Tracking Performance of the Graal Compiler on Public Benchmarks

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2018 – 2021

Department of Distributed and Dependable Systems D3S

Disclaimer

Development Versions

Performance and other measurements used in this presentation are collected using **development** versions of the software involved. As such, they do **not** represent product performance.

Modified Benchmarks

Benchmarks used to collect the measurements **were often modified** to facilitate integration into the measurement infrastructure. None of the benchmark results are standard benchmark scores.

Platform Specific

Measurements are **platform specific**. Platform information was omitted for brevity, contact us if you need more details.

... and we are only human

The data may be influenced by mistakes we are not aware of.

Outline

1. Quick Platform Overview
2. Handling Warm Up
3. Detecting Changes
4. Handling More Runs
5. Handling Different Metrics
6. Troublesome Performance Changes

About Graal Compiler

A just-in-time compiler for Java written in Java

- Functions as the last tier compiler
- Partial escape analysis and speculative optimizations

Part of a larger ecosystem surrounding the JVM

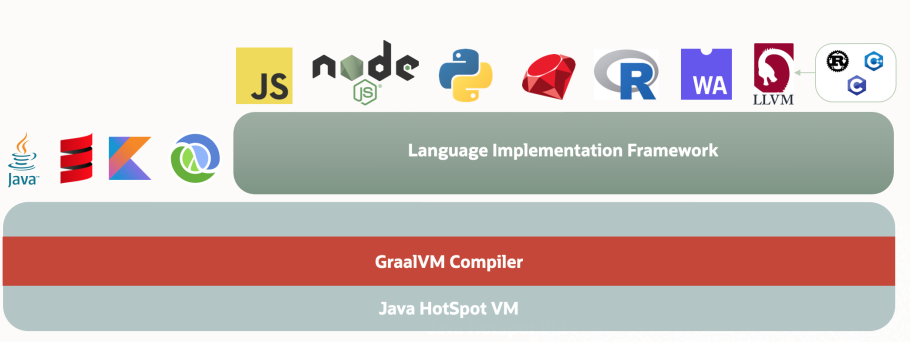

Image from `https://www.graalvm.org`

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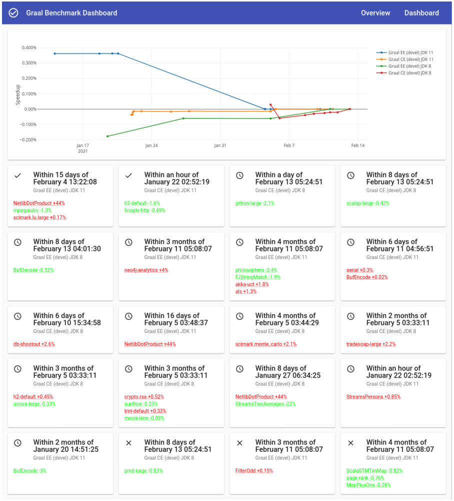

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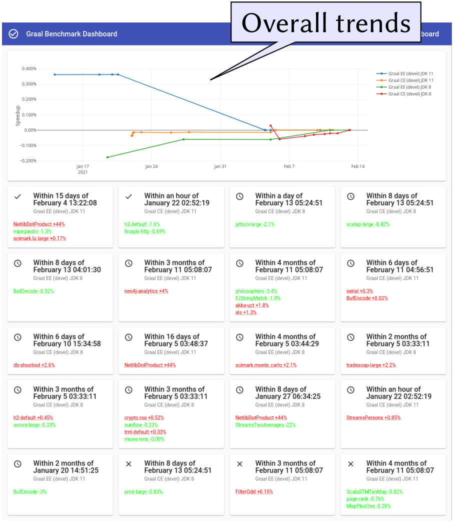

Overall trends

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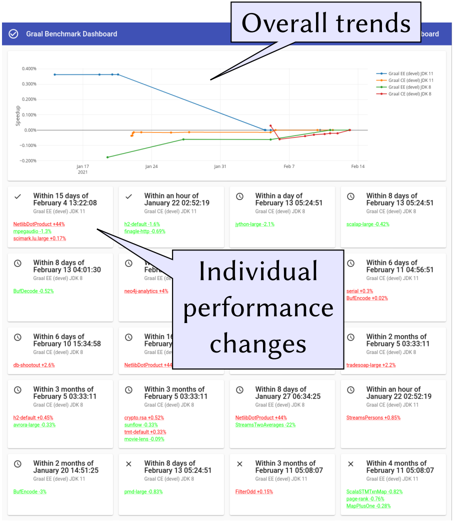

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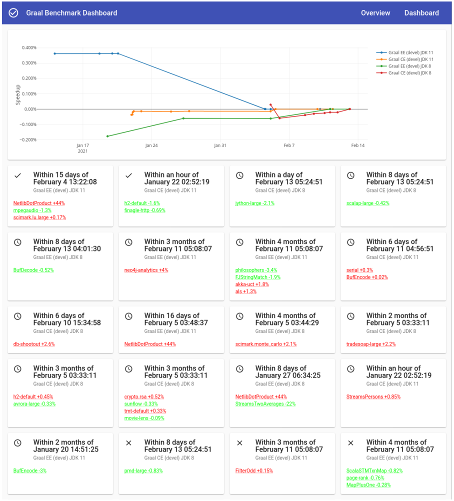

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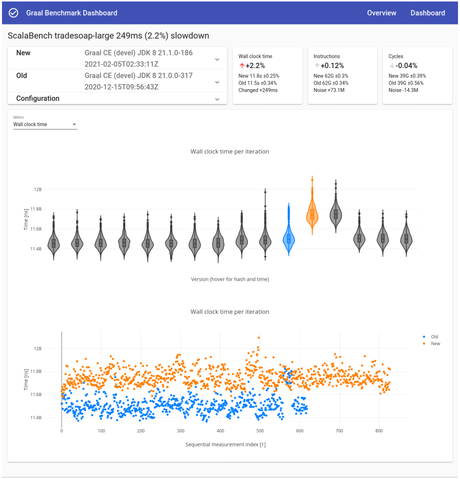

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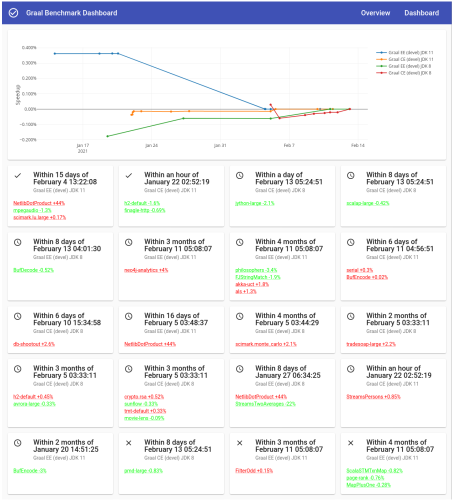

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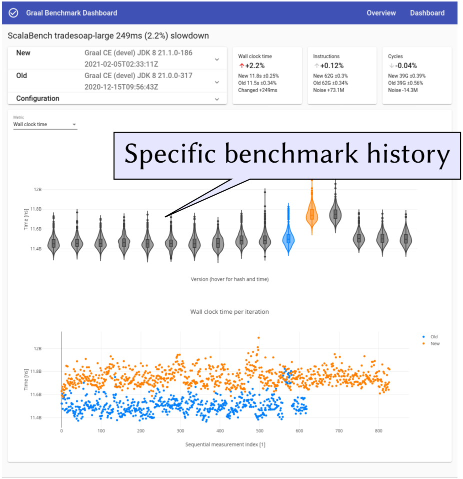

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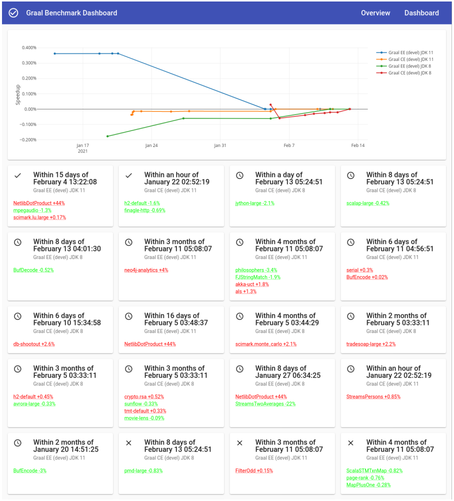

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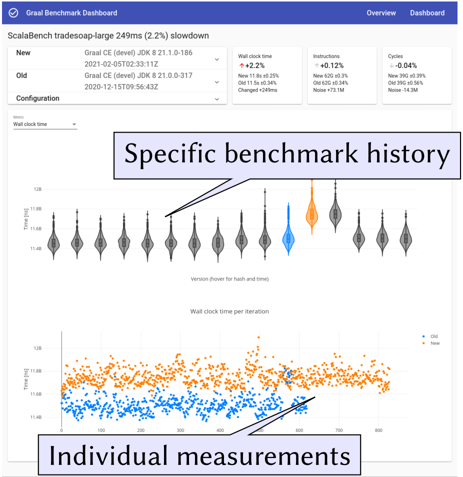

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Metric: Wall clock time

Specific benchmark history

Individual measurements

Dashboard Internals I

How to execute the measurements ?

- Resource sharing and background load matter
- Repetition count is determined on the fly
- Need more than latest software version
- Faulty setup may remain invisible

What we do

- Use dedicated hardware infrastructure
  - Multiple servers with equivalent parameters
  - No other load than the benchmarks
- Proprietary software to coordinate measurements
- Iterative selection of versions to measure

Dashboard Internals II

When to fail the test ?

- Noisy measurements
- Change can be legitimate
- Absolute performance requirements not given

What we do

- Compare performance of neighboring versions
- Focus on low false alarm rate
  - Iterative measurement planning
  - Observing multiple metrics together
- Alongside commit pipeline but not blocking

Dashboard Internals III

Platforms

- GraalVM CE and EE with OpenJDK and HotSpot JDK 8 and 11
- Only top level merge commits into master
- ... around 6000 versions last year

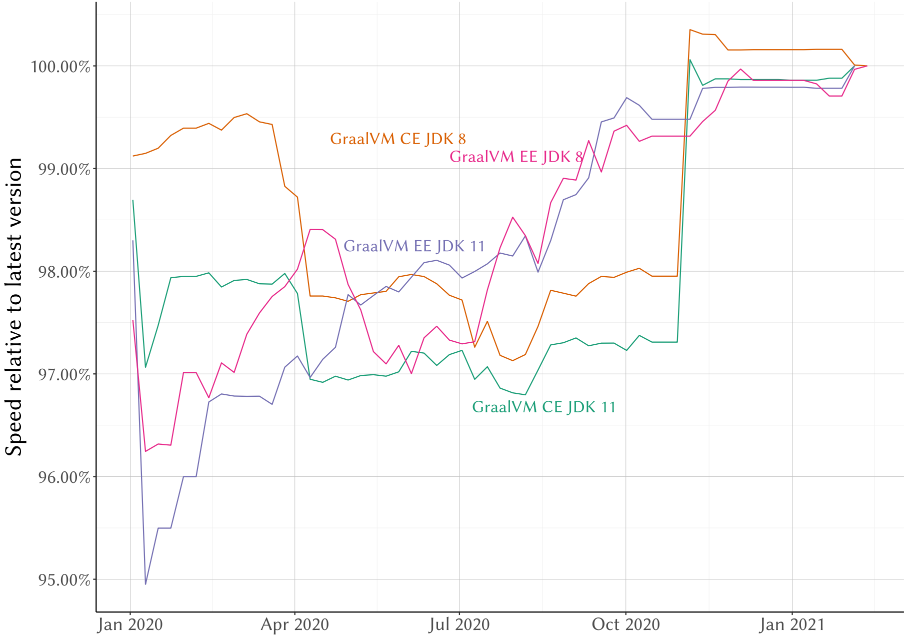
Benchmarks

- ScalaBench (includes DaCapo) `https://scalabench.org`
- SPECjvm2008 (non-compliant) `https://spec.org/jvm2008`
- Renaissance 0.10 `https://renaissance.dev`
- Plus internal microbenchmarks
- ... around 130 workloads in all

Hardware

- ... around 40 dedicated servers

Summary Performance History



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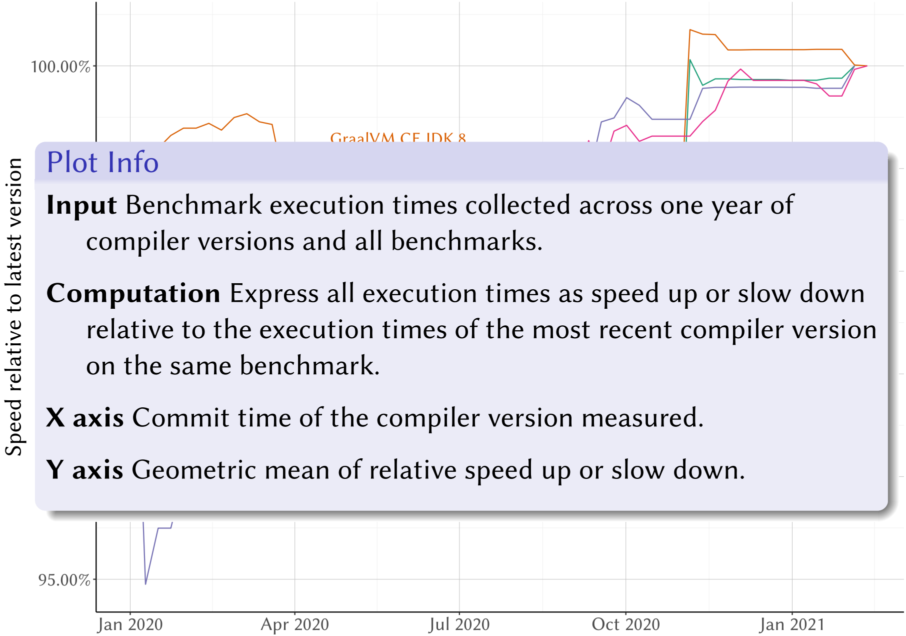


Plot Info

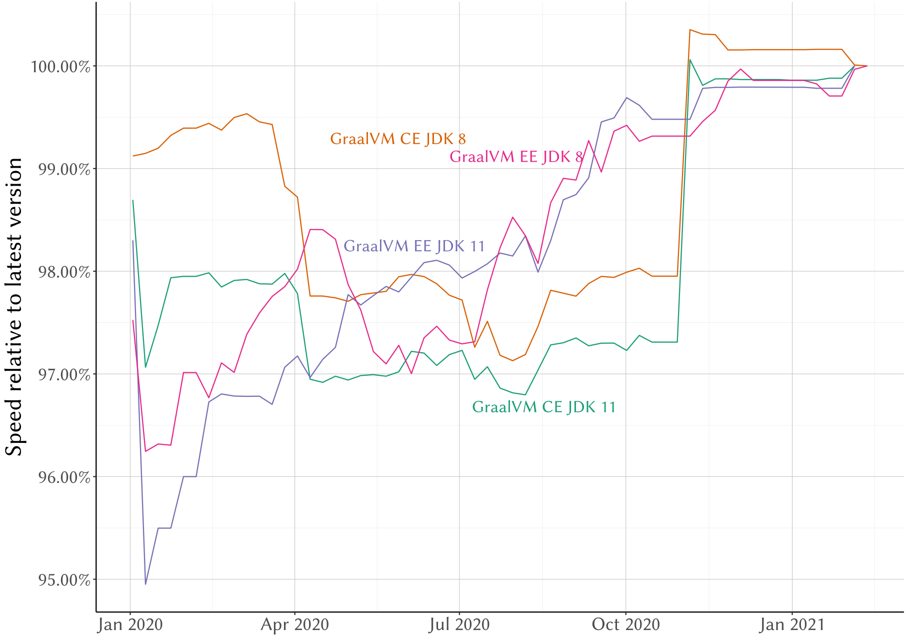
Input Benchmark execution times collected across one year of compiler versions and all benchmarks.

Computation Express all execution times as speed up or slow down relative to the execution times of the most recent compiler version on the same benchmark.

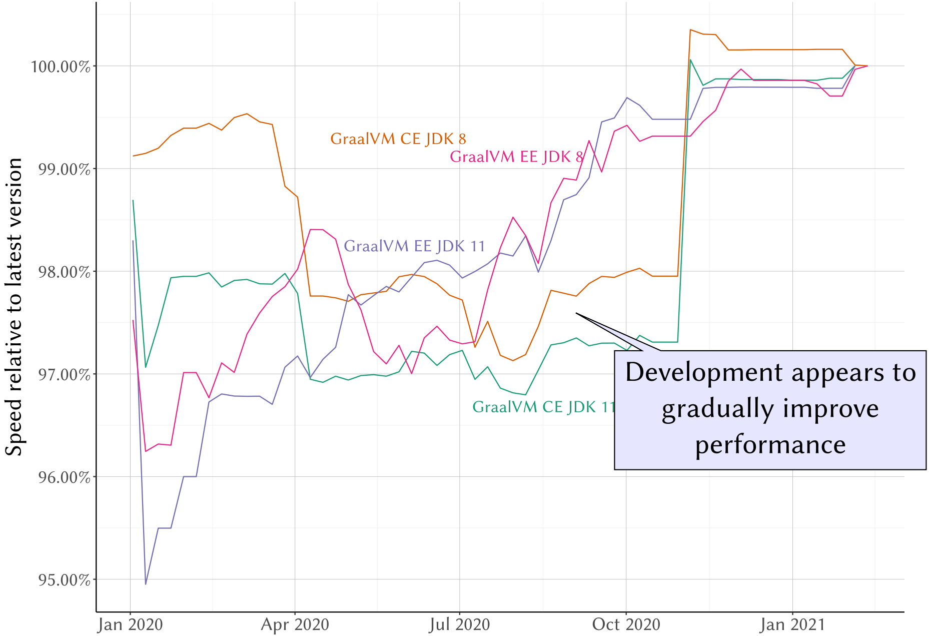
X axis Commit time of the compiler version measured.

Y axis Geometric mean of relative speed up or slow down.

Summary Performance History

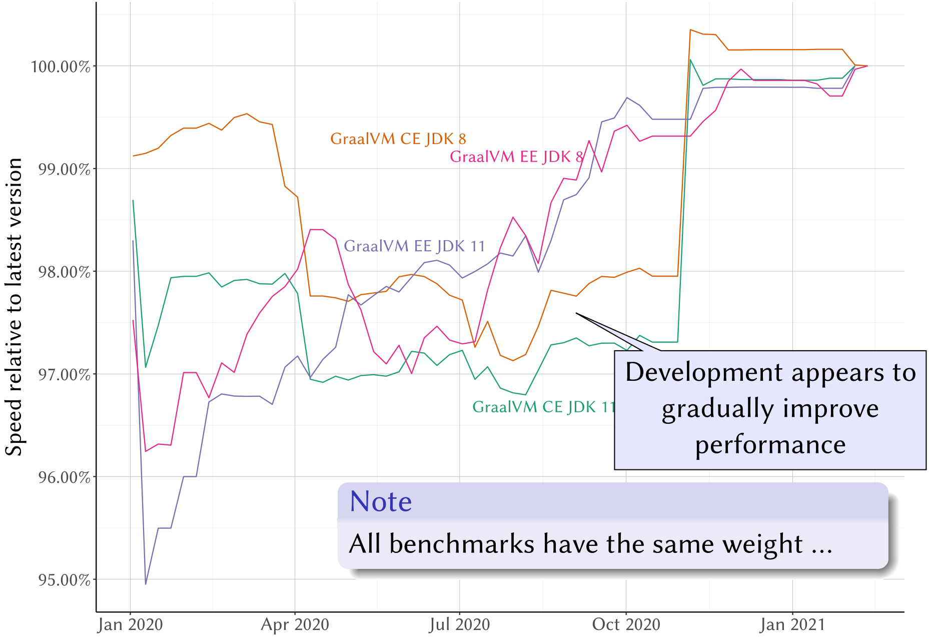


Summary Performance History



Development appears to gradually improve performance

Summary Performance History



Development appears to gradually improve performance

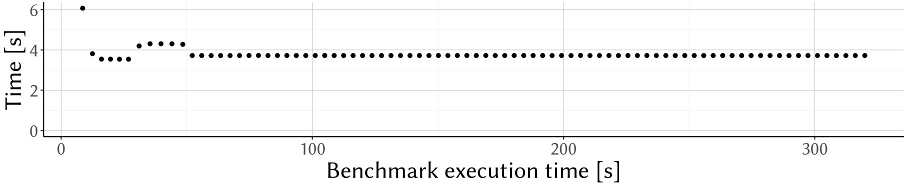
Note

All benchmarks have the same weight …

Outline

1. Quick Platform Overview
2. Handling Warm Up
3. Detecting Changes
4. Handling More Runs
5. Handling Different Metrics
6. Troublesome Performance Changes

Warm Up



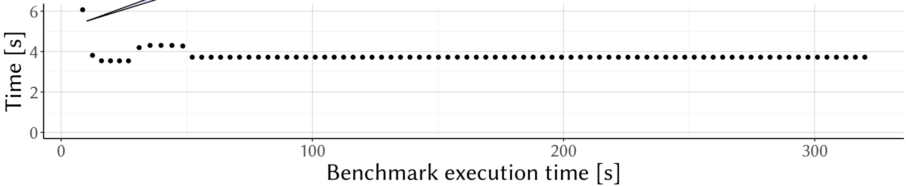
Plot Info

Input Benchmark repetition times for an arbitrarily selected benchmark and platform.

X axis Time from start of the benchmark execution.

Y axis Time of single benchmark repetition.

Warm Up



Initial measurements quite slow

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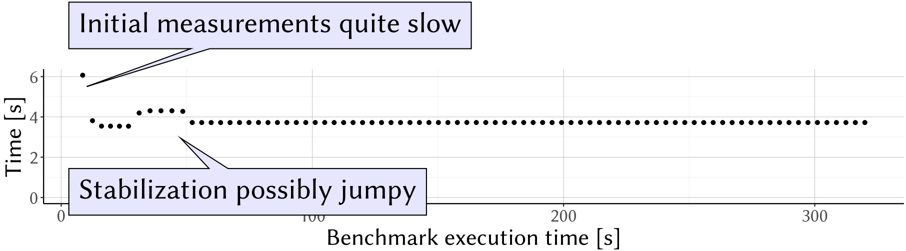

Initial measurements quite slow

Stabilization possibly jumpy

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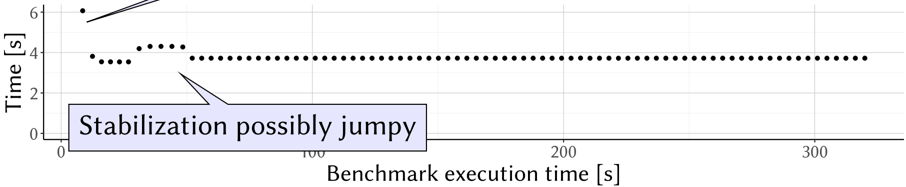

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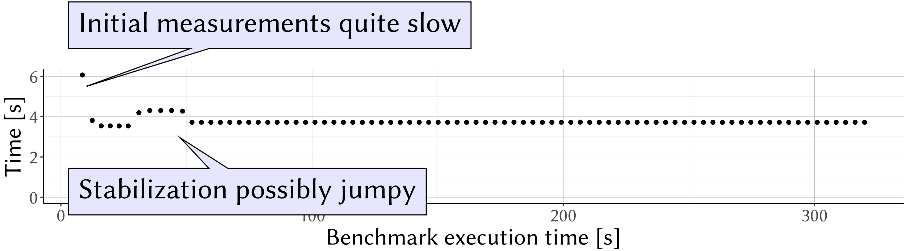

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Some reasons behind warm up eliminated in our setup

- Most power management features disabled
- Initial and maximum heap size equal and fixed
- Most (but not all) benchmarks stable after first repetition

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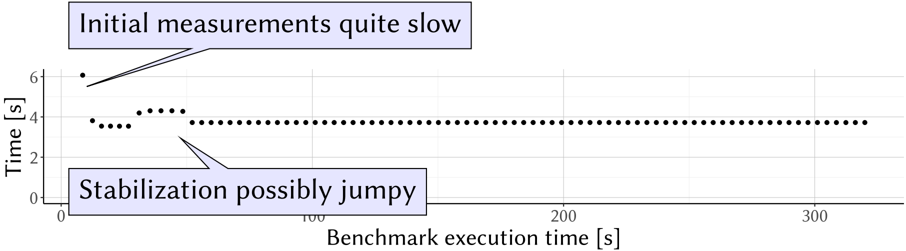

Initial measurements quite slow

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Some reasons behind warm up eliminated in our setup

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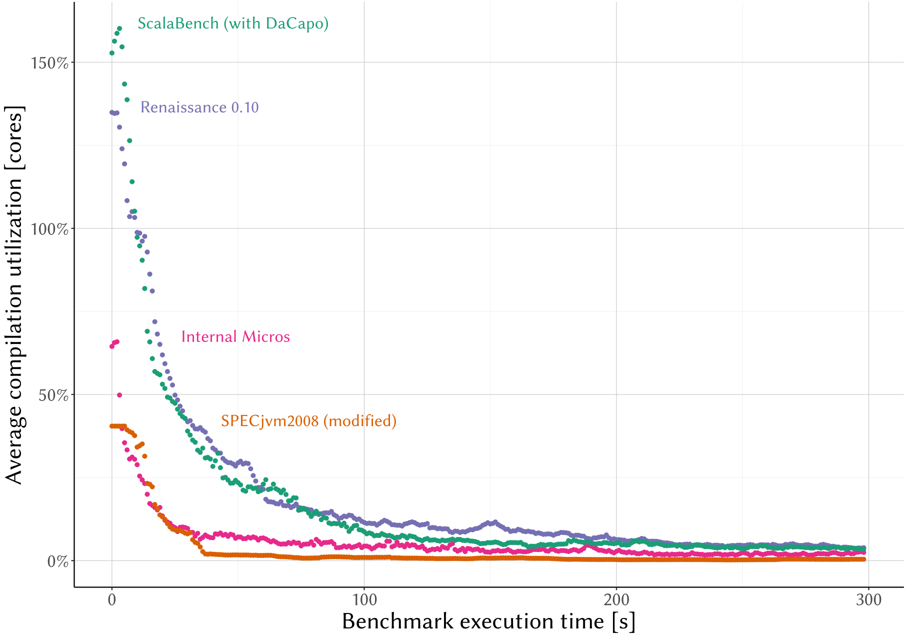
But the elephant in the room is **just-in-time compilation**

How Much Compilation On Average ?



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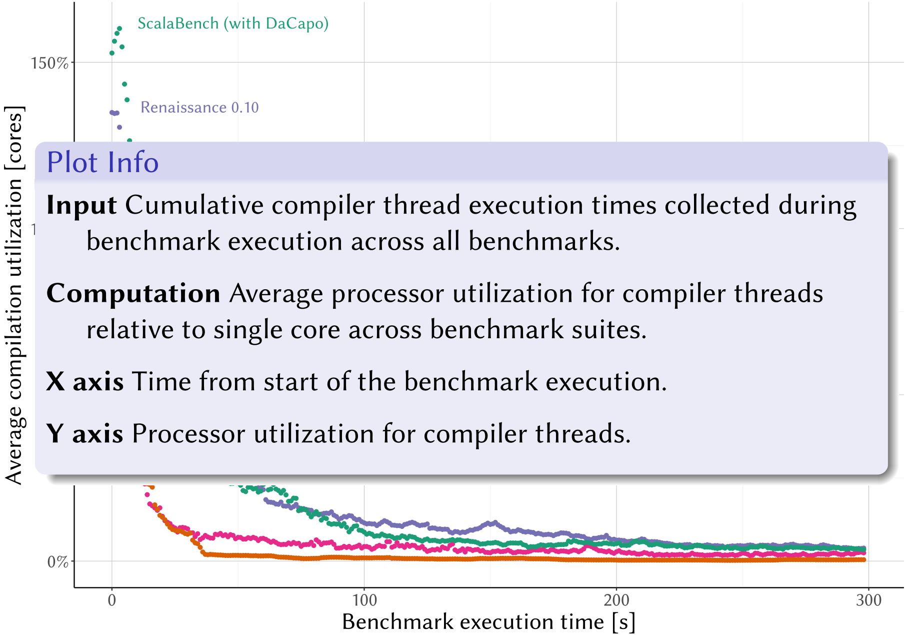


Plot Info

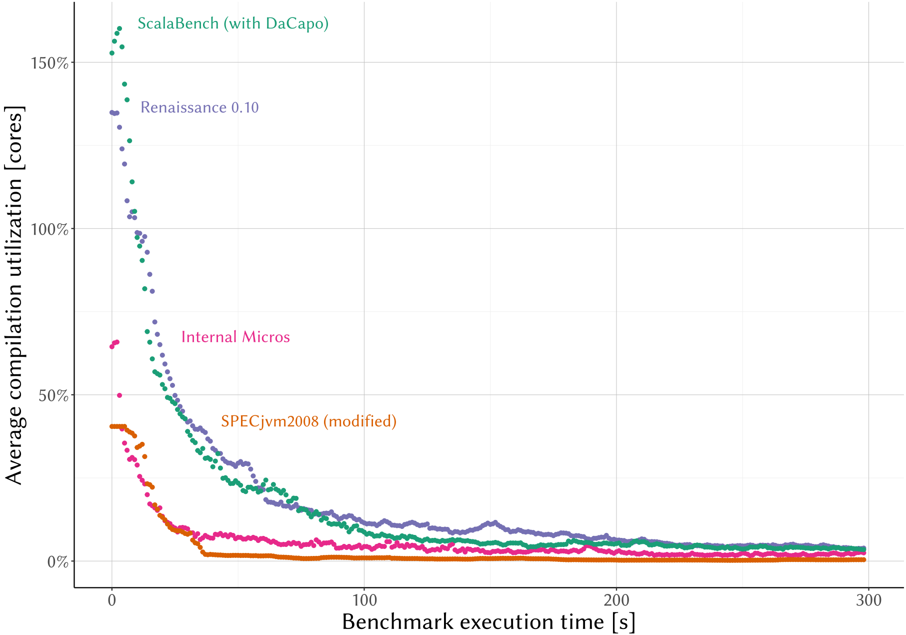
Input Cumulative compiler thread execution times collected during benchmark execution across all benchmarks.

Computation Average processor utilization for compiler threads relative to single core across benchmark suites.

X axis Time from start of the benchmark execution.

Y axis Processor utilization for compiler threads.

How Much Compilation On Average ?



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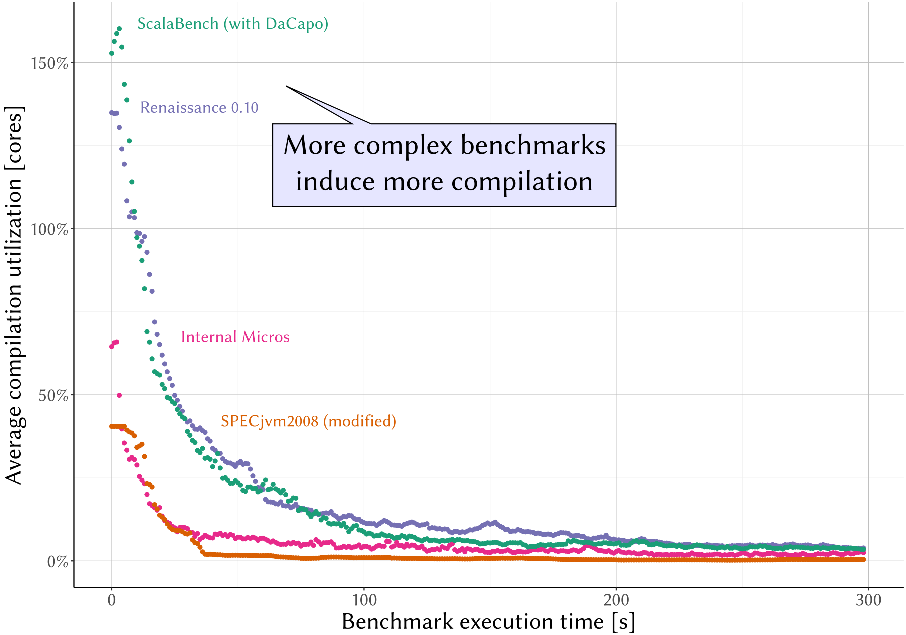
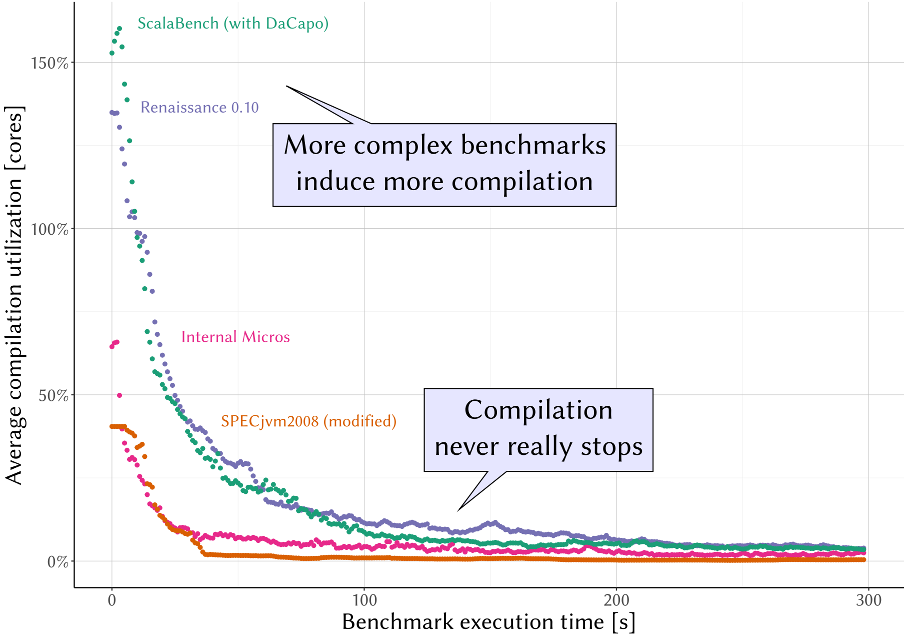


More complex benchmarks induce more compilation

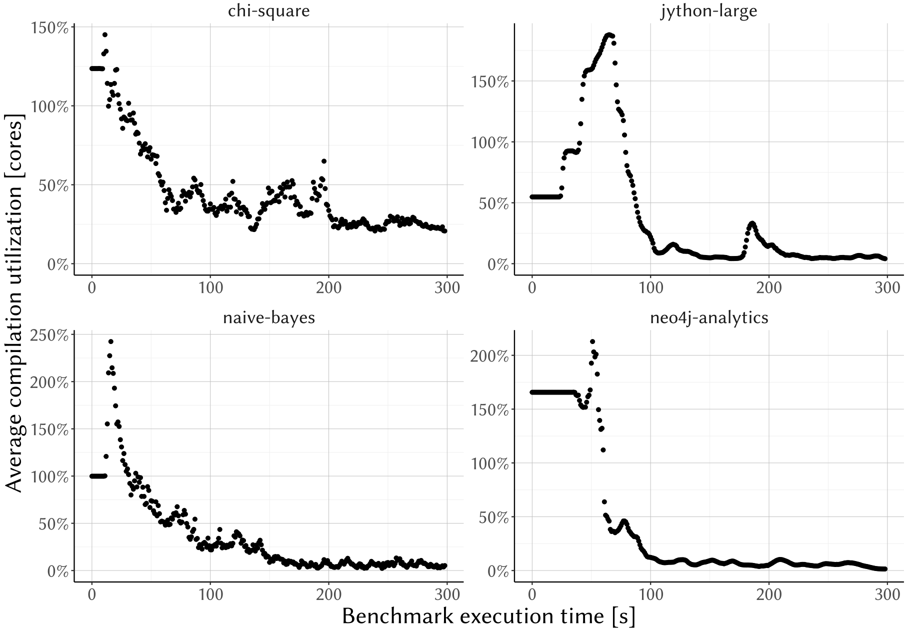
How Much Compilation On Average ?



More complex benchmarks induce more compilation

Compilation never really stops

How Much Compilation Per Benchmark ?



Detecting Warm Up

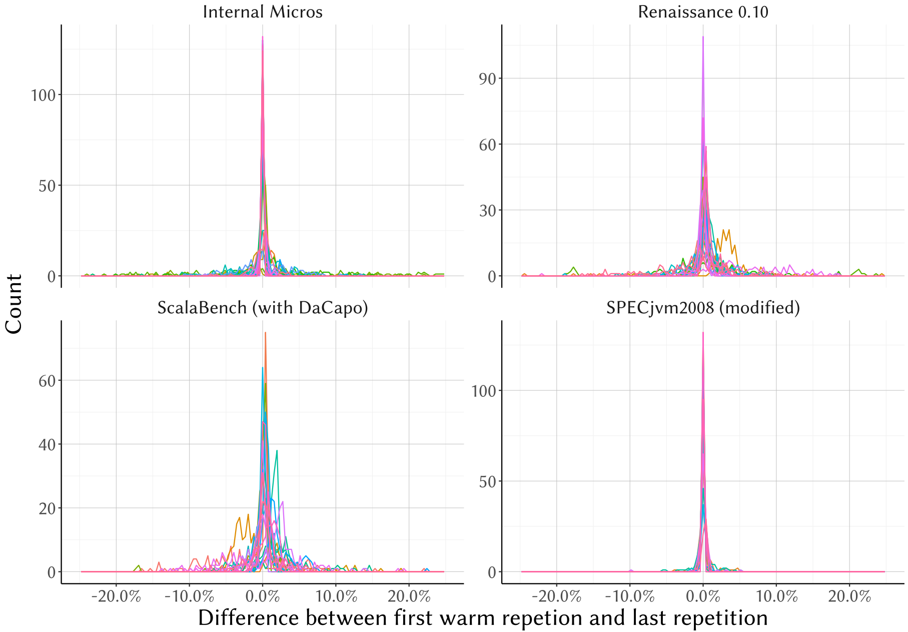
What do we want from warm up ?

- Make sure we measure code produced by the last tier compiler
- Move past the most egregious performance changes
- Do not waste too much time on warm up

What we do

- Monitor activity of background compiler threads
- Establish thresholds across 60 s sliding window
- The first window with activity within 10 % of minimum is warm
  - The algorithm is not online
  - Used with runs of 300 s to 600 s
  - Will always identify some repetitions as warm

Do We Warm Up Enough ?



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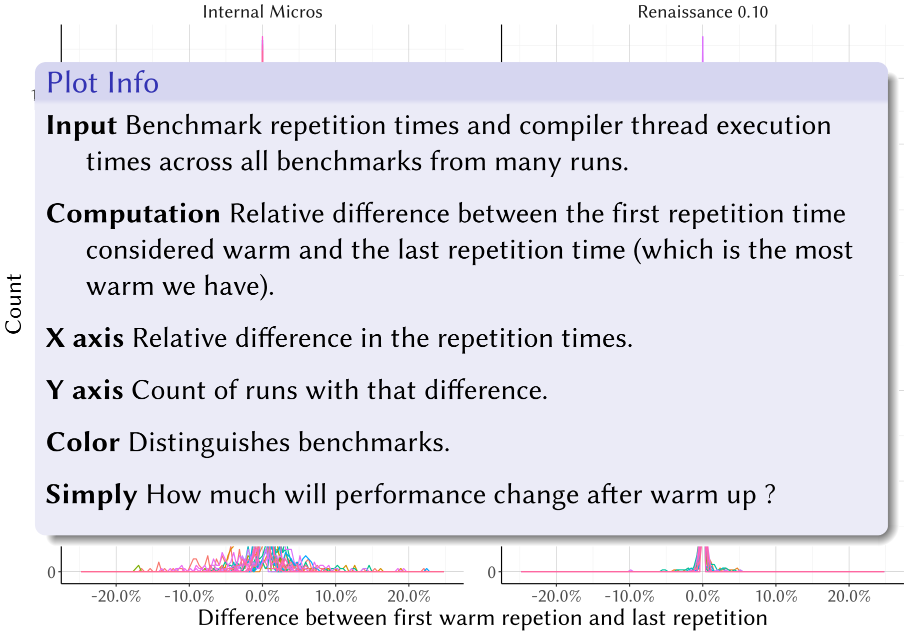


Plot Info

Input Benchmark repetition times and compiler thread execution times across all benchmarks from many runs.

Computation Relative difference between the first repetition time considered warm and the last repetition time (which is the most warm we have).

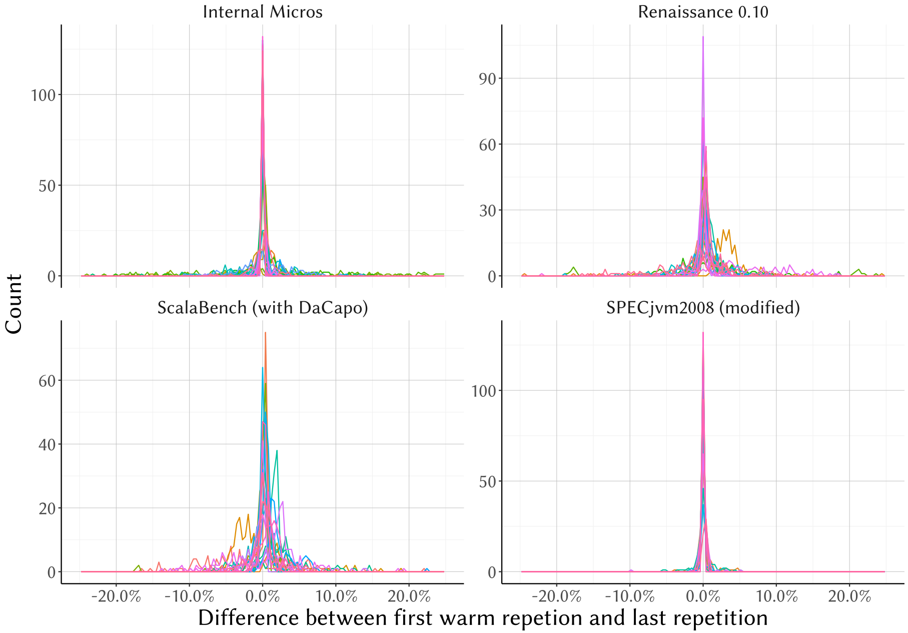
X axis Relative difference in the repetition times.

Y axis Count of runs with that difference.

Color Distinguishes benchmarks.

Simply How much will performance change after warm up ?

Do We Warm Up Enough ?



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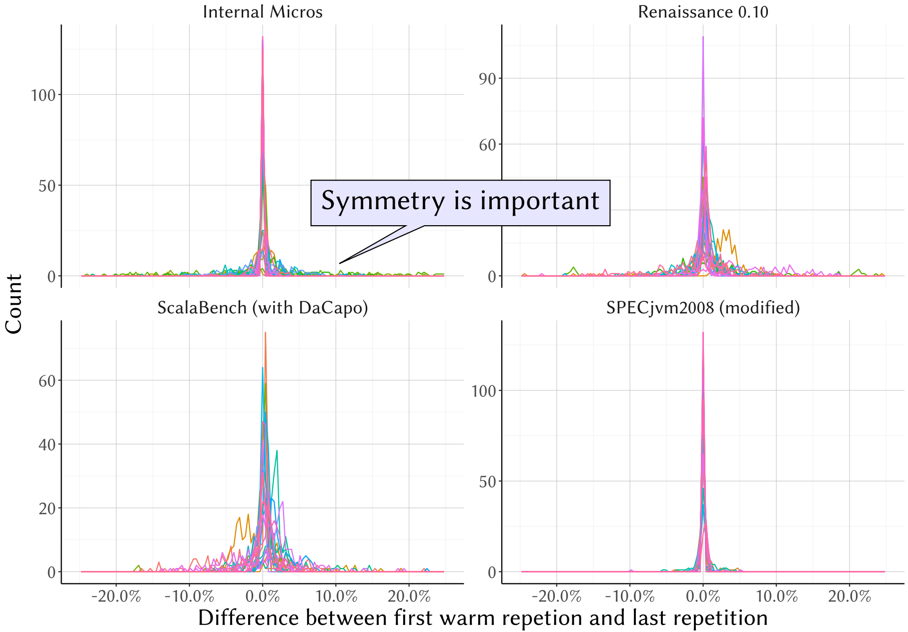
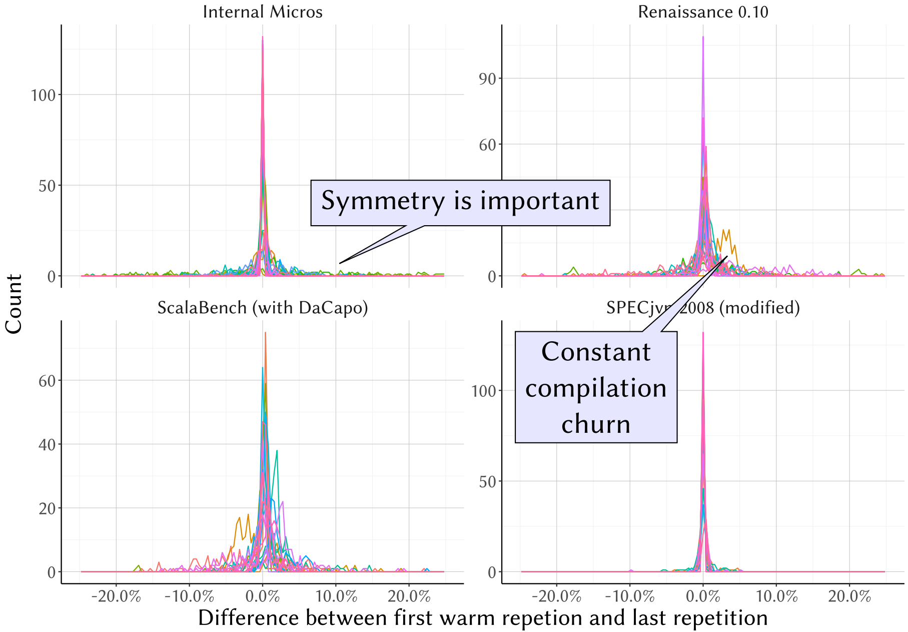


Symmetry is important

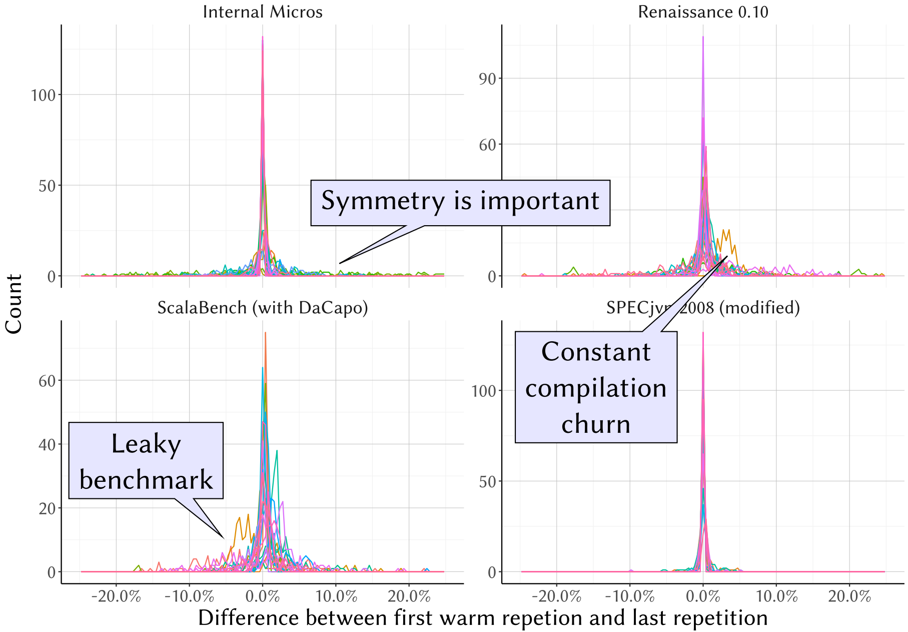
Do We Warm Up Enough ?



Symmetry is important

Constant compilation churn

Do We Warm Up Enough ?

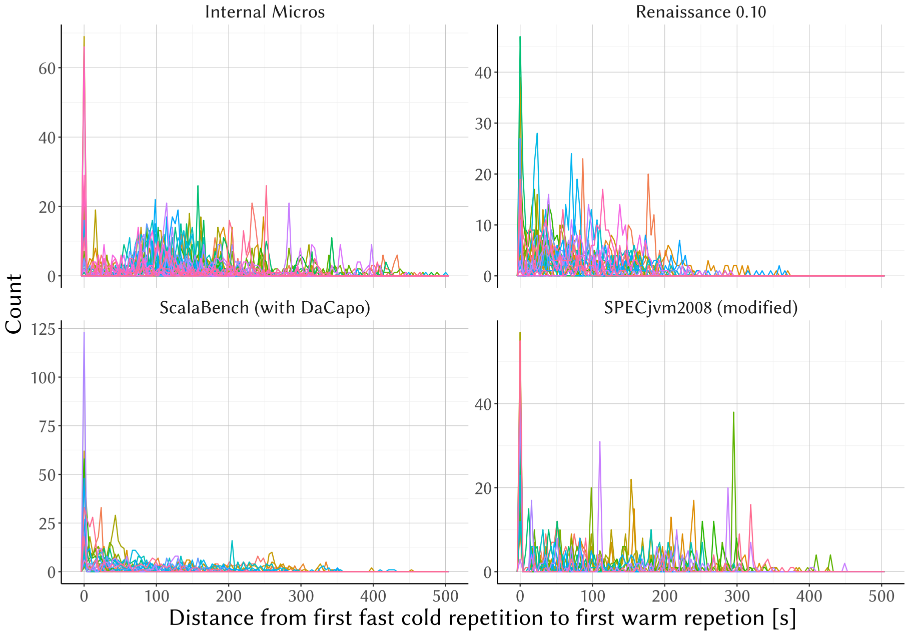


Symmetry is important

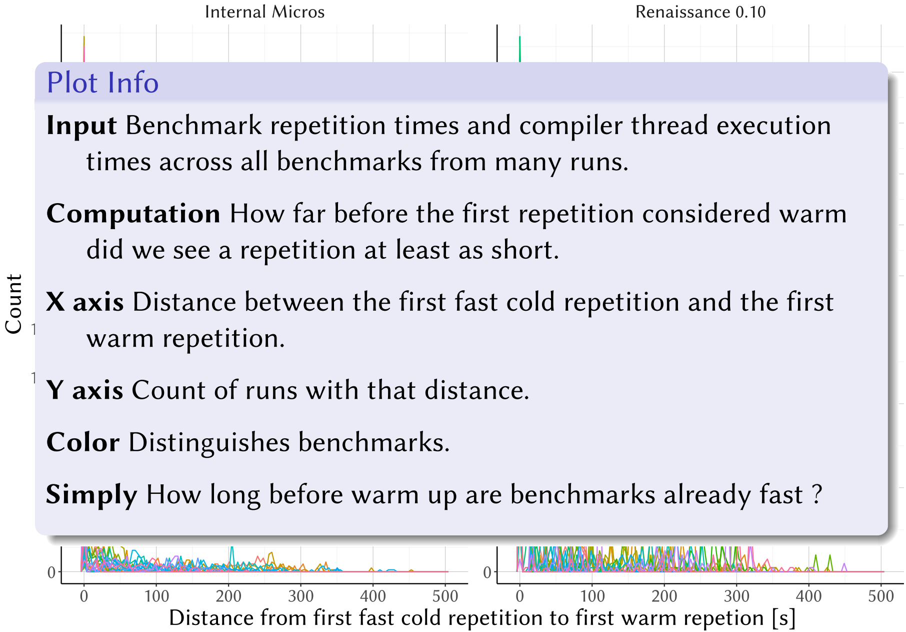
Constant compilation churn

Leaky benchmark

Do We Warm Up Too Much ?



Do We Warm Up Too Much ?



Plot Info

Input Benchmark repetition times and compiler thread execution times across all benchmarks from many runs.

Computation How far before the first repetition considered warm did we see a repetition at least as short.

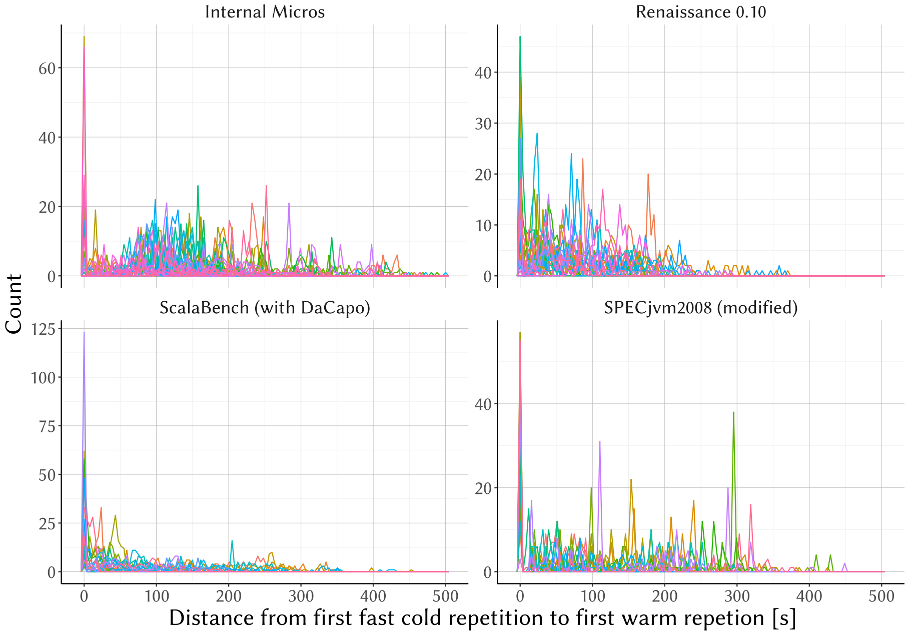
X axis Distance between the first fast cold repetition and the first warm repetition.

Y axis Count of runs with that distance.

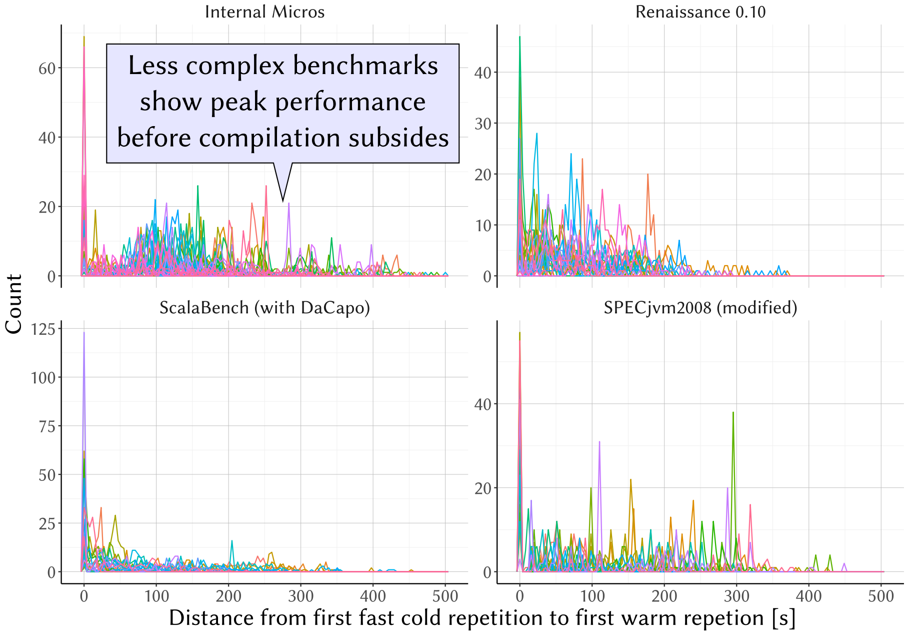
Color Distinguishes benchmarks.

Simply How long before warm up are benchmarks already fast ?

Do We Warm Up Too Much ?

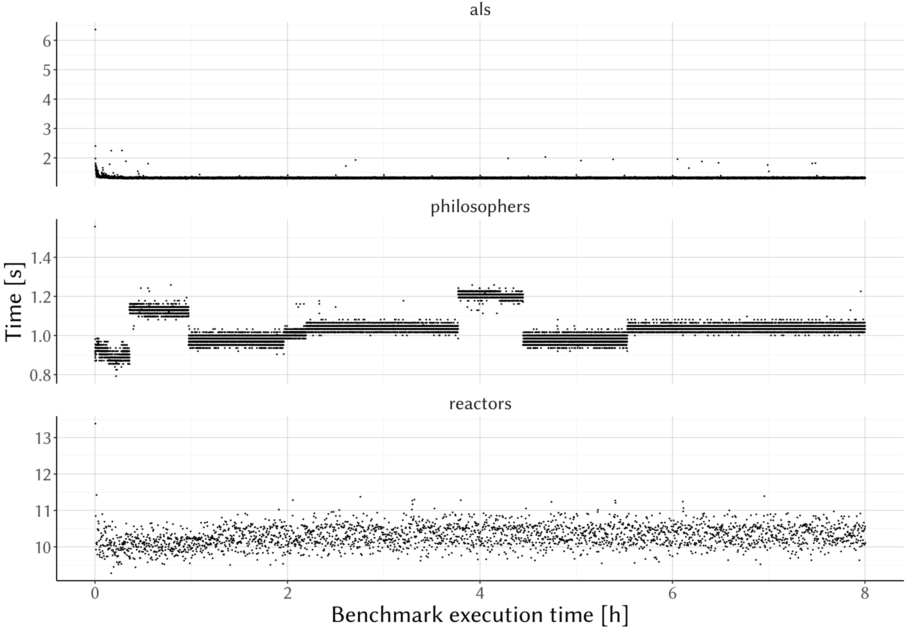


Do We Warm Up Too Much ?



Less complex benchmarks show peak performance before compilation subsides

What About (Much) Longer Warm Up ?



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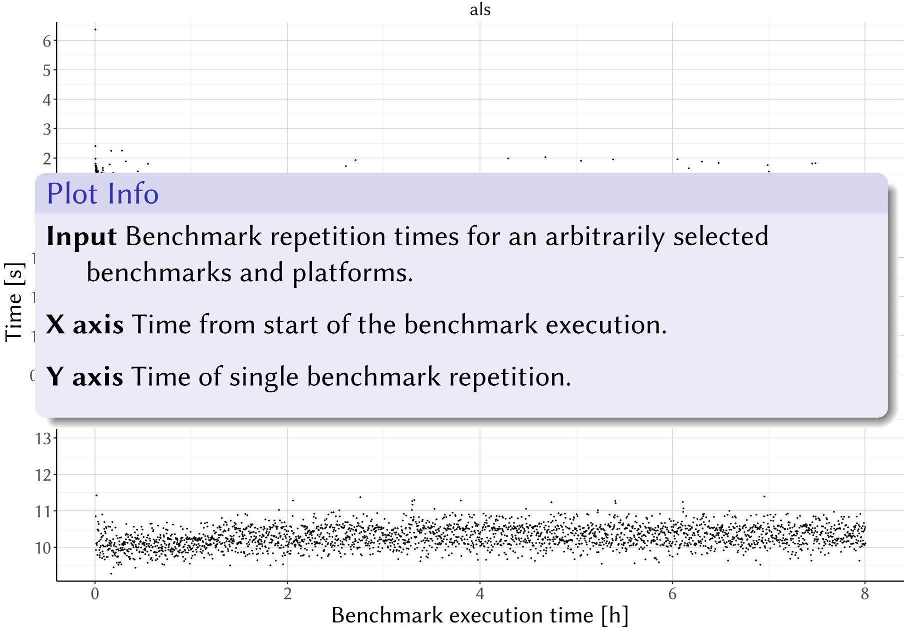

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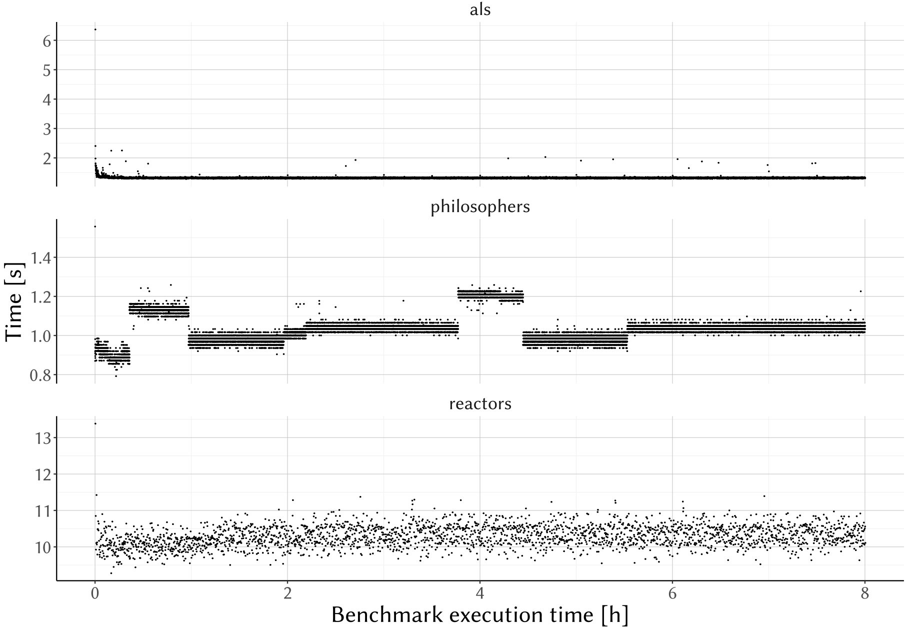

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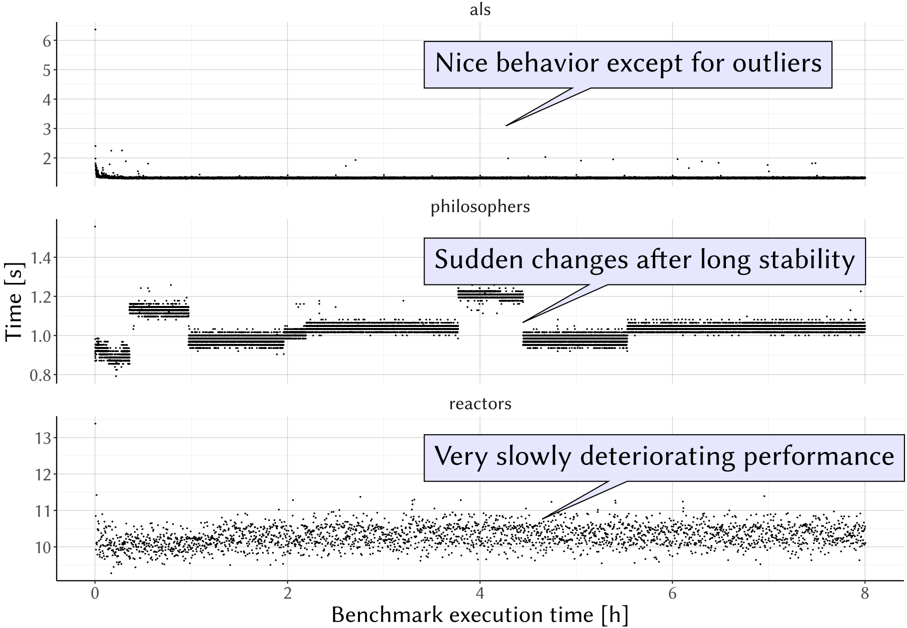


Nice behavior except for outliers

Sudden changes after long stability

Very slowly deteriorating performance

Take Away So Far …

Some warm up properties complicate detection from time measurements

- Performance can change at any time into benchmark execution
- Performance changes possibly rather sudden
- Performance changes in both directions

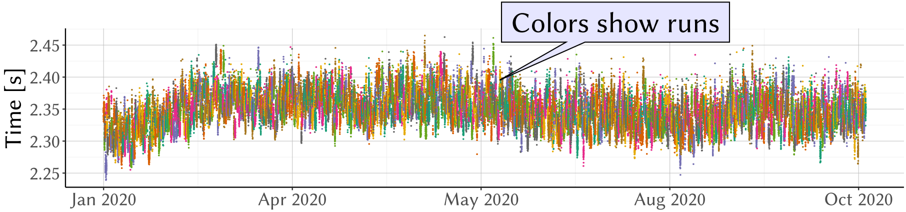
Reaching measurement stability not really the goal here

- Looking (only) at repetition times possibly wrong
- Warm up detection surprisingly important
  - Too much warmup is prohibitive resource hog
  - Too little warmup produces useless measurements

Outline

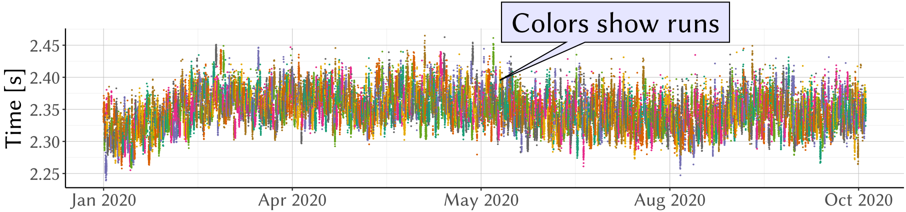
1. Quick Platform Overview
2. Handling Warm Up
3. Detecting Changes
4. Handling More Runs
5. Handling Different Metrics
6. Troublesome Performance Changes

Detecting Changes



https://doi.org/10.1007/s10515-015-0188-0

Detecting Changes



A time series change point detection problem with a few twists

- We have more correlated time series rather than just one
- We can add more data points to any version if required
- Data points are in fact hierarchical sets from runs
- We are more interested in changes near series end
- Almost no assumptions about data distribution

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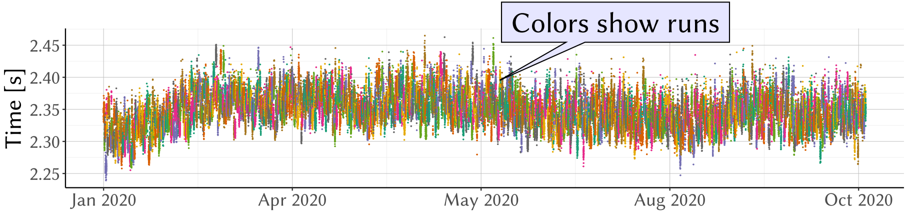
Detecting Changes



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- Almost no assumptions about data distribution

We use bootstrap confidence intervals of mean differences

https://doi.org/10.1007/s10515-015-0188-0

Detected Changes In Numbers

What share of versions have changes and how reliably are they detected ?

Renaissance 0.10			
bench	R	D	I
aka-uct	1%	100%	0%
als	5%	100%	0%
chi-sqr	2%	100%	0%
db-shot	2%		
dec-tre	2%	100%	0%
dotty	5%		
fin-chi	1%	100%	0%
fin-htt	3%	100%	0%
fj-kmns	5%	100%	0%
fut-gen	0%		
gauss	1%		
log-reg	6%	100%	0%
mne	5%	100%	0%
mov-len	6%		
nai-bay	2%		
neo-ana	4%	100%	0%
pg-rank	1%	100%	0%
par-mne	4%	100%	0%
philos	2%		
reactr	2%	100%	0%
rx-scrb	4%	100%	0%
sc-doku	1%	50%	50%
sc-kmns	6%		
sc-stmb	1%		
scrb	5%	100%	0%

ScalaBench (with DaCapo)			
bench	R	D	I
appar-d	3%	100%	0%
avror-l	1%		
batik-s	3%	67%	33%
eclps-s	1%		
factr-d	1%	100%	0%
fop-d	2%	100%	0%
h2-d	2%	100%	0%
jythn-l	1%	100%	0%
kiama-d	2%	89%	11%
luidx-d	1%	100%	0%
lusrc-l	2%	50%	44%
pmd-l	3%	67%	33%
scc-l	1%	100%	0%
scdoc-l	1%	100%	0%
scp-l	2%	17%	83%
scrfm-h	2%	50%	50%
scxb-h	2%	92%	8%
specs-l	1%	100%	0%
sunfl-l	2%	100%	0%
tmt-d	3%	25%	75%
trdb-d	1%	100%	0%
trds-l	2%	89%	11%
xalan-l	2%	90%	10%

SPECjvm2008 (modified)			
bench	R	D	I
cmp.cmp	2%		
cmp.sun	2%		
compr	4%	75%	25%
cry.aes	4%	100%	0%
cry.rsa	2%	100%	0%
cry.sgn	4%	75%	25%
derby	1%	60%	40%
mpega	4%	100%	0%
sci.ffl	1%	67%	33%
sci.lul	1%	50%	0%
sci.mtc	3%	88%	12%
sci.sol	3%	100%	0%
sci.spl	4%	100%	0%
serial	2%	75%	25%
sunflow	3%	100%	0%
xml.trn	3%	50%	50%
xml.val	2%	75%	25%

Internal Micros			
bench	R	D	I
StrDev	4%	33%	67%
SFndNeg	3%	36%	50%
SFldSum	3%	25%	50%
SForSum	3%	42%	11%
SMapRed	3%	43%	21%
STwoAvg	4%	60%	30%
TSP	4%	100%	0%
TxtSDF	2%	80%	10%
TxtRDD	2%	100%	0%
WrdCnt	1%	100%	0%
BufDec	6%	78%	15%
BufEnc	6%	88%	12%
ChrCnt	2%	100%	0%
ChrHis	3%	73%	20%
FJHis	7%	100%	0%
FJStr	7%	100%	0%
FltOdd	12%	50%	50%
FndNgt	3%	62%	8%
FntNgtR	2%	50%	0%
FldSum	3%	100%	0%
FldSumR	0%	0%	33%
ForSum	1%	50%	0%
ForSumR	2%	12%	75%
GrpRem	5%	85%	0%
MapOne	7%	76%	14%
NetDot	3%	57%	0%
NetEig	2%	62%	25%
Reduce	1%	50%	50%
STMLst	2%	50%	0%
STMMap	3%	100%	0%
Scan	1%	43%	57%
SrtRDD	2%	70%	30%
StdDev	3%	25%	44%
StrCnt	2%	50%	50%
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R - versions with changes D - manually confirmed I - invalid situations

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fut-gen	0%		
gauss	1%		
log-reg	6%	100%	0%
mne	[illegible]	100%	0%
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
pg-rank	1%	100%	0%
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philos	2%		
reactr	2%	100%	0%
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fop-d	2%	100%	0%
h2-d	2%	100%	0%
jythn-l	1%	100%	0%
[illegible]d	2%	89%	11%
[illegible]d	1%	100%	0%
[illegible]l	2%	50%	44%
pmd-l	3%	67%	33%
scc-l	1%	100%	0%
scdoc-l	1%	100%	0%
scp-l	2%	17%	83%
scrfm-h	2%	50%	50%
scxb-h	2%	92%	8%
specs-l	1%	100%	0%
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cry.sgn	4%	75%	25%
derby	1%	60%	40%
mpega	4%	100%	0%
sci.ffl	1%	67%	33%
sci.lul	1%	50%	0%
sci.mtc	3%	88%	12%
sci.sol	3%	100%	0%
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TxtSDF	2%	80%	10%
TxtRDD	2%	100%	0%
WrdCnt	1%	100%	0%
BufDec	6%	78%	15%
BufEnc	6%	88%	12%
ChrCnt	2%	100%	0%
ChrHis	3%	73%	20%
FJHis	7%	100%	0%
FJStr	7%	100%	0%
FltOdd	12%	50%	50%
FndNgt	3%	62%	8%
FntNgtR	2%	50%	0%
FldSum	3%	100%	0%
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Most benchmarks exhibit changes

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Detection mostly reliable enough

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mne	[illegible]	100%	0%
pg-rank	1%	100%	0%
par-mne	4%	100%	0%
philos	2%		
reactr	2%	100%	0%
rx-scrb	4%	100%	0%
sc-doku	1%	50%	50%
sc-kmns	6%		
sc-stmb	1%		
scrb	5%	100%	0%

ScalaBench (with DaCapo)			
bench	R	D	I
appar-d	3%	100%	0%
avror-l	1%		
batik-s	3%	67%	33%
eclps-s	1%		
factr-d	1%	100%	0%
fop-d	2%	100%	0%
h2-d	2%	100%	0%
jythn-l	1%	100%	0%
d	2%	89%	11%
d	1%	100%	0%
l	2%	50%	44%
pmd-l	3%	67%	33%
scc-l	1%	100%	0%
scdoc-l	1%	100%	0%
scp-l	2%	17%	83%
scrfm-h	2%	50%	50%
scxb-h	2%	92%	8%
specs-l	1%	100%	0%
sunfl-l	2%	100%	0%
tmt-d	3%	25%	75%
trdb-d	1%	100%	0%
trds-l	2%	89%	11%
xalan-l	2%	90%	10%

SPECjvm2008 (modified)			
bench	R	D	I
cmp.cmp	2%		
cmp.sun	2%		
compr	4%	75%	25%
cry.aes	4%	100%	0%
cry.rsa	2%	100%	0%
cry.sgn	4%	75%	25%
derby	1%	60%	40%
mpega	4%	100%	0%
sci.ffl	1%	67%	33%
sci.lul	1%	50%	0%
sci.mtc	3%	88%	12%
sci.sol	3%	100%	0%
sci.spl	4%	100%	0%
serial	2%	75%	25%
sunflow	3%	100%	0%
xml.trn	3%	50%	50%
xml.val	2%	75%	25%

Internal Micros			
bench	R	D	I
StrDev	4%	33%	67%
SFndNeg	3%	36%	50%
SFldSum	3%	25%	50%
SForSum	3%	42%	11%
SMapRed	3%	43%	21%
STwoAvg	4%	60%	30%
TSP	4%	100%	0%
TxtSDF	2%	80%	10%
TxtRDD	2%	100%	0%
WrdCnt	1%	100%	0%
BufDec	6%	78%	15%
BufEnc	6%	88%	12%
ChrCnt	2%	100%	0%
ChrHis	3%	73%	20%
FJHis	7%	100%	0%
FJStr	7%	100%	0%
FltOdd	12%	50%	50%
FndNgt	3%	62%	8%
FntNgtR	2%	50%	0%
FldSum	3%	100%	0%
FldSumR	0%	0%	33%
ForSum	1%	50%	0%
ForSumR	2%	12%	75%
GrpRem	5%	85%	0%
MapOne	7%	76%	14%
NetDot	3%	57%	0%
NetEig	2%	62%	25%
Reduce	1%	50%	50%
STMLst	2%	50%	0%
STMMap	3%	100%	0%
Scan	1%	43%	57%
SrtRDD	2%	70%	30%
StdDev	3%	25%	44%
StrCnt	2%	50%	50%
StrDem	2%	50%	0%
StrPer	4%	93%	0%

R - versions with changes

D - manually confirmed

I - invalid situations

Detected Changes In Numbers

What share of versions have changes and how reliably are they detected ?

Renaissance 0.10			
bench	R	D	I
aka-uct	1%	100%	0%
als	5%	100%	0%
chi-sqr	[illegible]	100%	0%
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
fin-chi	1%	100%	0%
fin-htt	3%	100%	0%
fj-kmns	5%	100%	0%
fut-gen	0%		
gauss	1%		
log-reg	6%	100%	0%
mne	[illegible]	100%	0%
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
pg-rank	1%	100%	0%
par-mne	4%	100%	0%
philos	2%		
reactr	2%	100%	0%
rx-scrb	4%	100%	0%
sc-doku	1%	50%	50%
sc-kmns	6%		
sc-stmb	1%		
scrb	5%	100%	0%

ScalaBench (with DaCapo)			
bench	R	D	I
appar-d	3%	100%	0%
avror-l	1%		
batik-s	3%	67%	33%
eclps-s	1%		
factr-d	1%	100%	0%
fop-d	2%	100%	0%
h2-d	2%	100%	0%
jythn-l	1%	100%	0%
[illegible]d	2%	89%	11%
[illegible]d	1%	100%	0%
[illegible]l	2%	50%	44%
pmd-l	3%	67%	33%
scc-l	1%	100%	0%
scdoc-l	1%	100%	0%
scp-l	2%	17%	83%
scrfm-h	2%	50%	50%
scxb-h	2%	92%	8%
specs-l	1%	100%	0%
sunfl-l	2%	100%	0%
tmt-d	3%	25%	75%
trdb-d	1%	100%	0%
trds-l	2%	89%	11%
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cmp.cmp	2%		
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compr	4%	75%	25%
cry.aes	4%	100%	0%
cry.rsa	2%	100%	0%
cry.sgn	4%	75%	25%
derby	1%	60%	40%
mpega	4%	100%	0%
sci.ffl	1%	67%	33%
sci.lul	1%	50%	0%
sci.mtc	3%	88%	12%
sci.sol	3%	100%	0%
sci.spl	4%	100%	0%
serial	2%	75%	25%
sunflow	3%	100%	0%
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Internal Micros			
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StrDev	4%	33%	67%
SFndNeg	3%	36%	50%
SFldSum	3%	25%	50%
SForSum	3%	42%	[illegible]
SMapRed	3%	43%	[illegible]
STwoAvg	4%	60%	[illegible]
TSP	4%	100%	0%
TxtSDF	2%	80%	10%
TxtRDD	2%	100%	0%
WrdCnt	1%	100%	0%
BufDec	6%	78%	15%
BufEnc	6%	88%	12%
ChrCnt	2%	100%	0%
ChrHis	3%	73%	20%
FJHis	7%	100%	0%
FJStr	7%	100%	0%
FltOdd	12%	50%	50%
FndNgt	3%	62%	8%
FntNgtR	2%	50%	0%
FldSum	3%	100%	0%
FldSumR	0%	0%	33%
ForSum	1%	50%	0%
ForSumR	2%	12%	75%
GrpRem	5%	85%	0%
MapOne	7%	76%	14%
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
STMEst	2%	50%	0%
STMMap	3%	100%	0%
Scan	1%	43%	57%
SrtRDD	2%	70%	30%
StdDev	3%	25%	44%
StrCnt	2%	50%	50%
StrDem	2%	50%	0%
StrPer	4%	93%	0%

Detection mostly reliable enough

Most benchmarks exhibit changes

Microbenchmarks sometimes misbehave

R - versions with changes D - manually confirmed I - invalid situations

Manual Change Classification

We examined all detected performance changes in ad hoc version intervals

- Benchmarks not necessarily represented equally
- More measurements added when not sure

We have no classification information about false negatives

- Likely impacts especially small changes relative to variance

Manual Change Classification

We examined all detected performance changes in ad hoc version intervals

- Benchmarks not necessarily represented equally
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We have no classification information about false negatives

- Likely impacts especially small changes relative to variance

Plot Info

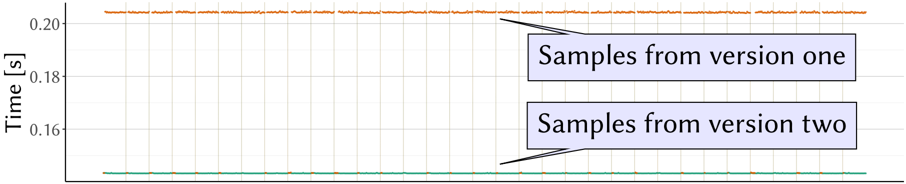
Input Benchmark repetition times for arbitrarily selected pairs of platform versions with suspected change.

X axis Benchmark repetitions and runs ordered sequentially.

Y axis Time of single benchmark repetition.

Color Distinguishes versions.

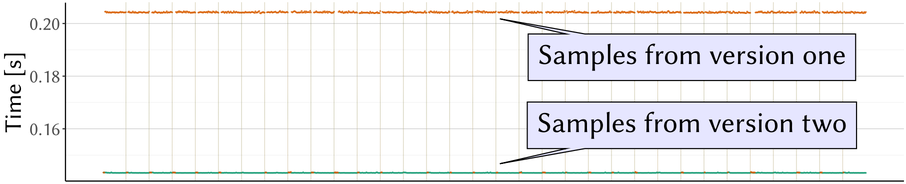
Classification Example: Trivial



Samples from version one

Samples from version two

Classification Example: Trivial



Samples from version one

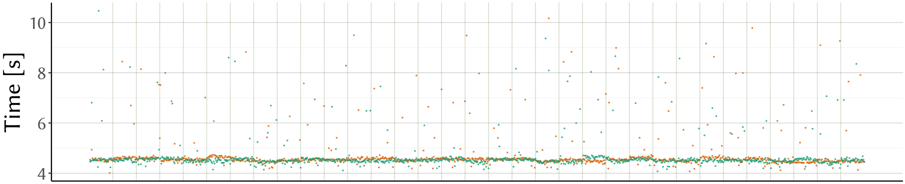
Samples from version two

An obvious difference that is trivial to classify

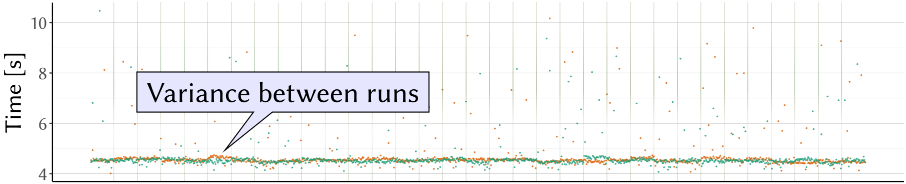
- Very low variance both within run and between runs
- Difference of large relative magnitude

If all data looked like this we would have little to talk about ...

Classification Example: Small Change



Classification Example: Small Change

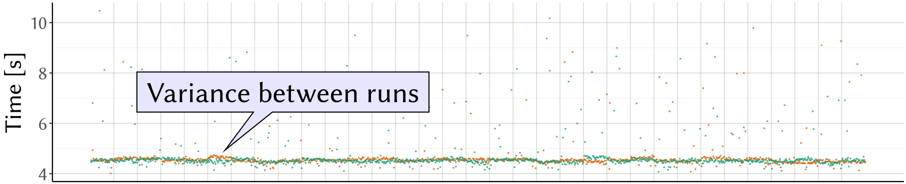


Variance between runs

Computed difference in average repetition time around 0.6 %

- Variance between runs large relative to the computed difference
- Outliers large relative to the computed difference
- Maybe we need more data ?

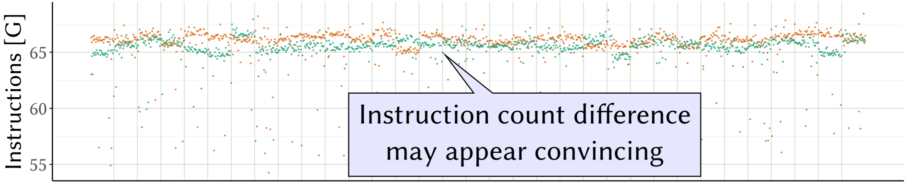
Classification Example: Small Change



Variance between runs

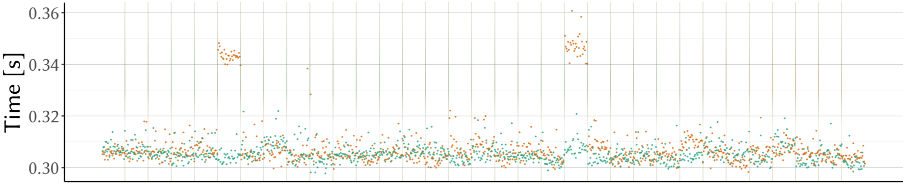
Computed difference in average repetition time around 0.6 %

- Variance between runs large relative to the computed difference
- Outliers large relative to the computed difference
- Maybe we need more data ?

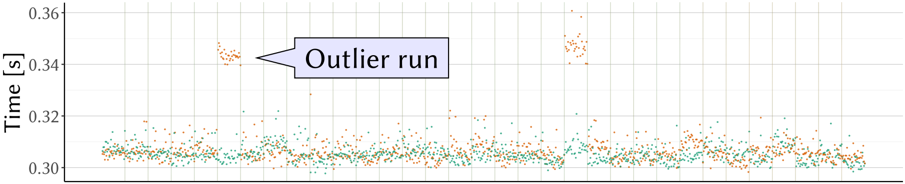


Instruction count difference may appear convincing

Classification Example: Outlier Definition Issues



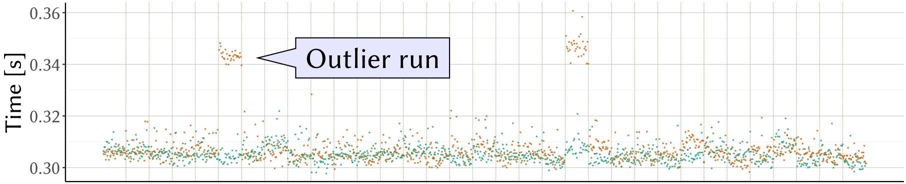
Classification Example: Outlier Definition Issues



Computed difference in average repetition time around 0.9 %

- The computed difference very much depends on outlier filtering
- Are we sure we have enough data ?

Classification Example: Outlier Definition Issues



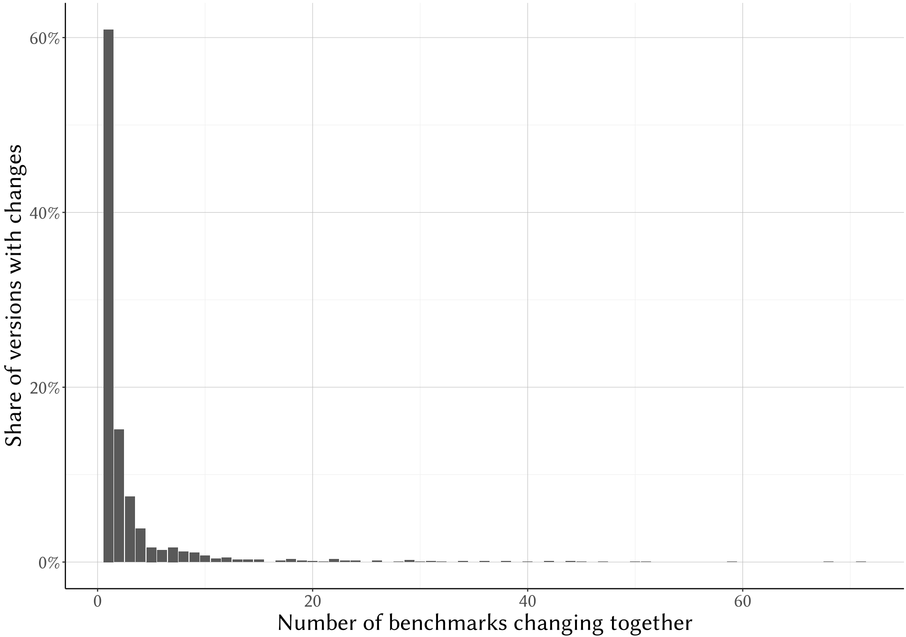
Computed difference in average repetition time around 0.9 %

- The computed difference very much depends on outlier filtering
- Are we sure we have enough data ?

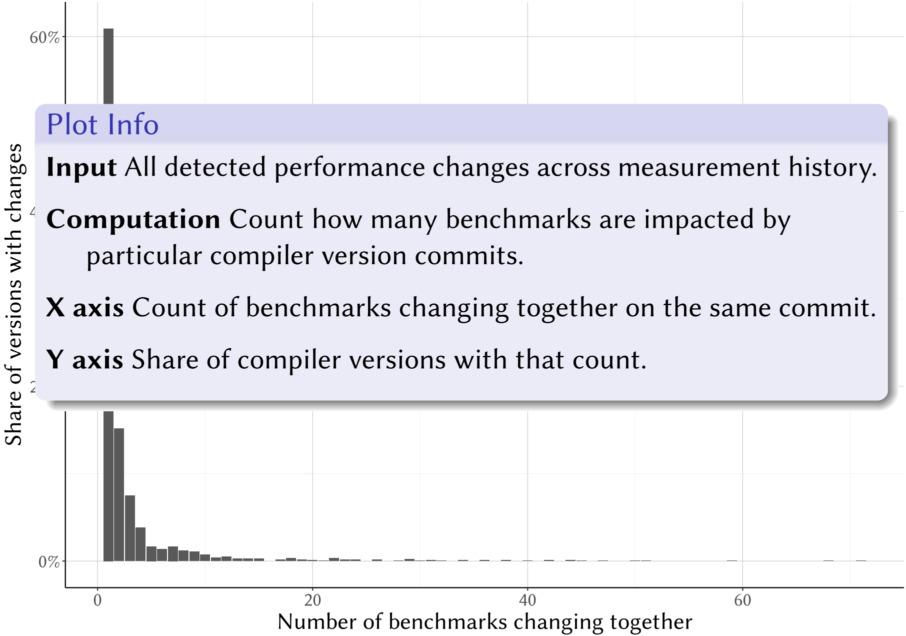
Assume 10 % change in outlier runs and 10 % chance of such runs

- This would result in an average repetition time change of 0.9 %
- There is around 35 % chance of getting 10 fine runs
- Obviously the example can be stretched in various directions

Do We Have Too Many Benchmarks ?



Do We Have Too Many Benchmarks ?



Plot Info

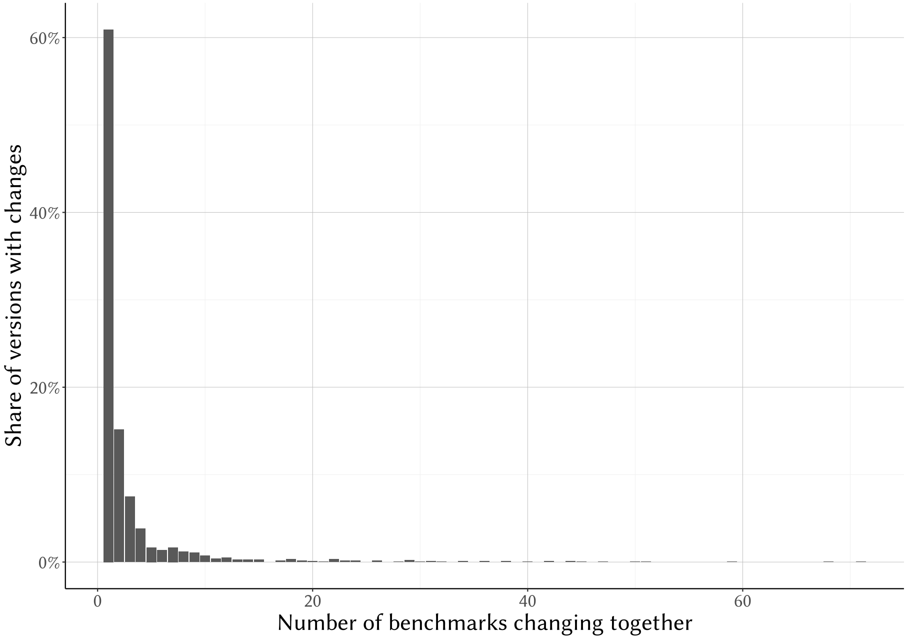
Input All detected performance changes across measurement history.

Computation Count how many benchmarks are impacted by particular compiler version commits.

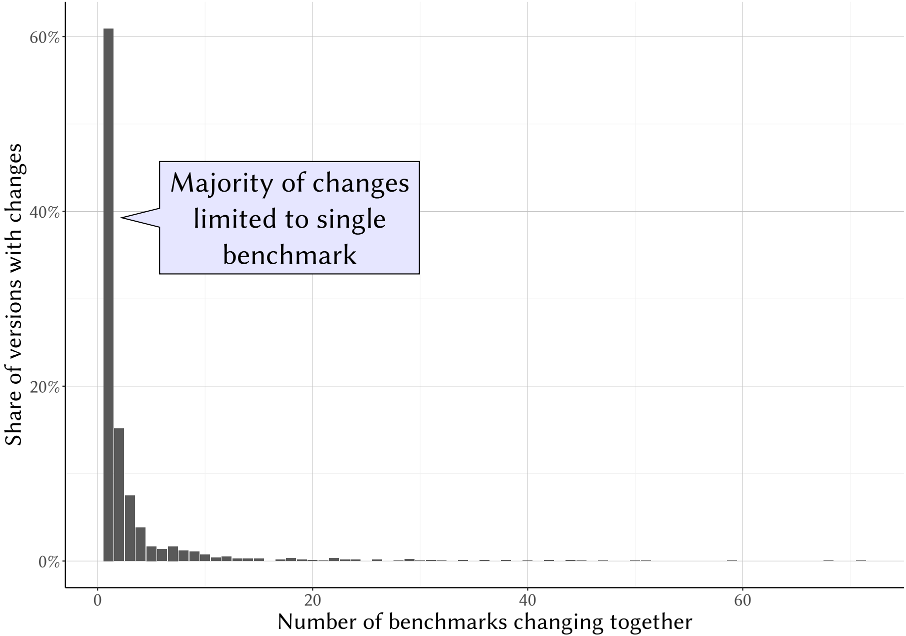
X axis Count of benchmarks changing together on the same commit.

Y axis Share of compiler versions with that count.

Do We Have Too Many Benchmarks ?

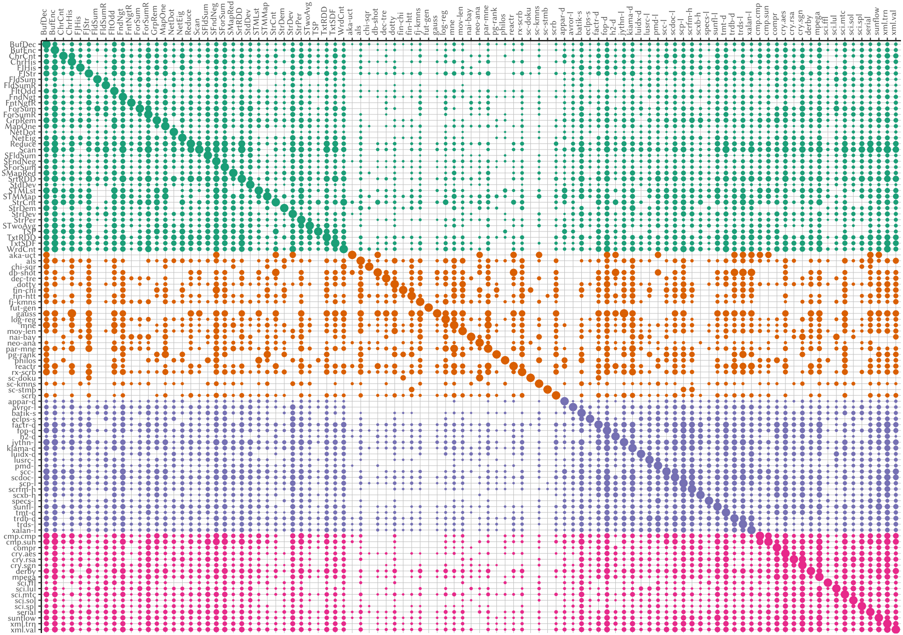


Do We Have Too Many Benchmarks ?

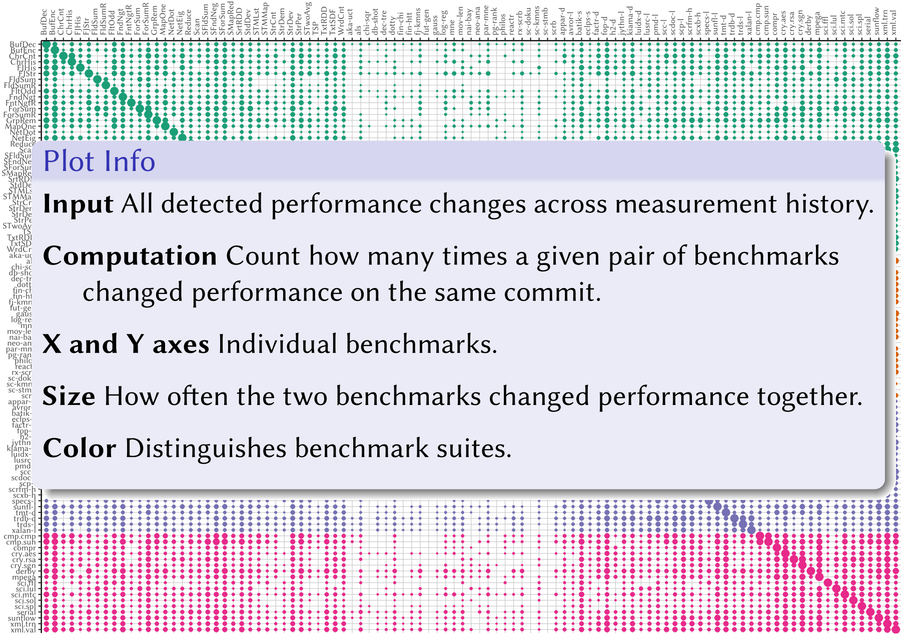


Majority of changes limited to single benchmark

Do Benchmarks Change Together ?



Do Benchmarks Change Together ?



Plot Info

Input All detected performance changes across measurement history.

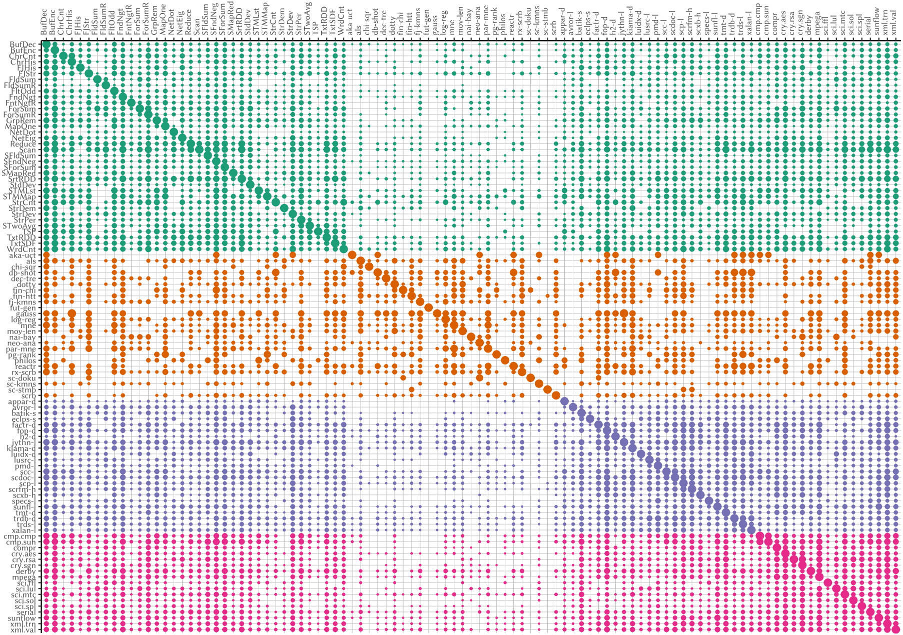
Computation Count how many times a given pair of benchmarks changed performance on the same commit.

X and Y axes Individual benchmarks.

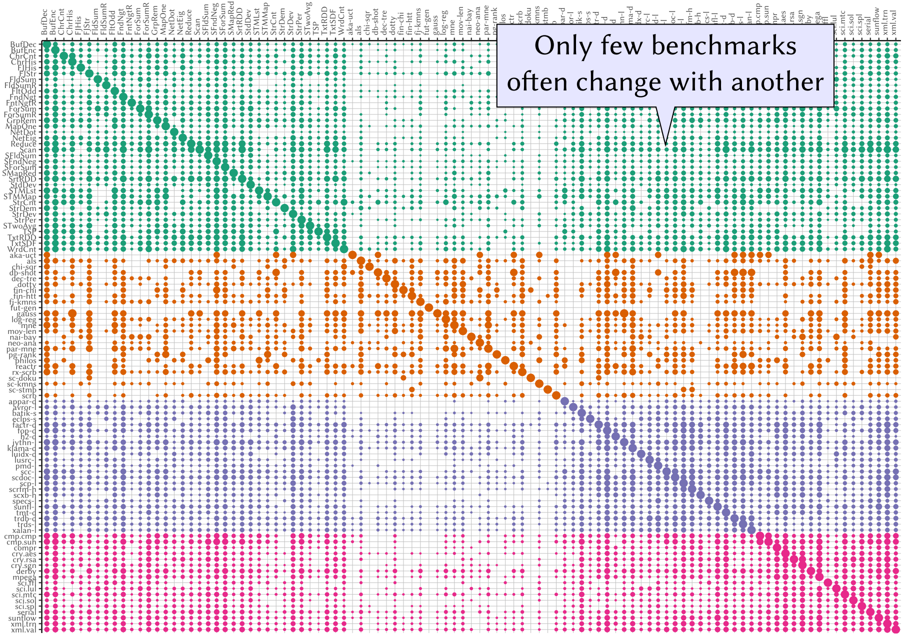
Size How often the two benchmarks changed performance together.

Color Distinguishes benchmark suites.

Do Benchmarks Change Together ?

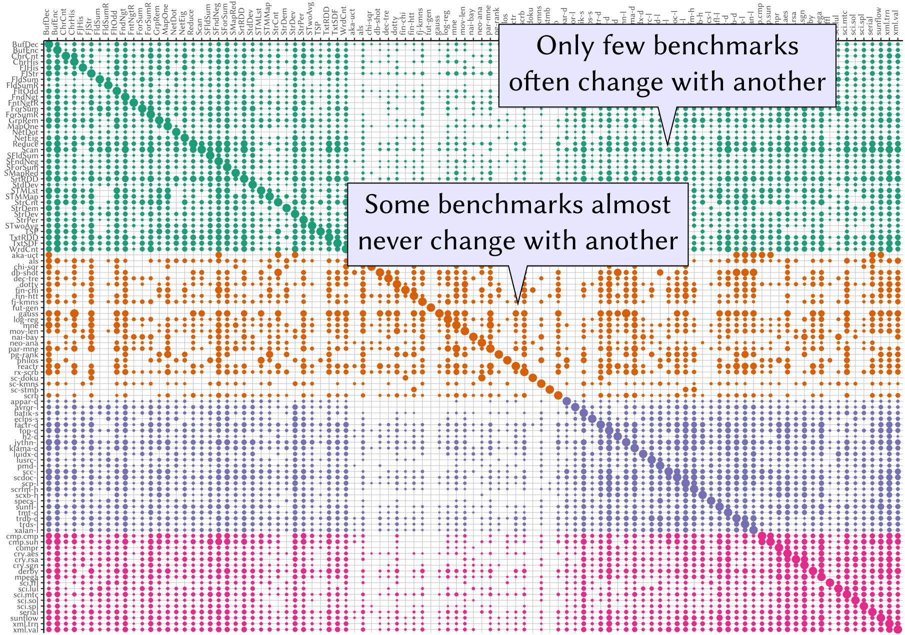


Do Benchmarks Change Together ?



Only few benchmarks often change with another

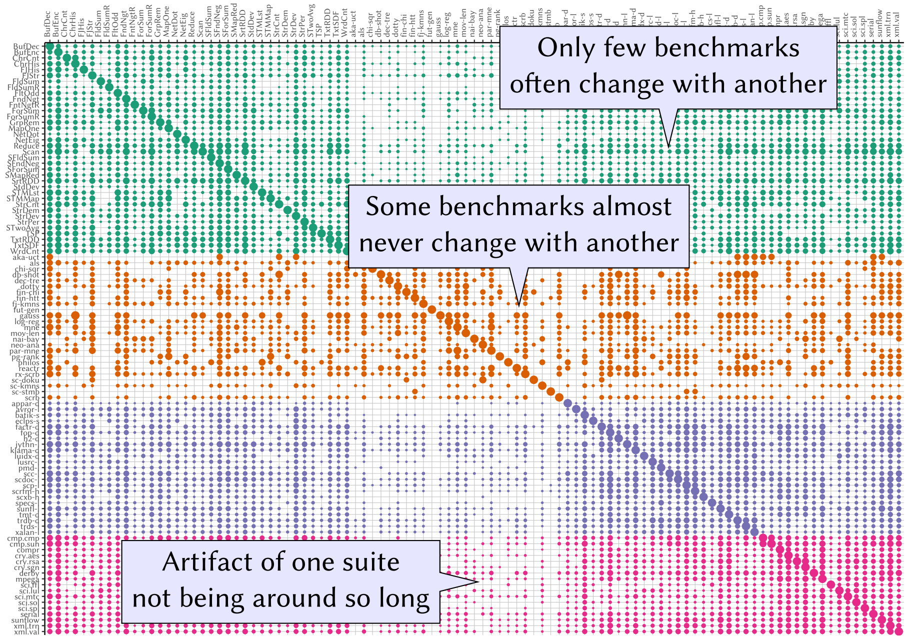
Do Benchmarks Change Together ?



Only few benchmarks often change with another

Some benchmarks almost never change with another

Do Benchmarks Change Together ?



Only few benchmarks often change with another

Some benchmarks almost never change with another

Artifact of one suite not being around so long

Take Away So Far ...

We probably do not have too many (or even enough) benchmarks

- Overlap in performance changes relatively rare
- Not really clear how to define coverage !

Change detection reliability per se not an issue

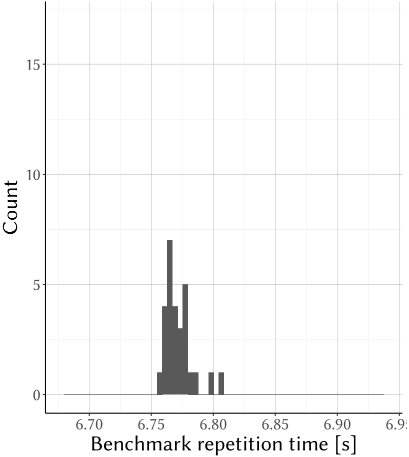
- Change definition issues beyond math
- Requires reasonable measurement procedure
- Some benchmarks may require special attention

Outline

1. Quick Platform Overview
2. Handling Warm Up
3. Detecting Changes
4. Handling More Runs
5. Handling Different Metrics
6. Troublesome Performance Changes

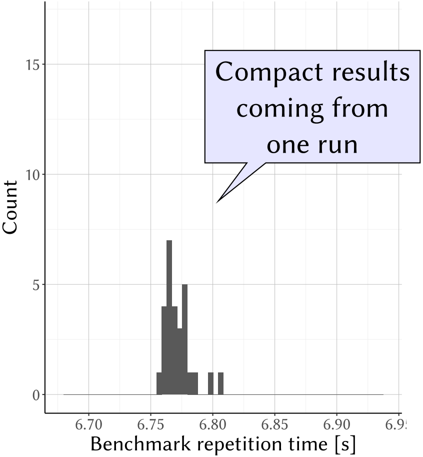
Handling More Runs

A single benchmark run does not really tell the whole story ...



Handling More Runs

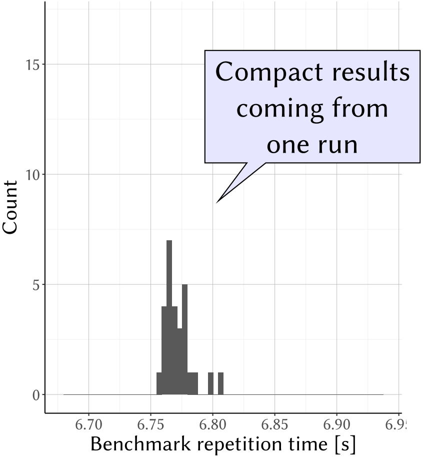
A single benchmark run does not really tell the whole story ...



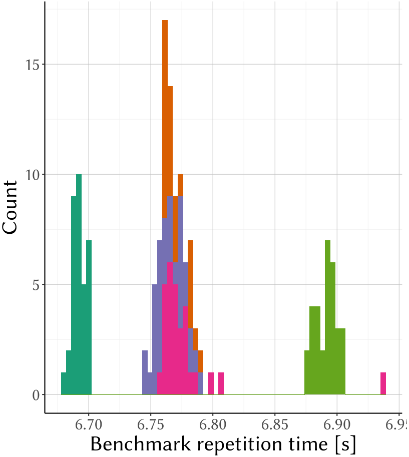
Compact results coming from one run

Handling More Runs

A single benchmark run does not really tell the whole story …



Compact results coming from one run



Handling More Runs

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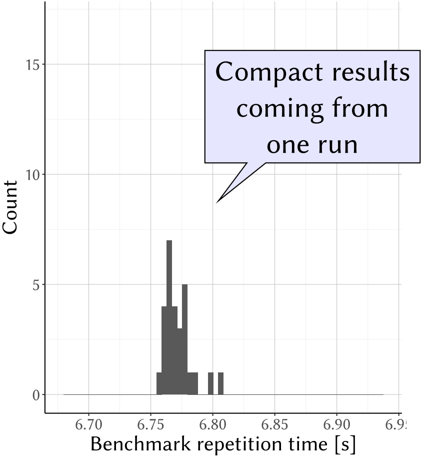
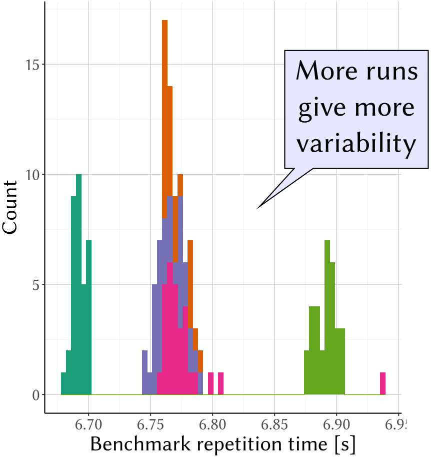


Compact results coming from one run



More runs give more variability

How Many Runs Needed …

… to compute average performance with at most 1 % error in 99 % of cases ?

Renaissance 0.10

bench	C8	C11	E8	E11
aka-uct	15	99+	86	99+
als	6	7	99+	99+
chi-sqr	99+	99+	99+	99+
db-shot	99+	99+	56	39
dec-tre	99+	55	99+	99+
dotty	13	16	21	8
fin-chi	99+	99+	99+	99+
fin-htt	25	21	19	24
fj-kmns	70	6	23	69
fut-gen	99+	99+	99+	99+
gauss	99+	99+	99+	99+
log-reg	10	11	21	40
mne	99+	99+	99+	99+
mov-len	5	8	10	4
nai-bay	10	4	99+	99+
neo-ana	99+	99+	100	99+
pg-rank	99+	99+	99+	62
par-mne	99+	84	99+	38
philos	99+	99+	99+	99+
reactr	36	42	99+	99+
rx-scrb	49	65	26	19
sc-doku	99+	99+	99+	99+
sc-kmns	8	5	27	19
sc-stmb	93	68	99+	99+
scrb	99+	99+	99+	99+

ScalaBench (with DaCapo)

bench	C8	C11	E8	E11
appar-d	99+	99+	27	41
avror-l	8	7	18	7
batik-s	2	1	2	1
eclps-s	10		11	
factr-d	99+	99+	99+	99+
fop-d	17	16	10	25
h2-d	24	32	33	87
jythn-l	31	99+	44	70
kiama-d	39	51	46	18
luidx-d	62	50	23	27
lusrc-l	42	30	27	11
pmd-l	32	61	99+	14
scc-l	99+	99+	23	20
scdoc-l	99+	20	46	19
scp-l	10	19	52	96
scrfm-h	33	13	44	34
scxb-h	99+	99+	99+	99+
specs-l	12	5	11	8
sunfl-l	6	16	99+	18
tmt-d	8	9	19	9
trdb-d	17	26	18	25
trds-l	7	5	3	5
xalan-l	35	26	28	23

SPECjvm2008 (modified)

bench	C8	C11	E8	E11
cmp.cmp	8		5	
cmp.sun	5		16	
compr	4	99+	15	16
cry.aes	13	21	99+	9
cry.rsa	11	9	6	7
cry.sgn	9	13	5	14
derby	28	8	35	70
mpega	1	1	1	2
sci.ffl	99+	99+	99+	99+
sci.lul	1	1	1	1
sci.mtc	12	6	99+	1
sci.sol	1	1	1	1
sci.spl	4	9	1	99+
serial	14	23	99+	99+
sunflow	9	13	7	3
xml.trn	10	7	9	7
xml.val	1	30	16	30

Internal Micros

bench	C8	C11	E8	E11
BufDec	1	93	40	99+
BufEnc	6	1	1	5
ChrHis	99+	99+	52	91
ChrCnt	99+	99+	99+	99+
FltOdd	2	99+	11	1
FndNgt	2	1	1	1
FntNgtR	1	1	1	2
FJHis	2	1	1	3
FJStr	17	7	91	66
FldSum	1	99+	99+	99+
FldSumR	1	1	1	1
ForSum	1	1	99+	99+
ForSumR	99+	1	1	4
GrpRem	99+	99+	5	35
MapOne	99+	99+	99+	99+
NetDot	1	1	12	30
NetEig	1	1	67	19
Reduce	72	99+	99+	99+
STMLst	99+	70	99+	49
STMMap	99+	99+	99+	99
Scan	99+	99+	99+	99+
SrtRDD	99+	99+	99+	99+
StdDev	99+	99+	99+	1
StrCnt	78	45	98	30
StrDem	99+	99+	99+	99+
StrDev	1	1	2	2
SFndNeg	99+	99+	99+	99+
SFldSum	99+	1	99+	99+
SForSum	1	1	35	99+
SMapRed	99+	99+	1	27
StrPer	99+	99+	99+	57
STwoAvg	50	99+	99+	99+
TxtSDF	80	21	99+	45
TxtRDD	99+	99+	53	85
TSP			99+	
WrdCnt	40	25	26	52

How Many Runs Needed …

… to compute average performance with at most 1 % error in 99 % of cases ?

Renaissance 0.10				
bench	C8	C11	E8	E11
aka-uct	15	99+	86	99+
als	6	7	99+	99+
chi-sqr	99+	99+	99+	99+
db-shot	99+	99+	56	39
dec-tre	99+	55	99+	99+
dotty	13	16	21	8
fin-chi	99+	99+	99+	99+
fin-htt	25	21	19	24
fj-kmns	70	6	23	69
fut-gen	99+	99+	99+	99+
gauss	99+	99+	99+	99+
log-reg	10	11	21	40
mne	99+	99+	99+	99+
mov-len	5	8	10	4
nai-bay	10	4	99+	99+
neo-ana	99+	99+	100	99+
pg-rank	99+	99+	99+	62
par-mne	99+	84	99+	38
philos	99+	99+	99+	99+
reactr	36	42	99+	99+
rx-scrb	49	65	26	19
sc-doku	99+	99+	99+	99+
sc-kmns	8	5	27	19
sc-stmb	93	68	99+	99+
scrb	99+	99+	99+	99+

ScalaBench (with DaCapo)				
bench	C8	C11	E8	E11
appar-d	99+	99+	27	41
avror-l	8	7	18	7
batik-s	2	1	2	1
eclps-s	10		11	
factr-d	99+	99+	99+	99+
fop-d	17	16	10	25
h2-d	24	32	33	87
jythn-l	31	99+	44	70
kiama-d	39	51	46	18
luidx-d	62	50	23	27
lusrc-l	42	30	27	11
pmd-l	32	61	99+	14
scc-l	99+	99+	23	20
scdoc-l	99+	20	46	19
scp-l	10	19	52	96
scrfm-h	33	13	44	34
scxb-h	99+	99+	99+	99+
specs-l	12	5	11	8
sunfl-l	6	16	99+	18
tmt-d	8	9	19	9
trdb-d	17	26	18	25
trds-l	7	5	3	5
xalan-l	35	26	28	23

SPECjvm2008 (modified)				
bench	C8	C11	E8	E11
cmp.cmp	8		5	
cmp.sun	5		16	
compr	4	99+	15	16
cry.aes	13	21	99+	9
cry.rsa	11	9	6	7
cry.sgn	9	13	5	14
derby	28	8	35	70
mpega	1	1	1	2
sci.ffl	99+	99+	99+	99+
sci.lul	1	1	1	1
sci.mtc	12	6	99+	1
sci.sol	1	1	1	1
sci.spl	4		1	99+
se				
sun				
xml				
xml.val	1	30	16	30

Internal Micros				
bench	C8	C11	E8	E11
BufDec	1	93	40	99+
BufEnc	6	1	1	5
ChrHis	99+	99+	52	91
ChrCnt	99+	99+	99+	99+
FltOdd	2	99+	11	1
FndNgt	2	1	1	1
FntNgtR	1	1	1	2
FJHis	2	1	1	3
FJStr	17	7	91	66
FldSum	1	99+	99+	99+
FldSumR	1	1	1	1
ForSum	1	1	99+	99+
ForSumR	99+	1	1	4
GrpRem	99+	99+	5	35
MapOne	99+	99+	99+	99+
NetDot	1	1	12	30
			67	19
			99+	99+
			99+	49
STMMap	99+	99+	99+	99
Scan	99+	99+	99+	99+
SrtRDD	99+	99+	99+	99+
StdDev	99+	99+	99+	1
StrCnt	78	45	98	30
StrDem	99+	99+	99+	99+
StrDev	1	1	2	2
SFndNeg	99+	99+	99+	99+
SFldSum	99+	1	99+	99+
SForSum	1	1	35	99+
SMapRed	99+	99+	1	27
StrPer	99+	99+	99+	57
STwoAvg	50	99+	99+	99+
TxtSDF	80	21	99+	45
TxtRDD	99+	99+	53	85
TSP			99+	
WrdCnt	40	25	26	52

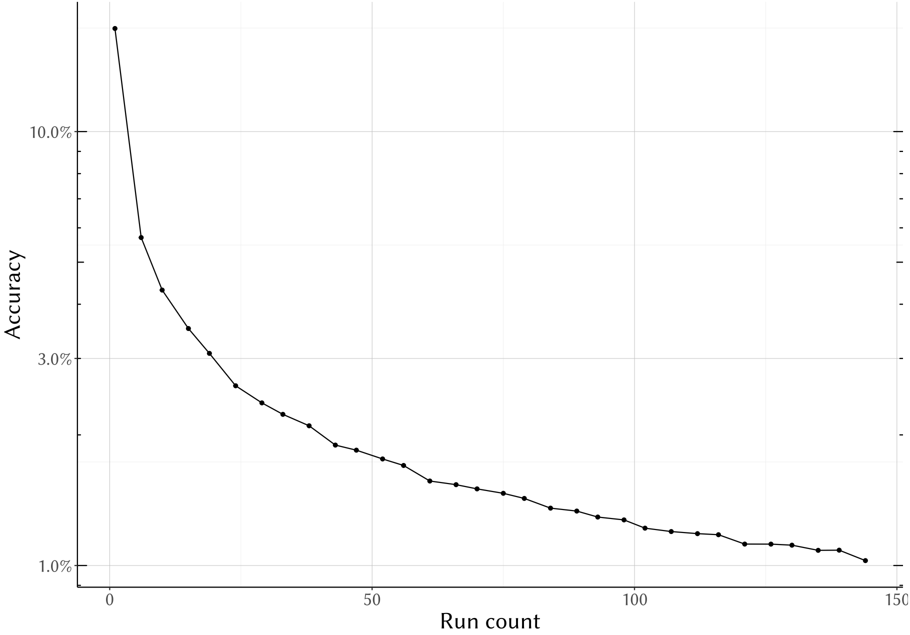
Perhaps 1 %
is asking too much ?

How Many Runs Needed …

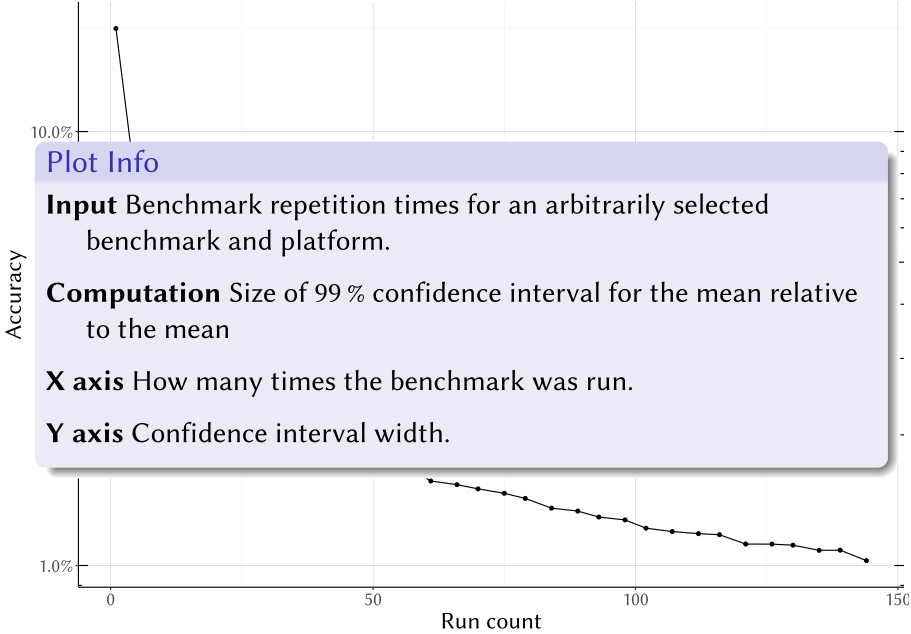
… to compute average performance with at most 5 % error in 99 % of cases ?

Renaissance 0.10				
bench	C8	C11	E8	E11
aka-uct	1	4	3	4
als	1	2	7	14
chi-sqr	23	22	36	26
db-shot	7	6	2	1
dec-tre	11	1	6	7
dotty	1	1	1	1
fin-chi	5	21	26	6
fin-htt	1	1	1	1
fj-kmns	1	3	2	1
fut-gen	6	6	3	8
gauss	25	13	99+	99+
log-reg	6	8	2	2
mne	7	13	29	12
mov-len	1	1	1	1
nai-bay	1	1	60	100
neo-ana	41	8	10	14
pg-rank	7	5	5	2
par-mne	8	5	99+	1
philos	10	99+	14	38
reactr	2	1	23	10
rx-scrb	2	2	1	1
sc-doku	67	18	99+	99+
sc-kmns	2	1	1	1
sc-stmb	2	2	4	6
scrb	20	10	25	42
ScalaBench (with DaCapo)				
bench	C8	C11	E8	E11
appar-d	99+	99+	3	2
avror-l	2	1	1	1
batik-s	1	1	1	1
eclps-s	2		2	
factr-d	6	7	38	59
fop-d	1	3	1	1
h2-d	1	2	1	2
jythn-l	3	9	1	3
kiama-d	1	6	2	1
luidx-d	1	1	1	2
lusrc-l	1	1	3	1
pmd-l	1	2	13	1
scc-l	5	11	1	1
scdoc-l	4	1	1	1
scp-l	1	1	1	3
scrfm-h	2	1	1	1
scxb-h	8	6	25	99+
specs-l	1	1	3	1
sunfl-l	1	1	2	1
tmt-d	1	1	2	1
trdb-d	1	3	1	1
trds-l	3	1	1	1
xalan-l	1	1	4	1
SPECjvm2008 (modified)				
bench	C8	C11	E8	E11
cmp.cmp	1		1	
cmp.sun	1		4	
compr	1	3	1	2
cry.aes	1	1	11	4
cry.rsa	1	1	1	1
cry.sgn	1	1	1	14
derby	2	1	1	2
mpega	1	1	1	1
sci.ffl	21	14	33	7
sci.lul	1	1	1	1
sci.mtc	1	1	12	1
sci.sol	1	1	1	1
sci.spl	1	1	1	99+
serial	2	8	3	13
sunflow	1	1	1	1
xml.trn	1	1	1	1
xml.val	1	3	1	3
Internal Micros				
bench	C8	C11	E8	E11
BufDec	1	5	8	2
BufEnc	1	1	1	5
ChrHis	4	10	4	3
ChrCnt	11	7	3	5
FltOdd	1	45	6	1
FndNgt	2	1	1	1
FntNgtR	1	1	1	1
FJHis	1	1	1	3
FJStr	1	5	3	2
FldSum	1	3	73	70
FldSumR	1	1	1	1
ForSum	1	1	81	80
ForSumR	10	1	1	4
GrpRem	7	7	4	9
MapOne	14	16	99+	99+
NetDot	1	1	12	30
NetEig	1	1	2	4
Reduce	14	11	8	15
STMLst	6	21	8	1
STMMap	18	99+	24	4
Scan	9	14	34	8
SrtRDD	4	7	5	19
StdDev	45	99+	99+	1
StrCnt	3	9	7	1
StrDem	99+	26	99+	51
StrDev	1	1	2	2
SFndNeg	11	9	18	12
SFldSum	34	1	99+	99+
SForSum	1	1	21	44
SMapRed	67	57	1	1
StrPer	13	99+	99+	1
STwoAvg	25	40	99+	99+
TxtSDF	3	1	8	10
TxtRDD	11	10	1	8
TSP			72	
WrdCnt	1	5	2	3

How Accuracy Relates To Run Count ?



How Accuracy Relates To Run Count ?



Plot Info

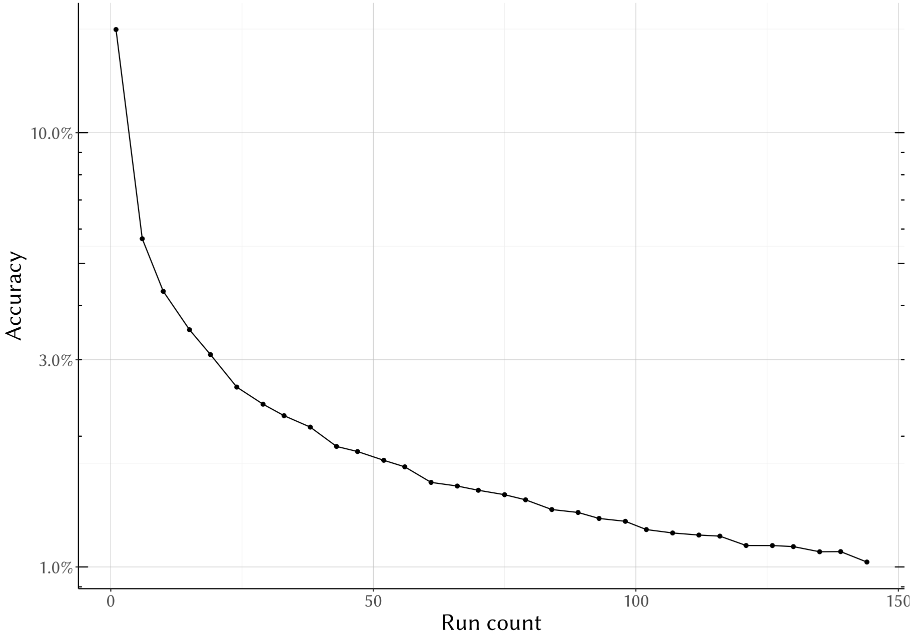
Input Benchmark repetition times for an arbitrarily selected benchmark and platform.

Computation Size of 99 % confidence interval for the mean relative to the mean

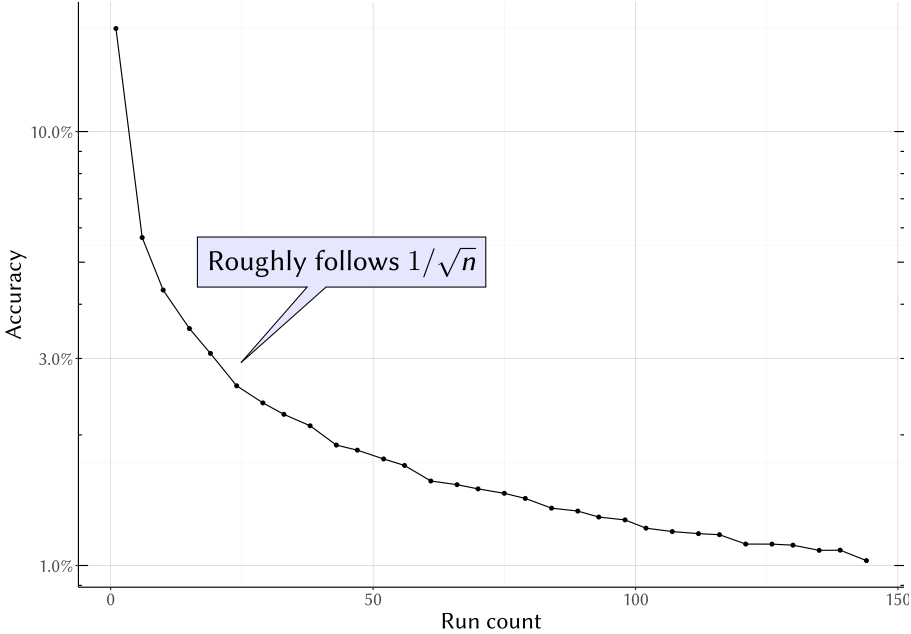
X axis How many times the benchmark was run.

Y axis Confidence interval width.

How Accuracy Relates To Run Count ?



How Accuracy Relates To Run Count ?



Take Away So Far ...

Running benchmarks only once may not be enough

- Non deterministic compilation visible especially with microbenchmarks
- But the presented tables also include simple cases of high variance

Aiming for excessive accuracy backfires quickly

Reasonable accuracy is a function of more than just the benchmark

- Tooling should consider benchmarks together with platforms
- Not yet sure how often relevant parameters tend to change

Outline

1. Quick Platform Overview
2. Handling Warm Up
3. Detecting Changes
4. Handling More Runs
5. Handling Different Metrics
6. Troublesome Performance Changes

Runs Needed When Different Metrics Used …

… to compute average performance with at most 1 % error in 99 % of cases.

Renaissance 0.10			
bench	time	clk	ins
aka-uct	15	16	21
als	6	4	4
chi-sqr	99+	99+	99+
db-shot	99+	99+	99+
dec-tre	99+	99+	99+
dotty	13	14	6
fin-chi	99+	99+	99+
fin-htt	25	49	15
fj-kmns	70	81	60
fut-gen	99+	99+	99+
gauss	99+	99+	99+
log-reg	10	11	2
mne	99+	99+	99+
mov-len	5	8	9
nai-bay	10	9	99
neo-ana	99+	99+	99+
pg-rank	99+	99+	99+
par-mne	99+	99+	99+
philos	99+	99+	50
reactr	36	85	48
rx-scrb	49	46	25
sc-doku	99+	99+	99+
sc-kmns	8	8	7
sc-stmb	93	99+	99+
scrb	99+	99+	99+

ScalaBench (with DaCapo)			
bench	time	clk	ins
appar-d	99+	99+	99+
avror-l	8	32	88
batik-s	2	2	1
eclps-s	10	12	1
factr-d	99+	99+	99+
fop-d	17	17	6
h2-d	24	10	12
jythn-l	31	31	9
kiama-d	39	66	51
luidx-d	62	7	5
lusrc-l	42	54	29
pmd-l	32	16	11
scc-l	99+	99+	99+
scdoc-l	99+	99+	99+
scp-l	10	65	56
scrfm-h	33	69	75
scxb-h	99+	99+	39
specs-l	12	27	14
sunfl-l	6	6	8
tmt-d	8	14	45
trdb-d	17	99+	99+
trds-l	7	12	7
xalan-l	35	99+	99+

SPECjvm2008 (modified)			
bench	time	clk	ins
cmp.cmp	8	8	8
cmp.sun	5	5	11
compr	4	4	1
cry.aes	13	13	1
cry.rsa	11	11	3
cry.sgn	9	9	18
derby	28	28	5
mpega	1	1	1
sci.ffl	99+	99+	1
sci.lul	1	1	1
sci.mtc	12	12	23
sci.sol	1	1	1
sci.spl	4	4	23
serial	14	14	2
sunflow	9	9	11
xml.trn	10	11	1
xml.val	1	3	1

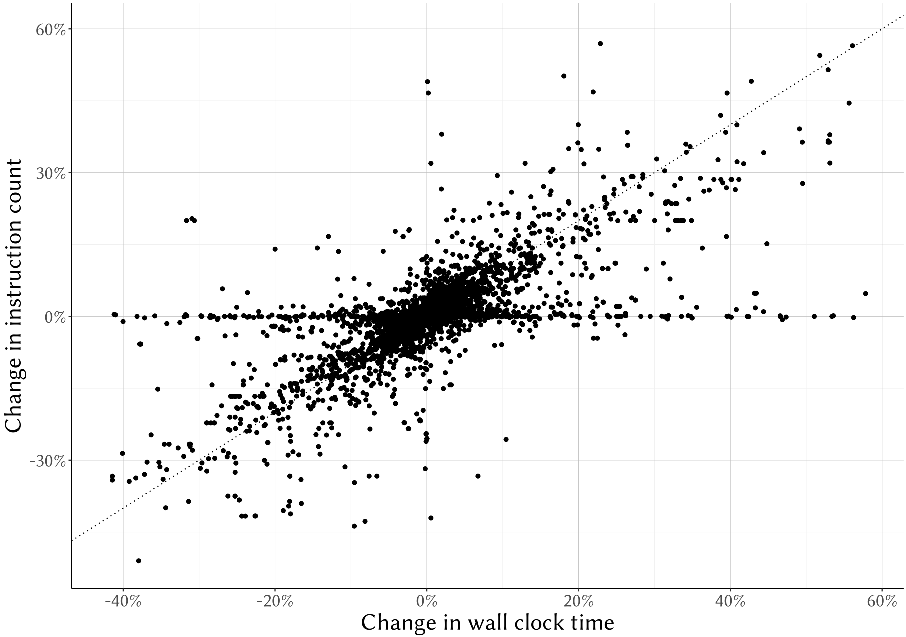
Internal Micros			
bench	time	clk	ins
BufDec	1	1	1
BufEnc	6	6	2
ChrHis	99+	99+	55
ChrCnt	99+	99+	50
FltOdd	2	2	1
FndNgt	2	1	1
FntNgtR	1	1	1
FJHis	2	2	3
FJStr	17	23	11
FldSum	1	1	1
FldSumR	1	1	1
ForSum	1	1	1
ForSumR	99+	99+	1
GrpRem	99+	99+	99+
MapOne	99+	99+	99+
NetDot	1	1	1
NetEig	1	1	1
Reduce	72	99+	60
STMLst	99+	99+	99+
STMMap	99+	99+	99+
Scan	99+	99+	32
SrtRDD	99+	99+	25
StdDev	99+	99+	99+
StrCnt	78	99+	63
StrDem	99+	99+	99+
StrDev	1	1	9
SFndNeg	99+	99+	99+
SFldSum	99+	99+	99+
SForSum	1	1	1
SMapRed	99+	99+	99+
StrPer	99+	99+	34
STwoAvg	50	51	38
TxtSDF	80	99+	29
TxtRDD	99+	99+	34
WrdCnt	40	65	32

time - wall clock time

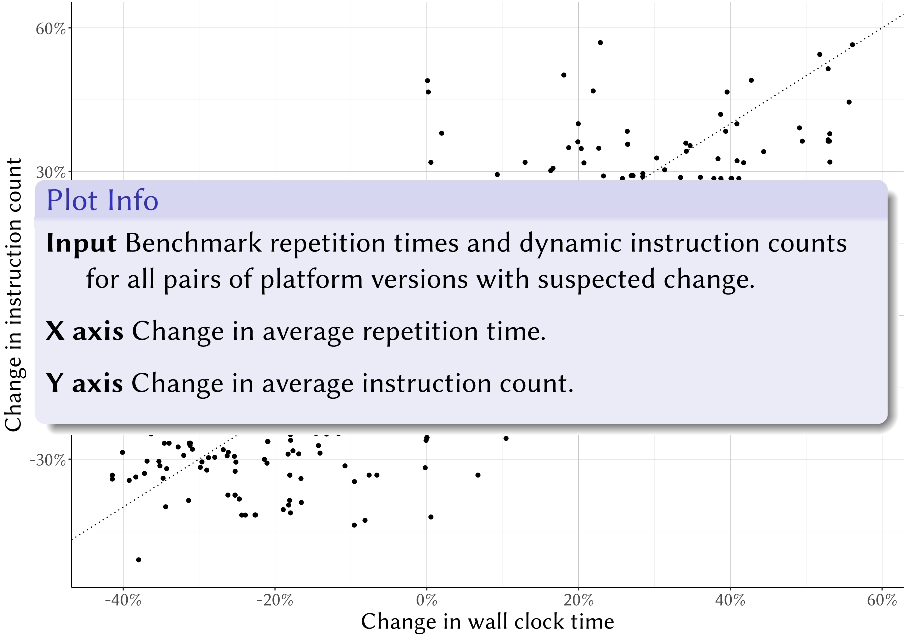
clk - thread clock time

ins - instruction count

Different Metrics Not Always In Sync



Different Metrics Not Always In Sync



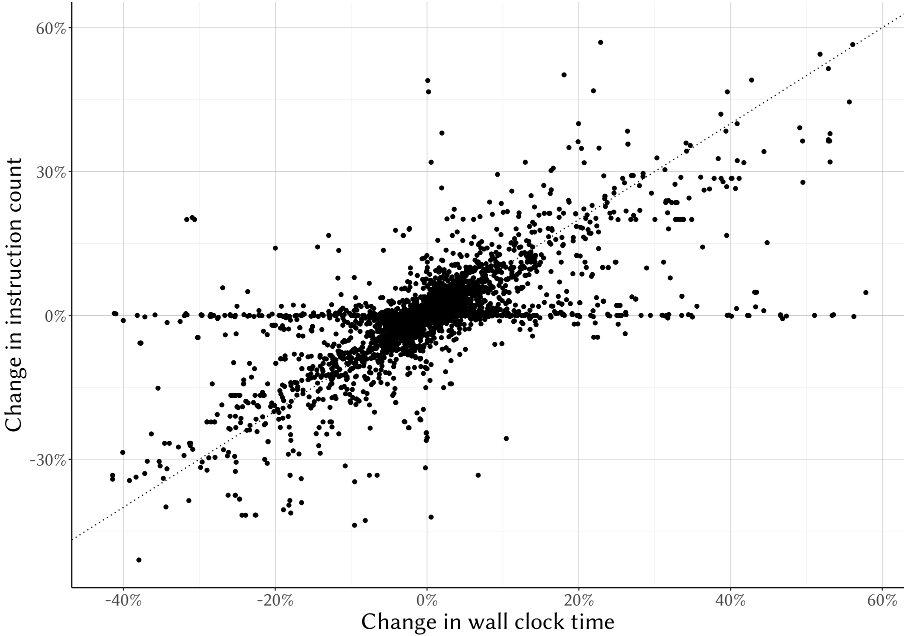
Plot Info

Input Benchmark repetition times and dynamic instruction counts for all pairs of platform versions with suspected change.

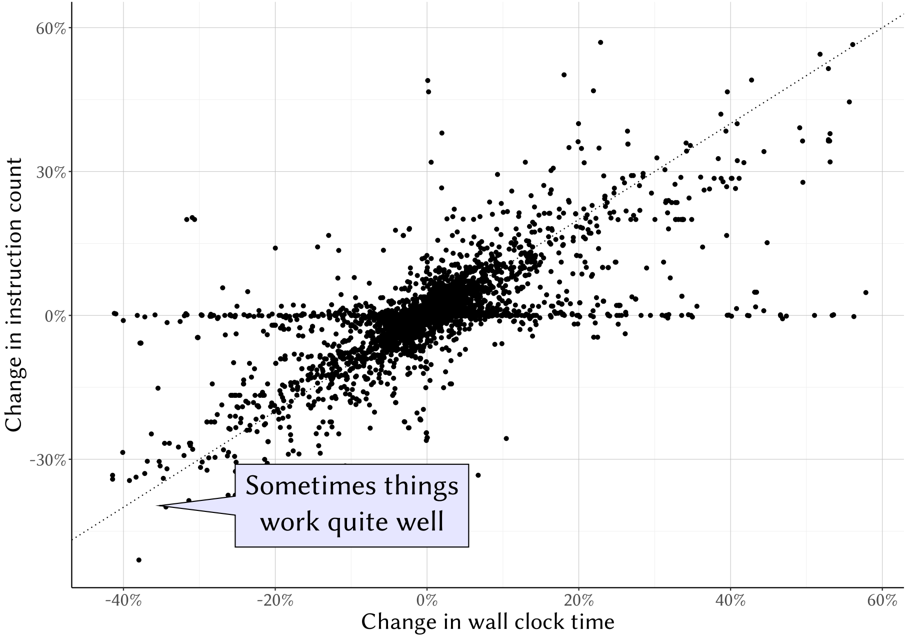
X axis Change in average repetition time.

Y axis Change in average instruction count.

Different Metrics Not Always In Sync

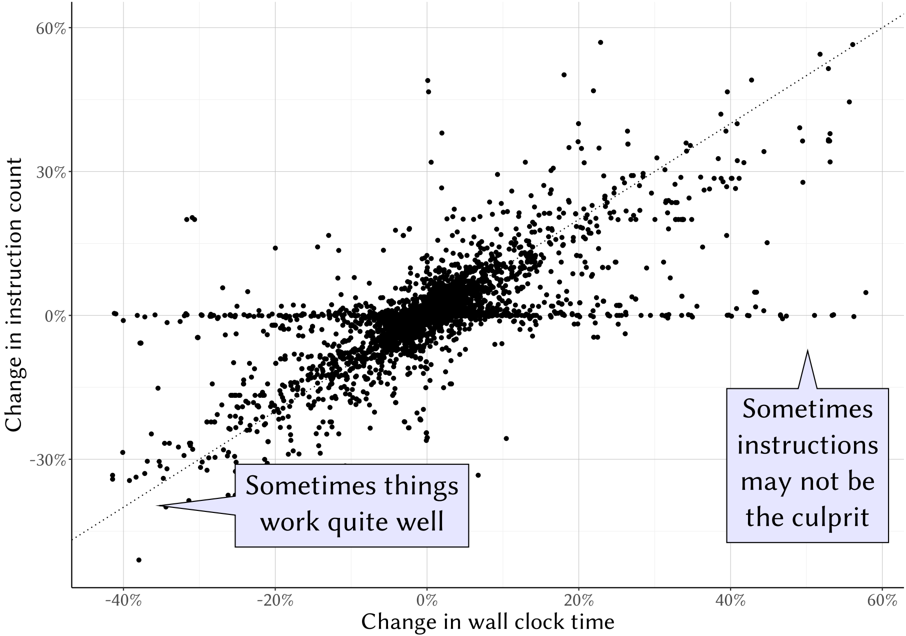


Different Metrics Not Always In Sync



Sometimes things work quite well

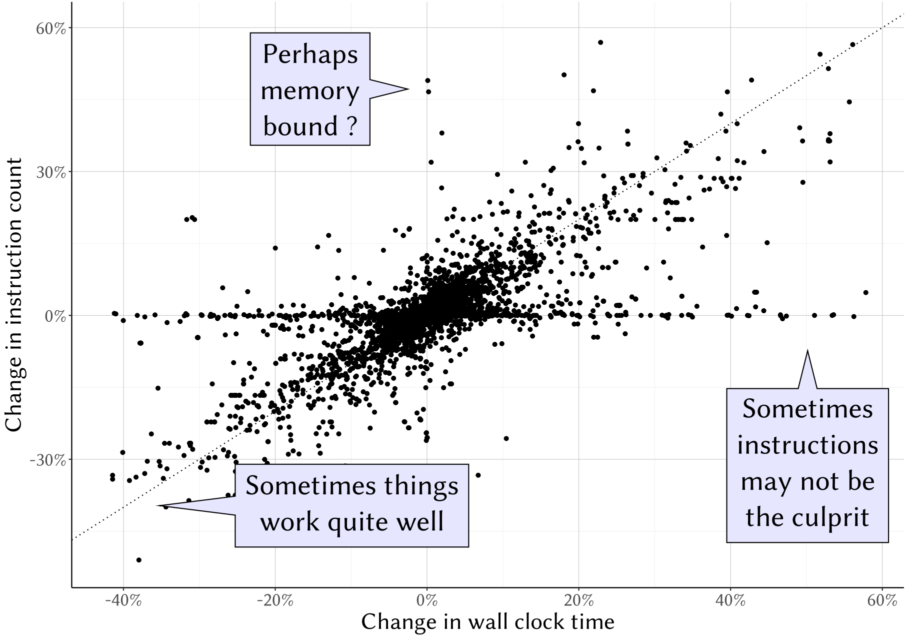
Different Metrics Not Always In Sync



Sometimes things work quite well

Sometimes instructions may not be the culprit

Different Metrics Not Always In Sync

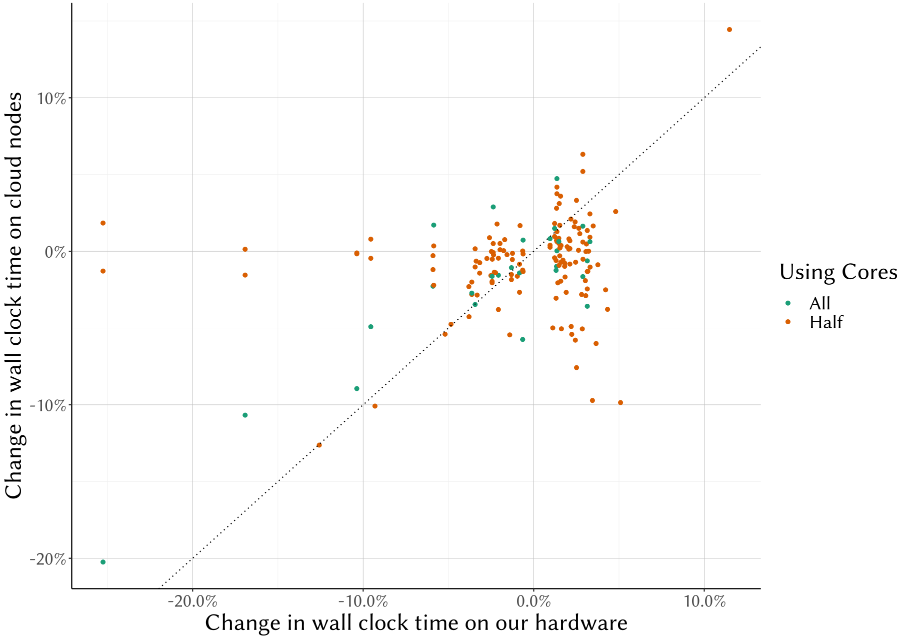


Perhaps memory bound ?

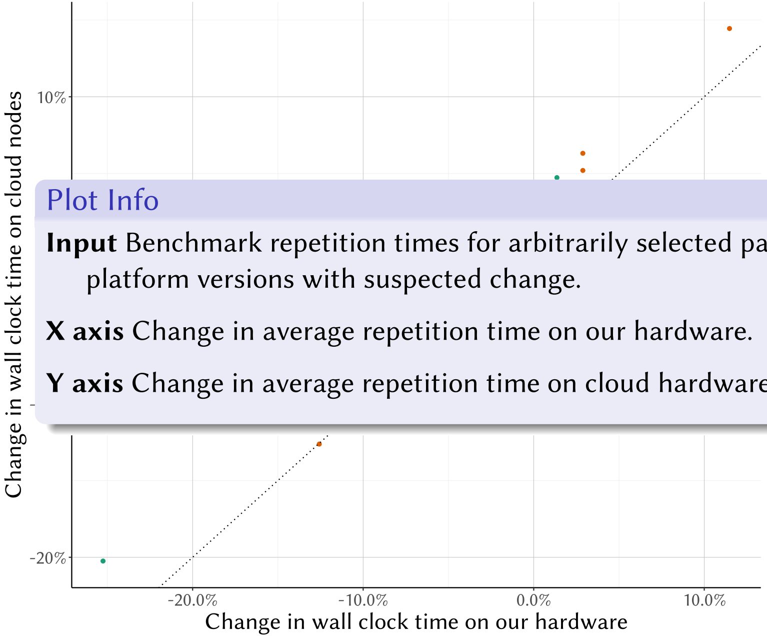
Sometimes things work quite well

Sometimes instructions may not be the culprit

Wall Clock Time Changes Not Always Portable



Wall Clock Time Changes Not Always Portable



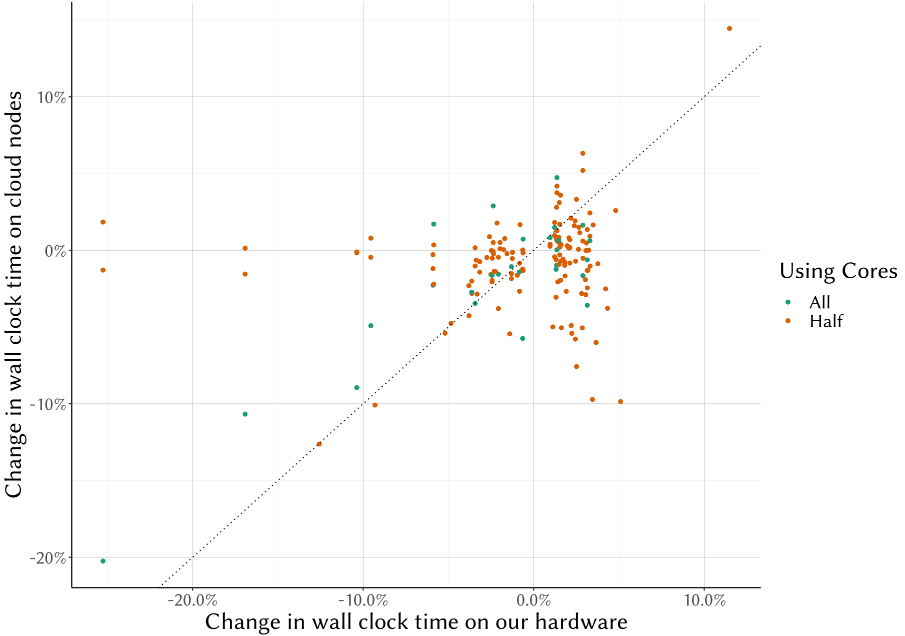
Plot Info

Input Benchmark repetition times for arbitrarily selected pairs of platform versions with suspected change.

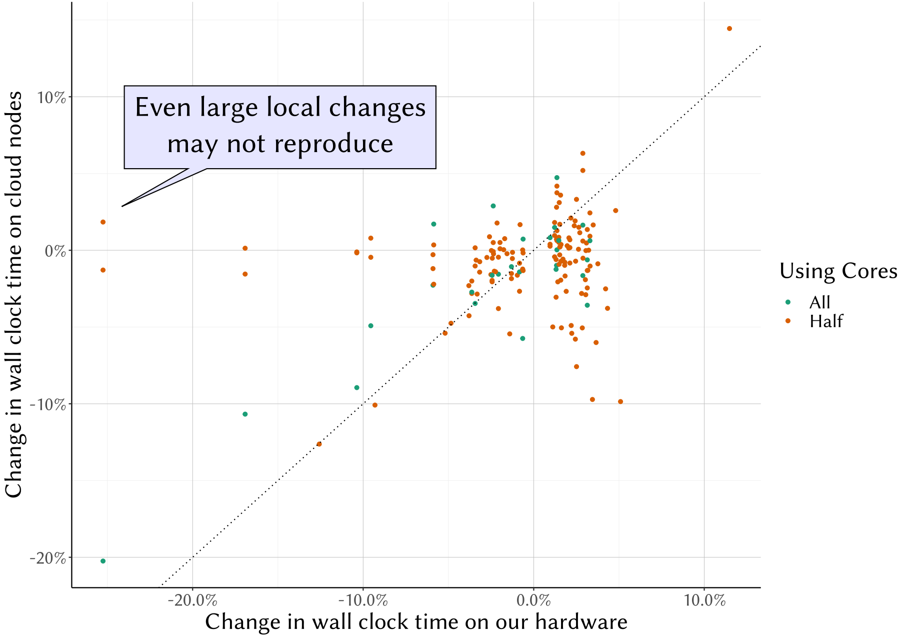
X axis Change in average repetition time on our hardware.

Y axis Change in average repetition time on cloud hardware.

Wall Clock Time Changes Not Always Portable

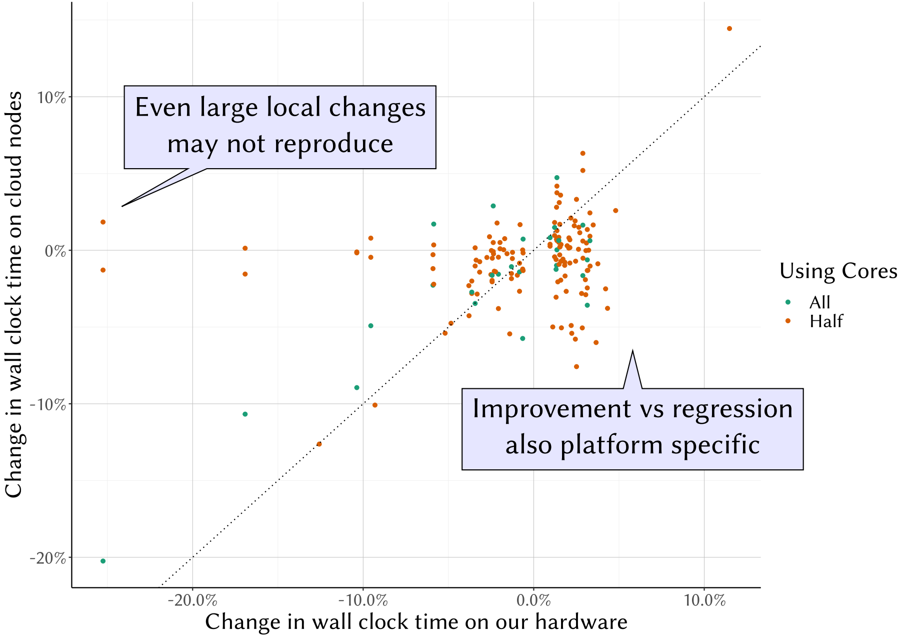


Wall Clock Time Changes Not Always Portable



Even large local changes may not reproduce

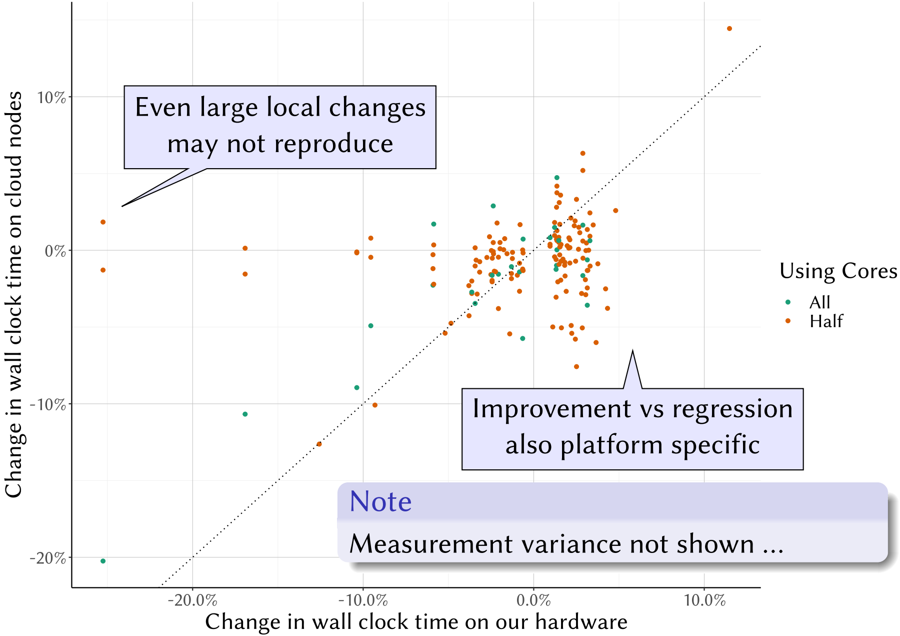
Wall Clock Time Changes Not Always Portable



Even large local changes may not reproduce

Improvement vs regression also platform specific

Wall Clock Time Changes Not Always Portable



Even large local changes may not reproduce

Improvement vs regression also platform specific

Note

Measurement variance not shown …

Take Away So Far ...

Looking at more execution metrics can improve accuracy

- Can help developers trust detected time changes
- Or even direct investigation of change causes

Not really clear how to combine multiple (possibly) conflicting results

- Some metrics changing and some not
- Some platforms improving and some regressing
- Some benchmarks improving and some regressing

Outline

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Regression Example: Processor Scheduling I

Code

A microbenchmark that locates the first negative array item.

```
def run () {
    for (i <- 0 until REPEATS) {
        blackhole += findNegative (numbers)
    }
}

def findNegative (numbers: Array[Int]): Option[Int] = {
    numbers.find(_ < 0)
}
```

What the measurements said

Clear repetition time change between roughly 230 ms and roughly 170 ms

No change in other observed counters like instruction count

Observed multiple times in versions across several days

Commit changes often clearly unrelated

Regression Example: Processor Scheduling II

Assembly

Compilation results in reasonably compact assembly code.

```
0x00007f115c894c00: cmp    %r13d,%edi                 ;loop iteration count test
0x00007f115c894c03: jbe    0x00007f115c89561c
0x00007f115c894c09: mov    0x10(%rdx,%r13,4),%r10d  ;fetch array item
0x00007f115c894c0e: test   %r10d,%r10d                ;negative test
0x00007f115c894c11: jl     0x00007f115c894c2a         ;found negative
0x00007f115c894c17: test   %eax,0x1942d3e9(%rip)      ;safepoint poll
0x00007f115c894c1d: inc    %r13d
0x00007f115c894c20: cmp    %r13d,%edi                 ;loop iteration count test (again)
0x00007f115c894c23: jg     0x00007f115c894c00
```

Analysis

Inner loop executes at IPC 6 when fast or IPC 4.5 when slow

Performance difference inflated from mere 0.5 cycle per iteration

Instruction scheduler counters report different μops port use as the reason

Actual scheduler choice only indirectly influenced by code

Regression Example: Inlining Heuristic I

Code

A microbenchmark that filters odd array items.

```
def run () {
    for (i <- 0 until REPEATS) {
        blackhole += filterOdd (numbers).length
    }
}

def filterOdd (numbers: ArrayBuffer[Int]): ArrayBuffer[Int] = {
    numbers.filter (_ % 2 == 1)
}
```

What the measurements said

Times always stable within each run

Repetition time of a run flipping between 5 s and 5.6 s

Rarely observed runs with repetition times of roughly 3.4 s

Share of runs with each time sometimes changes between versions

Regression Example: Inlining Heuristic II

Analysis

Fast and slow runs differed in what code gets inlined

Inlining heuristic (also) relies on low level graph size of the callee

- If callee previously compiled, a cached value was used
- If callee not yet compiled, an estimate was made

Caller and callee invocation counters necessarily similar

Hence compilation jobs launched close together in time

That increases the likelihood of the inliner flipping

Take Away So Far ...

Reasons for performance change not always directly connected to committed code

- Especially microbenchmarks may exhibit fragile performance
- Responsibility for addressing changes therefore not clear

Hard to tell whether performance regression should be addressed

- Especially with benchmarks that do not represent application performance
- Effort needed to investigate reasons is not very predictable

Broader Context

Multiple testing scenarios employed

- Quick benchmark run every commit
- Thorough benchmark run every week
- Interactive performance change detection (us)

Every commit

- Fast but low detection ability
- Useful to catch major bugs fast

Every week

- Resource intensive but high detection ability
- Useful to keep track of overall development
- Significant changes investigated manually

Thank You !

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Our work is kindly sponsored by Oracle Labs.

Thank You !

Do not treat all benchmarks the same ...

... using similar run sizes or expecting similar accuracy is not a good idea

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Do not treat all benchmarks the same …

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Microbenchmarks should get special treatment …

… good for seeing specific changes but bad for judging practical impact

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Evaluation cannot stay with developers only …

… users determine important workloads

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Do not treat all benchmarks the same …

… using similar run sizes or expecting similar accuracy is not a good idea

Microbenchmarks should get special treatment …

… good for seeing specific changes but bad for judging practical impact

Evaluation cannot stay with developers only …

… users determine important workloads

Contribute to Renaissance …

… and we will start benchmarking your code too :-)

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