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

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Warmup work in collaboration with:
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Software Development Team

2017-11-21

What to expect from this talk

What to expect from this talk

The gap

What we tell users to expect

The gap

What we tell users to expect

The gap

What users experience

The gap

The gap
is bigger than we think

A stroppy user? Or rightfully disappointed?

"You told me I'd get
a 10x speed-up,
but I only saw 1.2x"

Background

Dynamic ('JIT') compilation utilises information not known statically

Is this just about 'dynamic typing'?

Is this statically or dynamically typed?

```
fn f(a: Option<i64>) {
  match a {
    Some(i) => ...,
    None    => ...
  };
}
```

Is this just about ‘dynamic typing’?

Is this statically or dynamically typed? Both!

```
fn f(a: Option<i64>) {
  match a {
    Some(i) => ...,
    None    => ...
  };
}
```

The best VMs are close in performance to,
and sometimes faster than,
gcc -O2

VM claims

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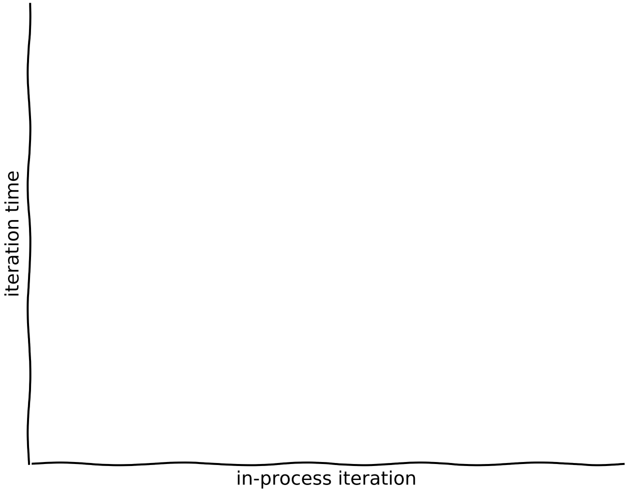
and sometimes faster than,
gcc -O2

What’s being measured?

What our claims pertain to



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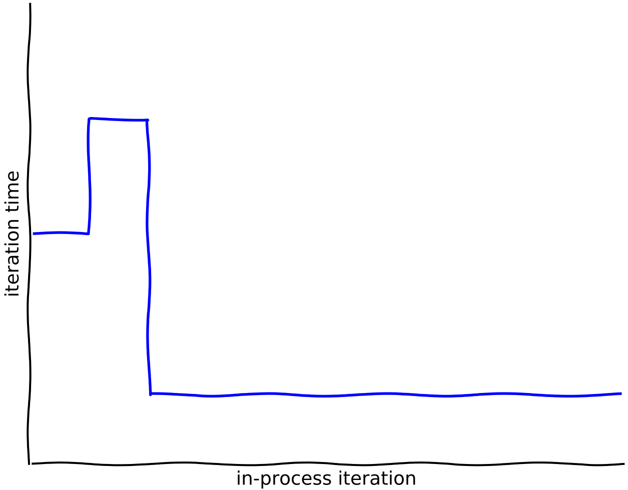

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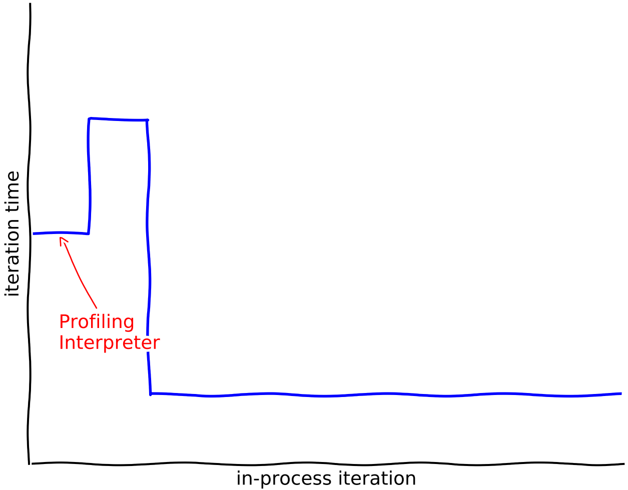

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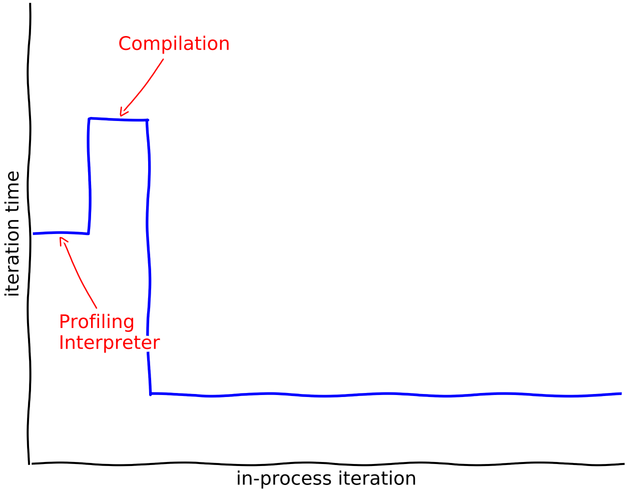

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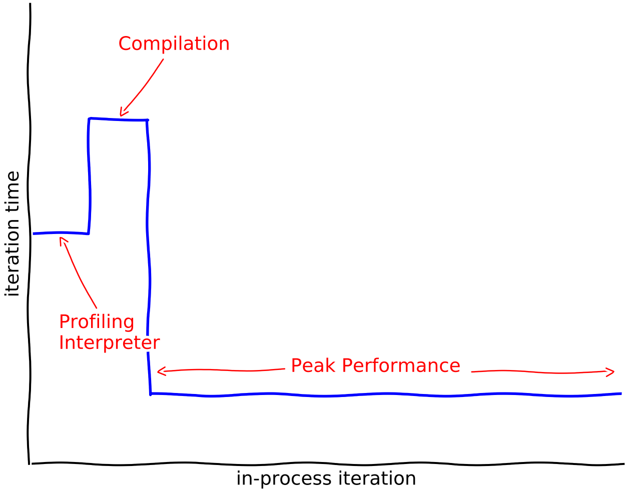

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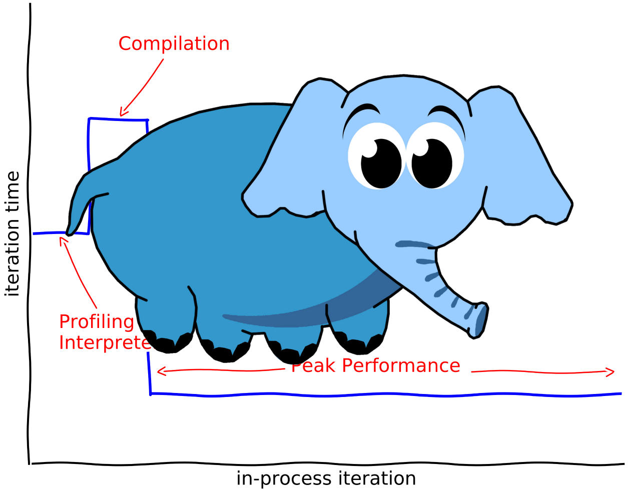
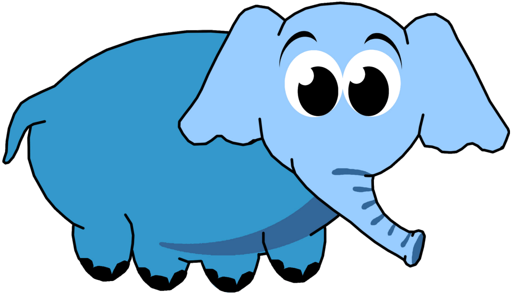
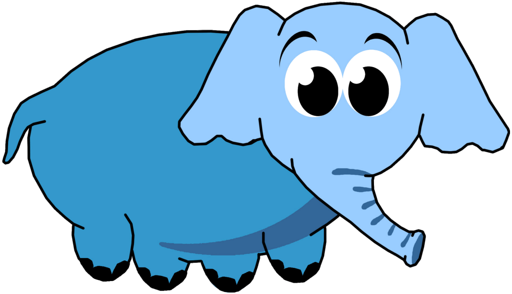




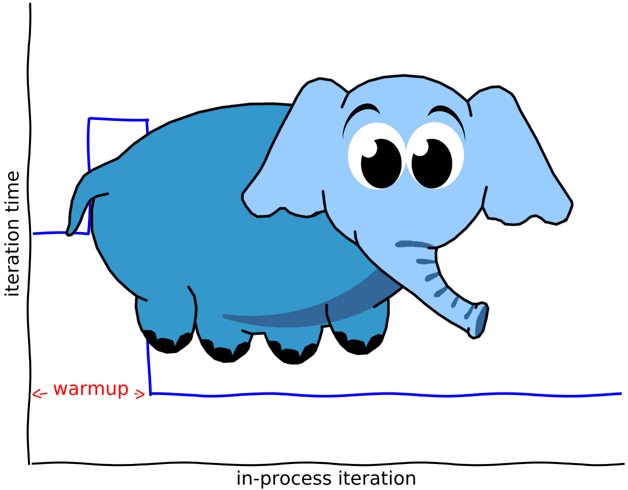
This is Barry

What our claims pertain to



This is Barry: the benchmarking elephant in the room

What our claims pertain to



Warmup

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?

The language benchmark games are perfect for us (unusually)

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We removed any CFG non-determinism

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The language benchmark games are perfect for us (unusually)

We removed any CFG non-determinism

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

Method 4: Machines

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

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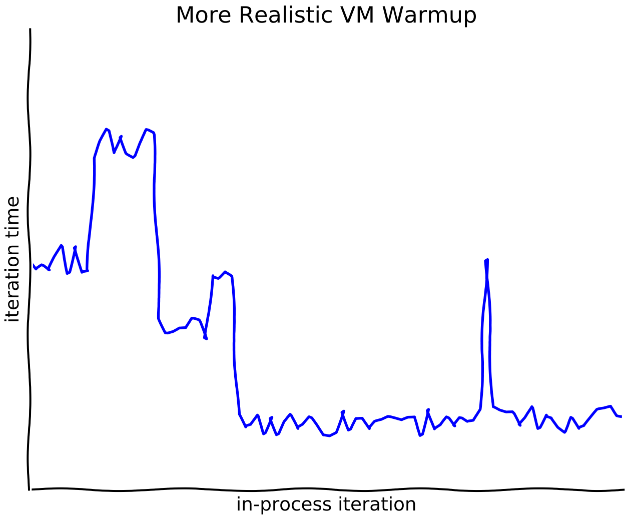
Benchmark runner: tries to control as many confounding variables as possible e.g.:

- 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, ...)

Method 6: Expectations



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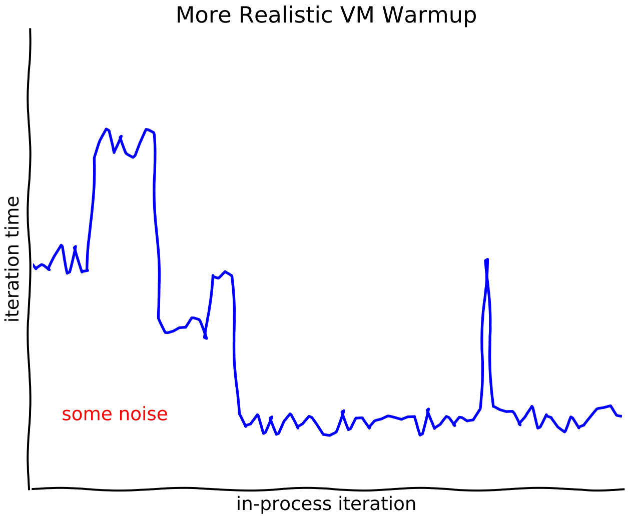
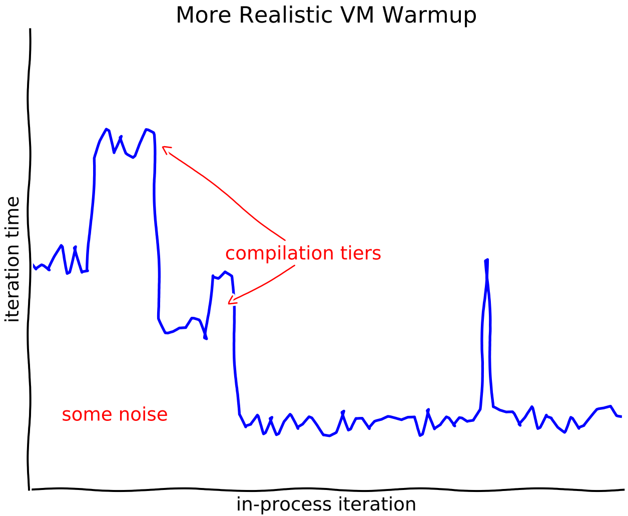
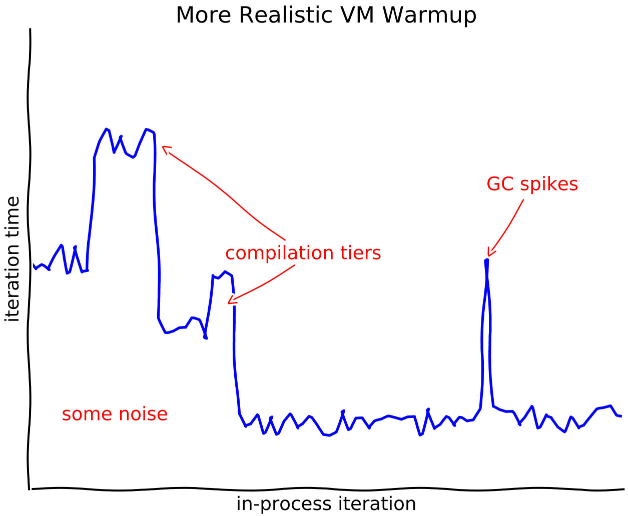
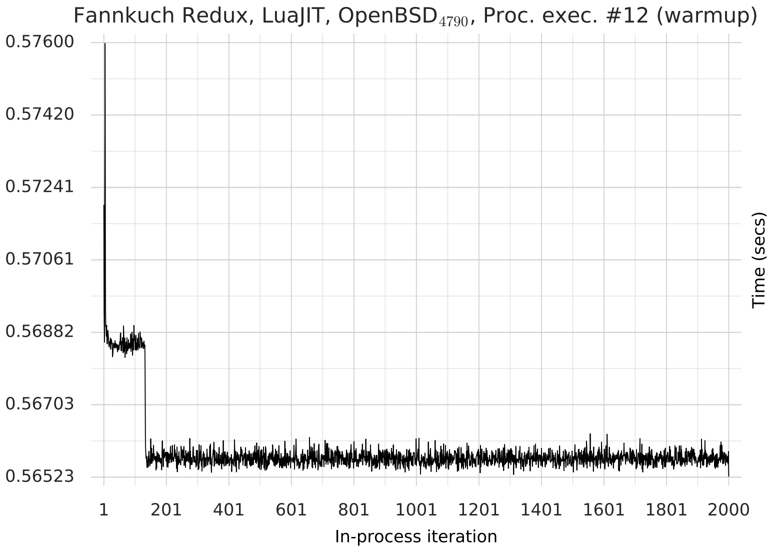



More Realistic VM Warmup
iteration time
compilation tiers
some noise
in-process iteration

Method 6: Expectations



Warmup & flat (1)



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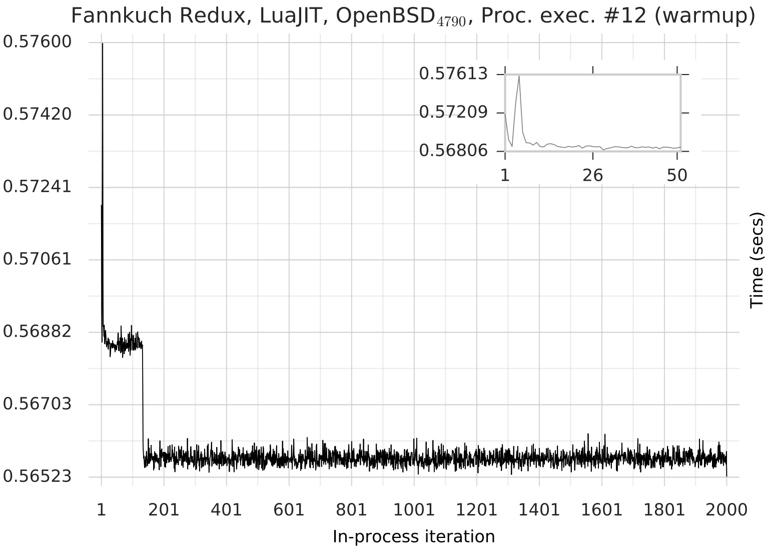

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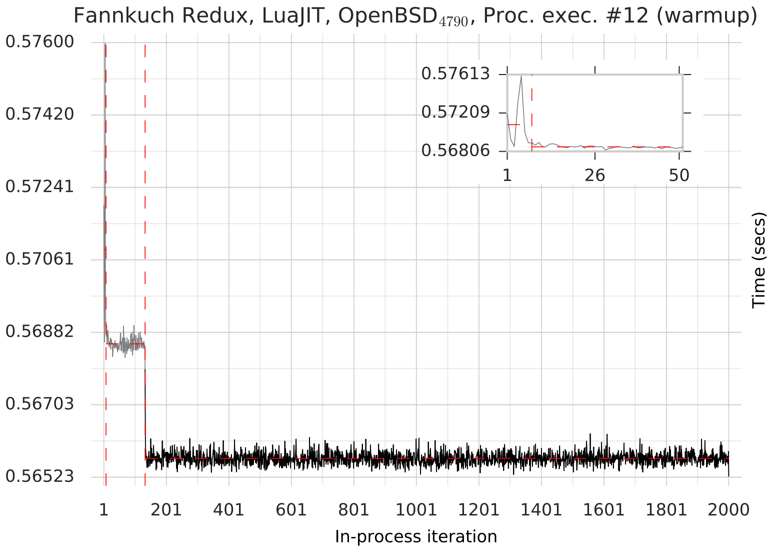

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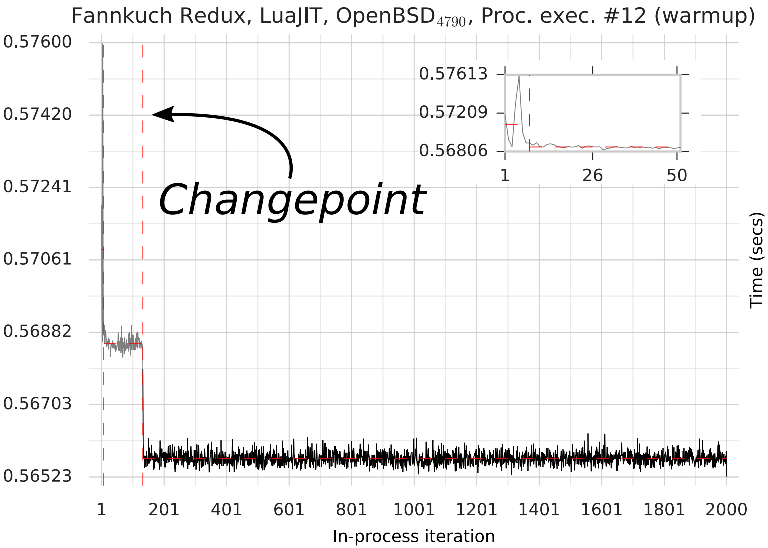

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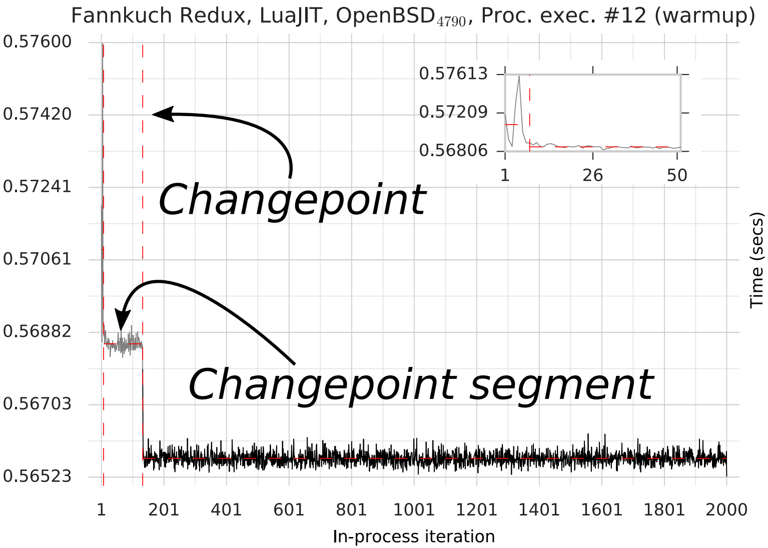

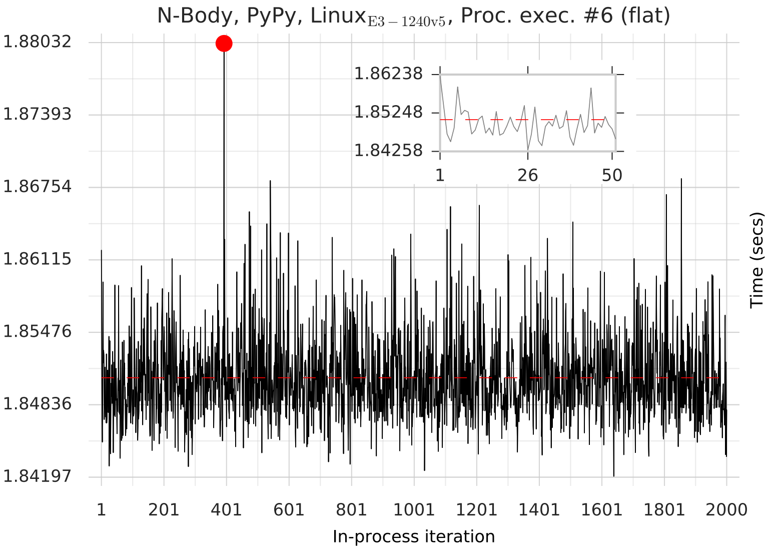
N-Body, PyPy, Linux$_{\mathrm{E3-1240v5}}$, Proc. exec. #6 (flat)
1.88032
1.87393
1.86754
1.86115
1.85476
1.84836
1.84197
1.86238
1.85248
1.84258
1
26
50
1
201
401
601
801
1001
1201
1401
1601
1801
2000
In-process iteration
Time (secs)

Method 7: Classification

Classification algorithm (steps in order):

- All segs are equivalent: *flat*

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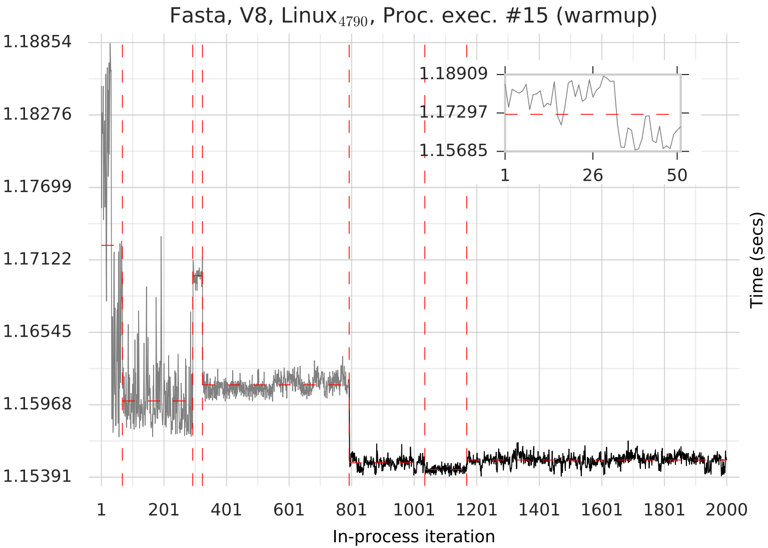
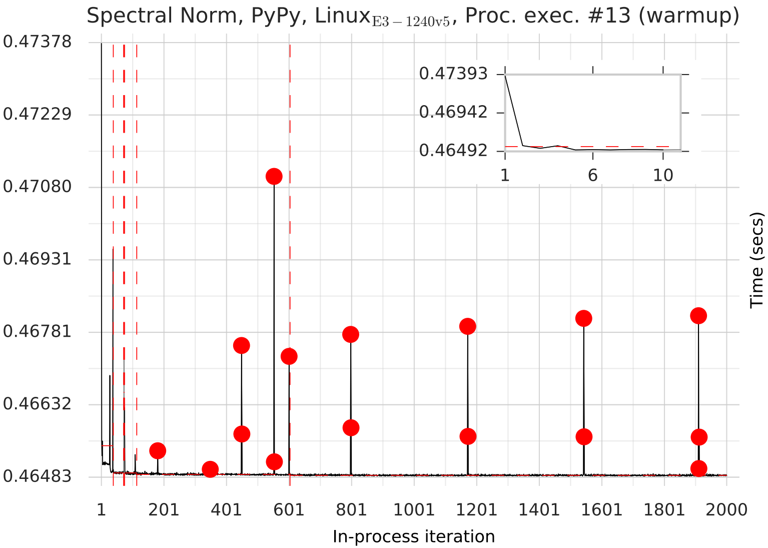
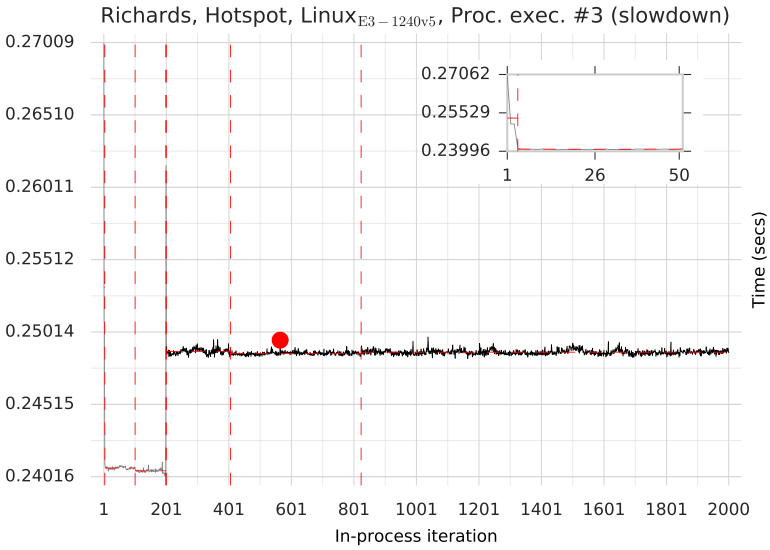
Warmup & flat (2)



Warmup & flat (2)





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

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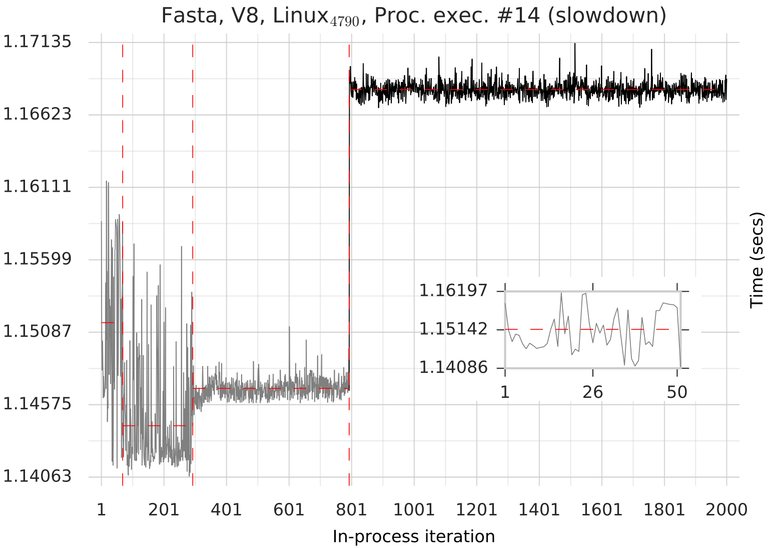
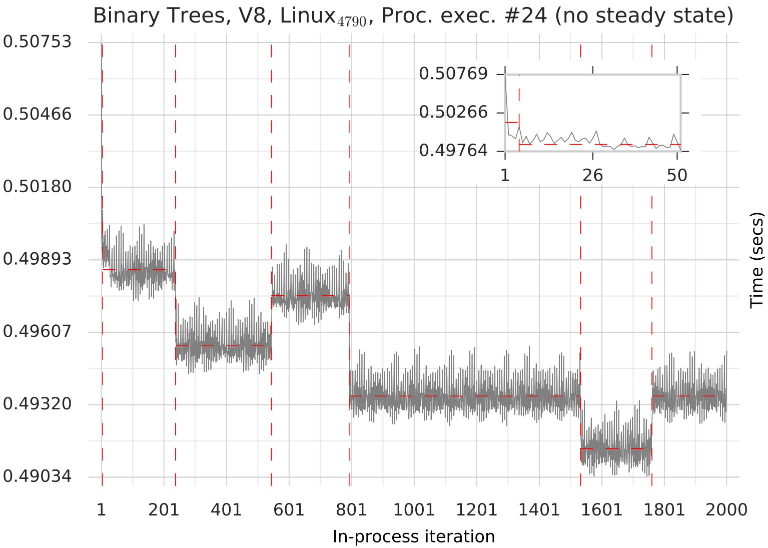
Slowdown (2)



Fasta, V8, Linux$_{4790}$, 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)



Classification algorithm (steps in order):

- All segs are equivalent: *flat*
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Classification (3)

Classification algorithm (steps in order):

- All segs are equivalent: *flat*
- Final seg is in fastest set: *warmup*
- Final seg is not in fastest set: *slowdown*
- Else: *no steady state*

Classification (3)

Classification algorithm, in order:

- All segs are equivalent: *flat*
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- Final seg is not in fastest set: *slowdown*
- Else: *no steady state*

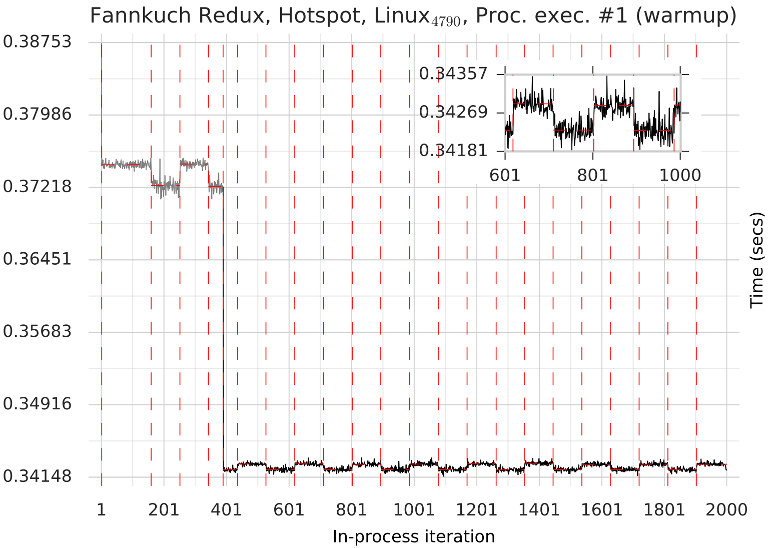
Good

Classification algorithm, in order:

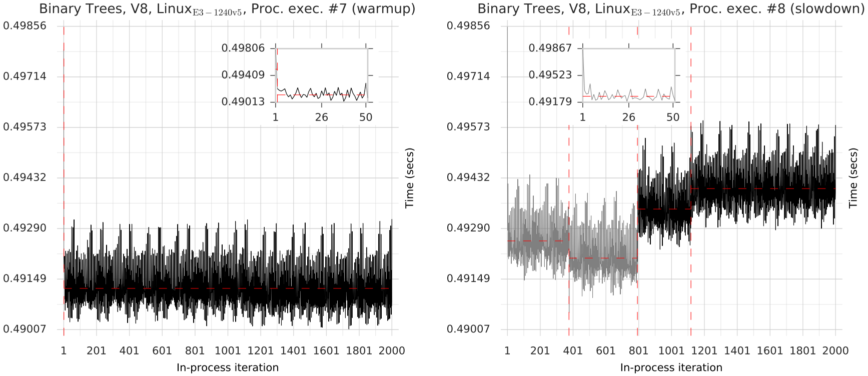
- All segs are equivalent: *flat*
- Final seg is in fastest set: *warmup*
- Final seg is not in fastest set: *slowdown*
- Else: *no steady state*

Bad

Warmup or no steady state?

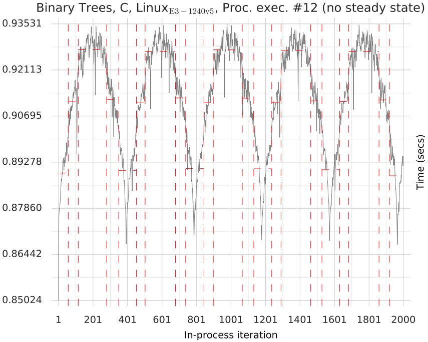


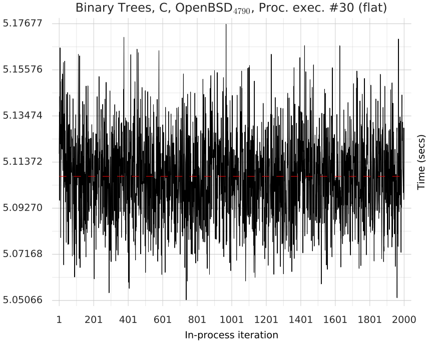
Inconsistent Process-executions



(Same machine)

Inconsistent Process-executions





(Different machines. Bouncing ball Linux-specific)

Individual benchmark stats

Benchmark	VM	Class.	Steady iter (#)	Steady iter (s)	Steady perf (s)
binary trees	C	⁓			
	Graal	⤫ (27ʅ, 3ʃ)	32.0 (17.0, 193.8)	6.60 (3.729, 36.608)	0.18594 ±0.000315
	HHVM	⤫ (24ʅ, 4ʃ, 2⁓)			
	HotSpot	⤫ (25ʅ, 5ʃ)	7.0 (7.0, 53.5)	1.19 (1.182, 9.703)	0.18279 ±0.000116
	JRuby+Truffle	ʃ	1082.0 (999.0, 1232.5)	2219.59 (2039.304, 2516.021)	2.05150 ±0.017738
	LuaJIT	⤫ (23ʅ, 4ʃ, 2–, 1⁓)			
	PyPy	⤫ (27ʃ, 3⁓)			
	V8	⤫ (15–, 9ʅ, 6ʃ)	1.5 (1.0, 794.0)	0.25 (0.000, 391.026)	0.49237 ±0.003198
fannkuch redux	C	⤫ (21–, 6ʅ, 2ʃ, 1⁓)			
	Graal	⤫ (28ʅ, 1⁓, 1ʃ)			
	HHVM	ʅ	10.0 (10.0, 10.0)	52.66 (52.660, 52.708)	1.35779 ±0.011948
	HotSpot	ʅ	390.0 (2.0, 390.0)	153.70 (0.407, 155.254)	0.36202 ±0.022767
	JRuby+Truffle	ʃ	1016.5 (999.0, 1023.1)	1039.04 (1014.290, 1059.967)	1.08833 ±0.038580
	LuaJIT	–			0.56285 ±0.000097
	PyPy	⤫ (15ʅ, 13–, 2ʃ)	2.0 (1.0, 28.9)	1.57 (0.000, 43.483)	1.55442 ±0.020549
	V8	= (19ʅ, 11–)	2.0 (1.0, 25.5)	0.31 (0.000, 7.525)	0.30401 ±0.000154
fasta	C	–			0.07048 ±0.000210
	Graal	⤫ (29ʅ, 1⁓)			
	HHVM	⤫ (27ʅ, 2⁓, 1ʃ)			
	HotSpot	⤫ (18ʅ, 12ʃ)	261.0 (6.0, 595.0)	30.73 (0.614, 70.021)	0.11744 ±0.001723
	JRuby+Truffle				
	LuaJIT	⁓			
	PyPy	⁓			
	V8	⤫ (19ʅ, 10ʃ, 1⁓)			

Benchmark	VM	Class.	Steady iter (#)	Steady iter (s)	Steady perf (s)
n-body	C	–			0.40555 ±0.005110
	Graal	ʅ	8.0 (7.5, 8.5)	1.22 (1.126, 1.358)	0.13334 ±0.000045
	HHVM	⤫ (16ʅ, 11ʃ, 3⁓)			
	HotSpot	ʅ	2.0 (2.0, 2.0)	0.14 (0.141, 0.143)	0.13699 ±0.000032
	JRuby+Truffle	ʅ	69.0 (69.0, 70.0)	17.95 (17.716, 18.127)	0.20644 ±0.001568
	LuaJIT	–			0.25399 ±0.004471
	PyPy	–			1.85835 ±0.012893
	V8	= (25–, 5ʅ)	1.0 (1.0, 361.6)	0.00 (0.000, 87.367)	0.24138 ±0.000389
Richards	C	⤫ (19–, 5ʃ, 4⁓, 2ʅ)			
	Graal	⤫ (28ʅ, 1⁓, 1ʃ)			
	HHVM				
	HotSpot	⤫ (26ʃ, 2⁓, 2ʅ)			
	JRuby+Truffle	ʃ	1021.0 (1014.9, 1027.0)	917.30 (901.708, 946.683)	0.89509 ±0.027590
	LuaJIT	⤫ (21⁓, 7ʃ, 2ʅ)			
	PyPy	ʅ	2.0 (2.0, 5.0)	1.12 (1.114, 4.054)	0.96809 ±0.010950
	V8	= (29ʅ, 1–)	4.0 (4.0, 16.0)	1.44 (1.434, 7.135)	0.47421 ±0.001218
spectralnorm	C	⤫ (28ʅ, 1–, 1ʃ)	997.0 (2.0, 1001.0)	546.38 (0.546, 547.717)	0.54547 ±0.002562
	Graal	⤫ (29ʃ, 1–)	15.0 (2.0, 21.0)	12.40 (0.812, 17.804)	0.89293 ±0.000087
	HHVM	ʅ	35.0 (34.0, 41.0)	139.18 (136.909, 147.626)	1.40690 ±0.011133
	HotSpot	ʅ	7.0 (7.0, 8.6)	1.90 (1.901, 2.425)	0.31470 ±0.000029
	JRuby+Truffle	ʅ	1011.0 (1007.5, 1014.0)	893.38 (888.985, 896.562)	0.83633 ±0.014403
	LuaJIT	–			0.22435 ±0.000020
	PyPy	ʅ	75.0 (75.0, 75.0)	34.43 (34.429, 34.437)	0.46489 ±0.000046
	V8	ʅ	3.0 (3.0, 3.0)	0.55 (0.554, 0.554)	0.24963 ±0.000039

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Overall benchmark stats

Class.	Linux_{4790}	Linux_{1240v5}	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%
⎡	16.7%	17.9%	11.1%
〰	8.7%	9.6%	2.8%

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≈	4.3%	6.5%	0.0%
=	6.5%	6.5%	13.3%
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⌋	16.7%	17.9%	11.1%
≈	8.7%	9.6%	2.8%

Classical warmup occurs for only:

Summary

Classical warmup occurs for only:

72.4%–74.7% of process executions

Classical warmup occurs for only:

72.4%–74.7% of process executions

43.4%–43.5% of (VM, benchmark) pairs

Summary

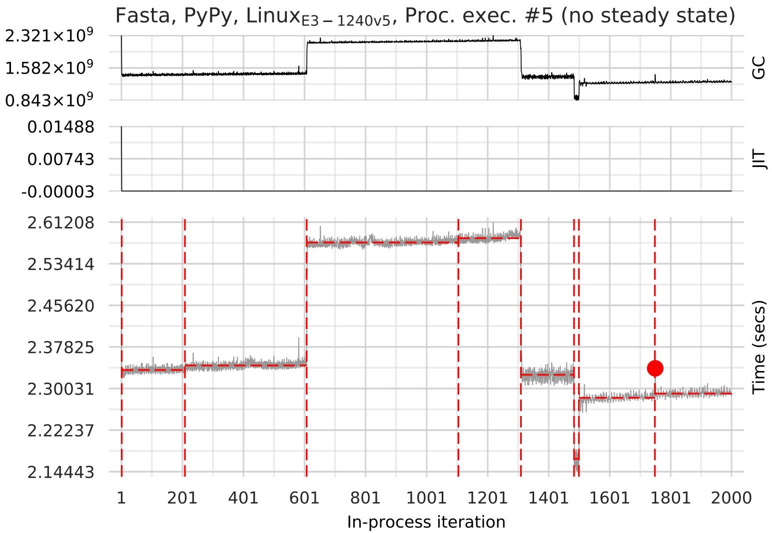
Classical warmup occurs for only:

72.4%–74.7% of process executions

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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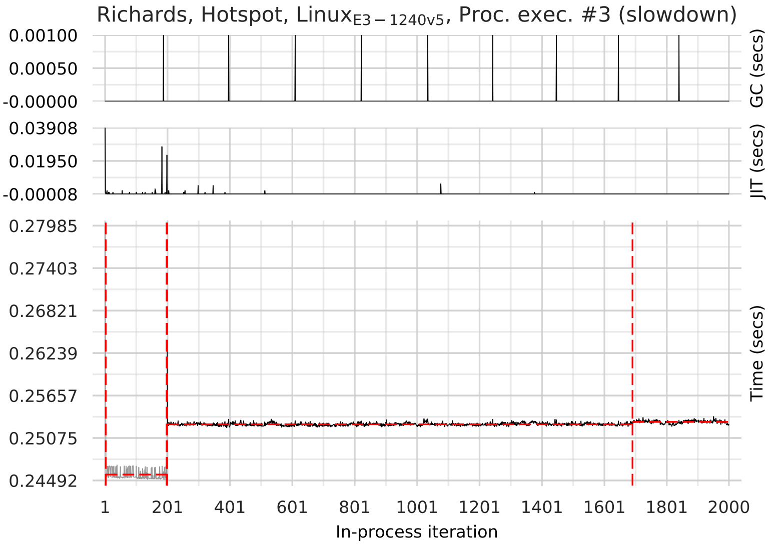
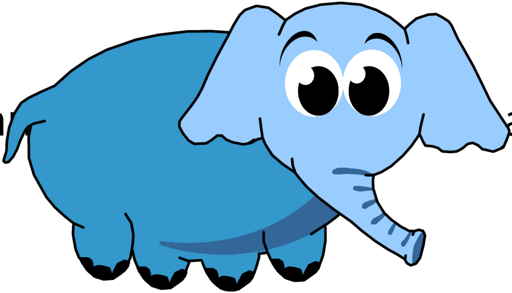


Benchmark suites

Benchmark suites

Benchmarks guide our optimisations

Benchmark suites

Bench  ations

Benchmarks guide our optimisations

Are they complete guides?

A war story

A war story

Symptom: poor performance of a Pyston benchmark on PyPy

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Cause: RPython traces recursion

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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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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

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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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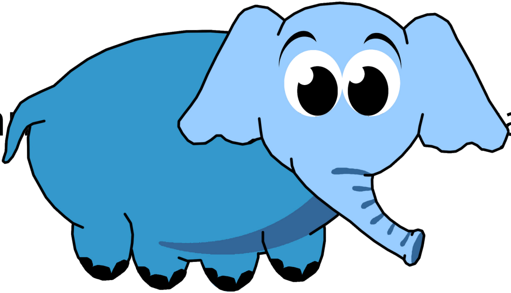
Bench



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Benchmark suites (2)

Benchmarks guide our optimisations

Are they correct guides?

Octane

17 JavaScript benchmarks from V8

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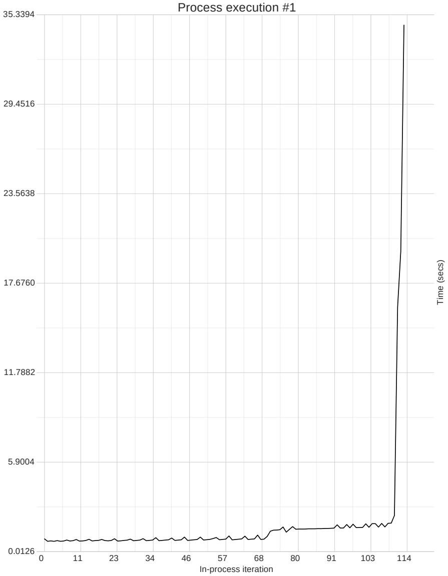
Let's make each benchmark run for 2000 iterations

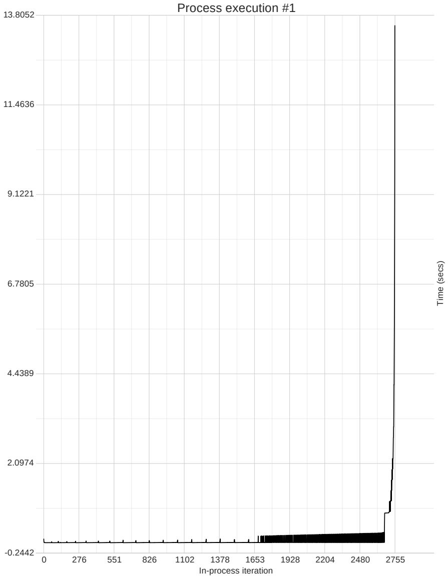
Octane: pdf.js explodes

```
$ 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
```

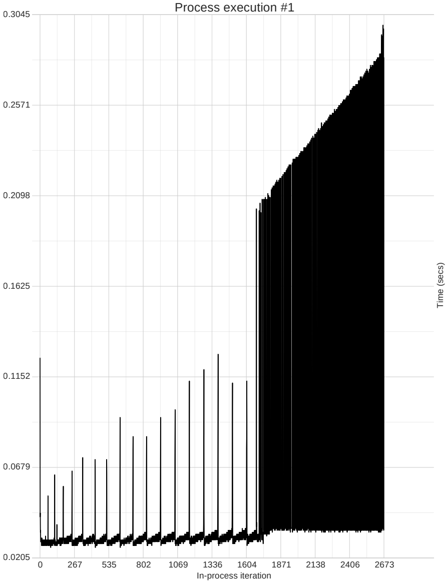
Octane: analysing pdf.js



Octane: analysing pdf.js



Octane: analysing pdf.js



Octane: debugging

pdfjs.js (/tmp/octane) - GVIM2

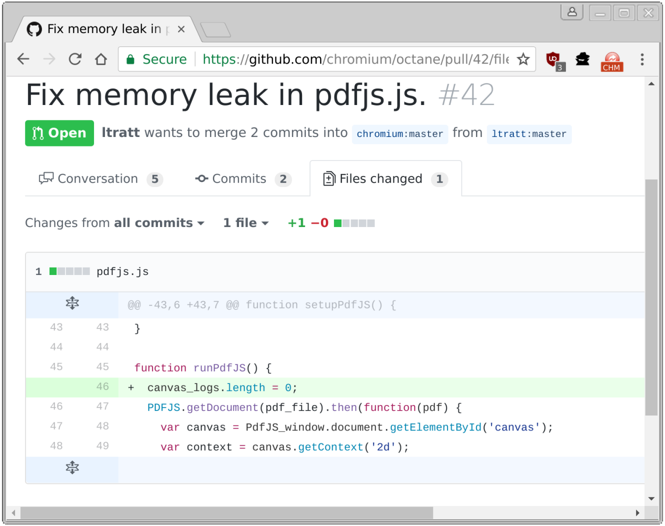
```
//////// Benchmark set-up. (c) by Google. ////////

var pdf_file = "test.pdf";
var canvas_logs = [];

var PdfJS = new BenchmarkSuite("PdfJS", [10124921], [
  new Benchmark("PdfJS", false, false, 24,
    runPdfJS, setupPdfJS, tearDownPdfJS, null, 4)
]);
```

```
NORMAL  master  pdfjs.js   jav…  utf-8[unix]  0% ¶  28/33053 :  1
```

```
function runPdfJS() {
  PDFJS.getDocument(pdf_file).then(function(pdf) {
    var canvas = PdfJS_window.document.getElementById('canvas');
    var context = canvas.getContext('2d');
    var renderContext = {canvasContext: context};
    canvas_logs.push(context.__log__);

    // Cycle through all pages.
    function renderPages(i, j) {
      if (i > j) return;
      context.clearRect(0, 0, canvas.width, canvas.height);
      pdf.getPage(i).then(function(page) {
        renderContext.viewport = page.getViewport(1);
        canvas.height = renderContext.viewport.height;
        canvas.width = renderContext.viewport.width;
        page.render(renderContext).then(renderPages.bind(null, i + 1, j));
      });
    }
    renderPages(1, pdf.numPages);
  });

  // Wait for everything to complete.
  PdfJS_window.flushTimeouts();
}
```

```
pdfjs.js   jav…  utf-8[unix]  0% ¶  50/33053 : 38
```

Octane: fixing



Octane: other issues

pdfjs isn't the only problem

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CodeLoadClosure also has a memory leak

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

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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: our benchmarking *and* our benchmarks 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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How to benchmark a bit better

1. Run benchmarks for longer to uncover issues.
2. Accept that peak performance may not occur.
3. Always report warmup time.
4. Stop over-training on small benchmark suites.
5. The more benchmarks, the better.
6. Focus on predictable performance.

What we're doing next

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: various.

K Whiteford for Barry, the Benchmarking Elephant in the Room

Thanks for listening

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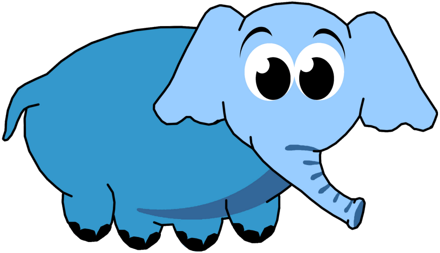

And don't forget Barry