Why Aren’t More Users More Happy With Our VMs?

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Warmup work in collaboration with:
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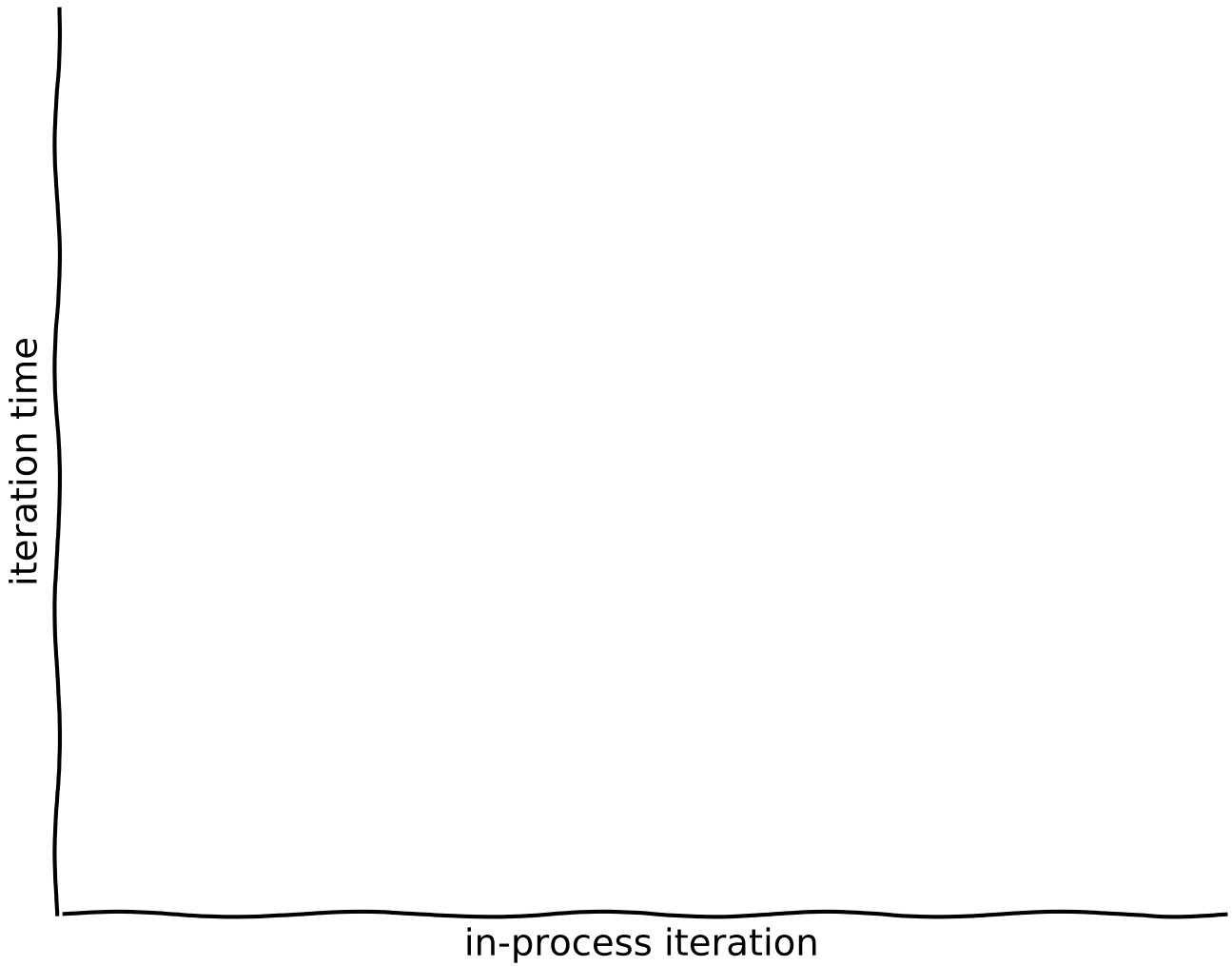
JVMs bring "gcc -O2" to the masses

–*Cliff Click*: A JVM does that?

What do VM claims pertain to?



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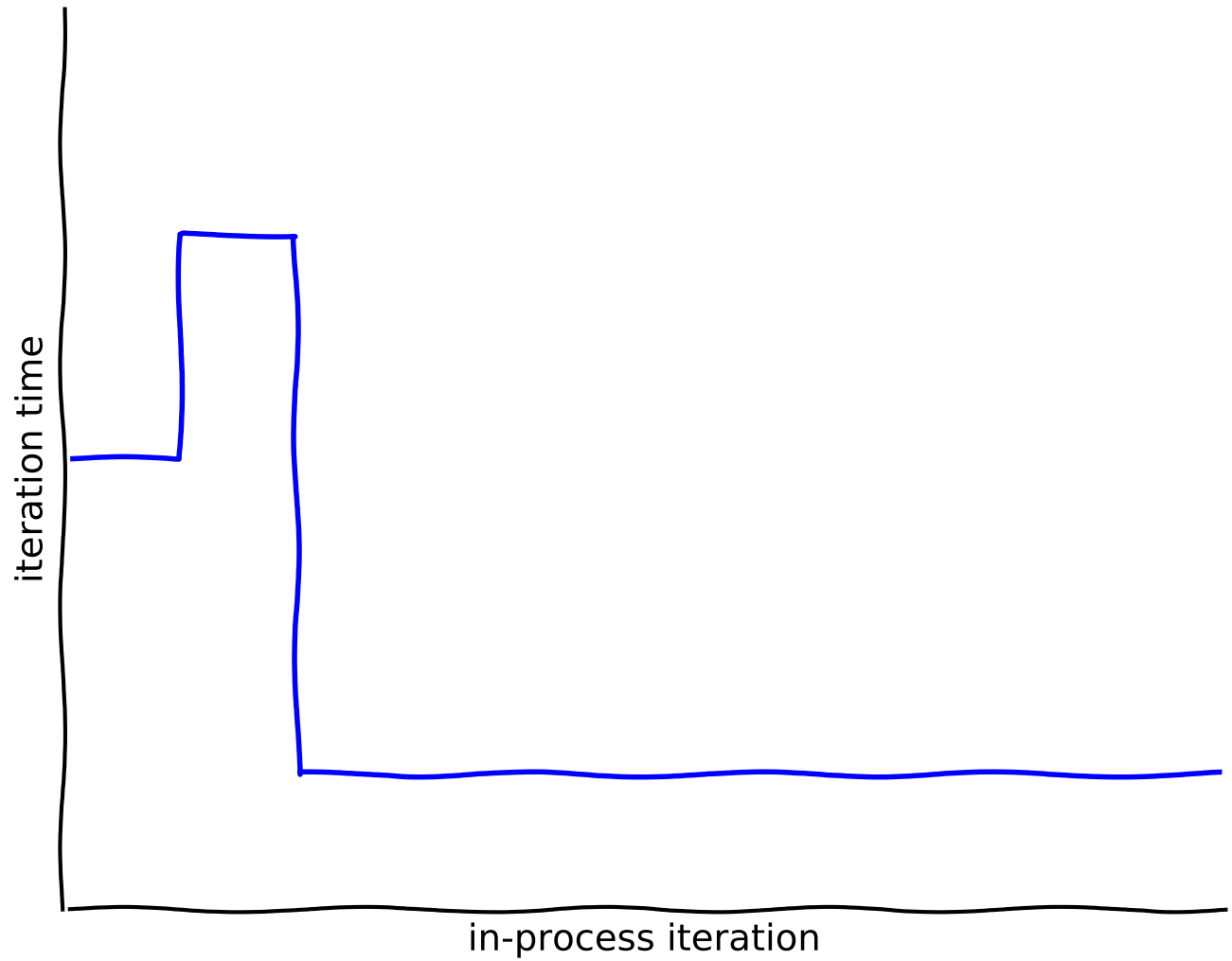

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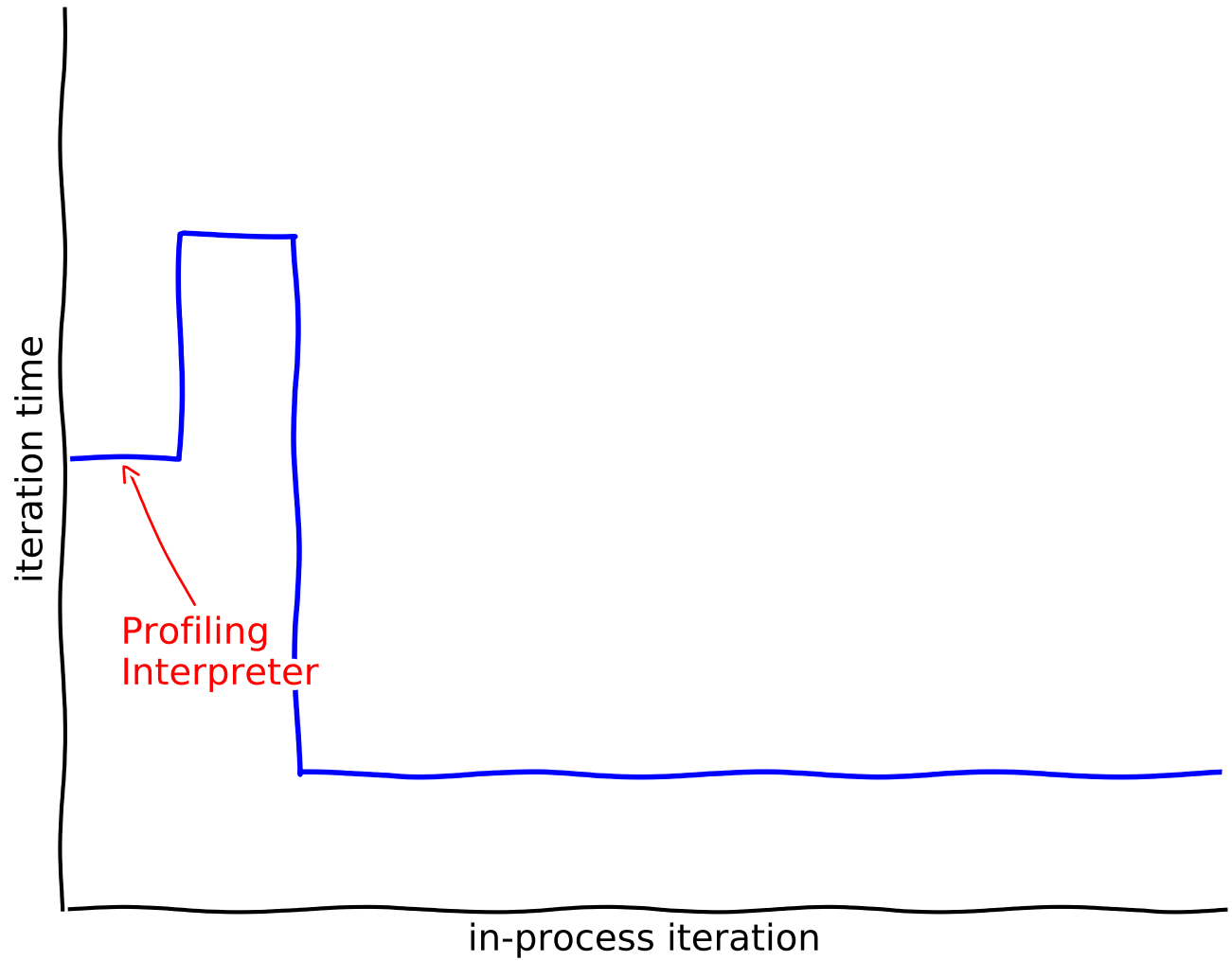

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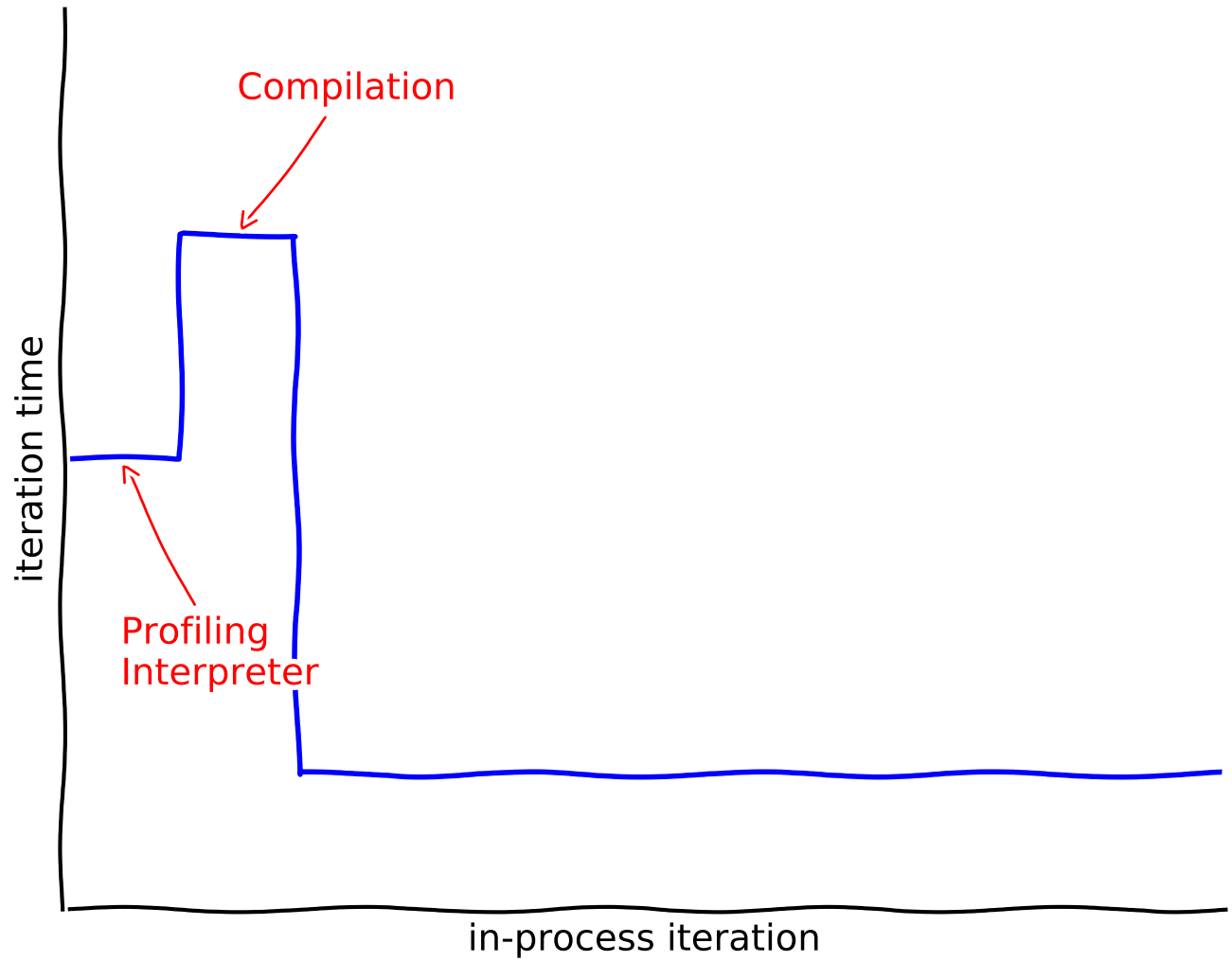

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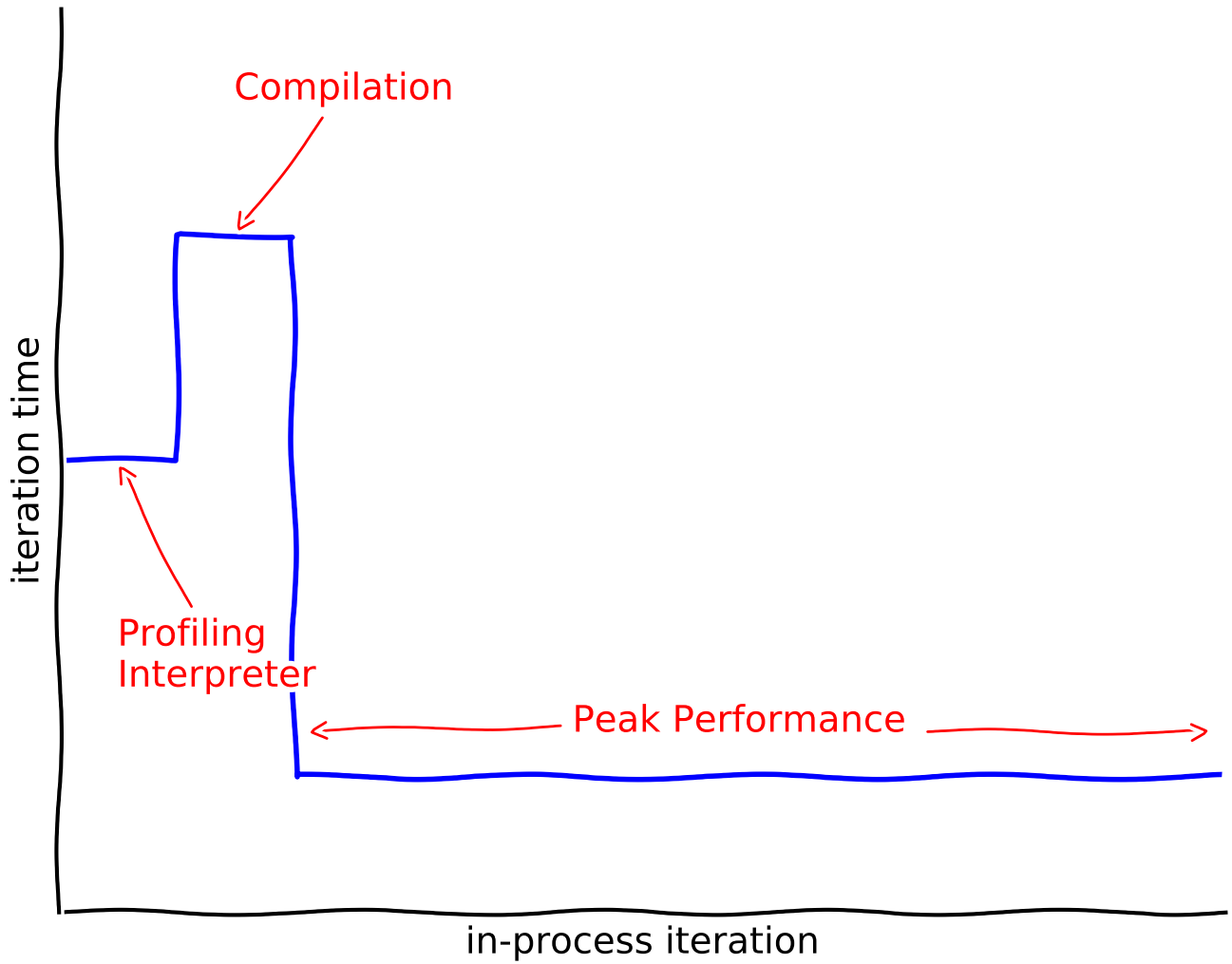

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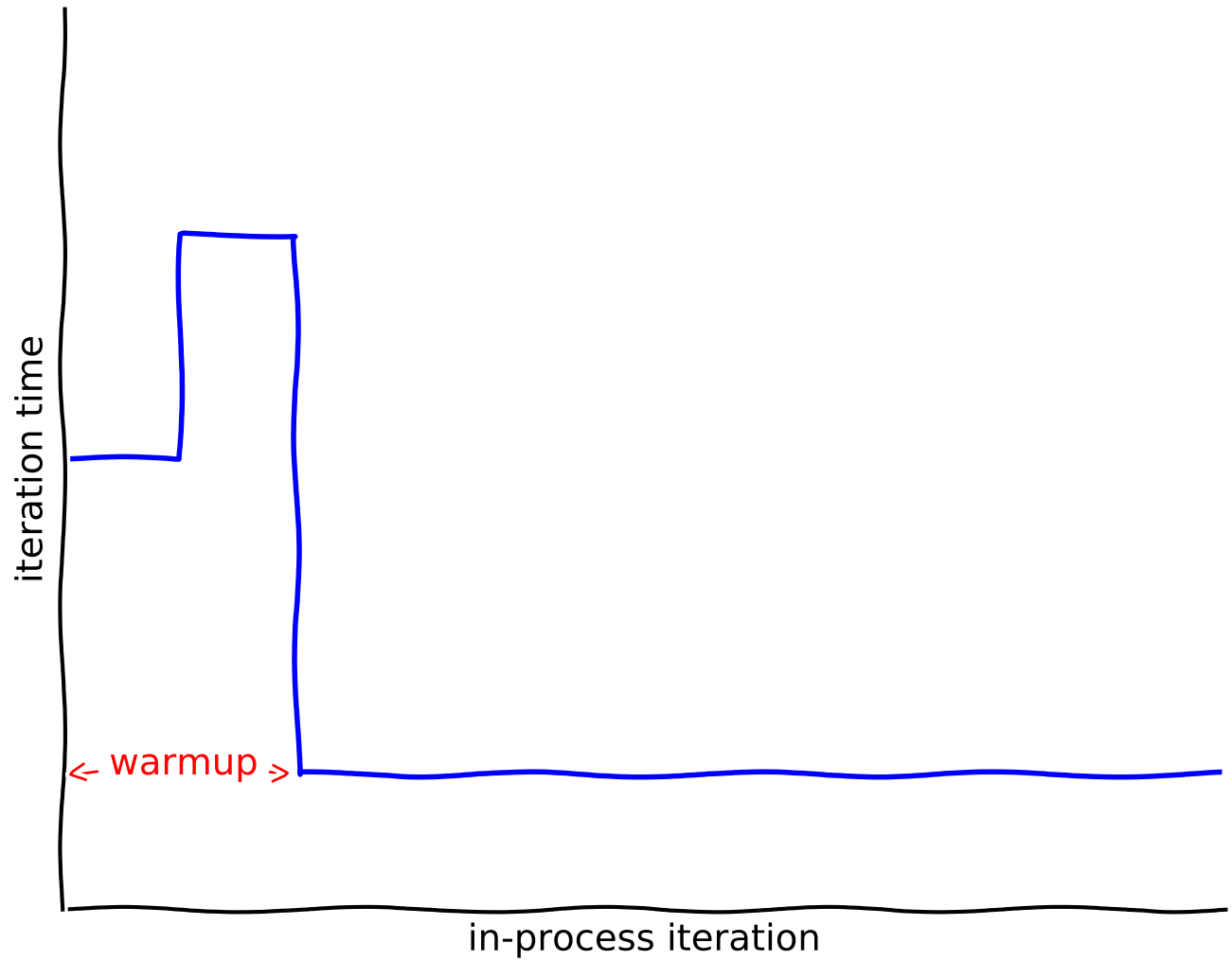

Users *always* perceive warmup

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Maybe we should know how long it is?

The Warmup Experiment

Measure warmup of modern language implementations

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Hypothesis: Small, deterministic programs reach a steady state of peak performance.

Method 1: Which benchmarks?

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We added checksums to all benchmarks

Method 2: How long to run?

2000 *in-process iterations*

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2000 *in-process iterations*

30 *process executions*

Method 3: VMs

- Graal-0.22
- HHVM-3.19.1
- JRuby/Truffle (git #6e9d5d381777)
- Hotspot-8u121b13
- LuaJit-2.0.4
- PyPy-5.7.1
- V8-5.8.283.32
- GCC-4.9.4

Note: same GCC (4.9.4) used for all compilation

Method 4: Machines

- Linux_{4790}, Debian 8, 24GiB RAM
- $\text{Linux}_{\text{E3-1240v5}}$, Debian 8, 32GiB RAM
- OpenBSD_{4790}, OpenBSD 6.0, 32GiB RAM

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- Turbo boost and hyper-threading disabled
- Network card turned off.
- Daemons disabled (cron, smtpd)

Method 5: Krun

Benchmark runner: tries to control as many confounding variables as possible

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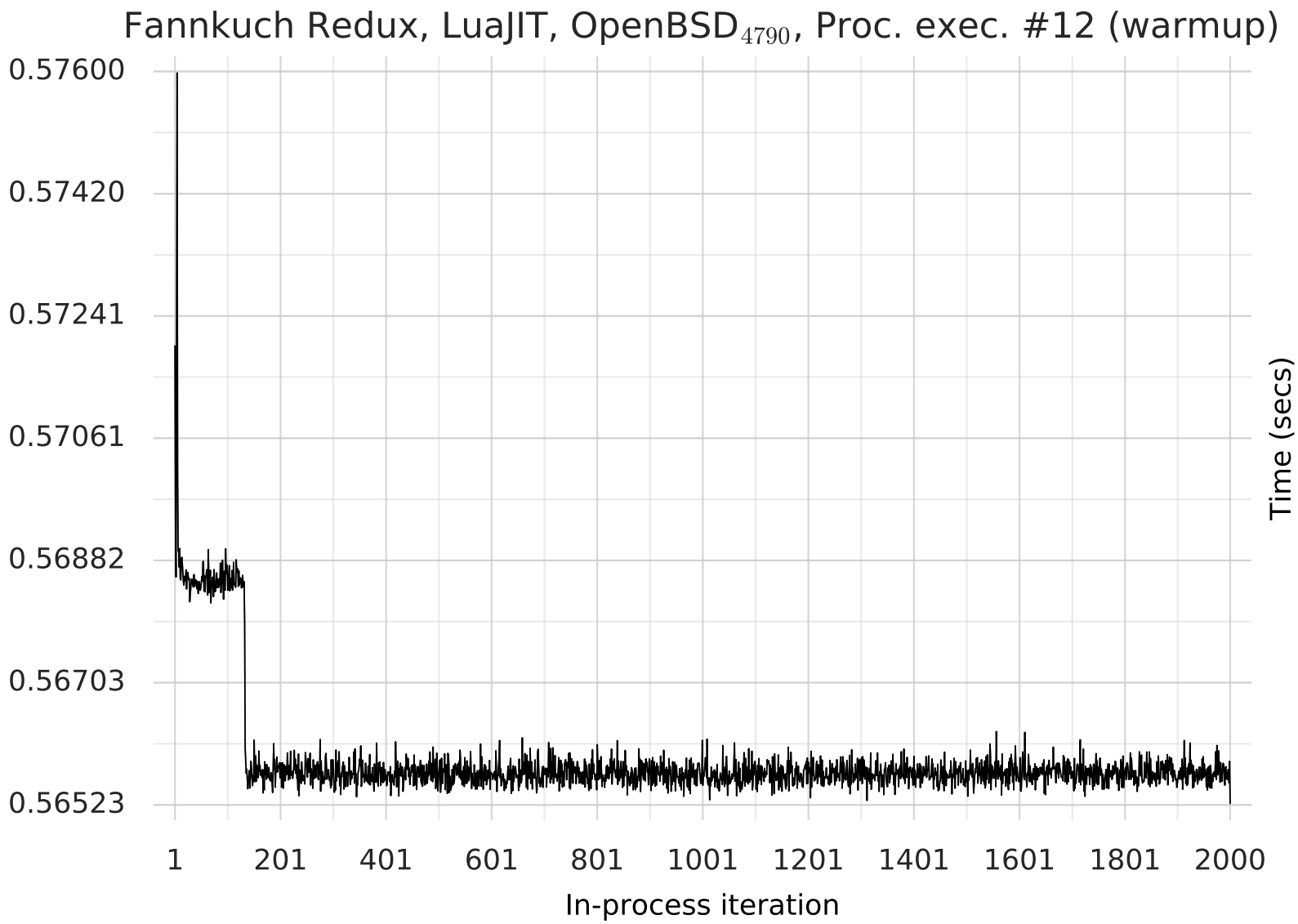
Benchmark runner: tries to control as many confounding variables as possible e.g.:

- Minimises I/O
- Sets fixed heap and stack ulimits
- Drops privileges to a ‘clean’ user account
- Automatically reboots the system prior to each proc. exec
- Checks `dmesg` for changes after each proc. exec
- Checks system at (roughly) same temperature for proc. execs
- Enforces kernel settings (tickless mode, CPU governors, ...)

Warmup & flat (1)



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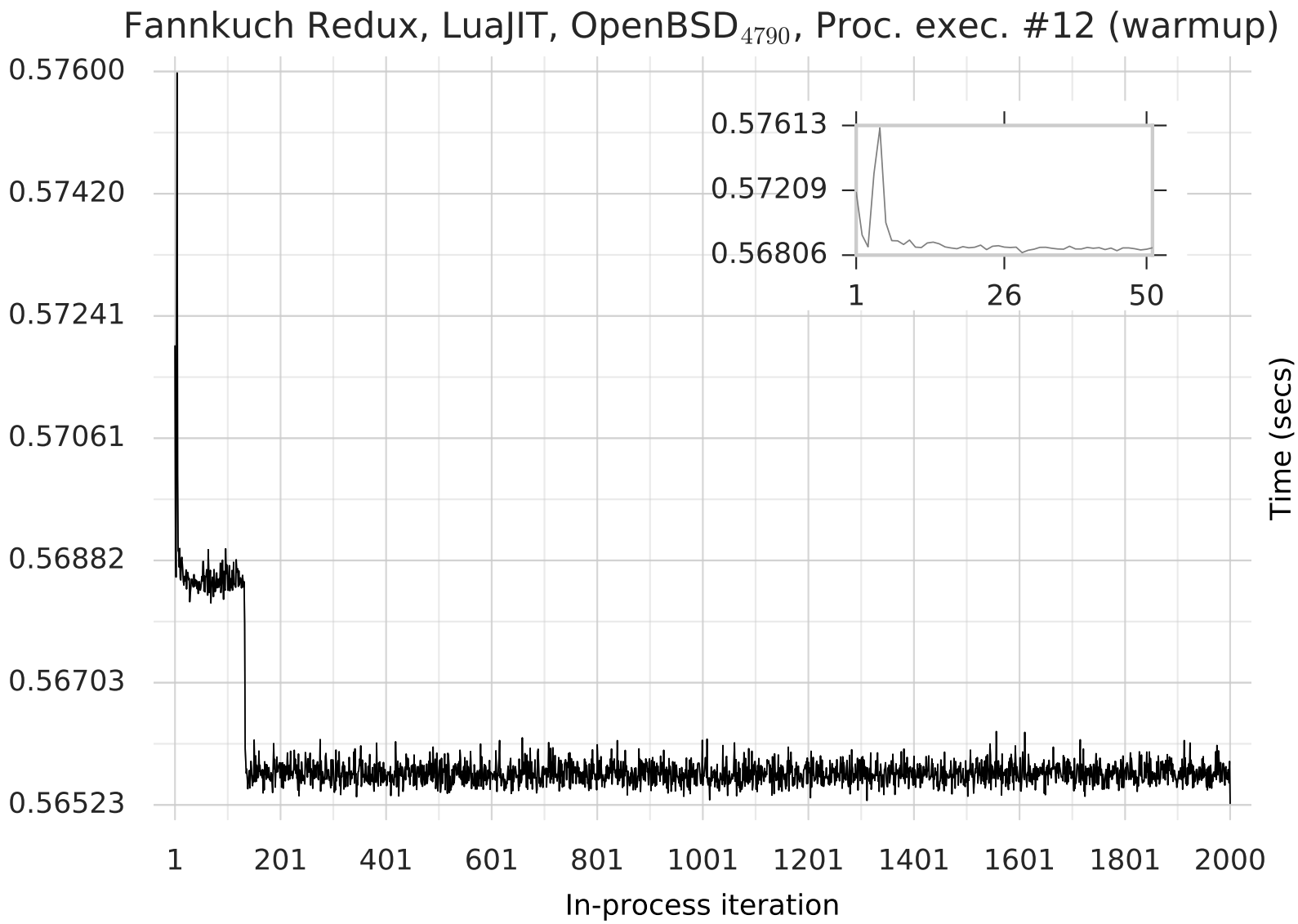

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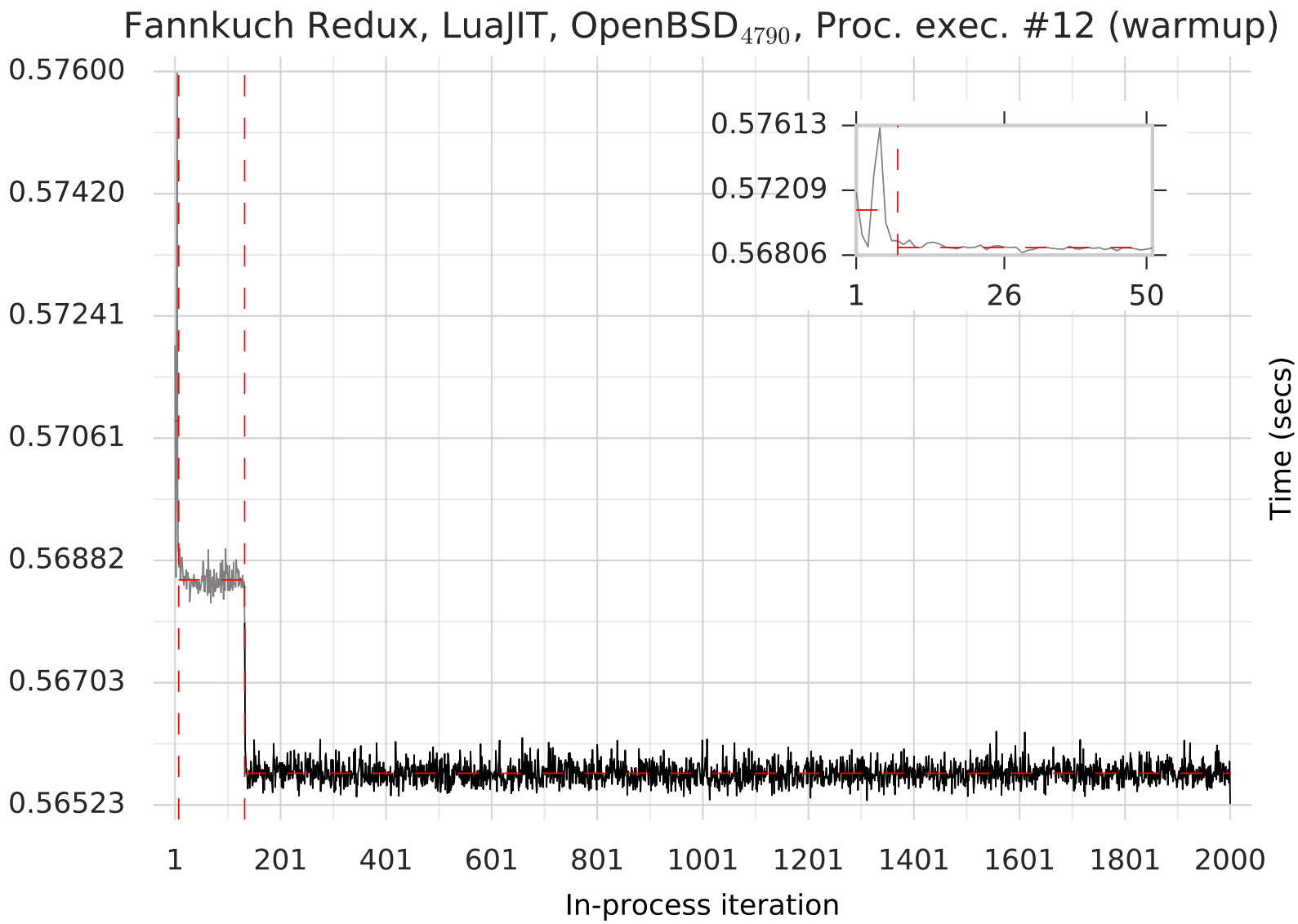

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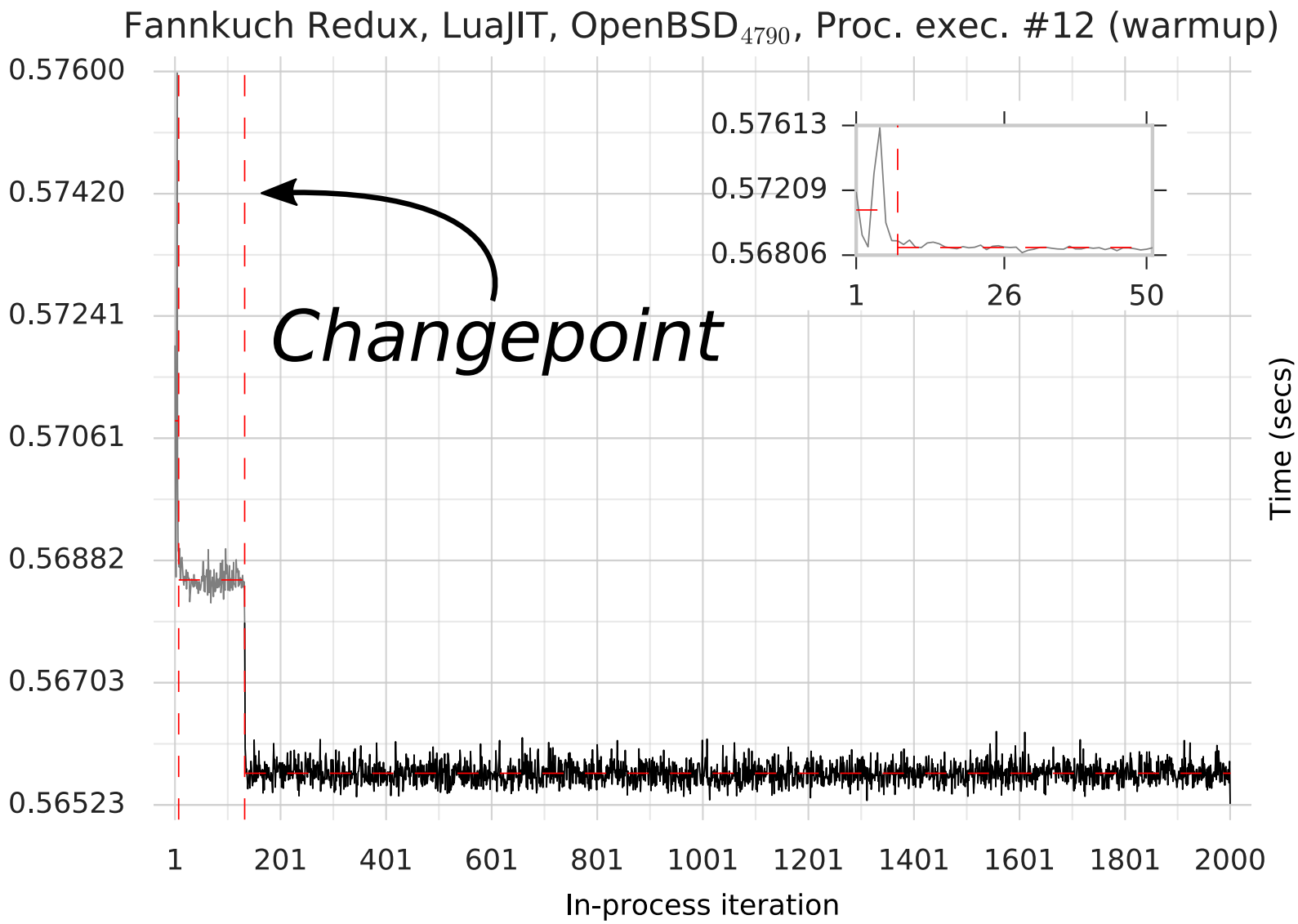

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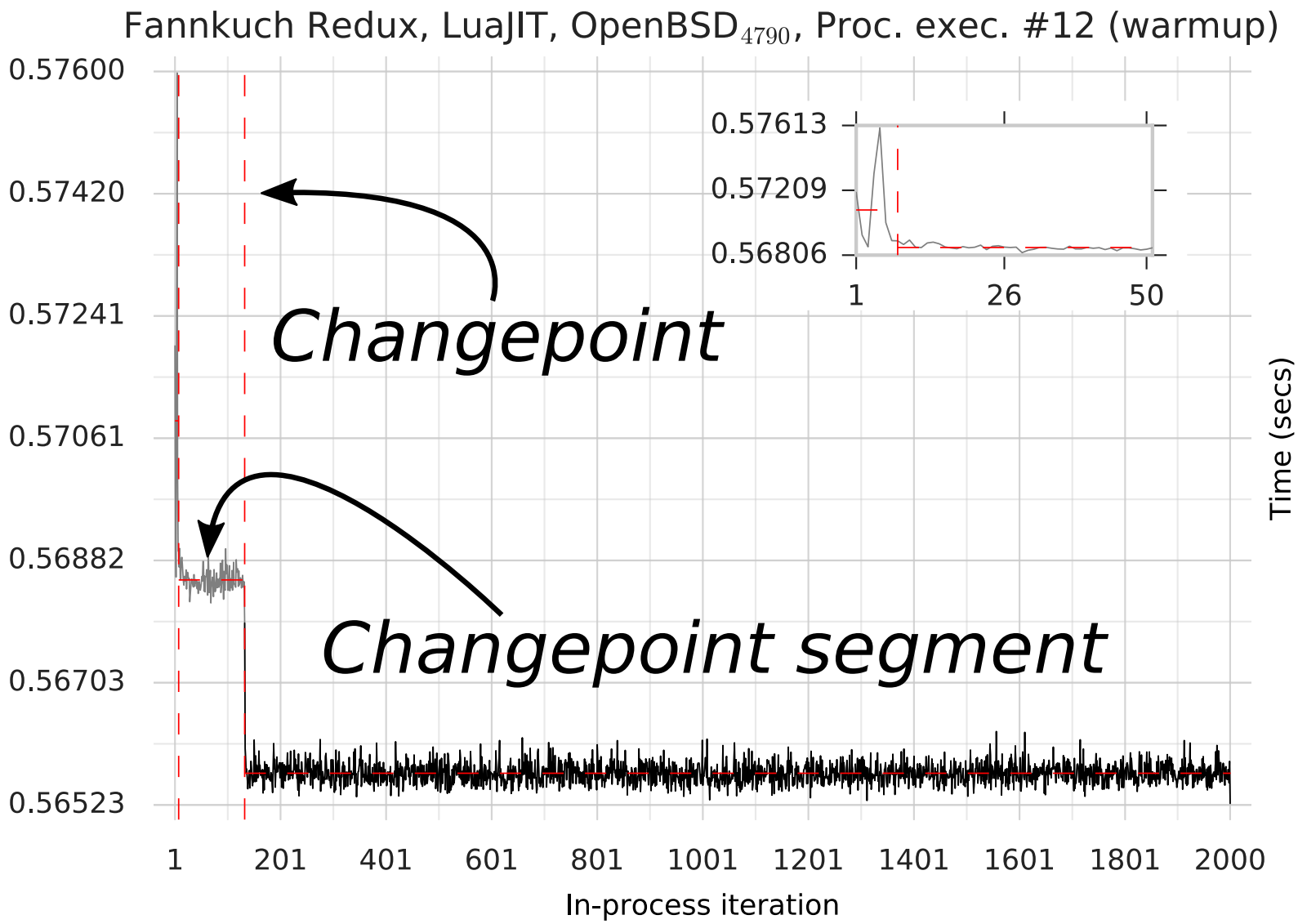

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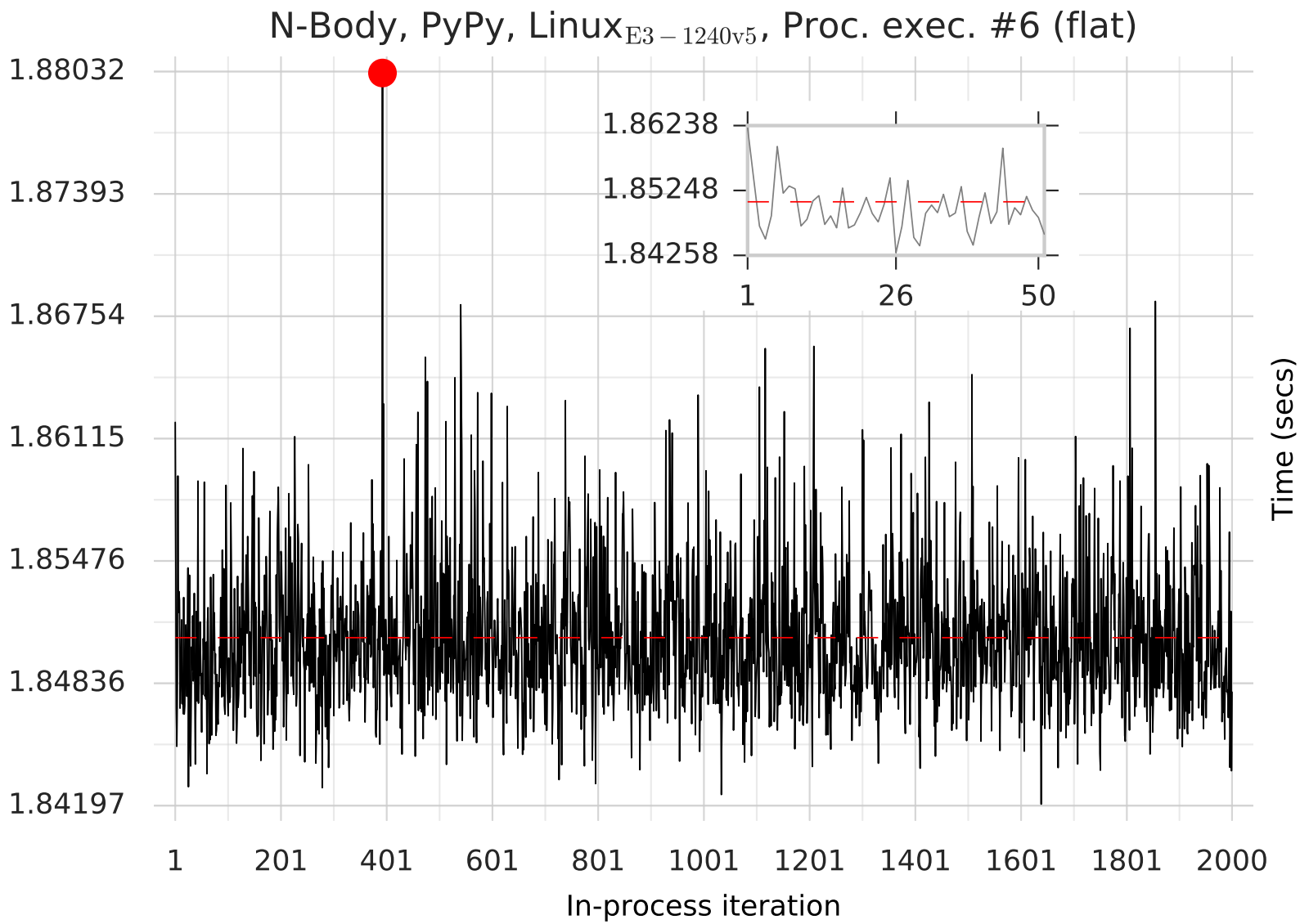

Method 7: Classification

Classification algorithm (steps in order):

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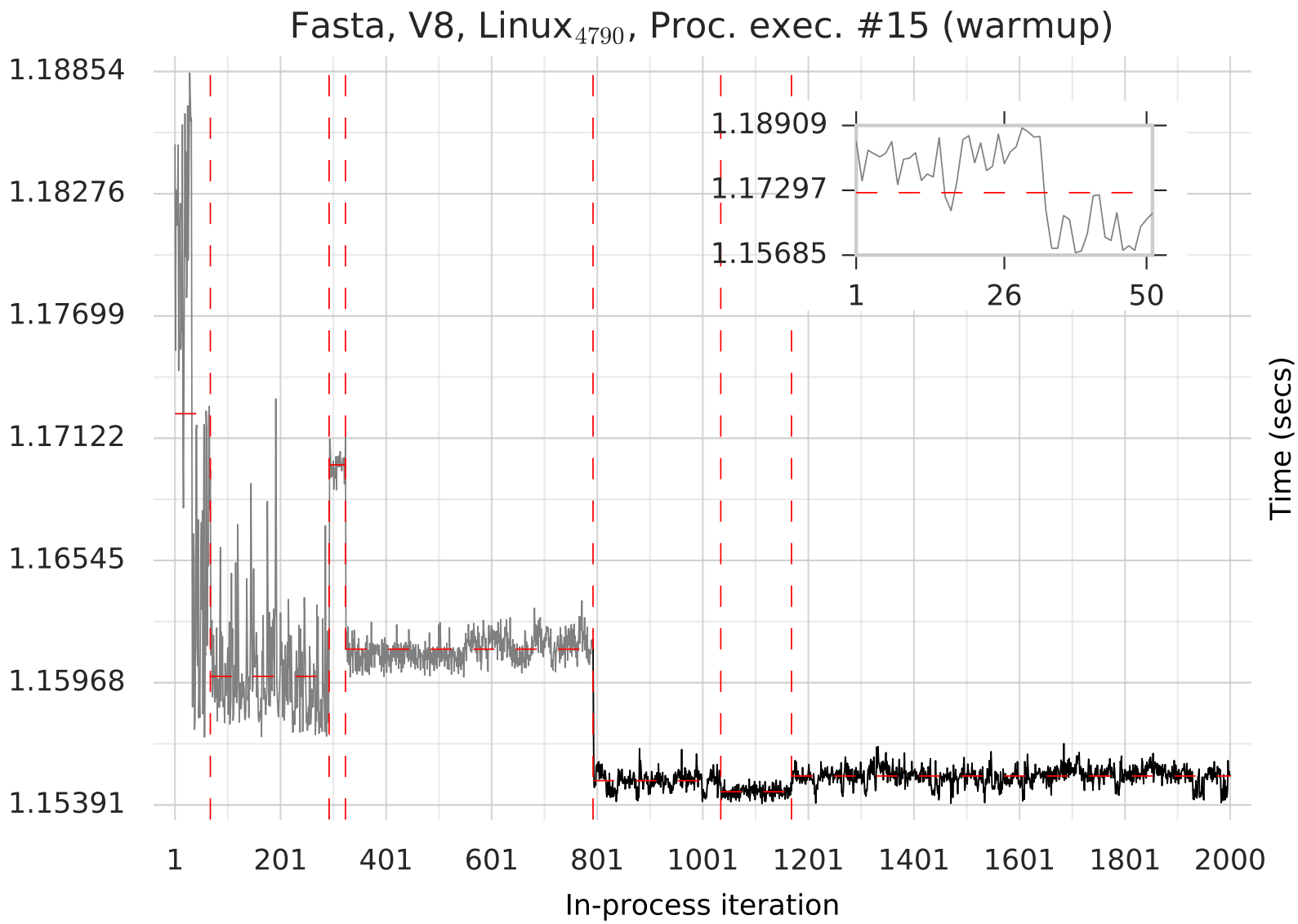
Warmup & flat (2)



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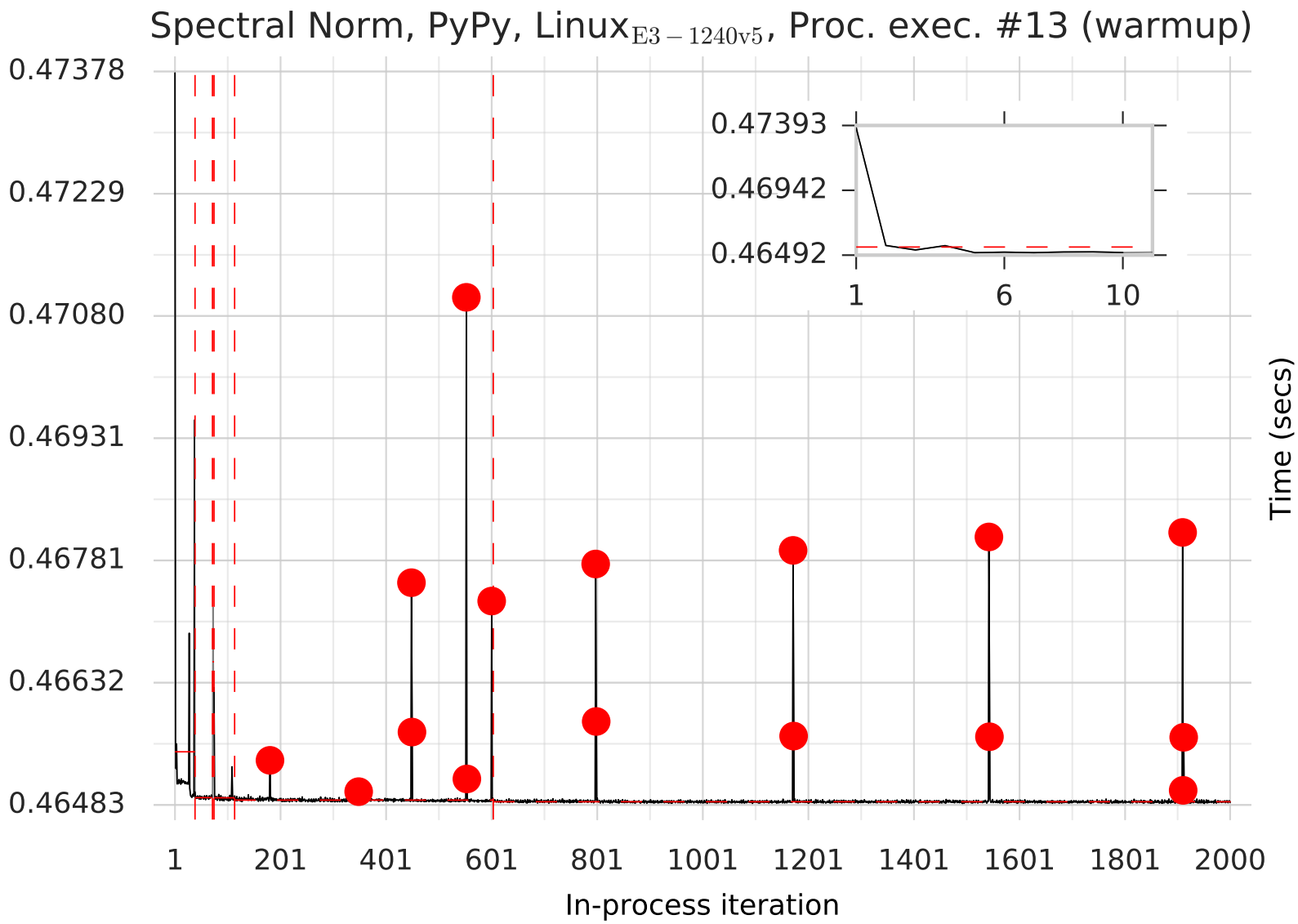
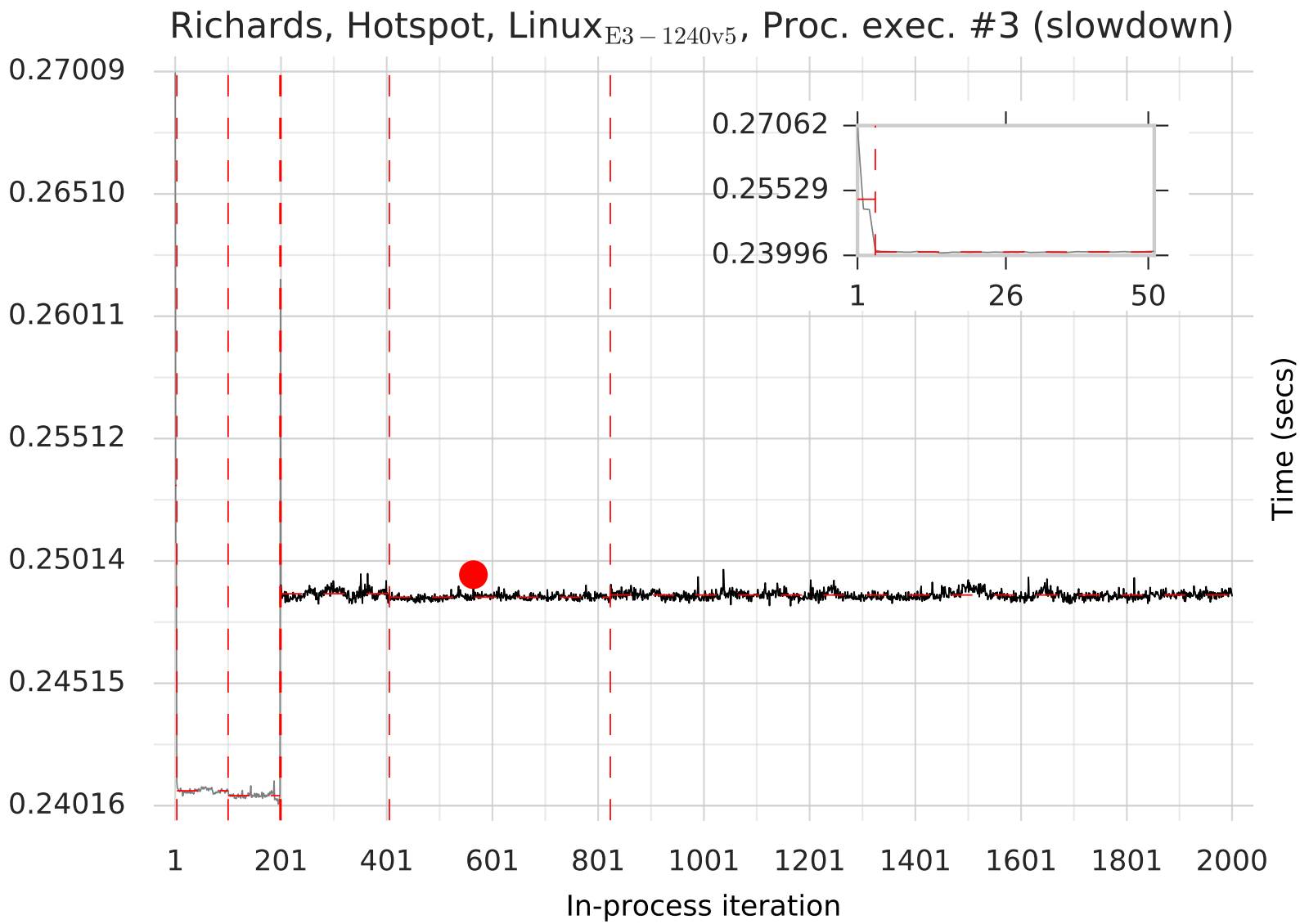


Slowdown (1)


Richards, Hotspot, Linux$_{E3-1240v5}$, Proc. exec. #3 (slowdown)
0.27009
0.26510
0.26011
0.25512
0.25014
0.24515
0.24016
1
201
401
601
801
1001
1201
1401
1601
1801
2000
In-process iteration
Time (secs)
0.27062
0.25529
0.23996
1
26
50

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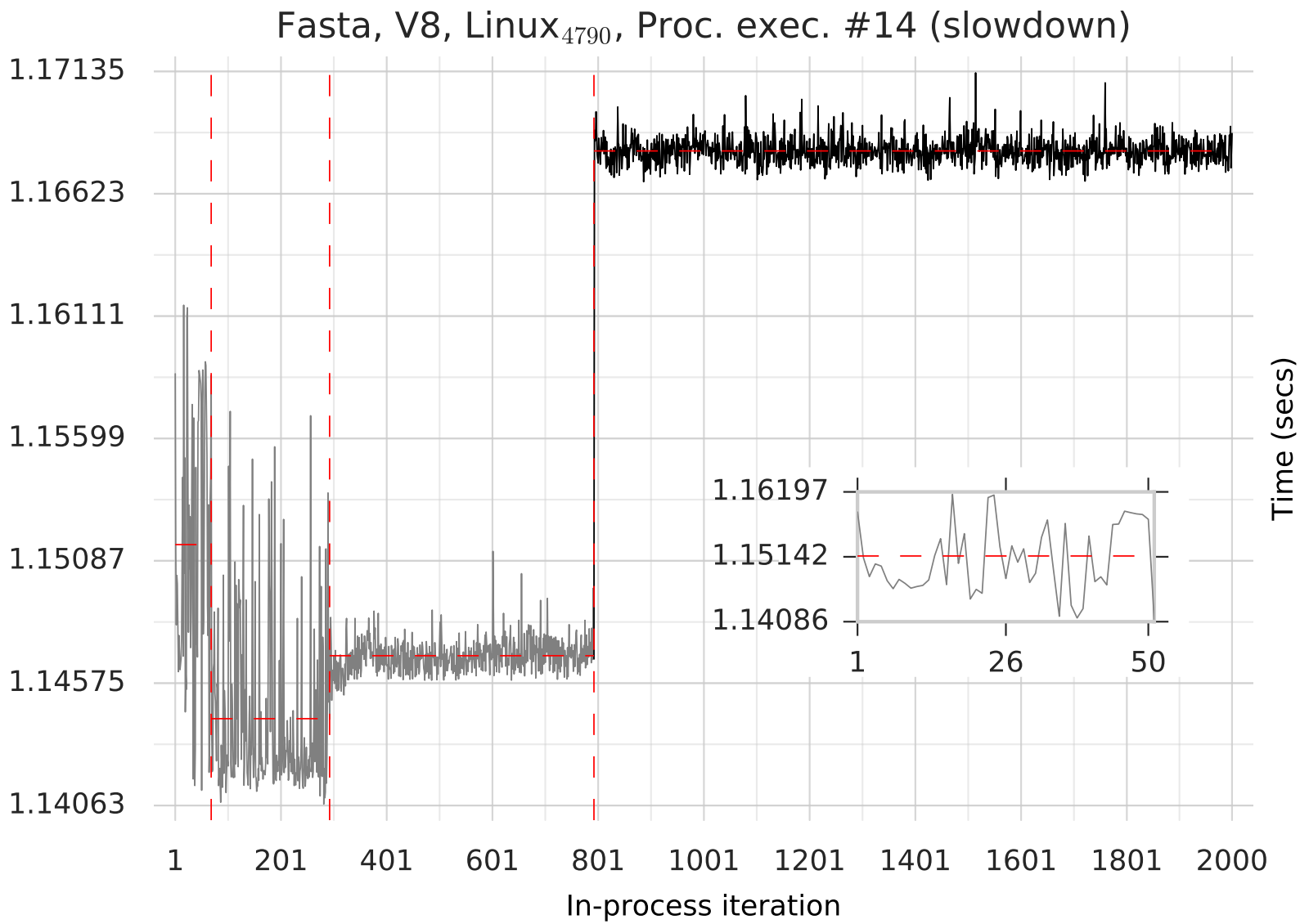
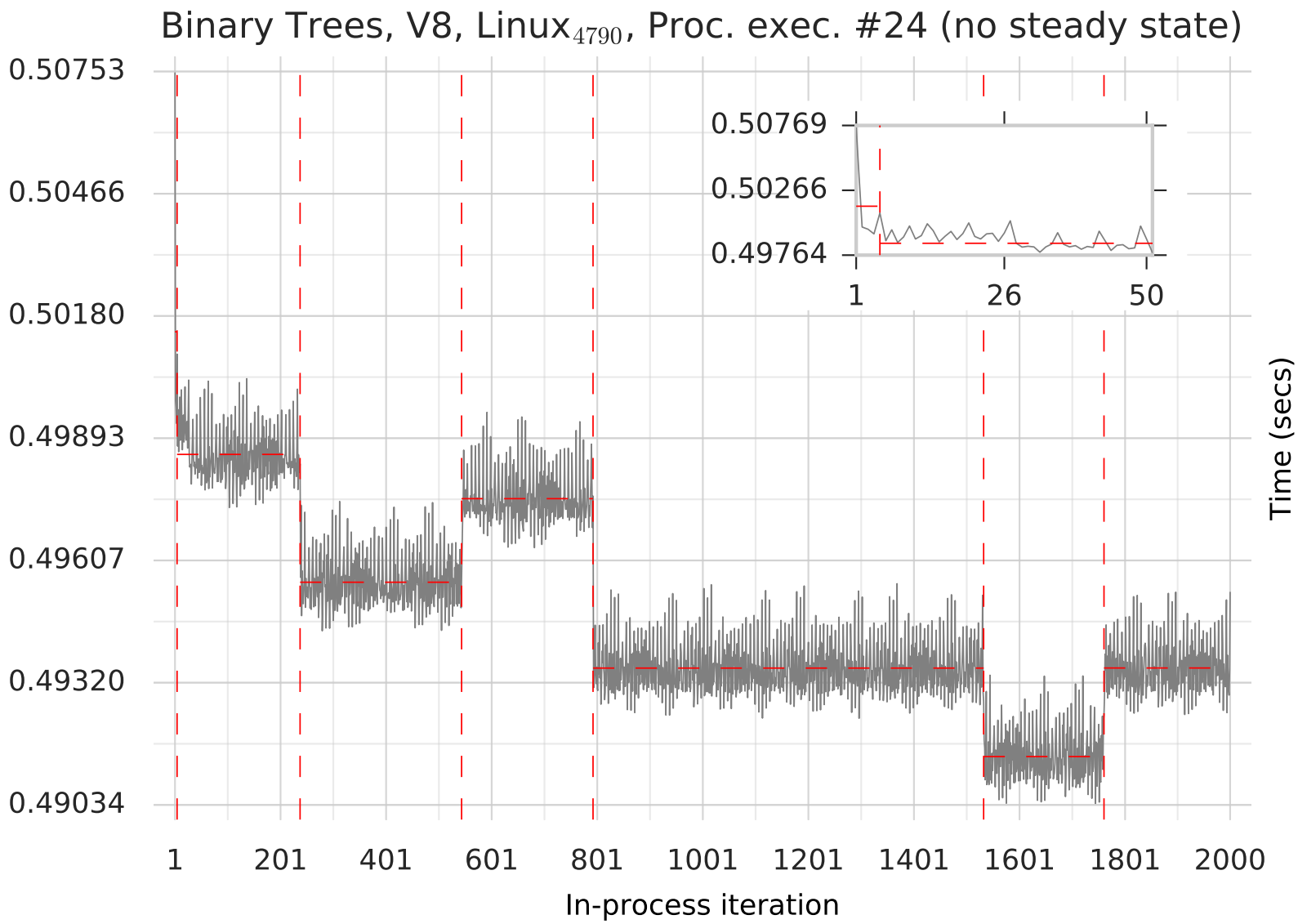

Fasta, V8, Linux4790, Proc. exec. #14 (slowdown)
1.17135
1.16623
1.16111
1.15599
1.15087
1.14575
1.14063
1
201
401
601
801
1001
1201
1401
1601
1801
2000
In-process iteration
Time (secs)
1.16197
1.15142
1.14086
1
26
50

No steady state (1)



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Classification (3)

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Else: *no steady state*

Good

Classification (3)

Classification algorithm, in order:

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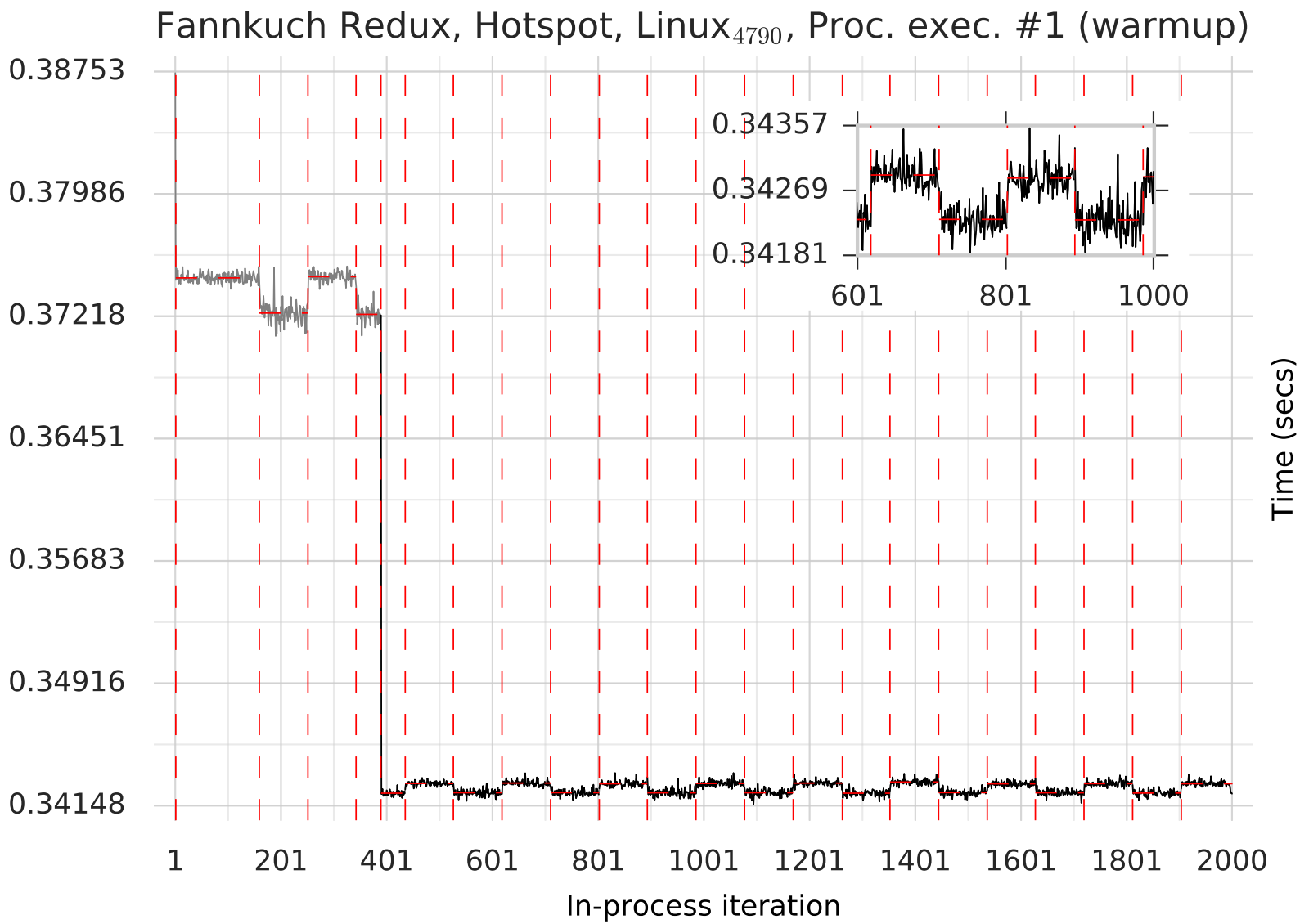
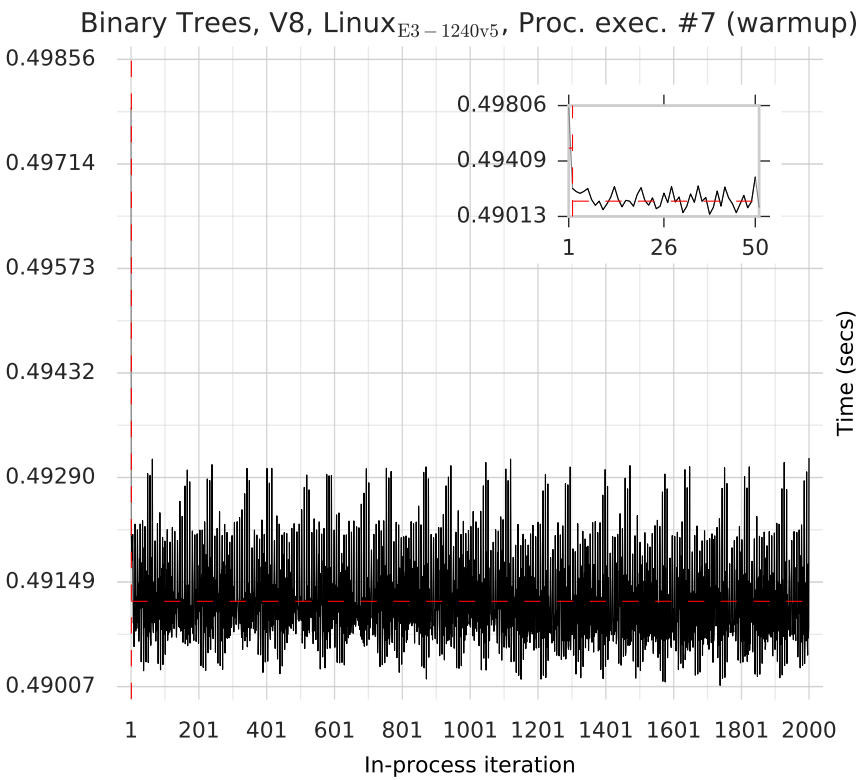
- Else: *no steady state*

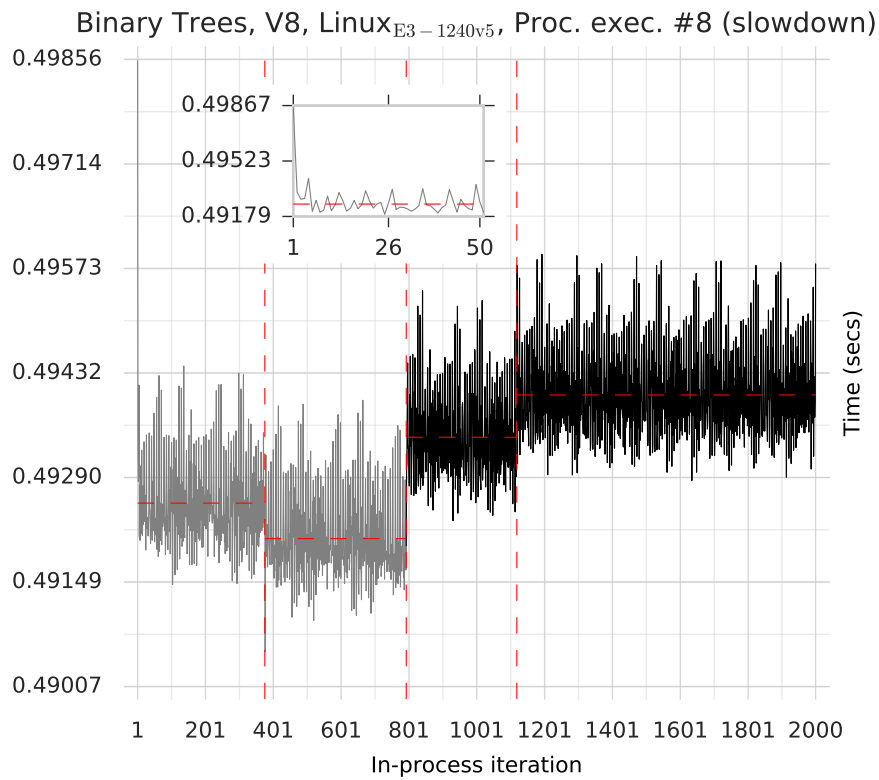
Bad

Warmup or no steady state?



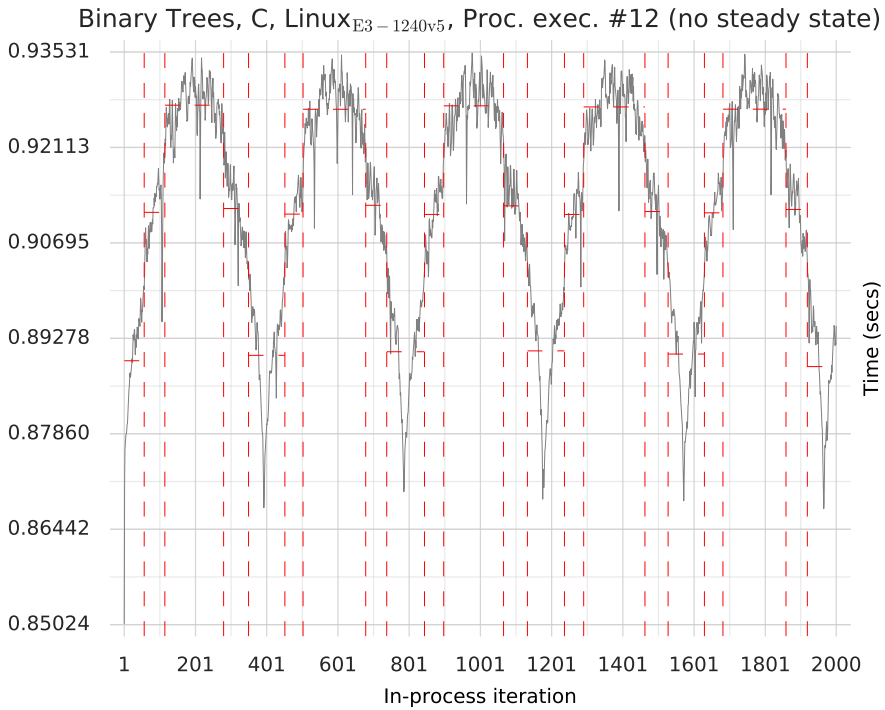
Inconsistent Process-executions

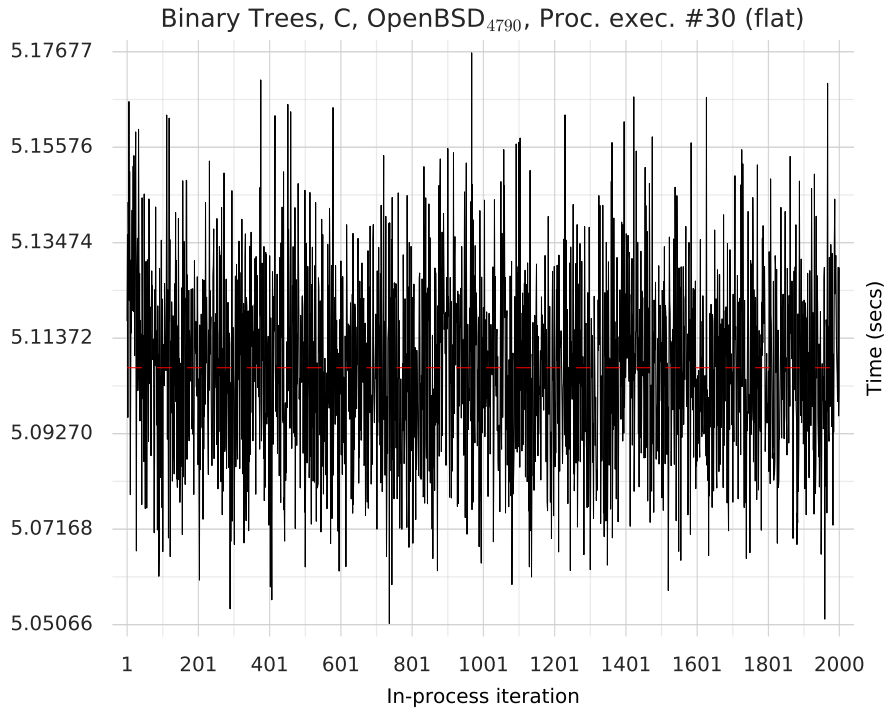




(Same machine)

Inconsistent Process-executions





(Different machines. Bouncing ball Linux-specific)

Individual benchmark stats

		Class.	Steady iter (#)	Steady iter (s)	Steady perf (s)		Class.	Steady iter (#)	Steady iter (s)	Steady perf (s)
C	*binary trees*	⇝				*n-body*	–			0.40555 ±0.005110
Graal		⇛ (27↴, 3↧)	32.0 (17.0, 193.8)	6.60 (3.729, 36.608)	0.18594 ±0.000315		↴	8.0 (7.5, 8.5)	1.22 (1.126, 1.358)	0.13334 ±0.000045
HHVM		⇛ (24↴, 4↧, 2⇝)					⇛ (16↴, 11↧, 3⇝)			
HotSpot		⇛ (25↴, 5↧)	7.0 (7.0, 53.5)	1.19 (1.182, 9.703)	0.18279 ±0.000116		↴	2.0 (2.0, 2.0)	0.14 (0.141, 0.143)	0.13699 ±0.000032
JRuby+Truffle		↧	1082.0 (999.0, 1232.5)	2219.59 (2039.304, 2516.021)	2.05150 ±0.017738		↴	69.0 (69.0, 70.0)	17.95 (17.716, 18.127)	0.20644 ±0.001568
LuaJIT		⇛ (23↴, 4↧, 2–, 1⇝)					–			0.25399 ±0.004471
PyPy		⇛ (27↧, 3⇝)					–			1.85835 ±0.012893
V8		⇛ (15–, 9↴, 6↧)	1.5 (1.0, 794.0)	0.25 (0.000, 391.026)	0.49237 ±0.003198		= (25–, 5↴)	1.0 (1.0, 361.6)	0.00 (0.000, 87.367)	0.24138 ±0.000389
C	*fannkuch redux*	⇛ (21–, 6↴, 2↧, 1⇝)				*Richards*	⇛ (19–, 5↧, 4⇝, 2↴)			
Graal		⇛ (28↴, 1⇝, 1↧)					⇛ (28↴, 1⇝, 1↧)			
HHVM		↴	10.0 (10.0, 10.0)	52.66 (52.660, 52.708)	1.35779 ±0.011948					
HotSpot		↴	390.0 (2.0, 390.0)	153.70 (0.407, 155.254)	0.36202 ±0.022767		⇛ (26↧, 2⇝, 2↴)			
JRuby+Truffle		↧	1016.5 (999.0, 1023.1)	1039.04 (1014.290, 1059.967)	1.08833 ±0.038580		↧	1021.0 (1014.9, 1027.0)	917.30 (901.708, 946.683)	0.89509 ±0.027590
LuaJIT		–			0.56285 ±0.000097		⇛ (21⇝, 7↧, 2↴)			
PyPy		⇛ (15↴, 13–, 2↧)	2.0 (1.0, 28.9)	1.57 (0.000, 43.483)	1.55442 ±0.020549		↴	2.0 (2.0, 5.0)	1.12 (1.114, 4.054)	0.96809 ±0.010950
V8		= (19↴, 11–)	2.0 (1.0, 25.5)	0.31 (0.000, 7.525)	0.30401 ±0.000154		= (29↴, 1–)	4.0 (4.0, 16.0)	1.44 (1.434, 7.135)	0.47421 ±0.001218
C	*fasta*	–			0.07048 ±0.000210	*spectralnorm*	⇛ (28↴, 1–, 1↧)	997.0 (2.0, 1001.0)	546.38 (0.546, 547.717)	0.54547 ±0.002562
Graal		⇛ (29↴, 1⇝)					⇛ (29↧, 1–)	15.0 (2.0, 21.0)	12.40 (0.812, 17.804)	0.89293 ±0.000087
HHVM		⇛ (27↴, 2⇝, 1↧)					↴	35.0 (34.0, 41.0)	139.18 (136.909, 147.626)	1.40690 ±0.011133
HotSpot		⇛ (18↴, 12↧)	261.0 (6.0, 595.0)	30.73 (0.614, 70.021)	0.11744 ±0.001723		↴	7.0 (7.0, 8.6)	1.90 (1.901, 2.425)	0.31470 ±0.000029
JRuby+Truffle							↴	1011.0 (1007.5, 1014.0)	893.38 (888.985, 896.562)	0.83633 ±0.014403
LuaJIT		⇝					–			0.22435 ±0.000020
PyPy		⇝					↴	75.0 (75.0, 75.0)	34.43 (34.429, 34.437)	0.46489 ±0.000046
V8		⇛ (19↴, 10↧, 1⇝)					↴	3.0 (3.0, 3.0)	0.55 (0.554, 0.554)	0.24963 ±0.000039

Individual benchmark stats

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JRuby+Truffle		⌋	1082.0 (999.0, 1232.5)		2219.59 (2039.304, 2516.021)		2.05150 ±0.017737	
LuaJIT		⤮ (23⌊, 4⌋, 2–, 1↜)						
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V8		⤮ (15–, 9⌊, 6⌋)	1.5 (1.0, 794.0)		0.25 (0.000, 391.026)		0.49237 ±0.003198	

Overall benchmark stats

Class.	Linux_{4790}	$\text{Linux}_{1240\text{v}5}$	OpenBSD_{4790} †
	⟨VM, benchmark⟩ pairs		
–	8.7%	13.0%	6.7%
⌞	28.3%	23.9%	10.0%
⌜	6.5%	6.5%	0.0%
∾	4.3%	6.5%	0.0%
=	6.5%	6.5%	13.3%
≭	45.7%	43.5%	70.0%
	Process executions		
–	26.4%	20.9%	34.0%
⌞	48.3%	51.5%	52.1%
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Summary

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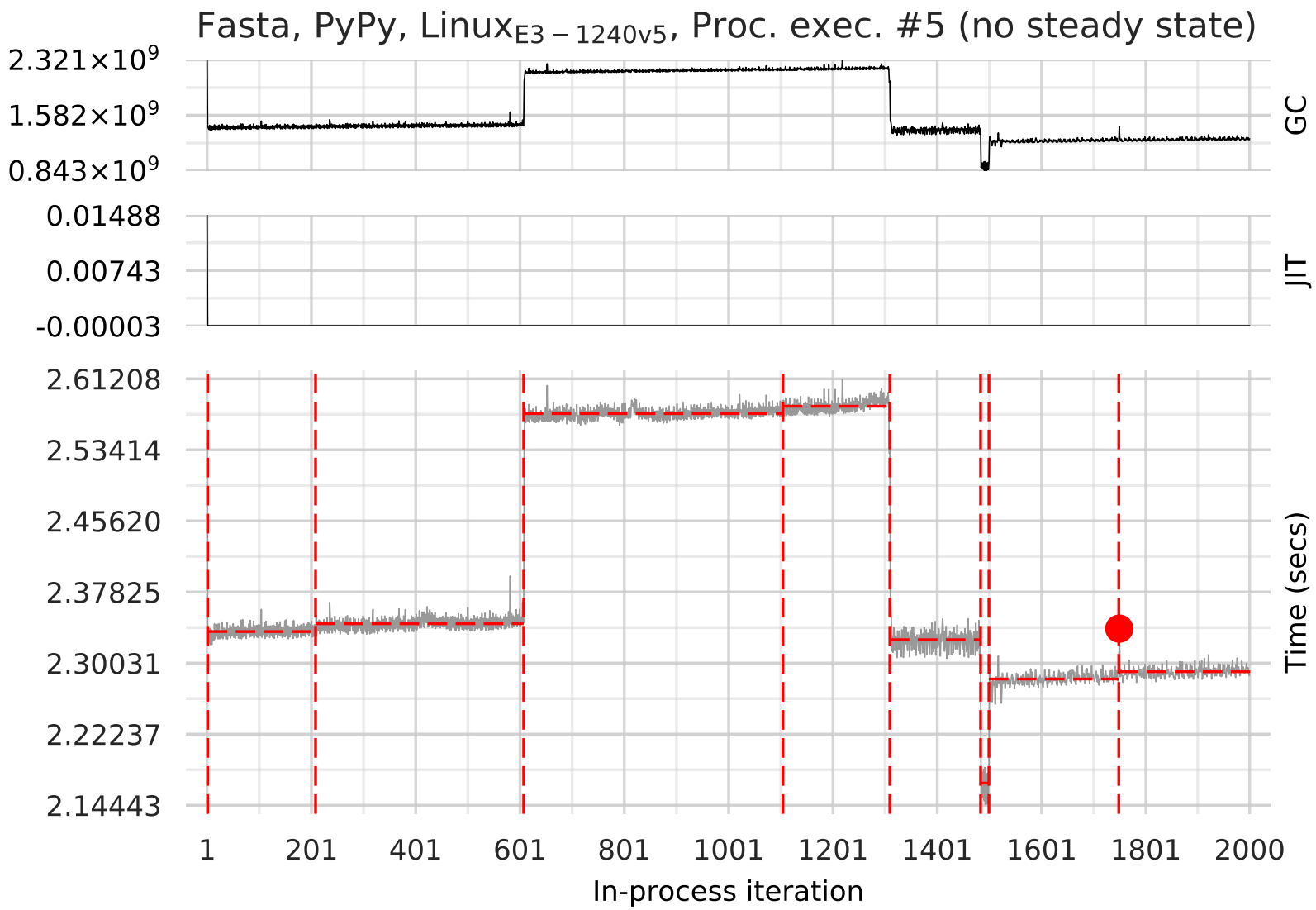
43.4%–43.5% of (VM, benchmark) pairs

0% of benchmarks for (VM, benchmark, machine) triples

Are odd effects correlated with compilation and GC?



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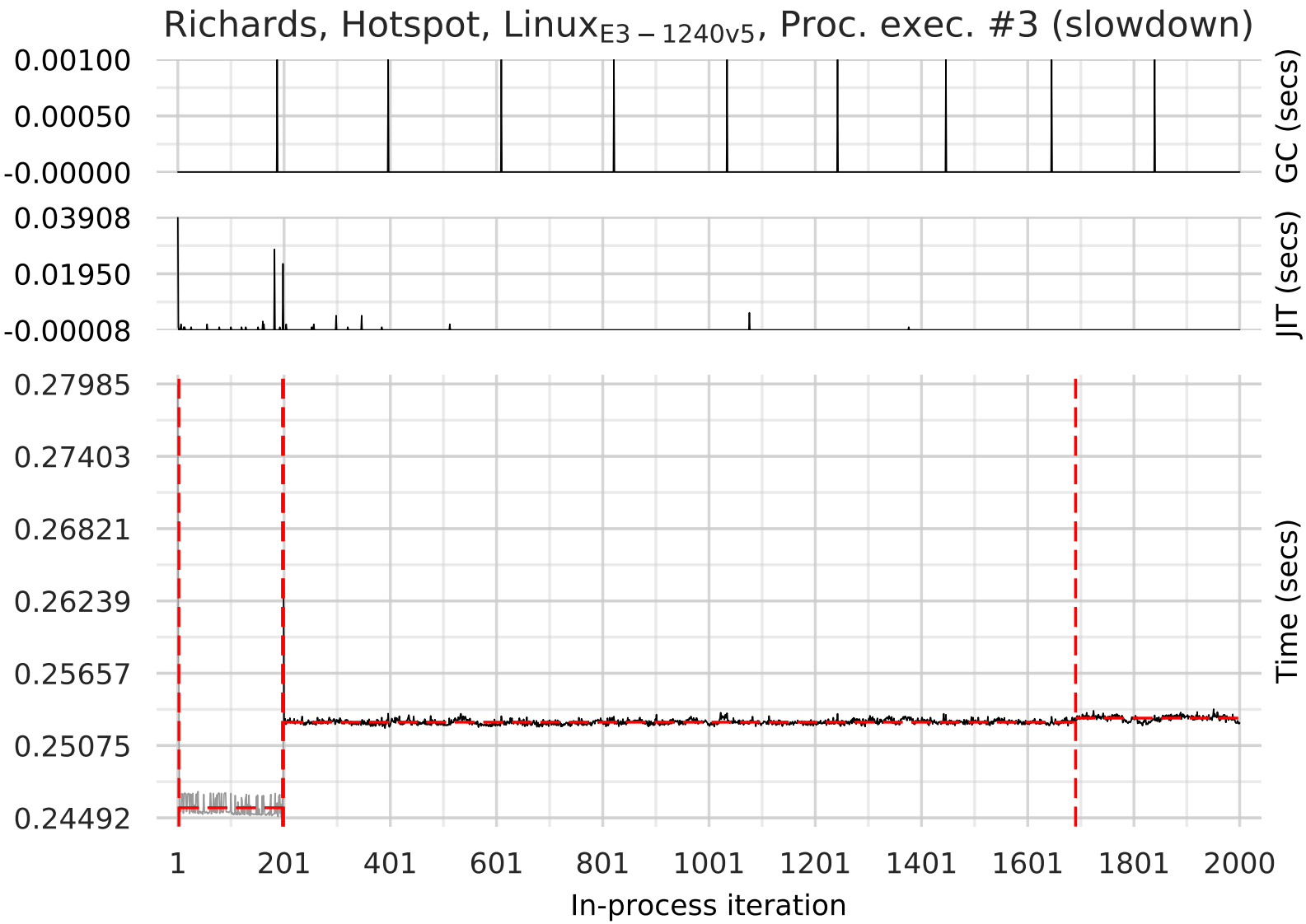

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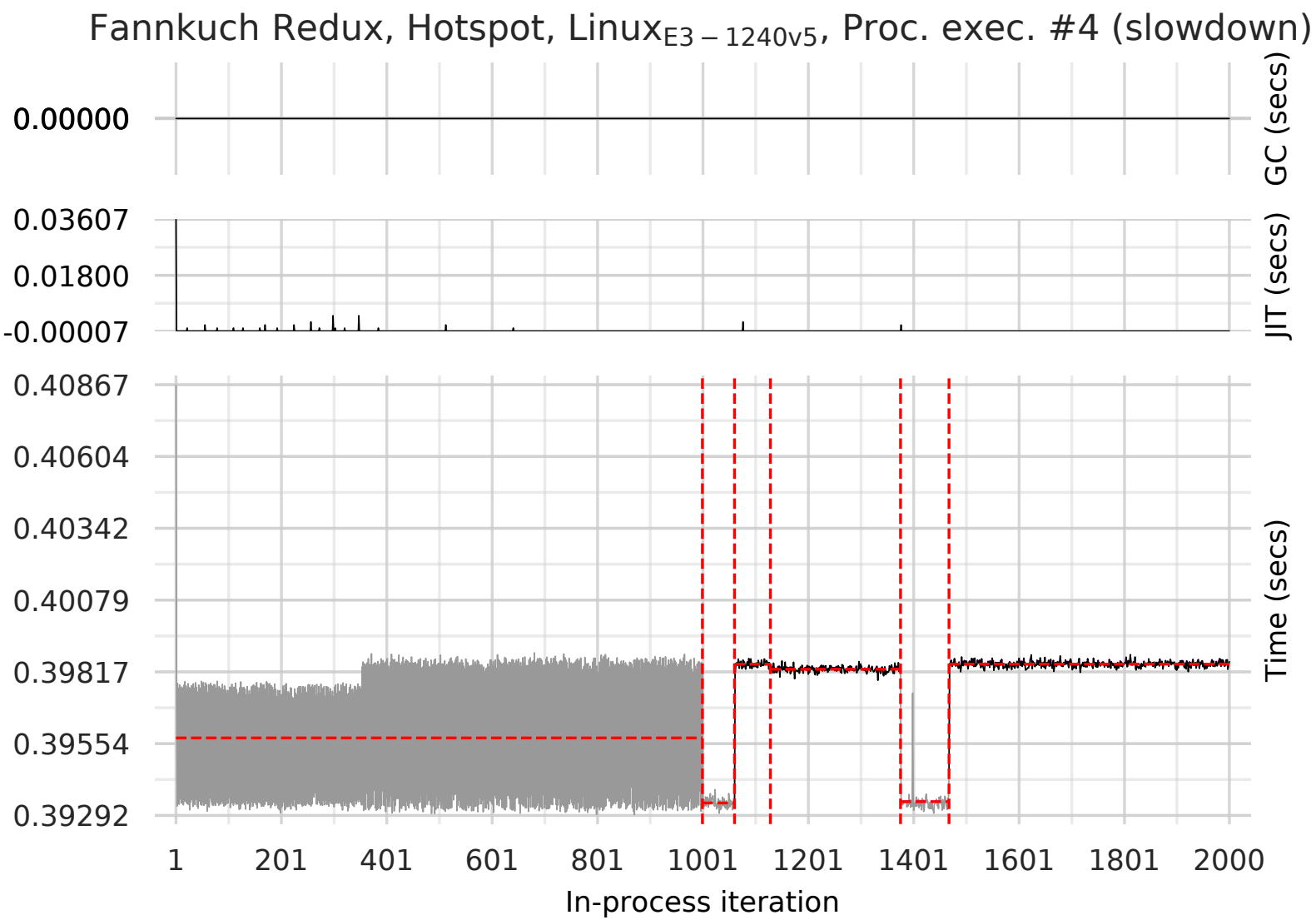

Benchmark suites

Benchmarks guide our optimisations

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Are they complete guides?

A war story

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Symptom: poor performance of a Pyston benchmark on PyPy

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Cause: RPython traces recursion

A war story

Symptom: poor performance of a Pyston benchmark on PyPy

Cause: RPython traces recursion

Fix: Check for recursion before tracing

A war story: the basis of a fix

```
diff --git a/rpython/jit/metainterp/pyjitpl.py b/rpython/jit/metainterp/pyjitpl.py
--- a/rpython/jit/metainterp/pyjitpl.py
+++ b/rpython/jit/metainterp/pyjitpl.py
@@ -951,9 +951,31 @@
         if warmrunnerstate.inlining:
             if warmrunnerstate.can_inline_callable(greenboxes):
+                # We've found a potentially inlinable function; now we need to
+                # see if it's already on the stack. In other words: are we about
+                # to enter recursion? If so, we don't want to inline the
+                # recursion, which would be equivalent to unrolling a while
+                # loop.
                 portal_code = targetjitdriver_sd.mainjitcode
-                return self.metainterp.perform_call(portal_code, allboxes,
-                                                    greenkey=greenboxes)
+                inline = True
+                if self.metainterp.is_main_jitcode(portal_code):
+                    for gk, _ in self.metainterp.portal_trace_positions:
+                        if gk is None:
+                            continue
+                        assert len(gk) == len(greenboxes)
+                        i = 0
+                        for i in range(len(gk)):
+                            if not gk[i].same_constant(greenboxes[i]):
+                                break
+                        else:
+                            # The greenkey of a trace position on the stack
+                            # matches what we have, which means we're definitely
+                            # about to recurse.
+                            inline = False
+                            break
+                if inline:
+                    return self.metainterp.perform_call(portal_code, allboxes,
+                                                        greenkey=greenboxes)
```

A war story: mixed fortunes

Success: slow benchmark now 13.5x faster

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Failure: some PyPy benchmarks slow down

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Success: slow benchmark now 13.5x faster

Failure: some PyPy benchmarks slow down

Solution: allow *some* tracing into recursion

A war story: data

#unrollings	1	2	3	5	7	10
hexiom2	1.3	1.4	1.1	1.0	1.0	1.0
raytrace-simple	3.3	3.1	2.8	1.4	1.0	1.0
spectral-norm	3.3	1.0	1.0	1.0	1.0	1.0
sympy_str	1.5	1.0	1.0	1.0	1.0	1.0
telco	4	2.5	2.0	1.0	1.0	1.0
polymorphism	0.07	0.07	0.07	0.07	0.08	0.09

http://marc.info/?l=pypy-dev&m=141587744128967&w=2

A war story: conclusion

The benchmark suite said 7 levels, so that’s what I suggested

A war story: conclusion

The benchmark suite said 7 levels, so that's what I suggested

Even though I doubted it was the right global value

Benchmark suites (2)

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Benchmarks guide our optimisations

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Benchmarks guide our optimisations

Are they correct guides?

Octane

17 JavaScript benchmarks from V8

Octane

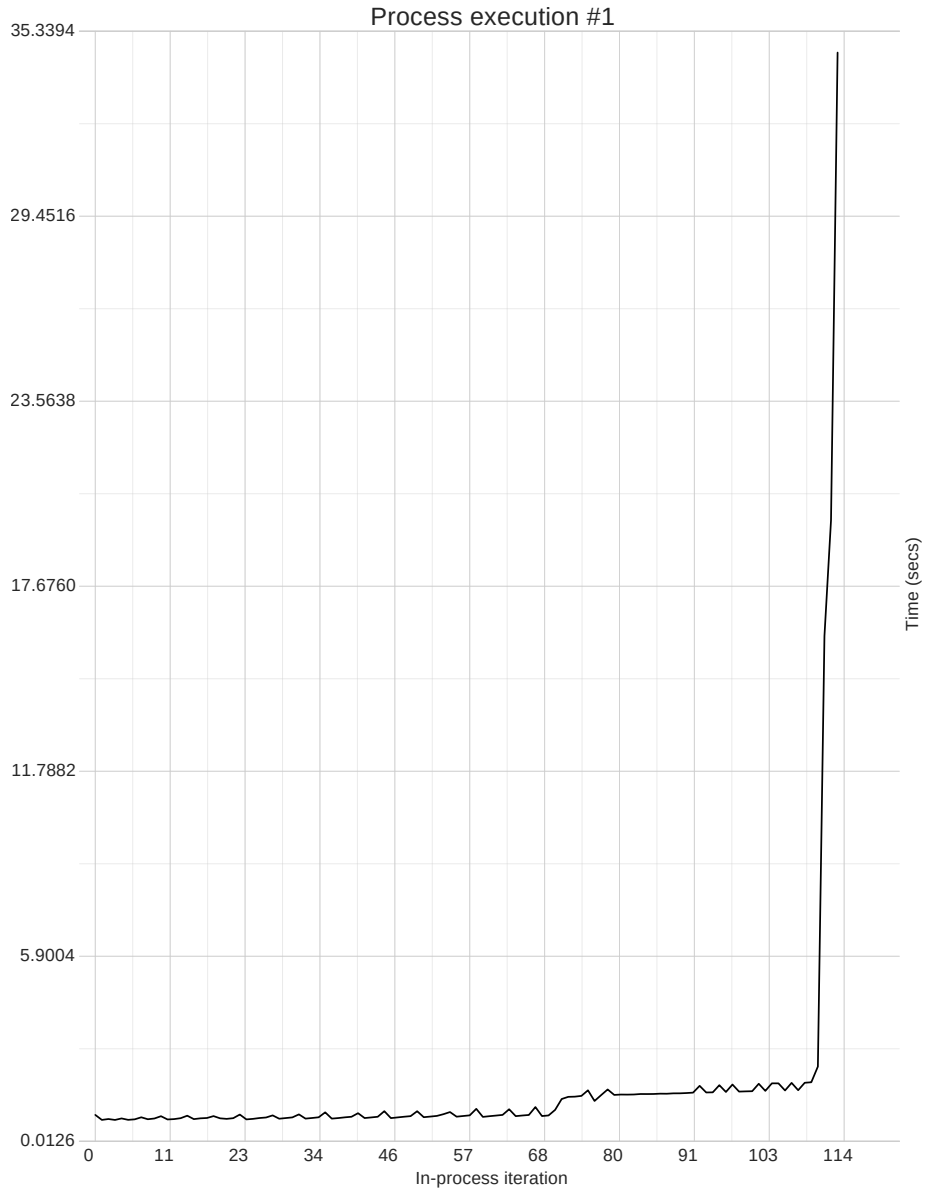
17 JavaScript benchmarks from V8

Let’s make each benchmark run for 2000 iterations

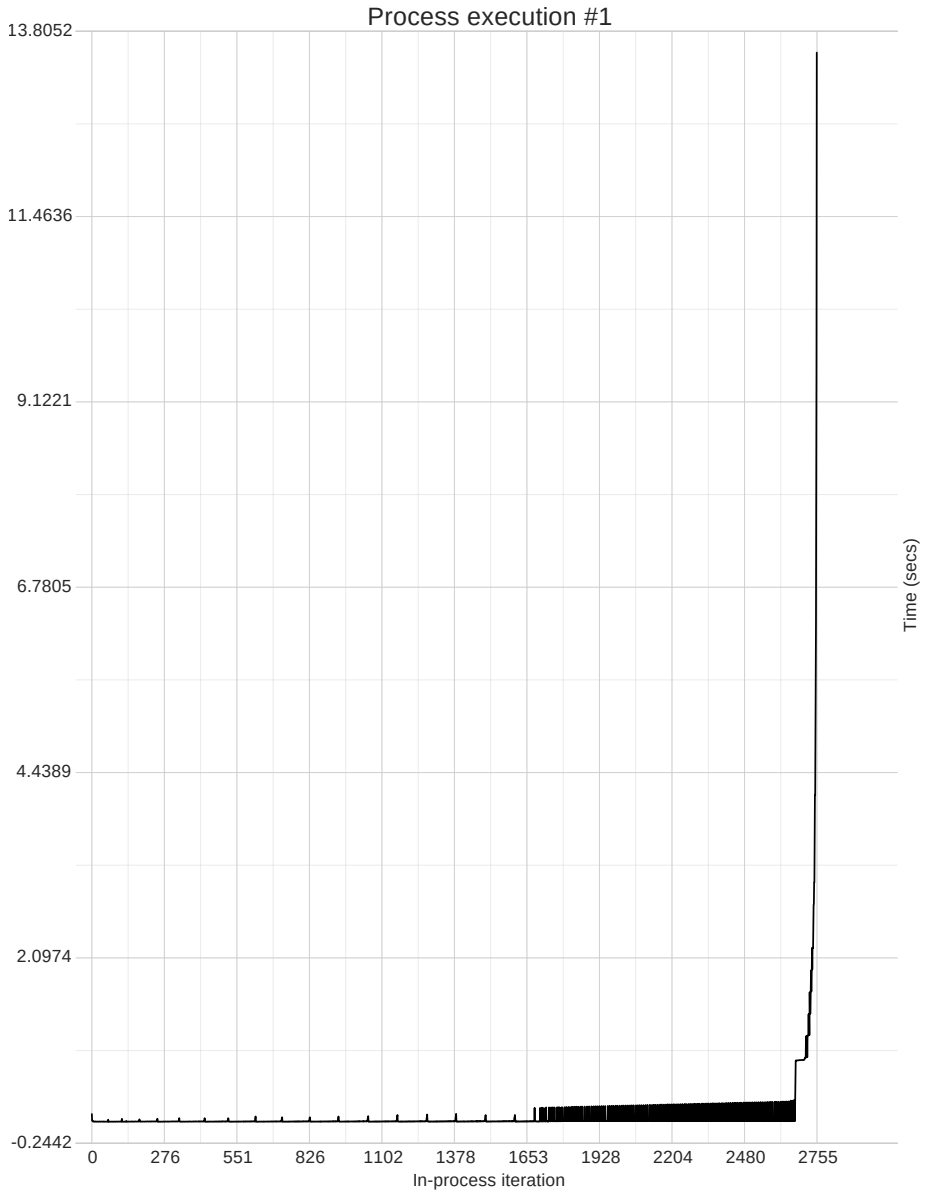
Octane: pdf.js explodes

```
$ d8 run.js
Richards
DeltaBlue
Encrypt
Decrypt
RayTrace
Earley
Boyer
RegExp
Splay
NavierStokes
PdfJS

<--- Last few GCs --->

14907865 ms: Mark-sweep 1093.9 (1434.4) -> 1093.4 (1434.4) MB, 274.8 / 0.0 ms [allocation failure] [GC in old space
14908140 ms: Mark-sweep 1093.4 (1434.4) -> 1093.3 (1434.4) MB, 274.4 / 0.0 ms [allocation failure] [GC in old space
14908421 ms: Mark-sweep 1093.3 (1434.4) -> 1100.5 (1418.4) MB, 280.9 / 0.0 ms [last resort gc].
14908703 ms: Mark-sweep 1100.5 (1418.4) -> 1107.8 (1418.4) MB, 282.1 / 0.0 ms [last resort gc].


<--- JS stacktrace --->

==== JS stack trace =========================================

Security context: 0x20d333ad3ba9 <JS Object>
    2: extractFontProgram(aka Type1Parser_extractFontProgram) [pdfjs.js:17004] [pc=0x3a13b275421b] (this=0x3de358283
    3: new Type1Font [pdfjs.js:17216] [pc=0x3a13b2752078] (this=0x4603fbdaea9 <a Type1Font with map 0x1f822134f7e1>,


#
# Fatal error in CALL_AND_RETRY_LAST
# Allocation failed - process out of memory
#

zsh: illegal hardware instruction  d8 run.js
```

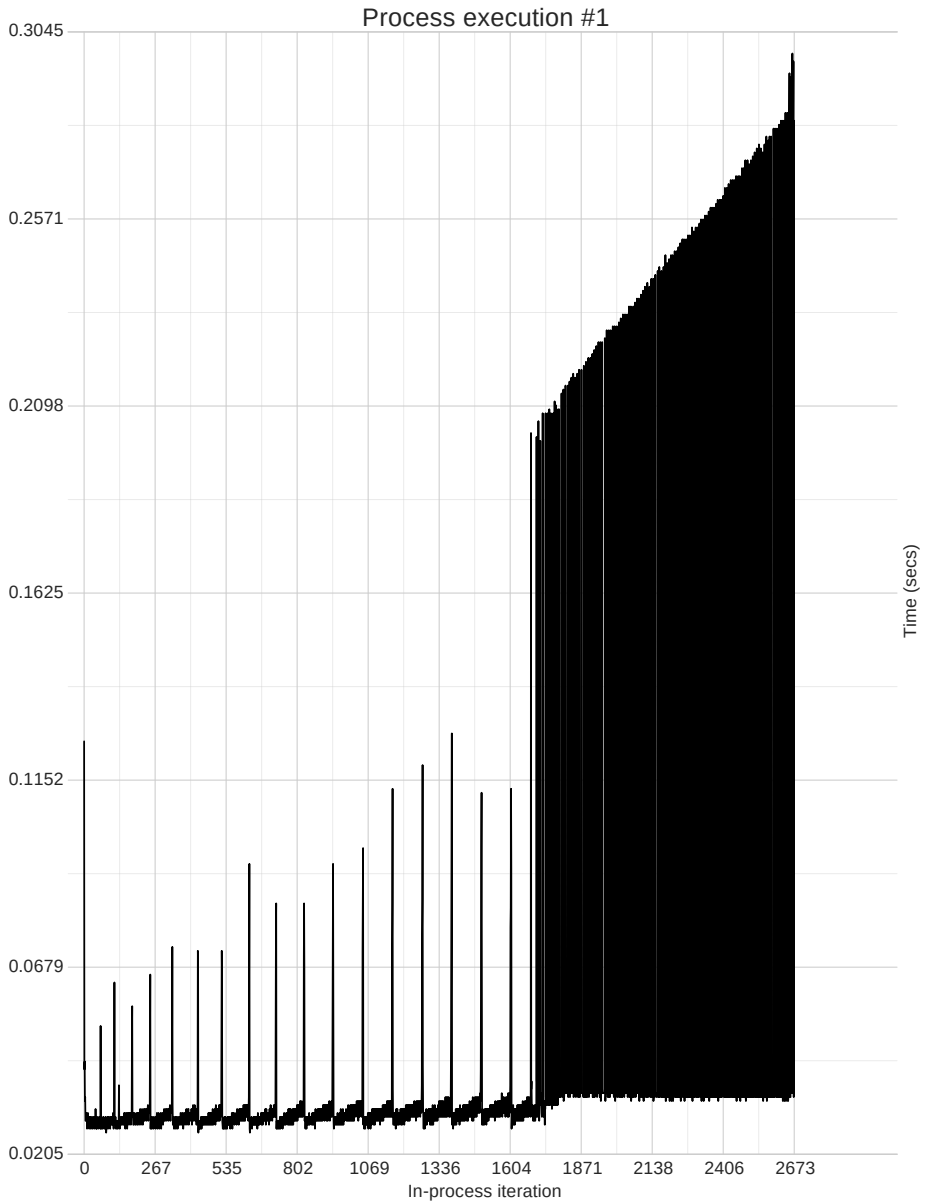
Octane: analysing pdf.js



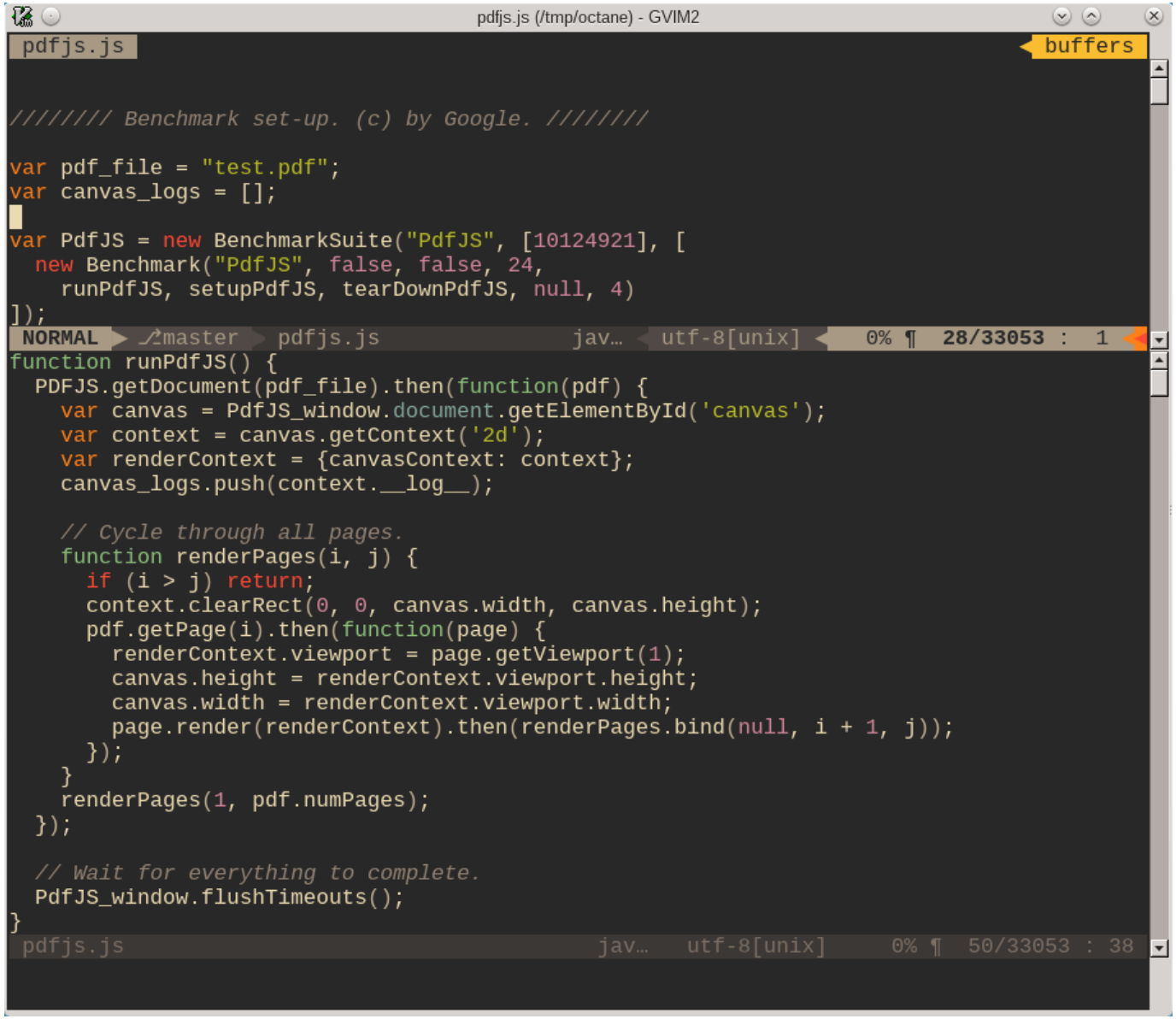
Octane: analysing pdf.js



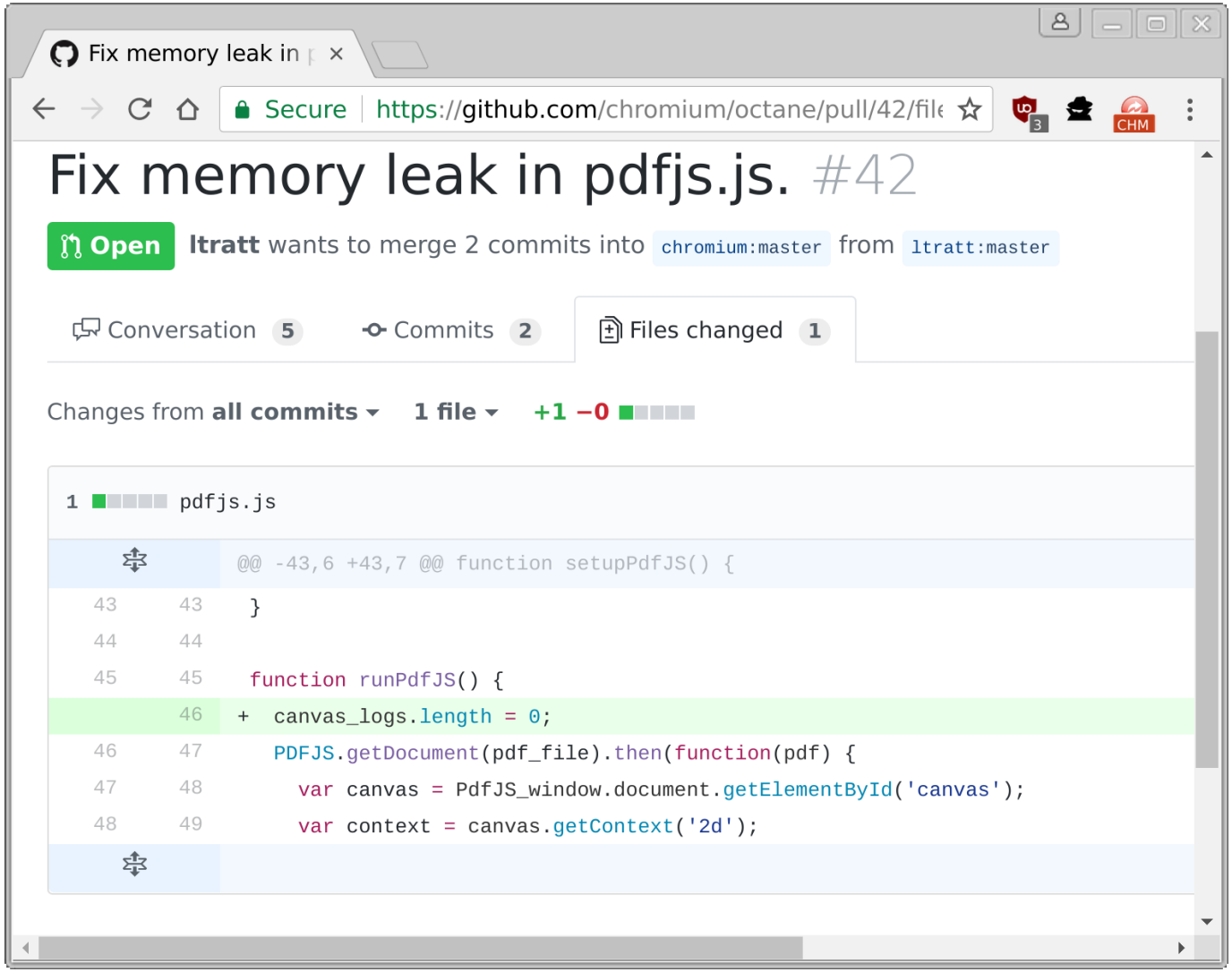
Octane: analysing pdf.js



Octane: debugging



Octane: fixing



Octane: other issues

pdfjs isn’t the only problem

Octane: other issues

pdfjs isn’t the only problem

CodeLoadClosure also has a memory leak

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CodeLoadClosure also has a memory leak

zlib complains that `Cannot enlarge memory arrays in asm.js` (a memory leak? I don’t know)

Octane: other issues

pdfjs isn’t the only problem

CodeLoadClosure also has a memory leak

zlib complains that `Cannot enlarge memory arrays in asm.js` (a memory leak? I don’t know)

Timings are made with a non-monotonic microsecond timer

Summary

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Why aren’t more users more happy with our VMs?

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My thesis: benchmarking *and* benchmarks are performance destiny.

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Why aren't more users more happy with our VMs?

My thesis: benchmarking *and* benchmarks are performance destiny.

Ours have misled us.

How to benchmark a bit better

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1. Run benchmarks for longer to uncover issues.

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2. Accept that peak performance may not occur.

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2. Accept that peak performance may not occur.
3. Always report warmup time.
4. Stop over-training on small benchmark suites.
5. Collect more benchmarks.
6. Focus on predictable performance.

The big question

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Can we fix existing VMs?

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At least a bit... but a lot? Unclear.

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At least a bit... but a lot? Unclear.

In case we can't, I have an idea...

FL Interpreter

```
program_counter = 0; stack = []
vars = {...}
while True:
  jit_merge_point(program_counter)
  instr = load_instruction(program_counter)
  if instr == INSTR_VAR_GET:
    stack.push(
     vars[read_var_name_from_instruction()])
    program_counter += 1
  elif instr == INSTR_VAR_SET:
    vars[read_var_name_from_instruction()]
     = stack.pop()
    program_counter += 1
  elif instr == INSTR_INT:
    stack.push(read_int_from_instruction())
    program_counter += 1
  elif instr == INSTR_LESS_THAN:
    rhs = stack.pop()
    lhs = stack.pop()
    if isinstance(lhs, int) and isinstance(rhs, int):
      if lhs < rhs:
        stack.push(True)
      else:
        stack.push(False)
    else: ...
    program_counter += 1
```

```
  elif instr == INSTR_IF:
    result = stack.pop()
    if result == True:
      program_counter += 1
    else:
      program_counter +=
        read_jump_if_instruction()
  elif instr == INSTR_ADD:
    lhs = stack.pop()
    rhs = stack.pop()
    if isinstance(lhs, int)
     and isinstance(rhs, int):
      stack.push(lhs + rhs)
    else: ...
    program_counter += 1
```

FL Interpreter

```
program_counter = 0; stack = []
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    program_counter += 1
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    program_counter += 1
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    program_counter += 1
  elif instr == INSTR_LESS_THAN:
    rhs = stack.pop()
    lhs = stack.pop()
    if isinstance(lhs, int) and isinstance(rhs, int):
      if lhs < rhs:
        stack.push(True)
      else:
        stack.push(False)
    else: ...
    program_counter += 1
```

User program (lang *FL*)

```
if x < 0:
  x = x + 1
else:
  x = x + 2
x = x + 3
```

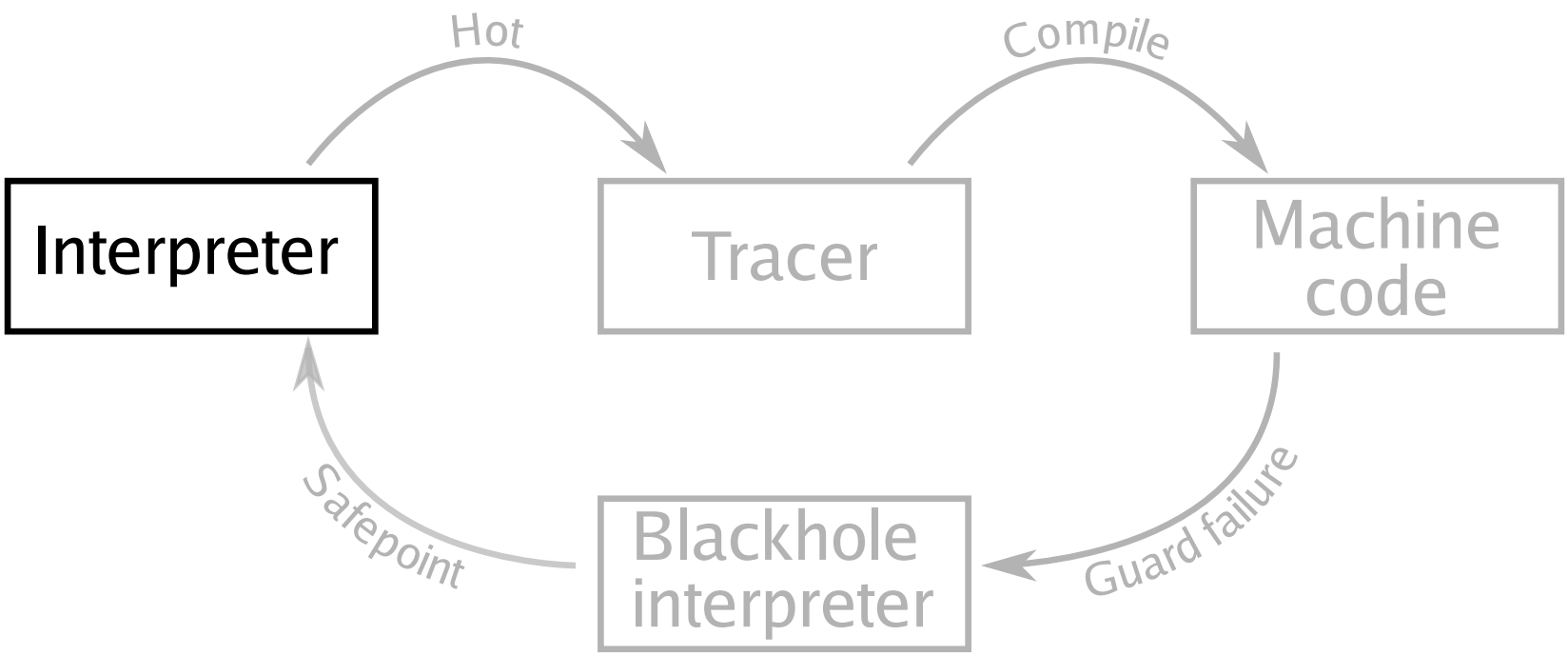
FL Interpreter

```
program_counter = 0; stack = []
vars = {...}
while True:
  jit_merge_point(program_counter)
  instr = load_instruction(program_counter)
  if instr == INSTR_VAR_GET:
    stack.push(
     vars[read_var_name_from_instruction()])
    program_counter += 1
  elif instr == INSTR_VAR_SET:
    vars[read_var_name_from_instruction()]
     = stack.pop()
    program_counter += 1
  elif instr == INSTR_INT:
    stack.push(read_int_from_instruction())
    program_counter += 1
  elif instr == INSTR_LESS_THAN:
    rhs = stack.pop()
    lhs = stack.pop()
    if isinstance(lhs, int) and isinstance(rhs, int):
      if lhs < rhs:
        stack.push(True)
      else:
        stack.push(False)
    else: ...
    program_counter += 1
```

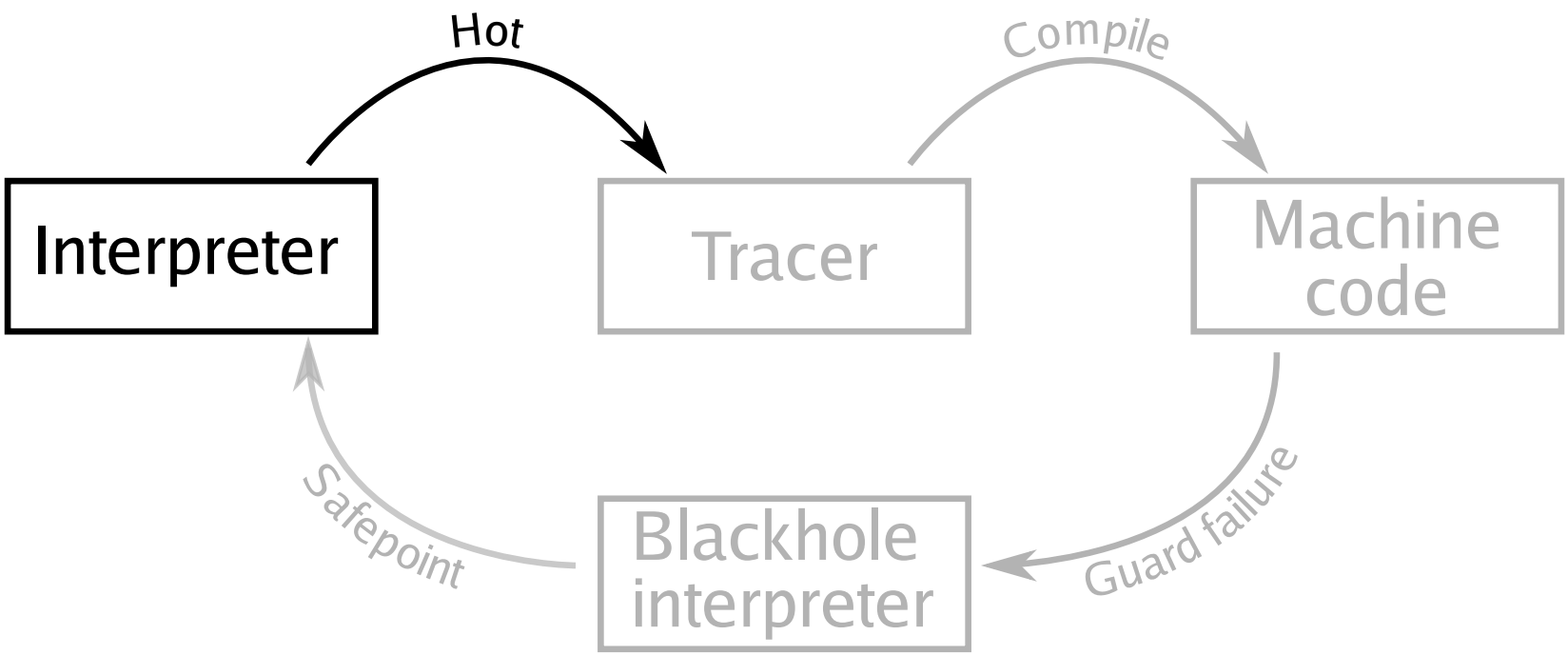
Initial trace

```
v0 = <program_counter>
v1 = <stack>
v2 = <vars>
v3 = load_instruction(v0)
guard_eq(v3, INSTR_VAR_GET)
v4 = dict_get(v2, "x")
list_append(v1, v4)
v5 = add(v0, 1)
v6 = load_instruction(v5)
guard_eq(v6, INSTR_INT)
list_append(v1, 0)
v7 = add(v5, 1)
v8 = load_instruction(v7)
guard_eq(v8, INSTR_LESS_THAN)
v9 = list_pop(v1)
v10 = list_pop(v1)
guard_type(v9, int)
guard_type(v10, int)
guard_not_less_than(v9, v10)
list_append(v1, False)
v11 = add(v7, 1)
v12 = load_instruction(v11)
guard_eq(v12, INSTR_IF)
v13 = list_pop(v1)
guard_false(v13)
...
```

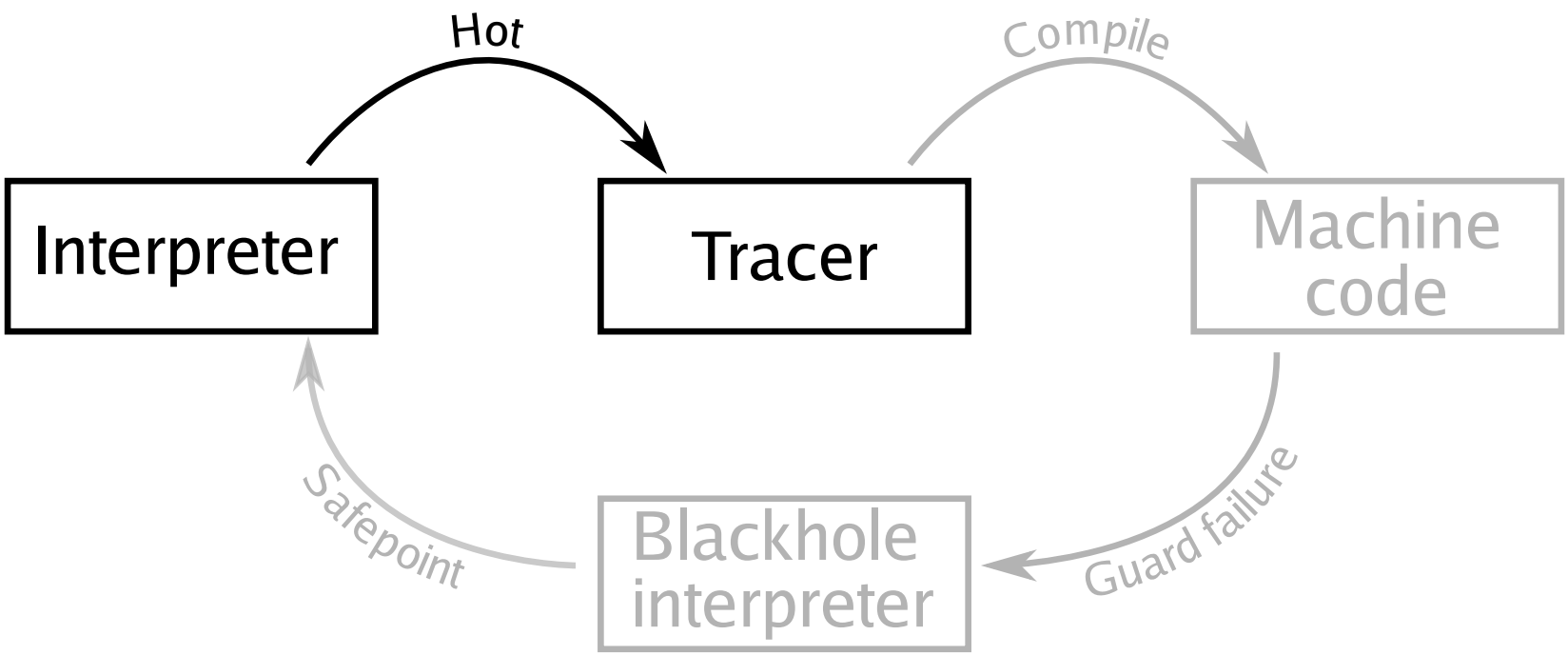
Meta-tracer states



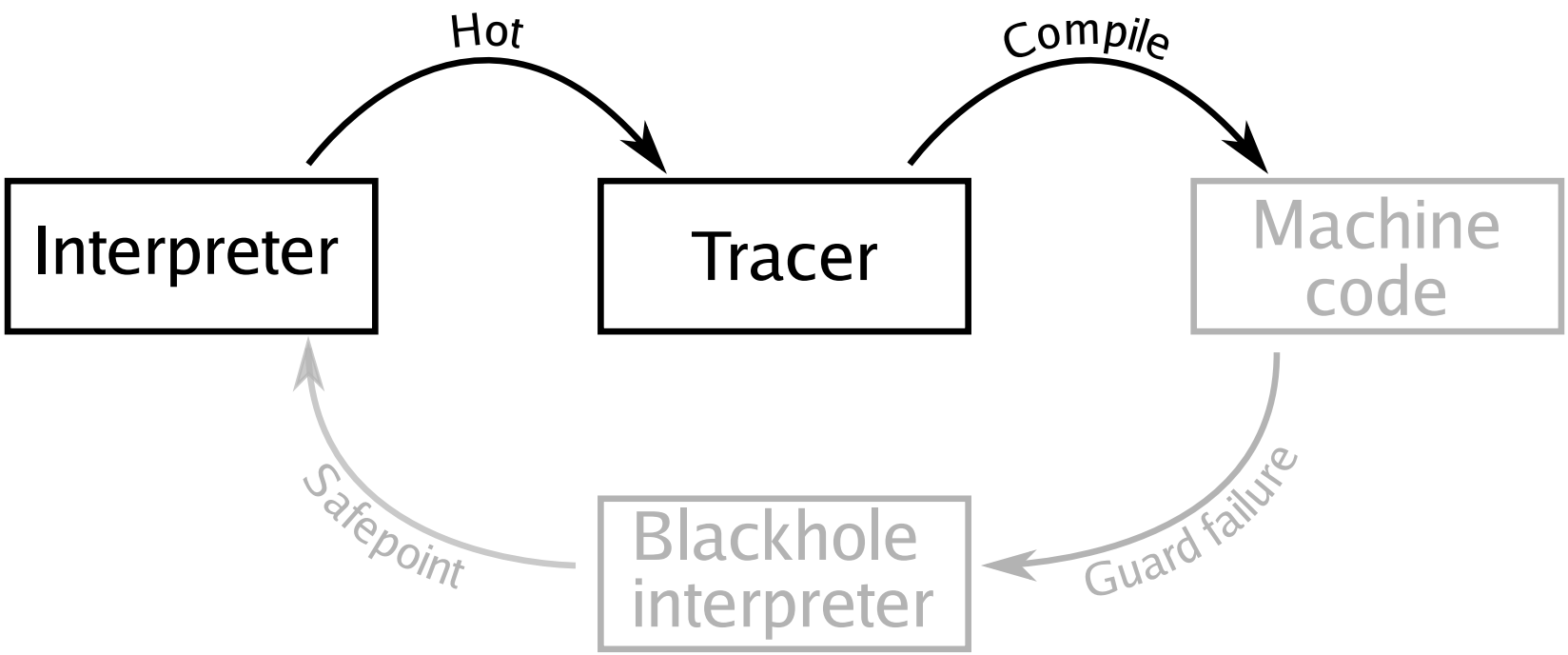
Meta-tracer states



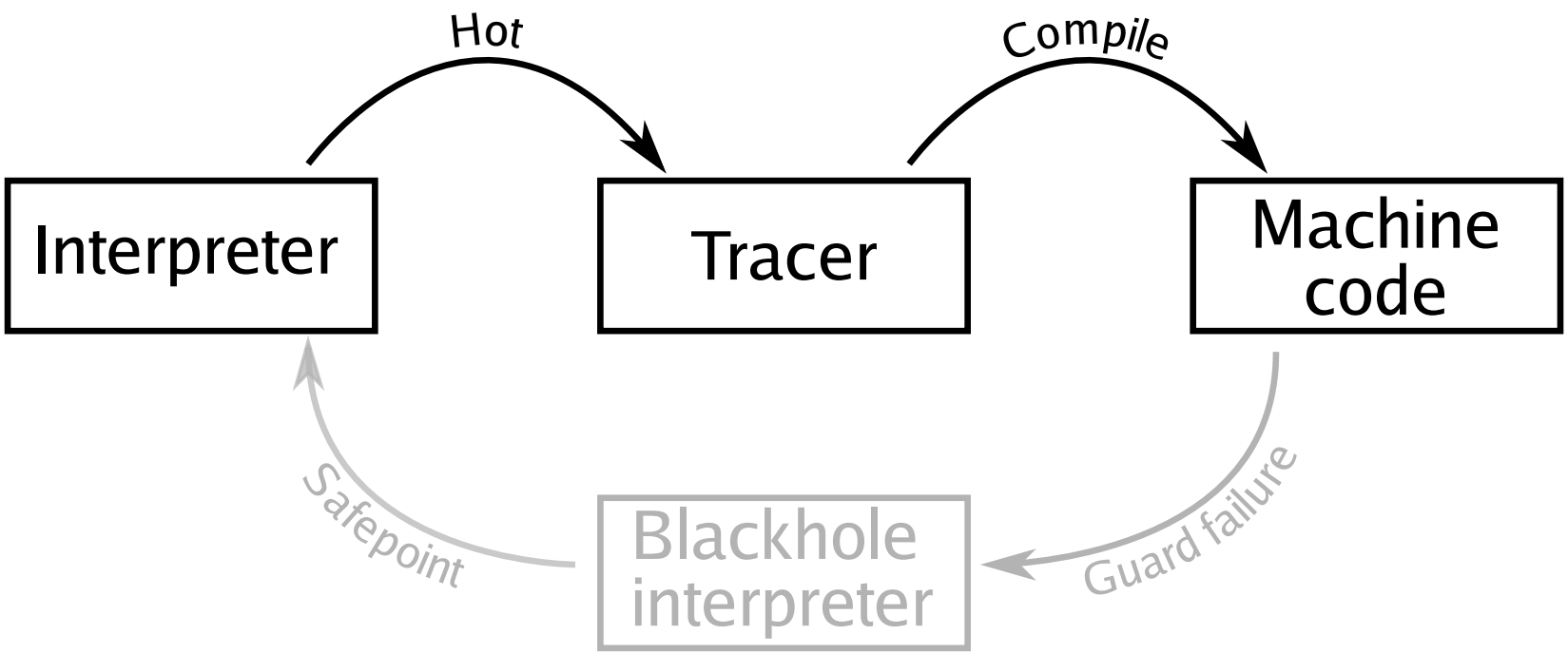
Meta-tracer states



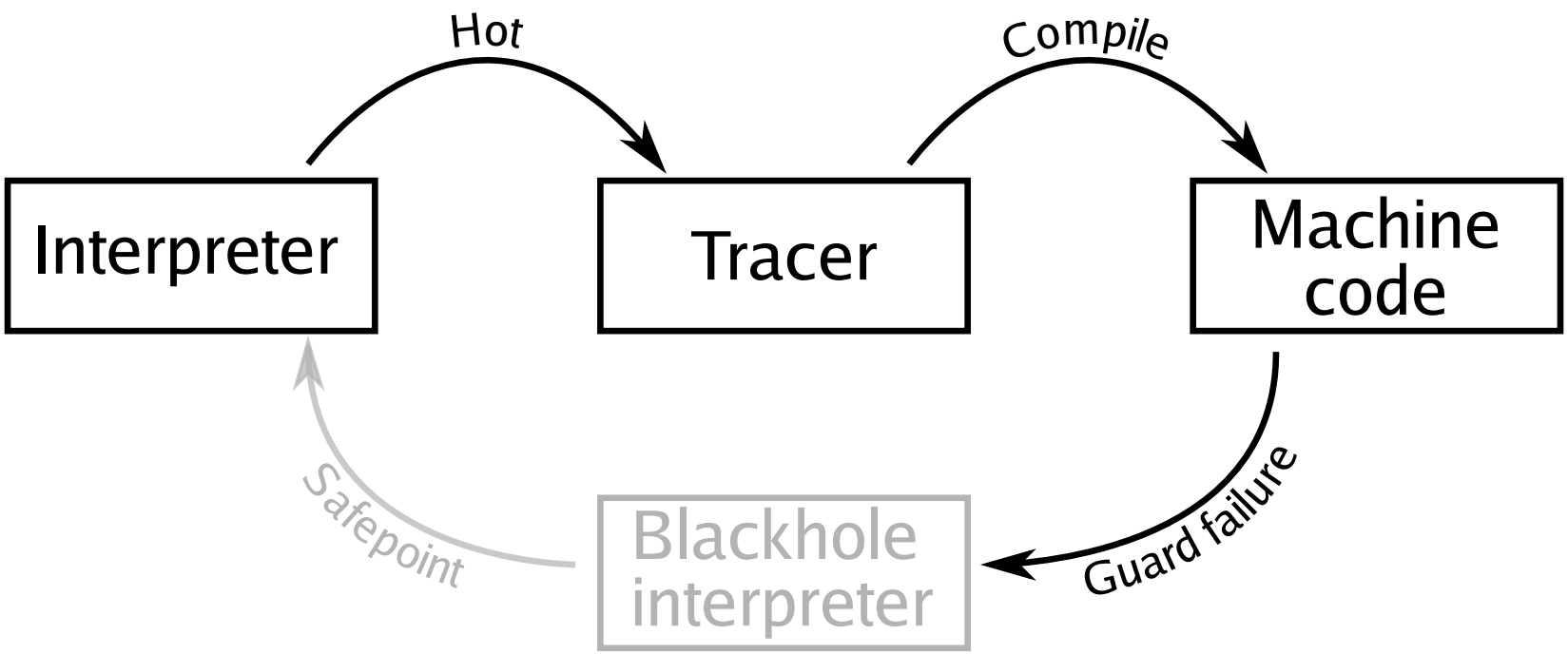
Meta-tracer states



Meta-tracer states



Meta-tracer states



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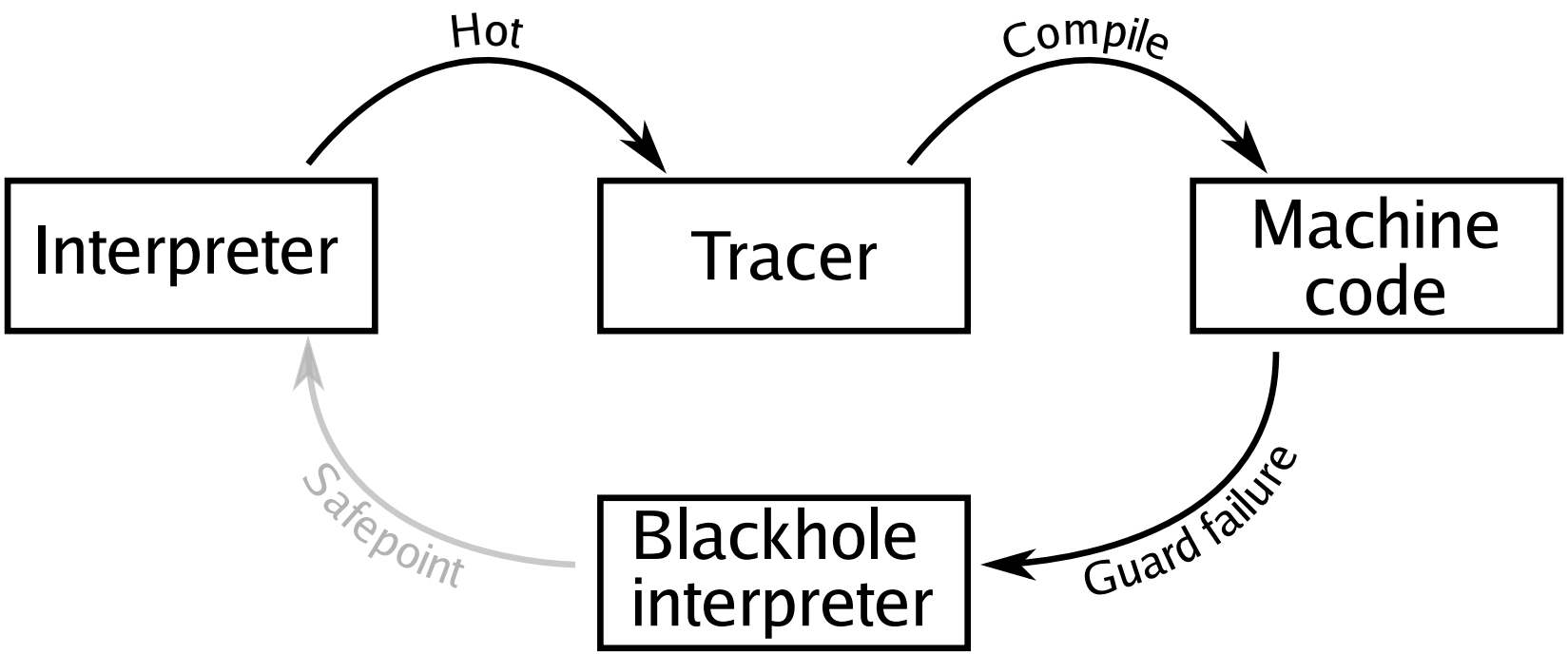
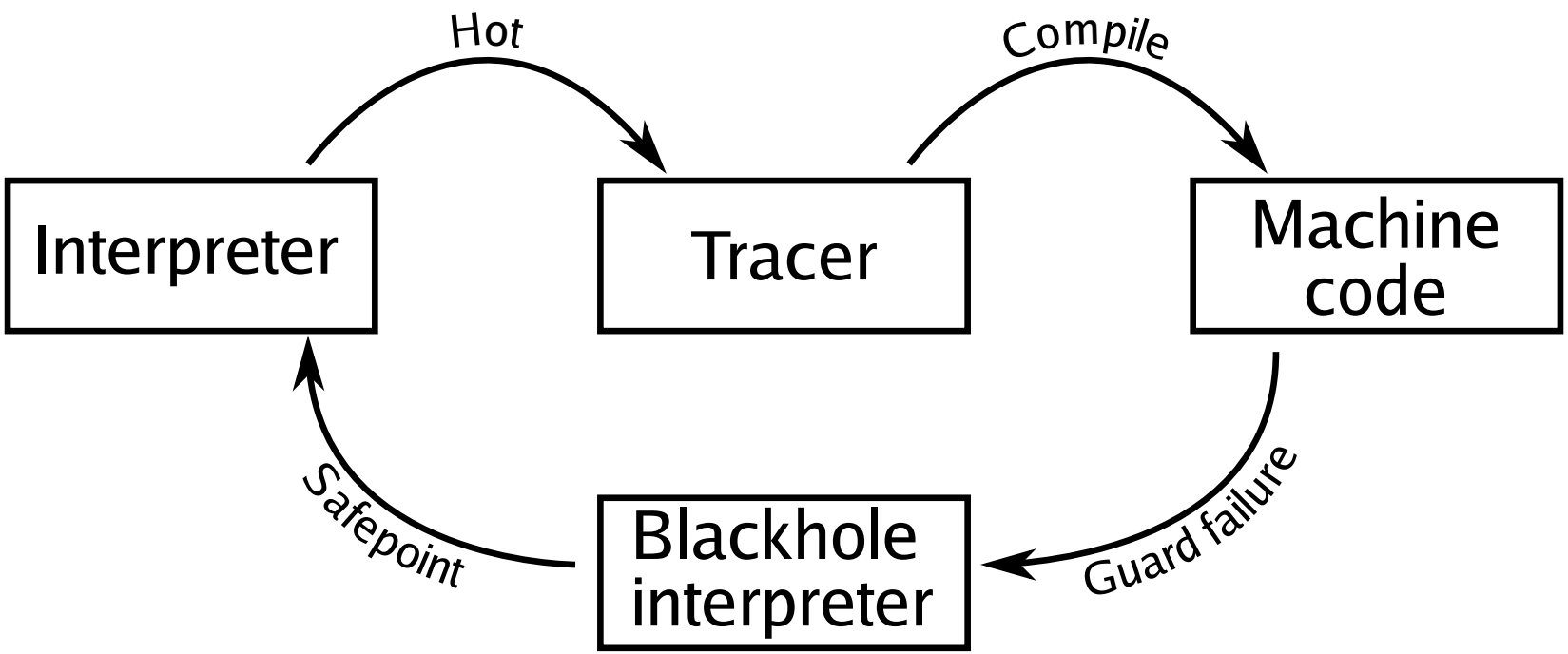
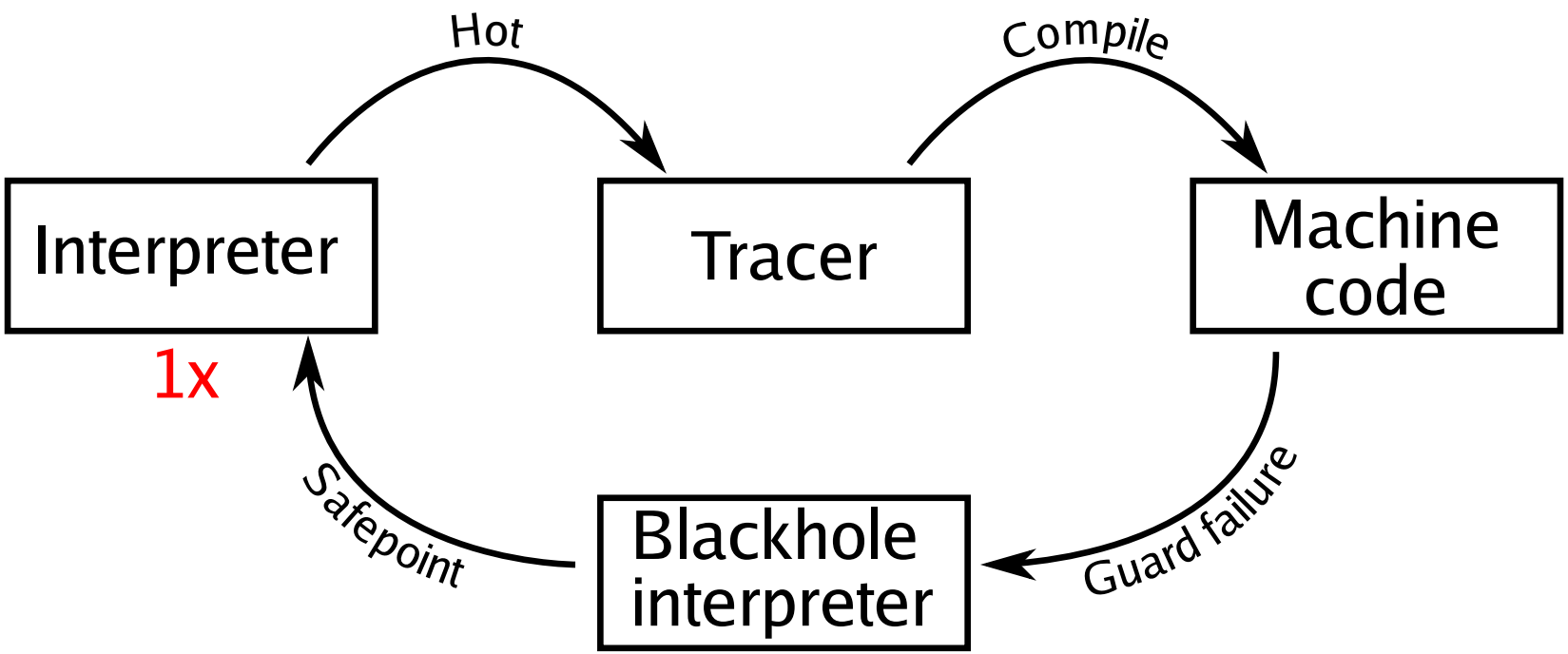


Meta-tracer states



Meta-tracer performance (now)



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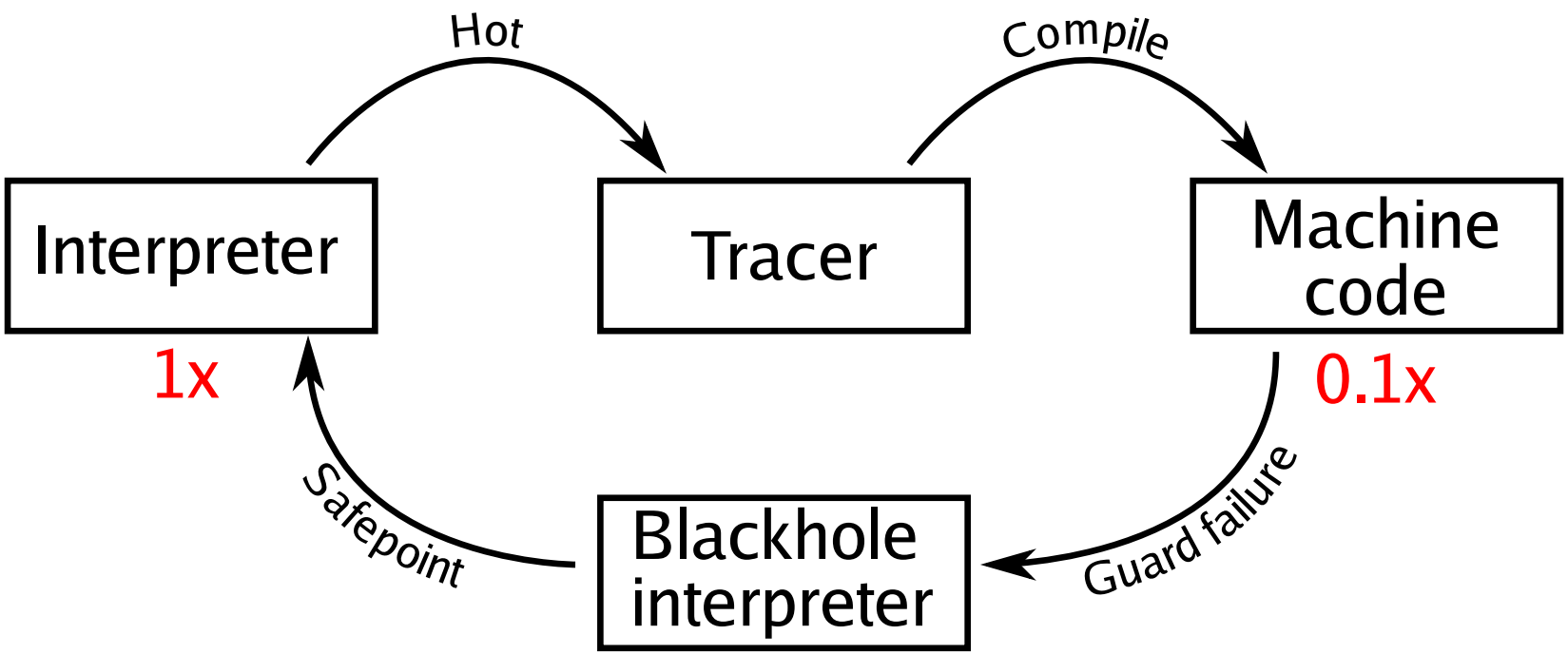
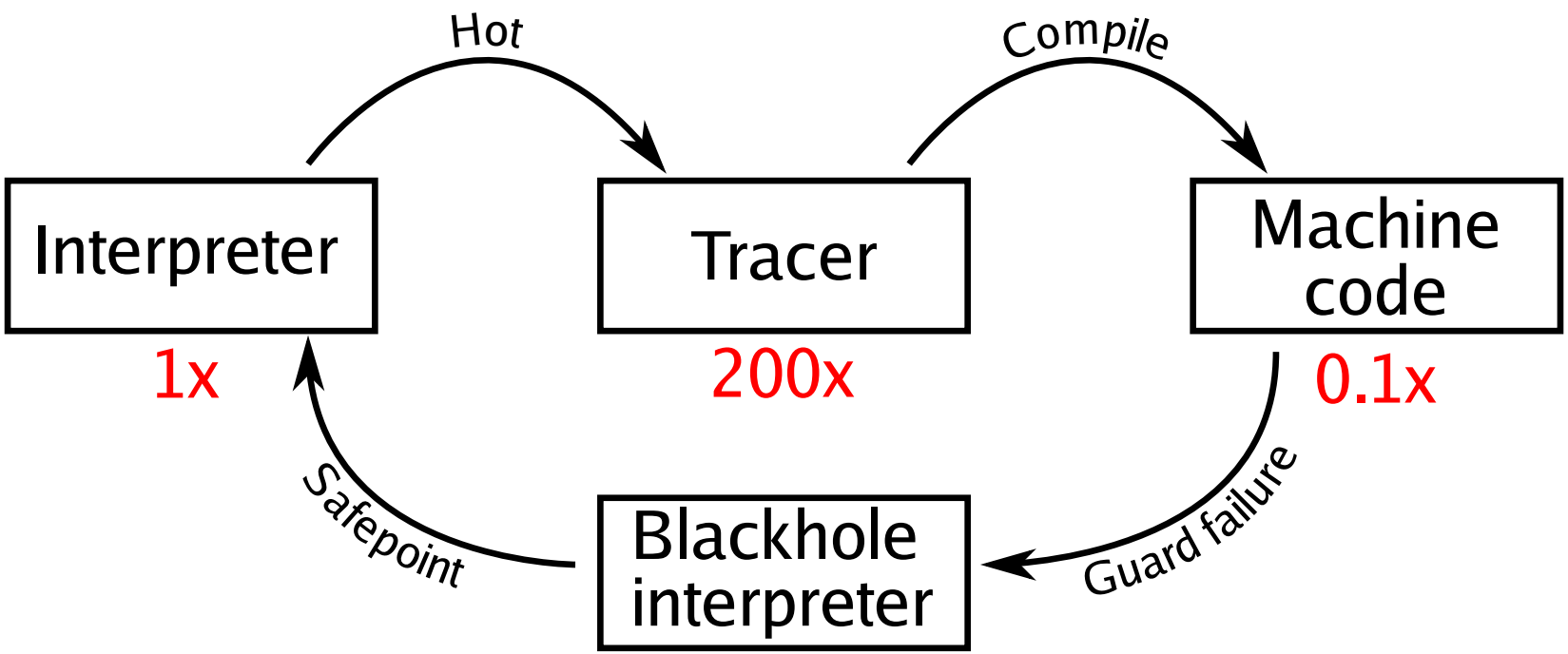
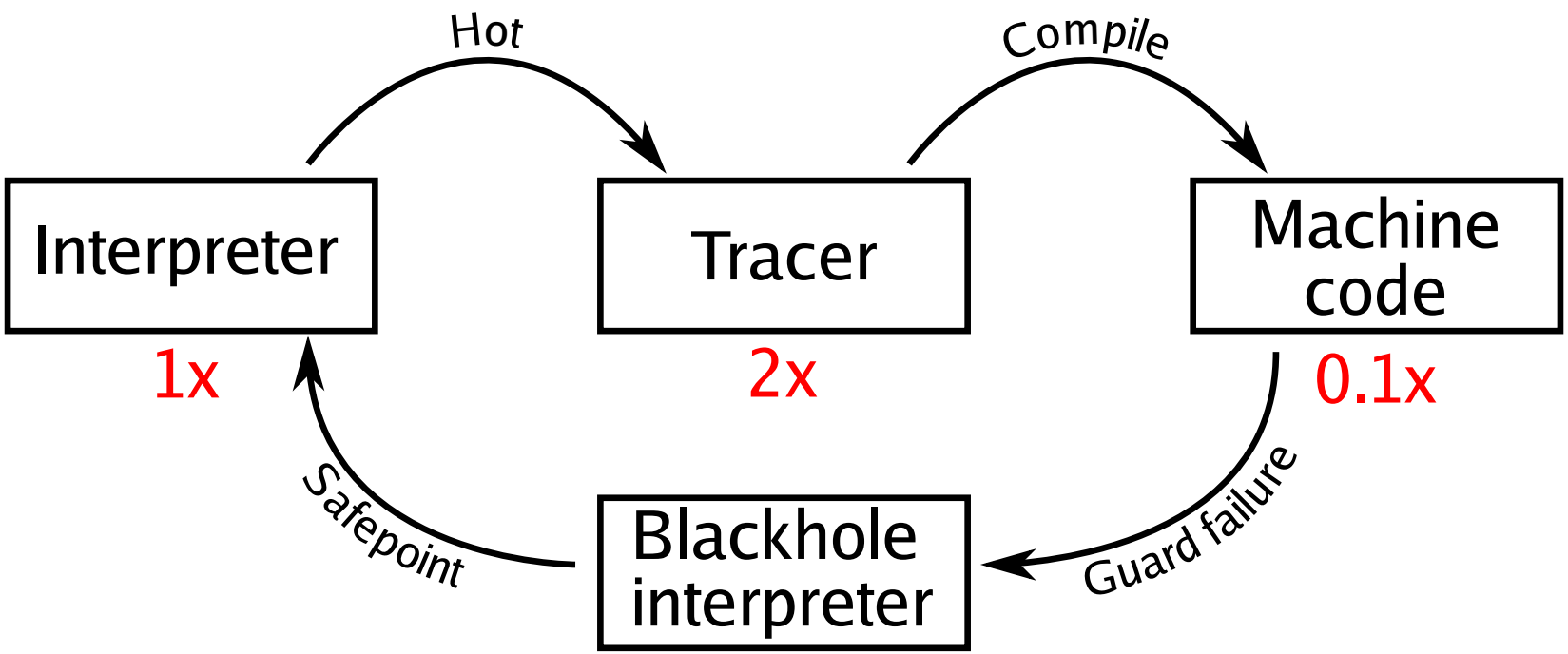


Meta-tracer performance (now)



Meta-tracer performance (our aim)



References

VM Warmup Blows Hot and Cold
E. Barrett, C. F. Bolz, R. Killick, V. Knight, S. Mount and L. Tratt.

Rigorous Benchmarking in Reasonable Time
T. Kalibera and R. Jones

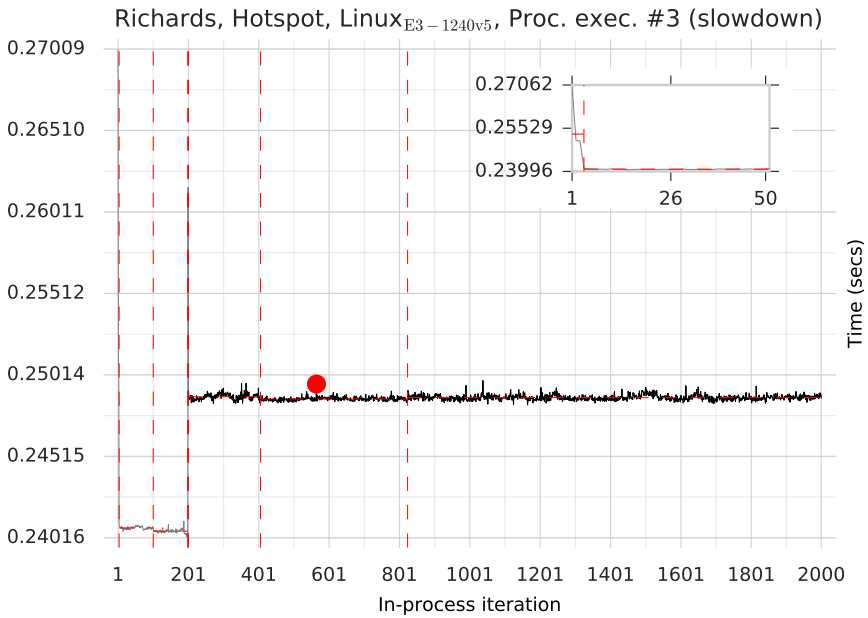
Specialising Dynamic Techniques for Implementing the Ruby Programming Language
C. Seaton (Chapter 4)

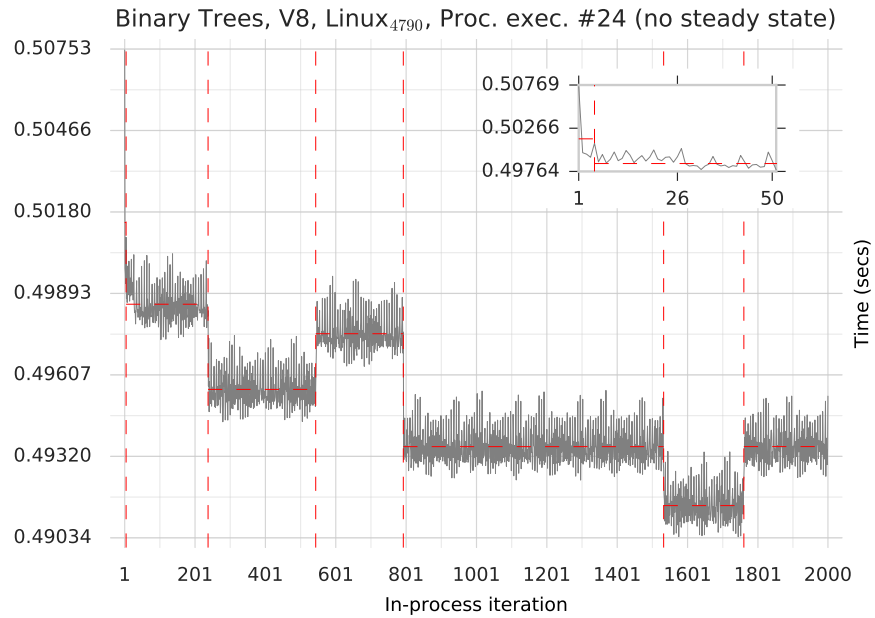
Quantifying performance changes with effect size confidence intervals
T. Kalibera and R. Jones

Thanks

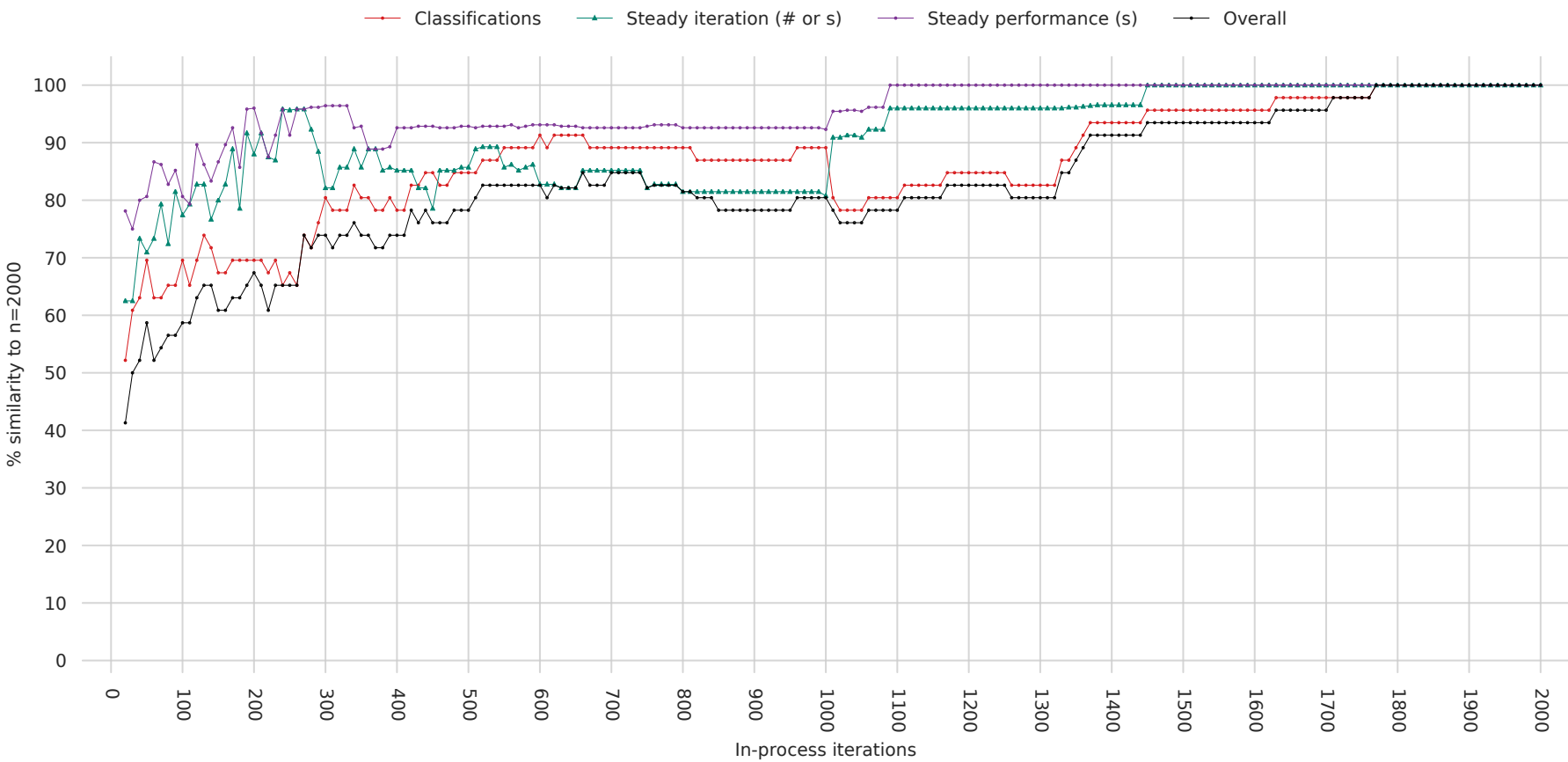
- EPSRC: *COOLER* and *Lecture*.
- Oracle.
- Cloudflare.

Thanks for listening





How long to run things for



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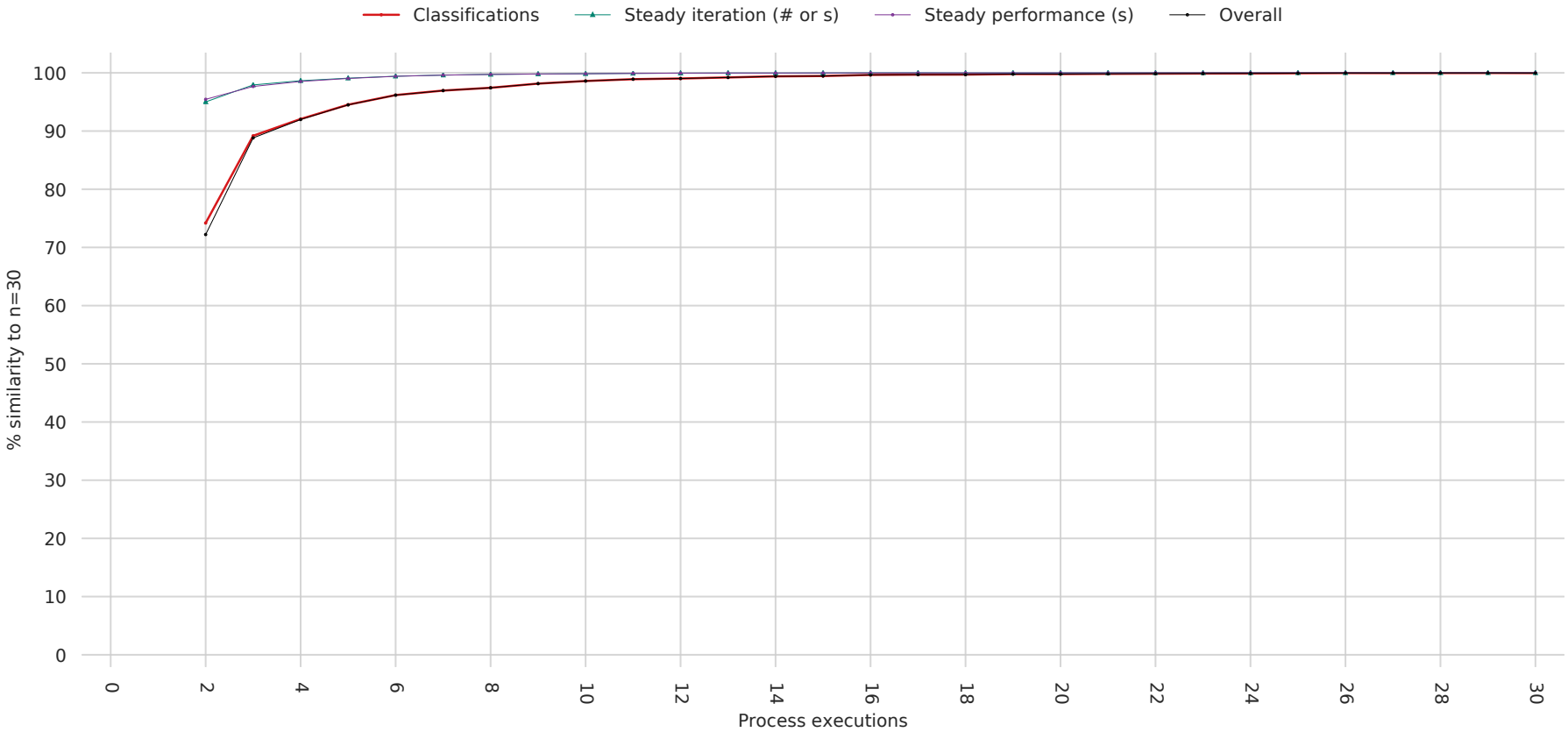

Comparing results

		Class.	Steady iter (#)	Steady iter (s)	Steady perf (s)
binarytrees	Normal	= (13–, 2↰)	1.0 (1.0,701.3)	0.00 (0.000,88.313)	0.12555 ±0.001198
capnproto_decode	Normal	—			0.12813 ±0.001797
capnproto_encode	Normal	↰	4.0 δ=−115.5 (4.0,4.3)	0.11 δ=−18.177 (0.105,0.118)	0.03364 δ=−0.087450 ±0.000527
fannkuch_redux	Normal	↰	2.0 (2.0,71.3)	0.13 (0.129,9.026)	0.12620 δ=+0.006686 ±0.001135
fasta	Normal	—			0.12122 ±0.000403
jsonlua_decode	Normal	—			0.11448 ±0.002019
jsonlua_encode	Normal	—			0.13125 ±0.002070
luacheck	Normal	—			1.00955 ±0.004522
luacheck_parser	Normal	⤫ (14–, 1↜)			
luafun	Normal	= (14↰, 1–)	42.0 (29.7,42.3)	6.36 (4.431,6.447)	0.15423 δ=−0.013313 ±0.000905
md5	Normal	—			0.11168 δ=−0.001118 ±0.000947
nbody	Normal	—			0.18291 δ=+0.023855 ±0.004045
richards	Normal	↰	2.0 (2.0,2.0)	0.15 (0.146,0.149)	0.14306 ±0.002472
series	Normal	↰	2.0 (2.0,2.0)	0.35 (0.347,0.347)	0.33403 ±0.000320
spectralnorm	Normal	—			0.13988 ±0.000001