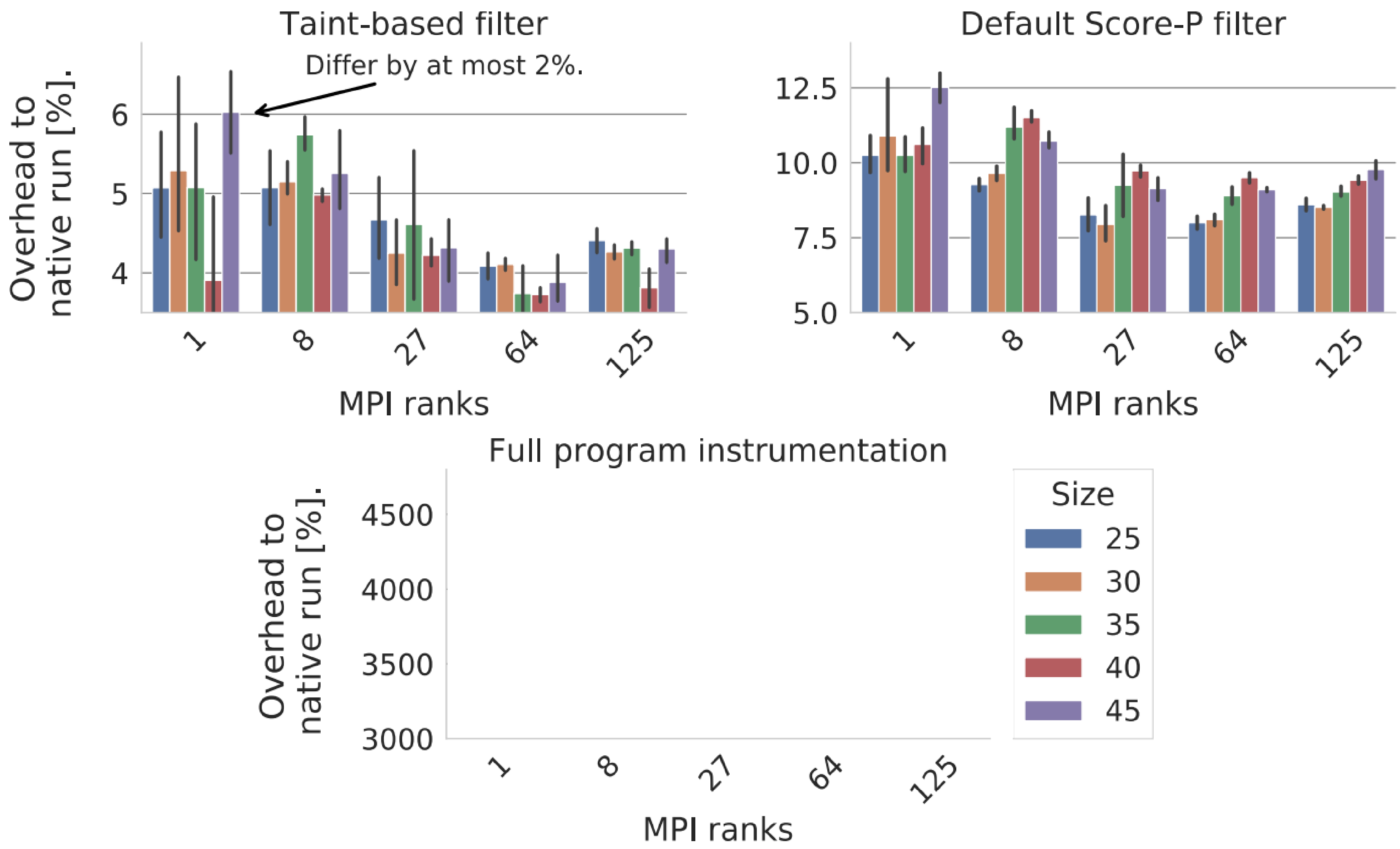

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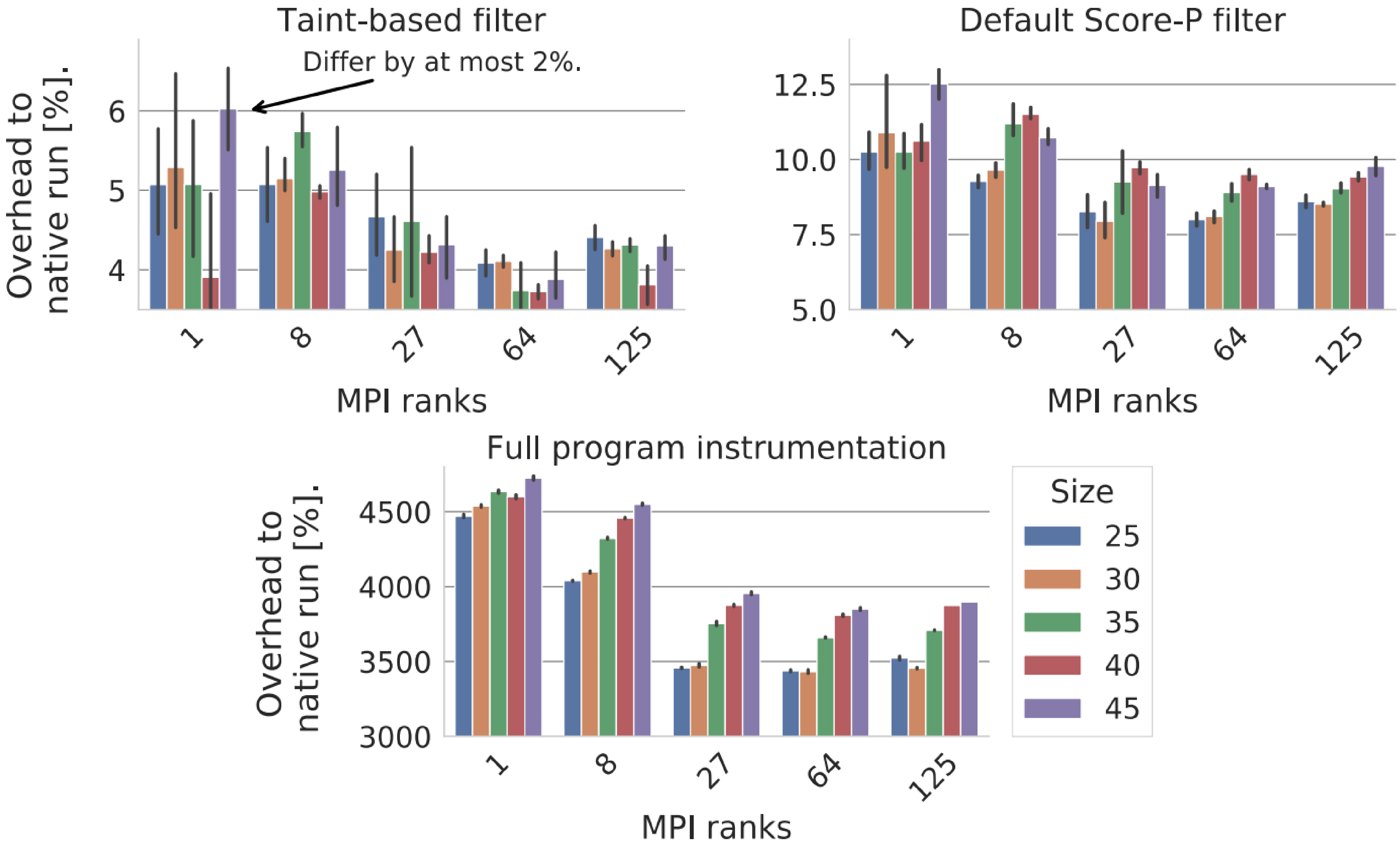

Less Noise

```
int foo(int a, int b, int& result) {
  for(int i = 0 ; i < a; ++i)
       result += b * i;
}
```

$$0.5a + 10^{-3}b$$

Separate **program** from **noise**.

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- TOP 5 models with perf-taint: parse 14 functions
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MILC su3_rmd

- 87.7% of functions are constant
- TOP 5 models with perf-taint: parse 32 functions
- Same TOP 5 models with black-box modeling: parse 43 functions

Less Intrusion

```
int bar(int a) {
  instrument();
  return a * a;
}
```

```
int foo(int a, int& res) {
  instrument();
  for(int i = 0 ; i < a; ++i)
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}
```

$$1.3a + 10^{-4}\sqrt{a}$$

Separate **program** and **instrumentation**.

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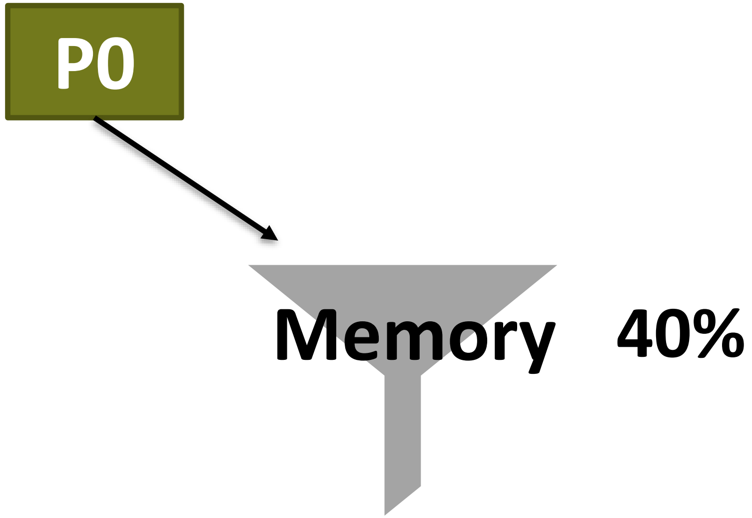
$2.4 * 10^{-8} * p^{0.25} * size^3$

Hardware Contention



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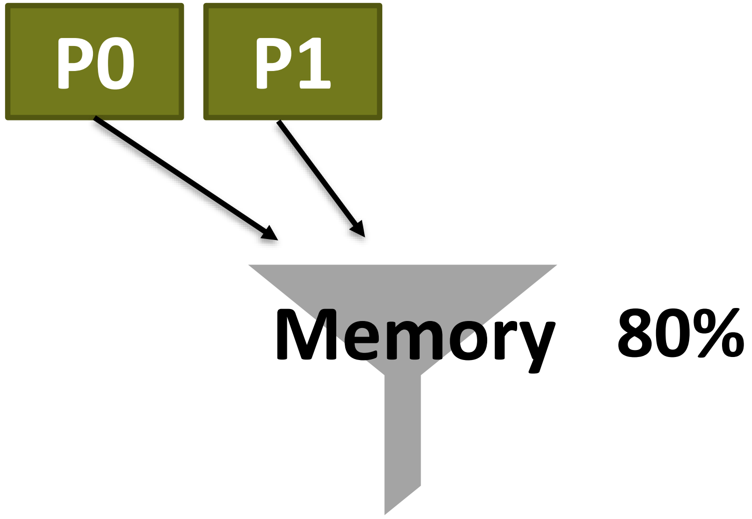

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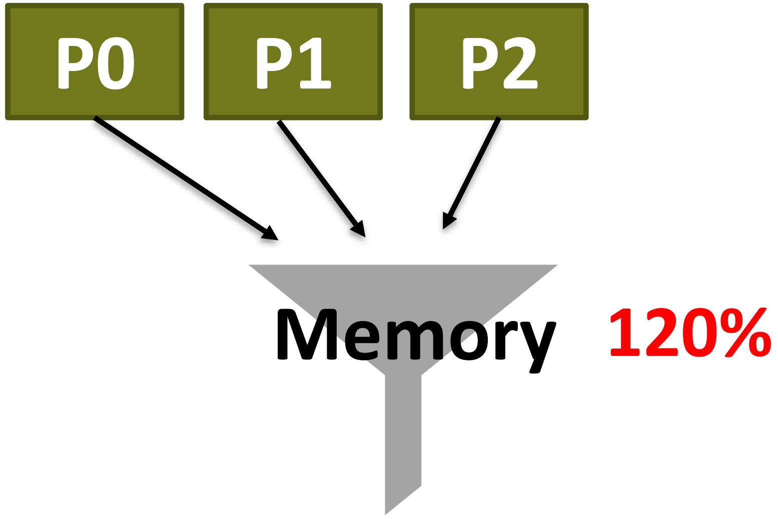

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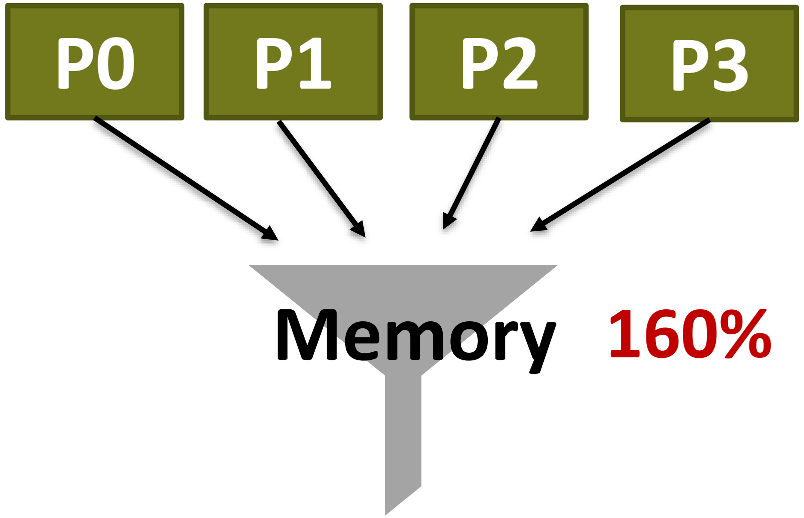

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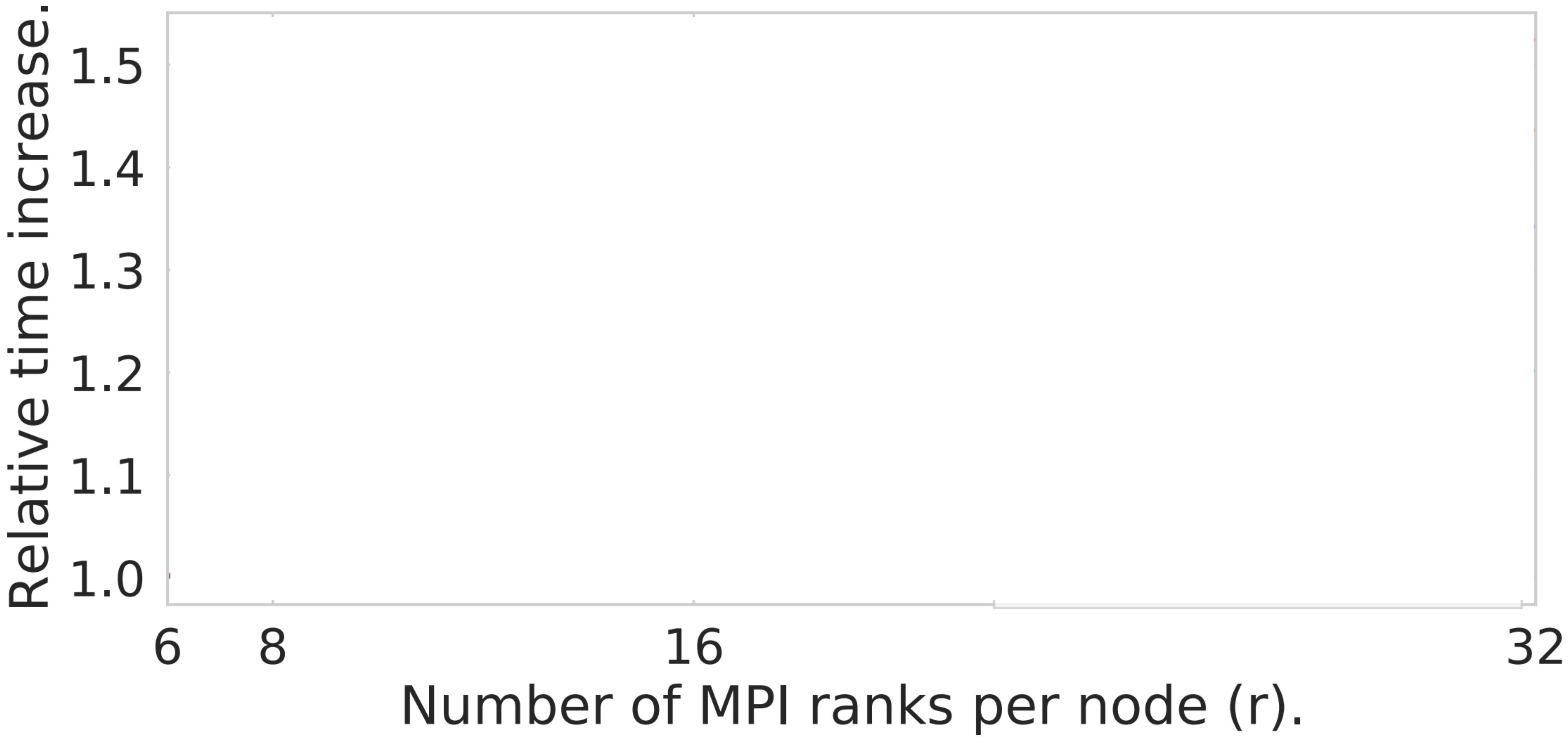

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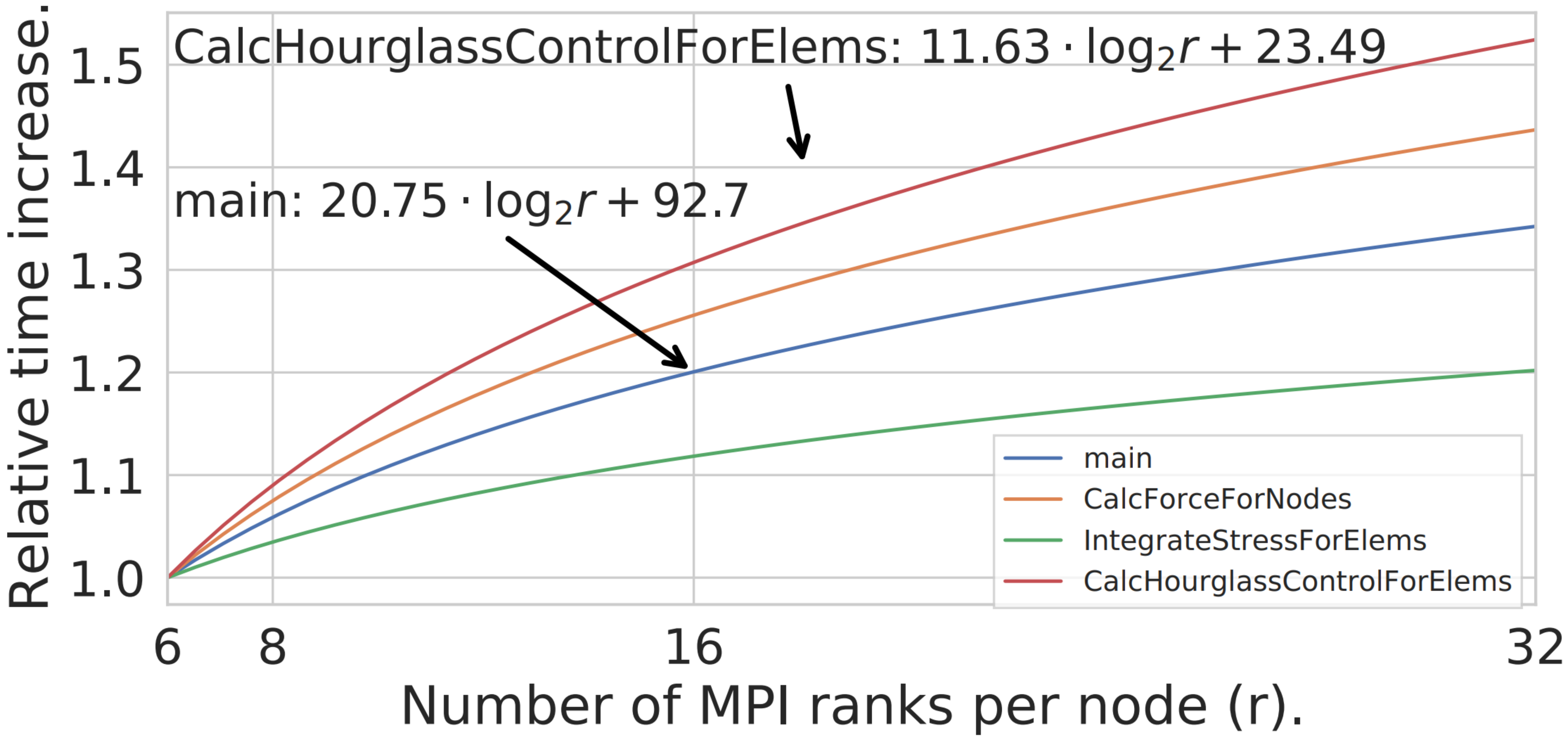

Experiment Design

```
int foo(int a) {
  if(a < 4) kernel_linear(a);
  else      kernel_log(a);
}
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$$f: \begin{cases} a & a < 4 \\ \log_2 a & a \geq 8 \end{cases}$$

Qualitative change of behavior.
Modeling requires **consistency**.

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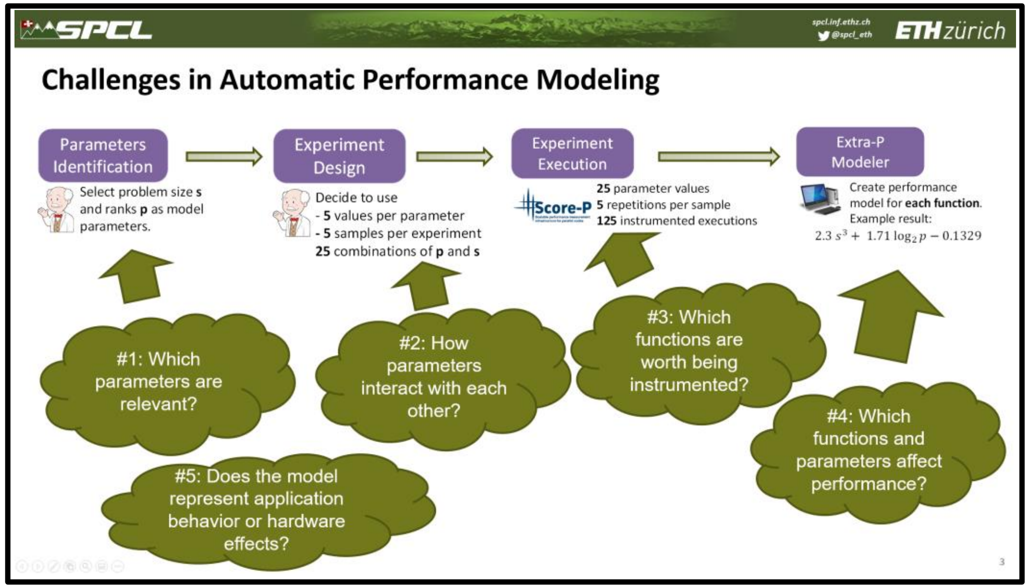
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Decide to use
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Create performance model for each function.
Example result:
2.3 s^3 + 1.71 log_2 p − 0.1329
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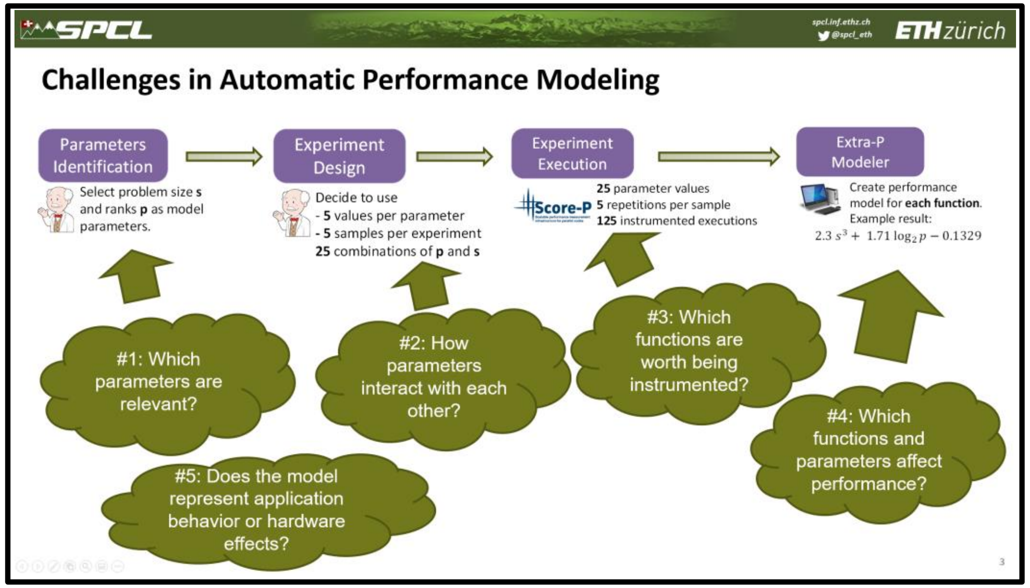
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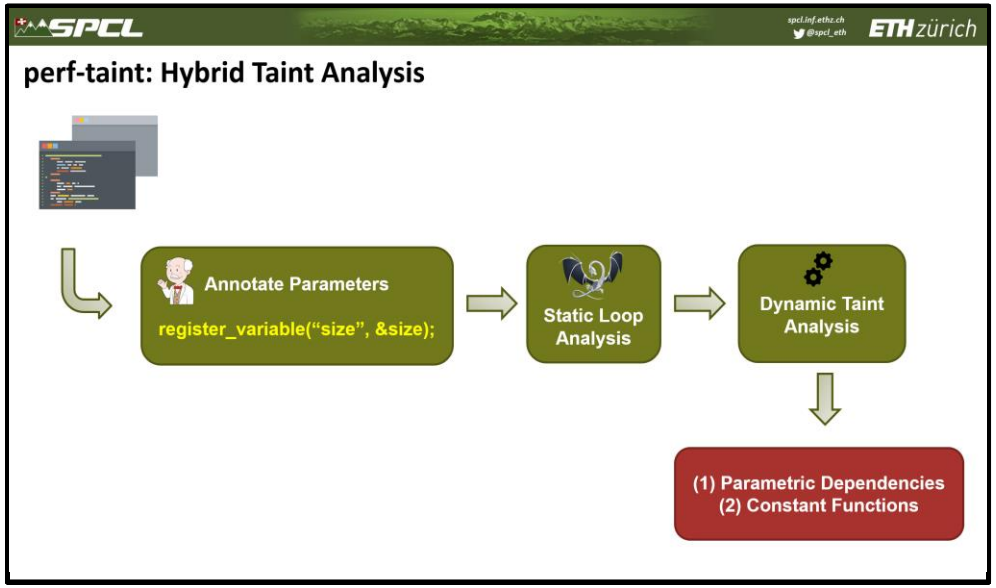
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Annotate Parameters
register_variable("size", &size);
Static Loop Analysis
Dynamic Taint Analysis
(1) Parametric Dependencies
(2) Constant Functions

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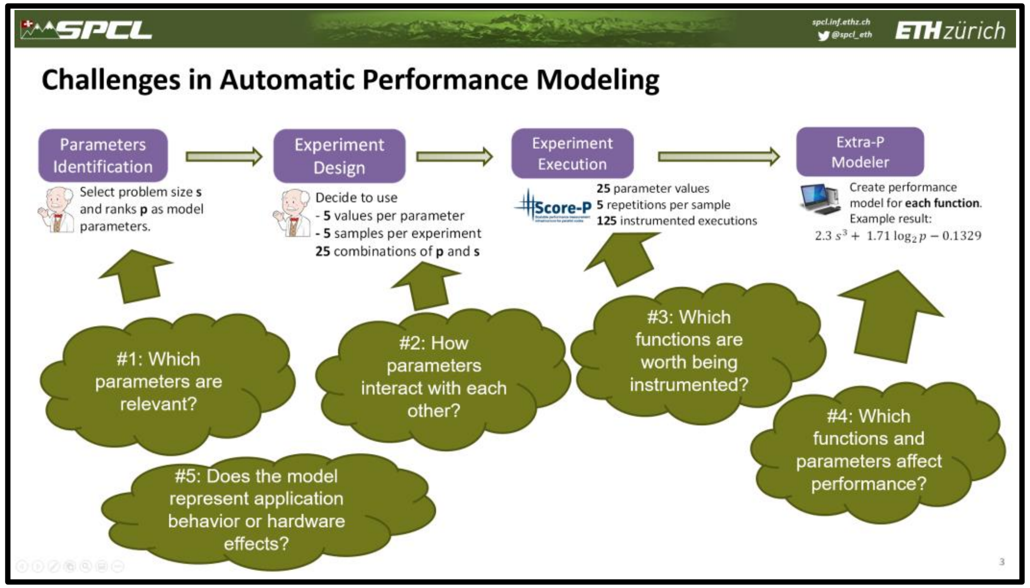
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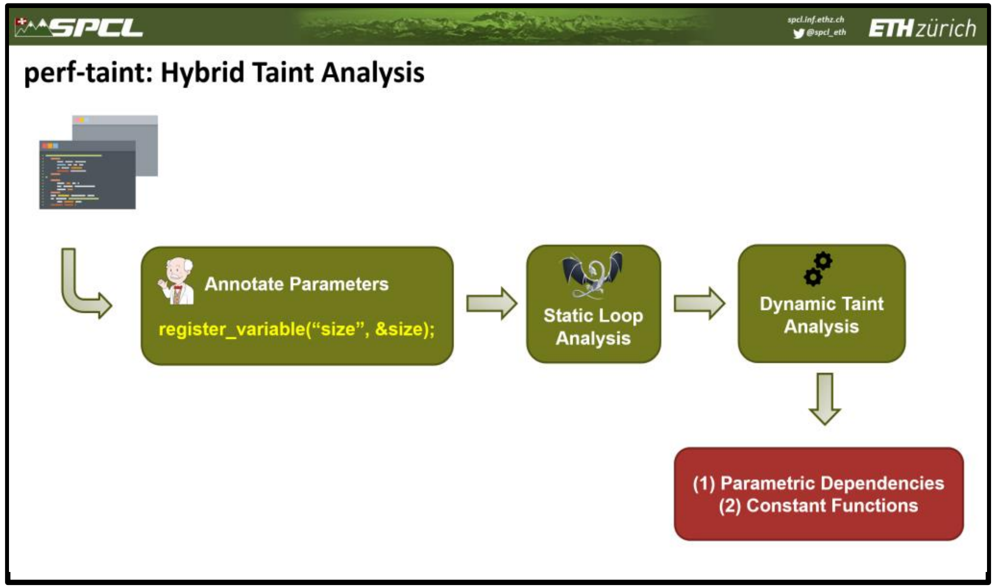
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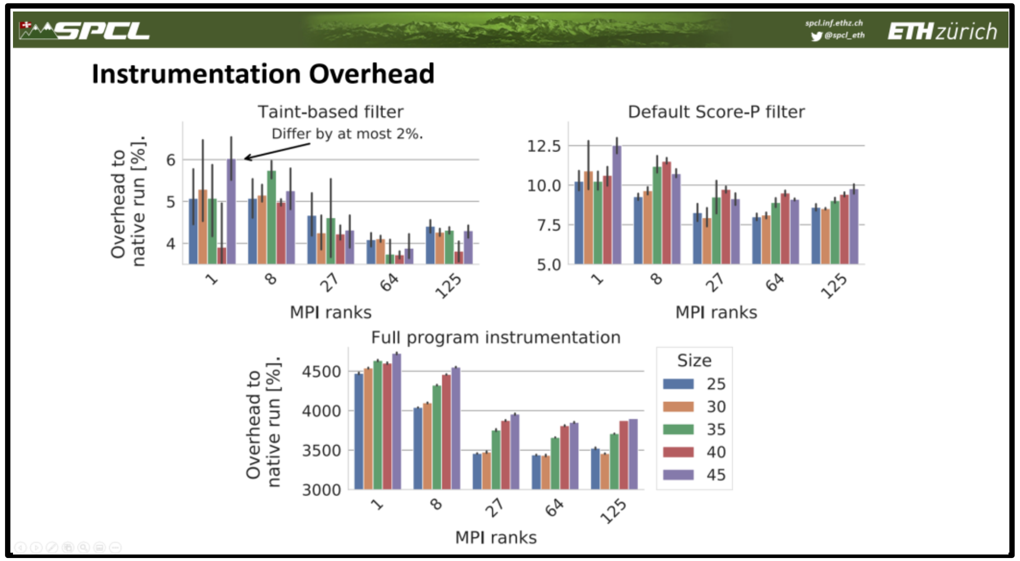
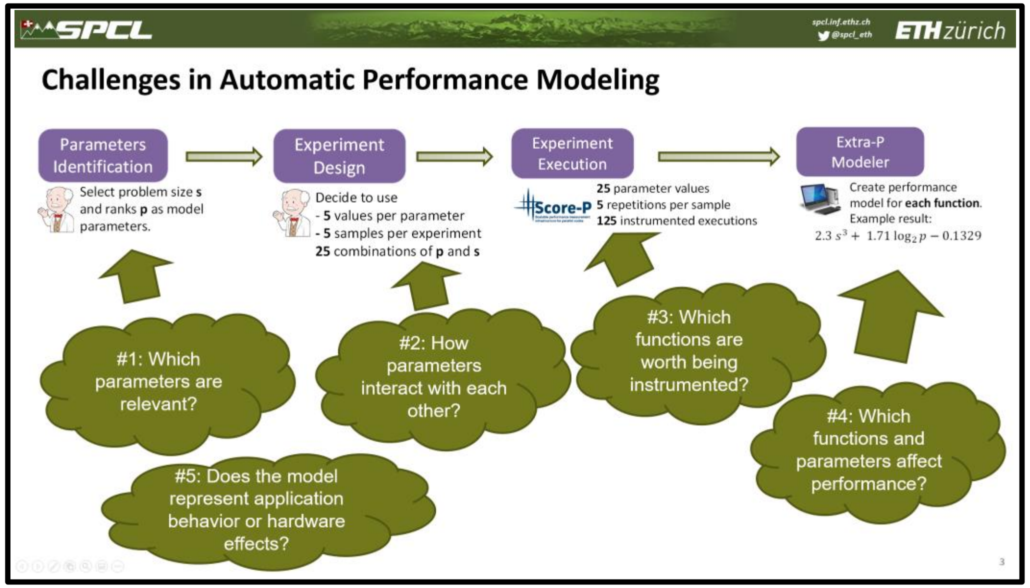
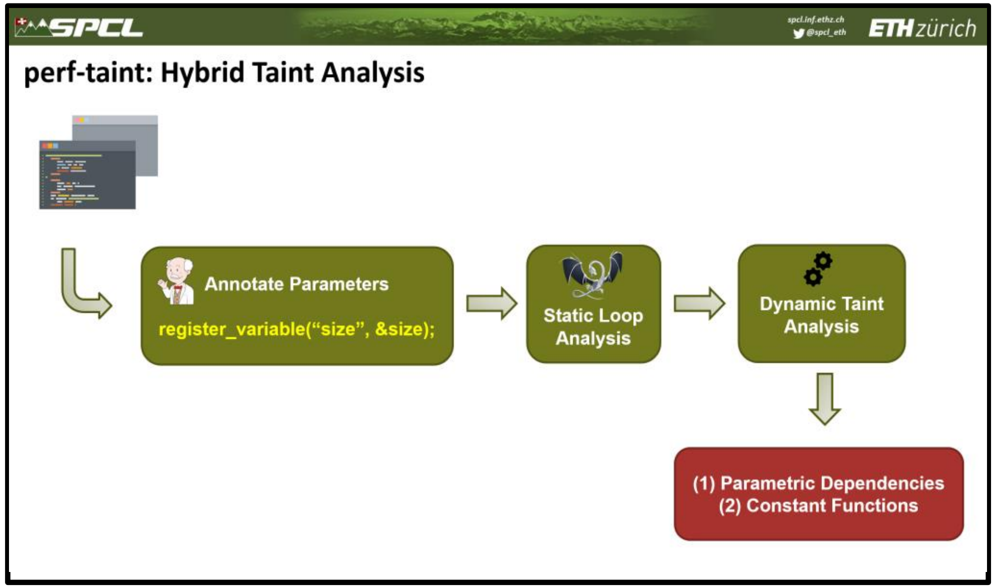
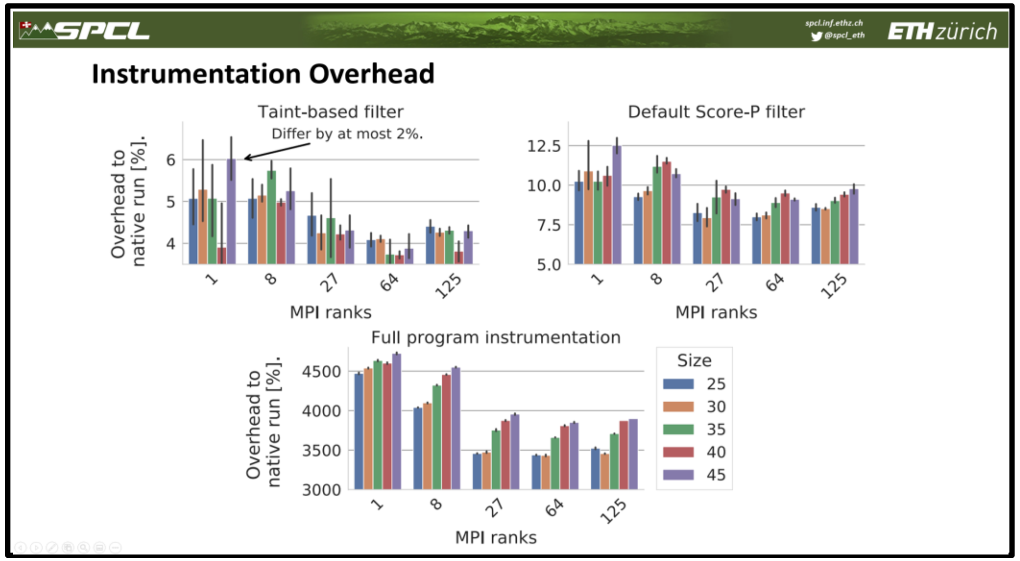

Instrumentation Overhead
Taint-based filter
Differ by at most 2%.
Default Score-P filter
Full program instrumentation
Overhead to native run [%].
MPI ranks
Size
25
30
35
40
45

Summary







spcl/perf-taint