VM Warmup Blows Hot and Cold

OOPSLA 2017, Vancouver

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How to benchmark a JIT:

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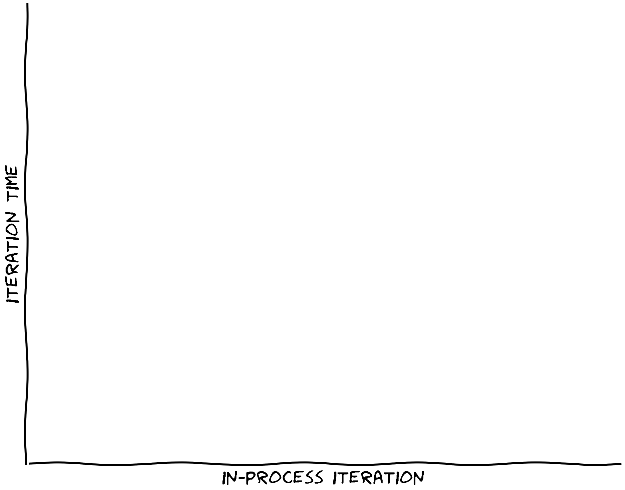
- Run Benchmark in a Loop

How to benchmark a JIT:

- Invoke VM
  - *“process execution”*
- Run Benchmark in a Loop
  - *“in-process iterations”*

The Current State of the Art of Benchmarking



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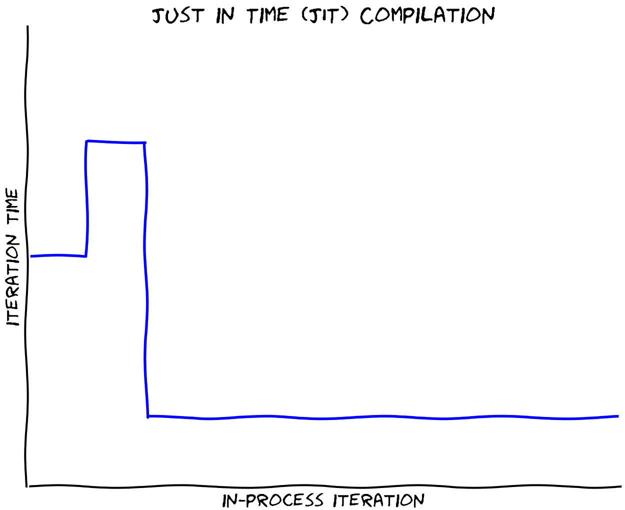

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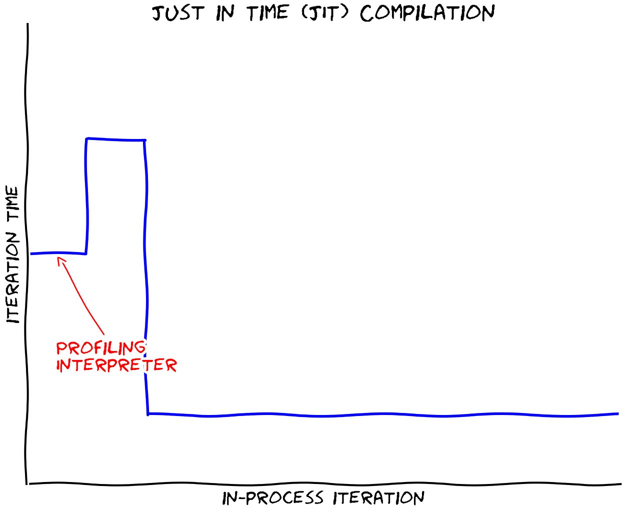

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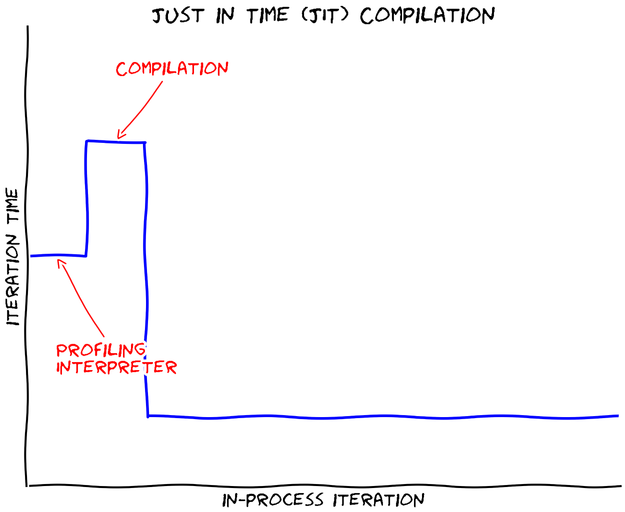

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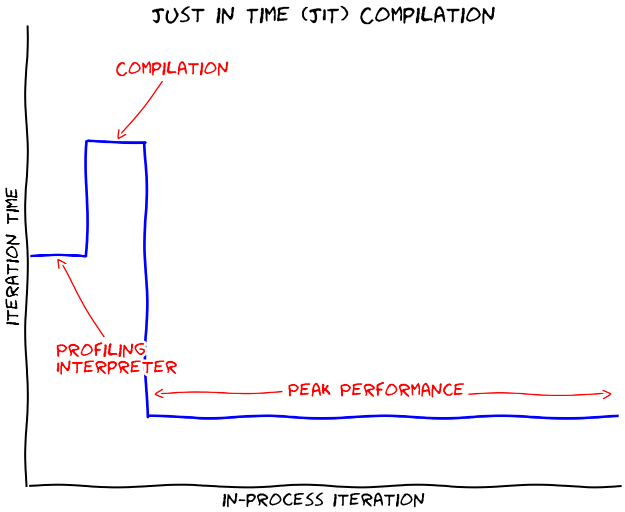

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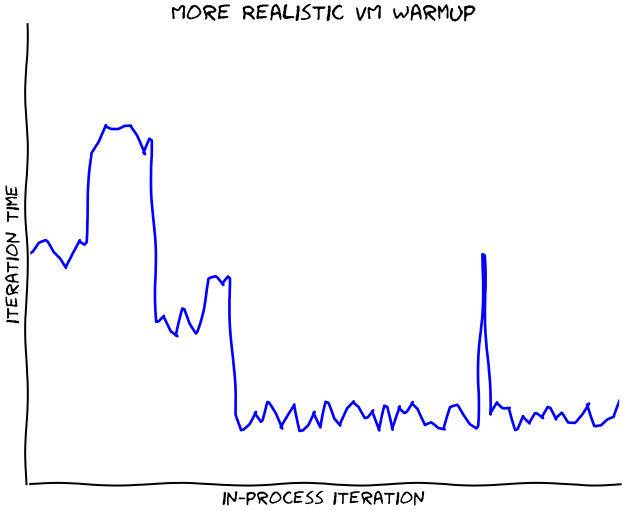

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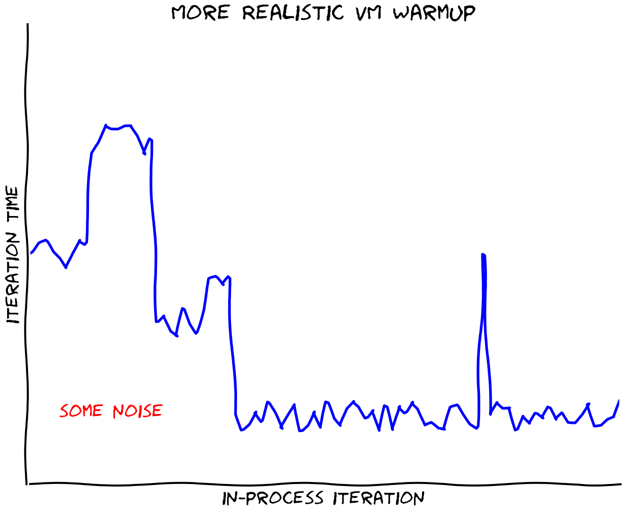
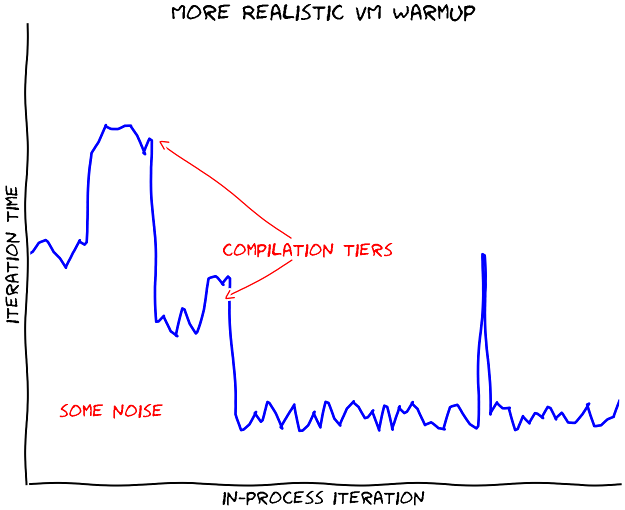
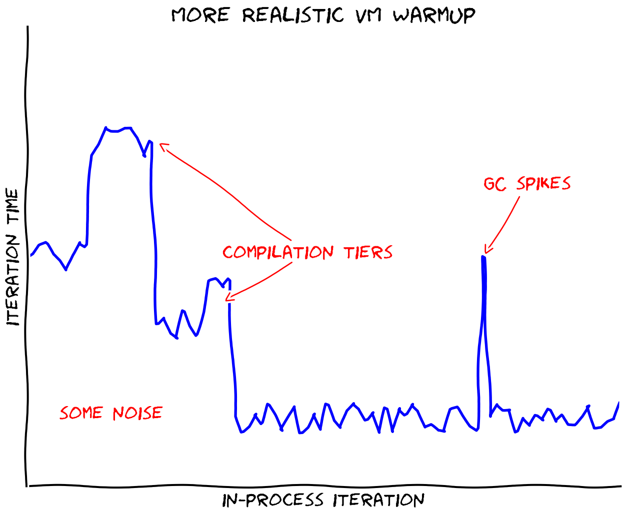



MORE REALISTIC VM WARMUP
ITERATION TIME
COMPILATION TIERS
SOME NOISE
IN-PROCESS ITERATION


MORE REALISTIC VM WARMUP
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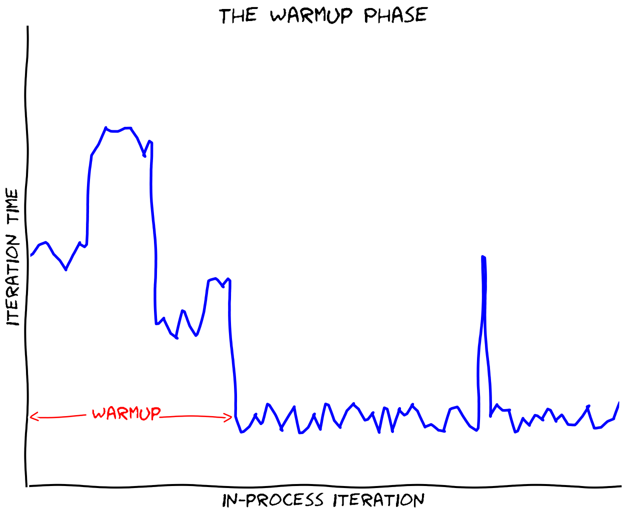

1. Users dislike poor warmup.

Warmup Matters

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Warmup is important!

The Warmup Experiment

We should measure the 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 CLBG benchmarks are perfect for us (unusually)

`http://benchmarksgame.alioth.debian.org/`

Method 2: How Long to Run?

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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

- Linux_{4790}, Debian 8, 24GiB RAM
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- Turbo boost off.
- Hyper-threading off.

Method 5: Benchmark Harness

KRUN

Control as many confounding variables as possible

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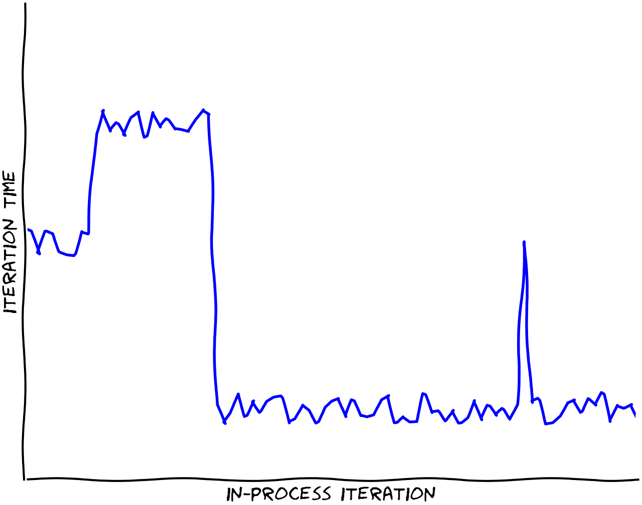
KRUN

Control as many confounding variables as possible

- 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: Changepoint Analysis and Classification



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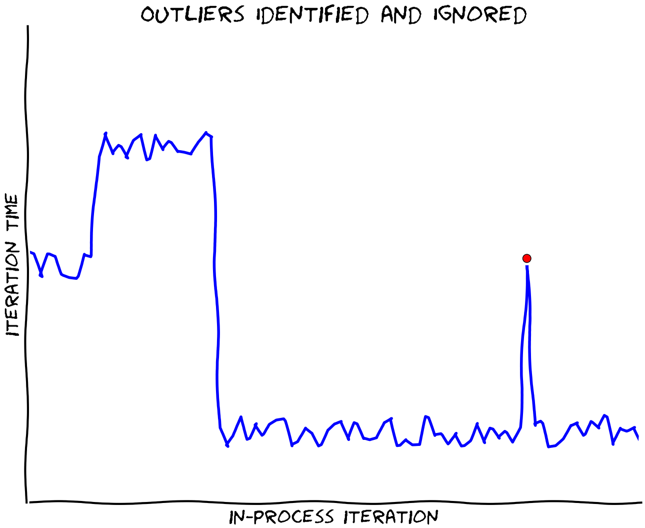

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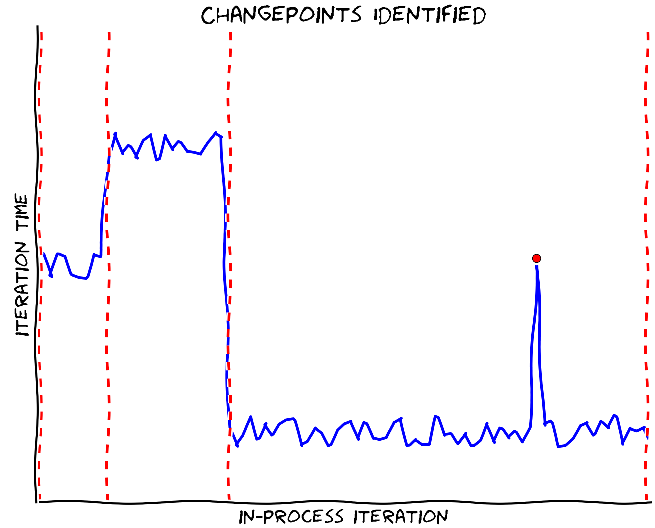

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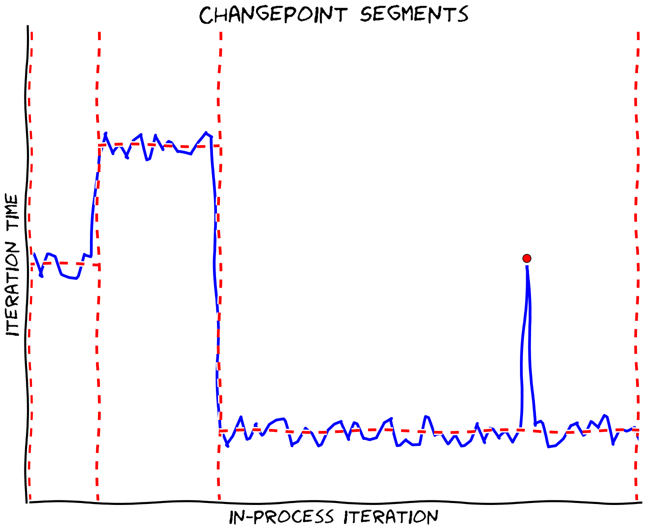

- All segs are equivalent:
  FLAT ($-$)

Method 6: Changepoint Analysis and Classification

- All segs are equivalent:
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- Length(final equivalent segs) >= 500 iters:
  - and are the fastest segs:
    WARMUP (⌉⌊)

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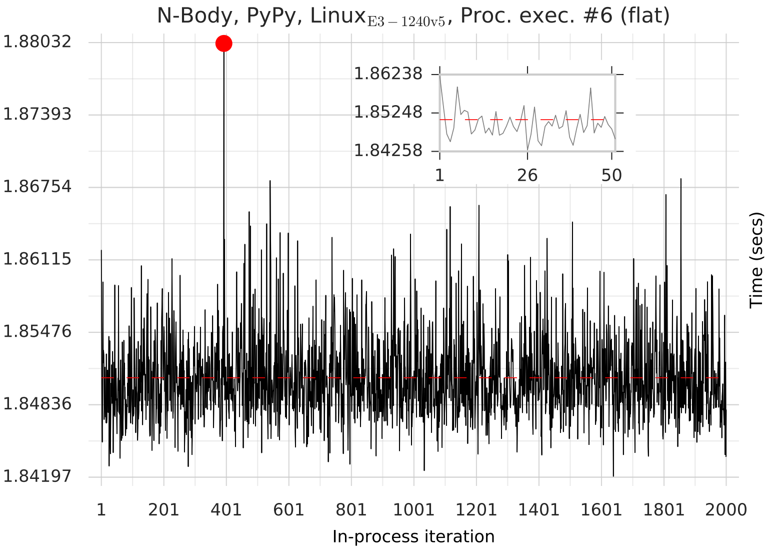
    WARMUP (⎺⎽)
  - but not the fastest segs:
    SLOWDOWN (⎽⎺)

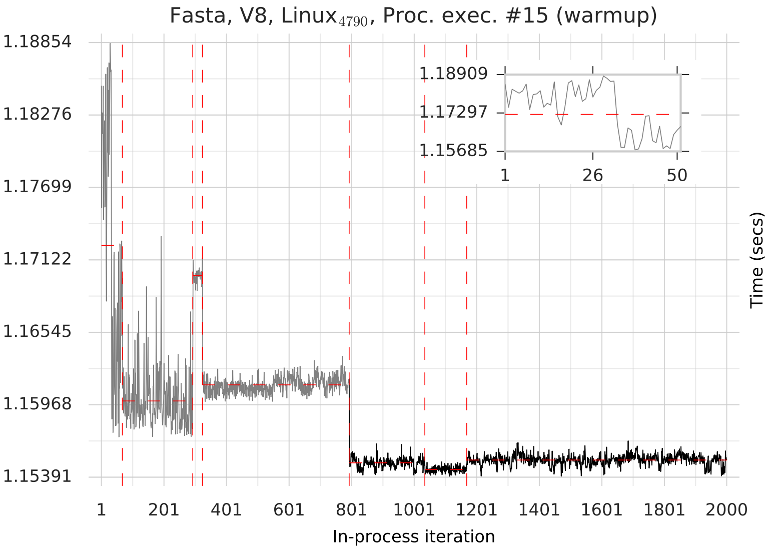
Method 6: Changepoint Analysis and Classification

- All segs are equivalent:
  FLAT (—)
- Length(final equivalent segs) >= 500 iters:
  - and are the fastest segs:
    WARMUP ()
  - but not the fastest segs:
    SLOWDOWN ()
- Otherwise:
  NO STEADY STATE ()

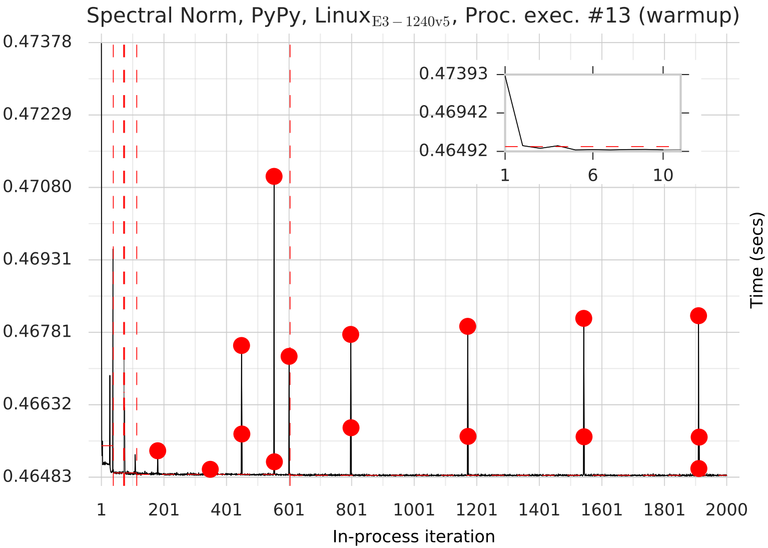
Results

Results: Flat

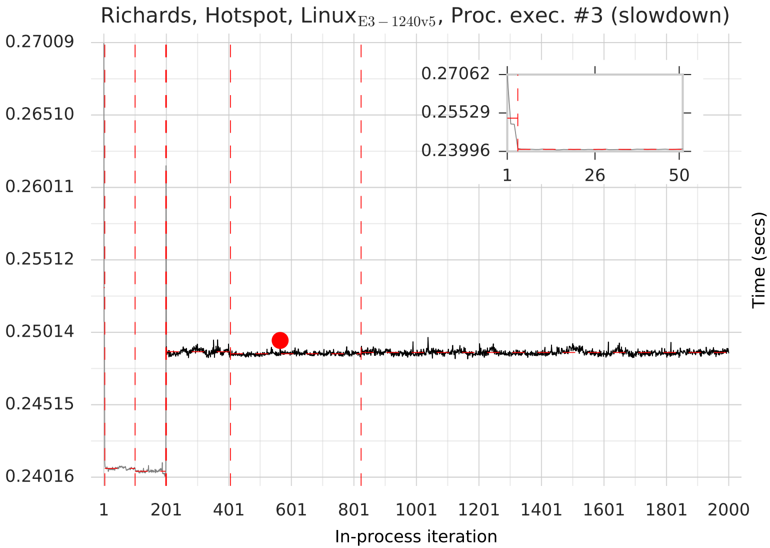



Fasta, V8, Linux$_{4790}$, Proc. exec. #15 (warmup)
1.18854
1.18276
1.17699
1.17122
1.16545
1.15968
1.15391
1.18909
1.17297
1.15685
1
26
50
Time (secs)
1
201
401
601
801
1001
1201
1401
1601
1801
2000
In-process iteration

Results: Warmup



Results: Slowdown



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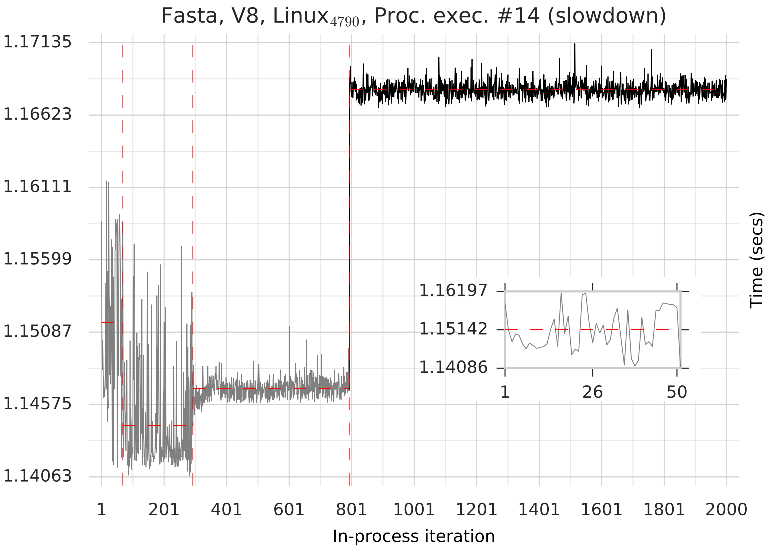
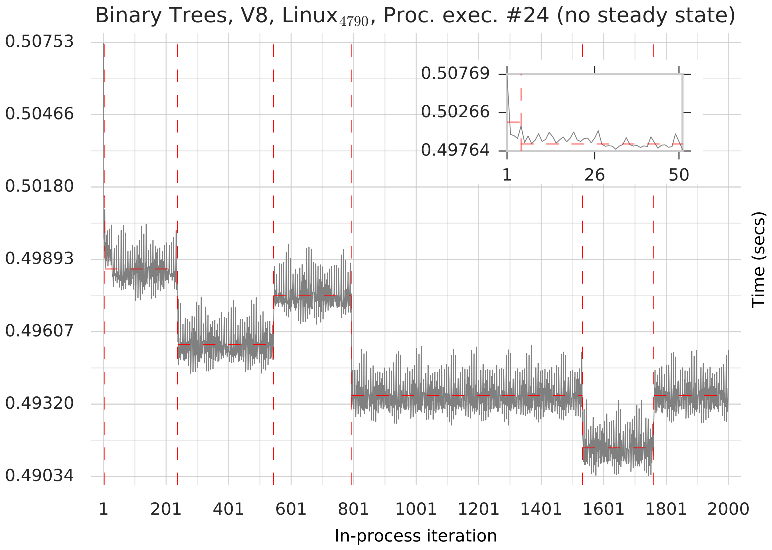
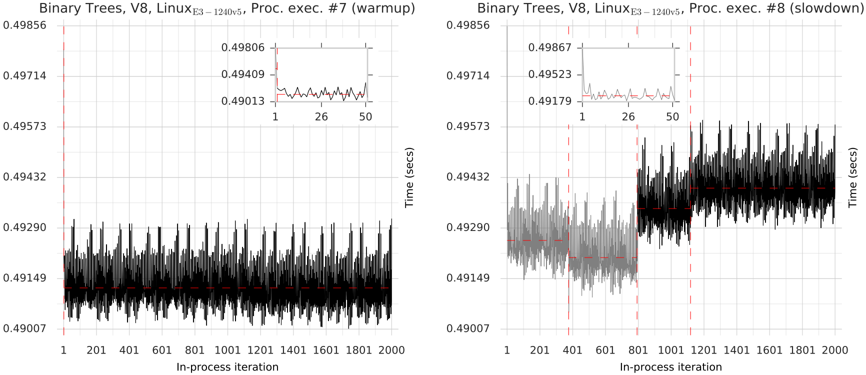


Results: No Steady State



Results: Inconsistent Process-executions



(Same machine)

Quantitative Results

VM	Benchmark	Class.	Steady iter (#)	Steady iter (s)	Steady perf (s)	Benchmark	Class.	Steady iter (#)	Steady iter (s)	Steady perf (s)
C	*binary trees*	ʍ				*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⅃, 2ʍ)					≭ (16⅂, 11⅃, 3ʍ)			
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—, 1ʍ)					—			0.25399 ±0.004471
PyPy		≭ (27⅃, 3ʍ)					—			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⅃, 1ʍ)				*Richards*	≭ (19—, 5⅃, 4ʍ, 2⅂)			
Graal		≭ (28⅂, 1ʍ, 1⅃)					≭ (28⅂, 1ʍ, 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⅃, 2ʍ, 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		≭ (21ʍ, 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⅂, 1ʍ)					≭ (29⅃, 1—)	15.0 (2.0, 21.0)	12.40 (0.812, 17.804)	0.89293 ±0.000087
HHVM		≭ (27⅂, 2ʍ, 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		ʍ					—			0.22435 ±0.000020
PyPy		ʍ					⅂	75.0 (75.0, 75.0)	34.43 (34.429, 34.437)	0.46489 ±0.000046
V8		≭ (19⅂, 10⅃, 1ʍ)					⅂	3.0 (3.0, 3.0)	0.55 (0.554, 0.554)	0.24963 ±0.000039

Results

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Results: Summary

Class.	Linux_{4790}	Linux_{1240v5}	OpenBSD_{4790}
	⟨VM, benchmark⟩ pairs		
—	8.7%	13.0%	6.7%
ʅ	28.3%	23.9%	10.0%
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∿	4.3%	6.5%	0.0%
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⨯	45.7%	43.5%	70.0%
	Process executions		
—	26.4%	20.9%	34.0%
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Best case no. good process executions: 86.1%

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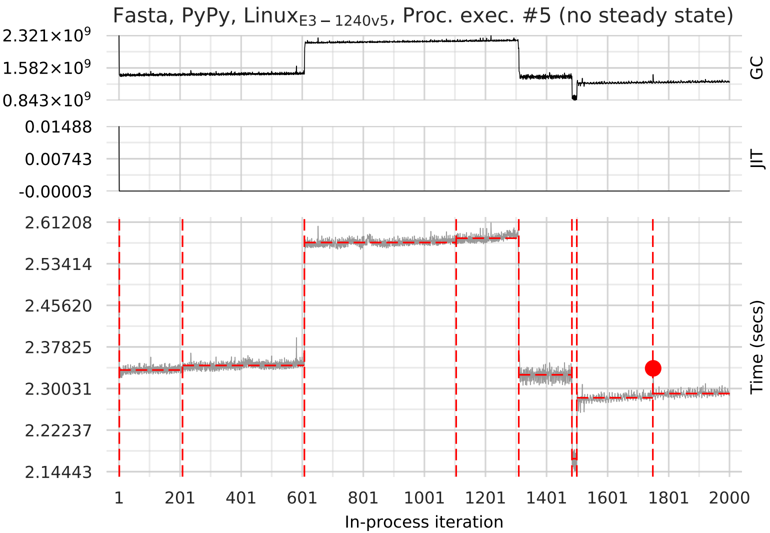
Best case good ⟨VM, benchmark⟩ pairings: 43.5%

Hypothesis Invalid!

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

Are the Effects due to JIT and GC?



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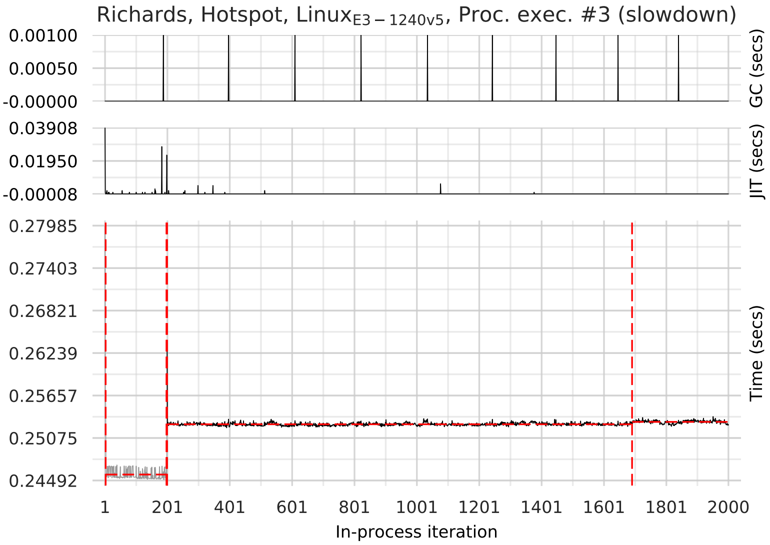

Are the Effects due to JIT and GC?

However

In many cases, the JIT/GC can’t explain oddness

What Have We Learned?

- Benchmarks often don’t warmup as we expect.
- Repeating a benchmark often gives a different warmup characteristic.
- Have we been misled?
  - Ineffectual or bad optimisations?

What Can We Do?

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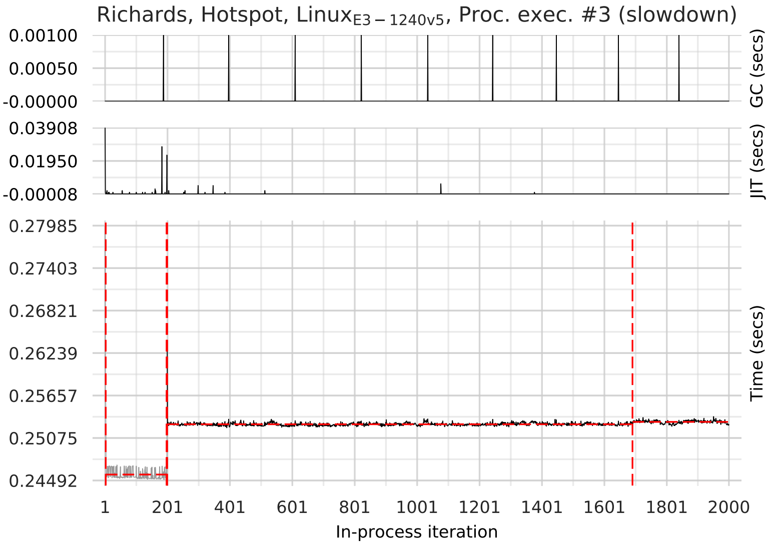
3. We can’t always blame GC or JIT compilation.
4. Always report warmup time.
5. Engineer VMs for predictable performance?

Next Version of the Paper

`https://arxiv.org/abs/1602.00602`

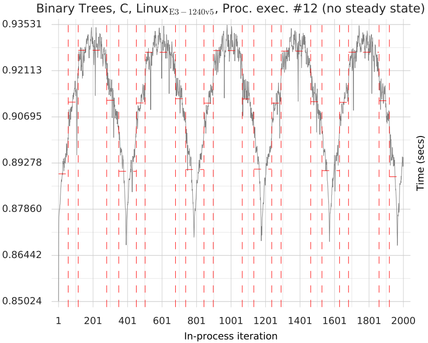
(These slides correspond to version 6 of the paper)

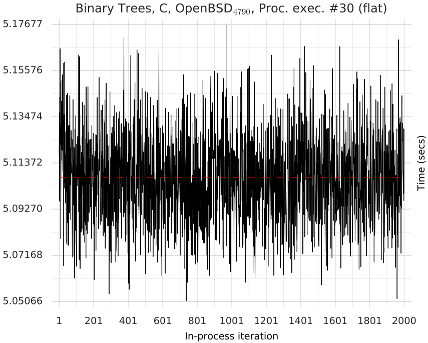
Thanks for Listening



Backup Slides

The Bouncing Ball Pattern





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All 30 process executions were classified the same.

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— ⎤⎣ ⎦⎡ ʌʌ

Inconsistent

A mix of classifications arose within the 30 process executions. E.g.:

- Good inconsistent: $=$ (25—, 5⎤⎣)
- Bad inconsistent: $\not\asymp$ (20—, 3⎦⎡, 7ʌʌ)

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— ⎿ ⎾ ʌʌ

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- Bad inconsistent: $\asymp\!\!\!\!\times$ (20—, 3⎾, 7ʌʌ)

If possible report: steady state performance, time until steady state, etc.