Relative Factors in Performance Analysis of Java Virtual Machines

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Outline

Have you ever ...

As an application developer

- Rewritten the code for better performance
- But, obtained no speedup as expected?

Application

Compiler

VM

GC

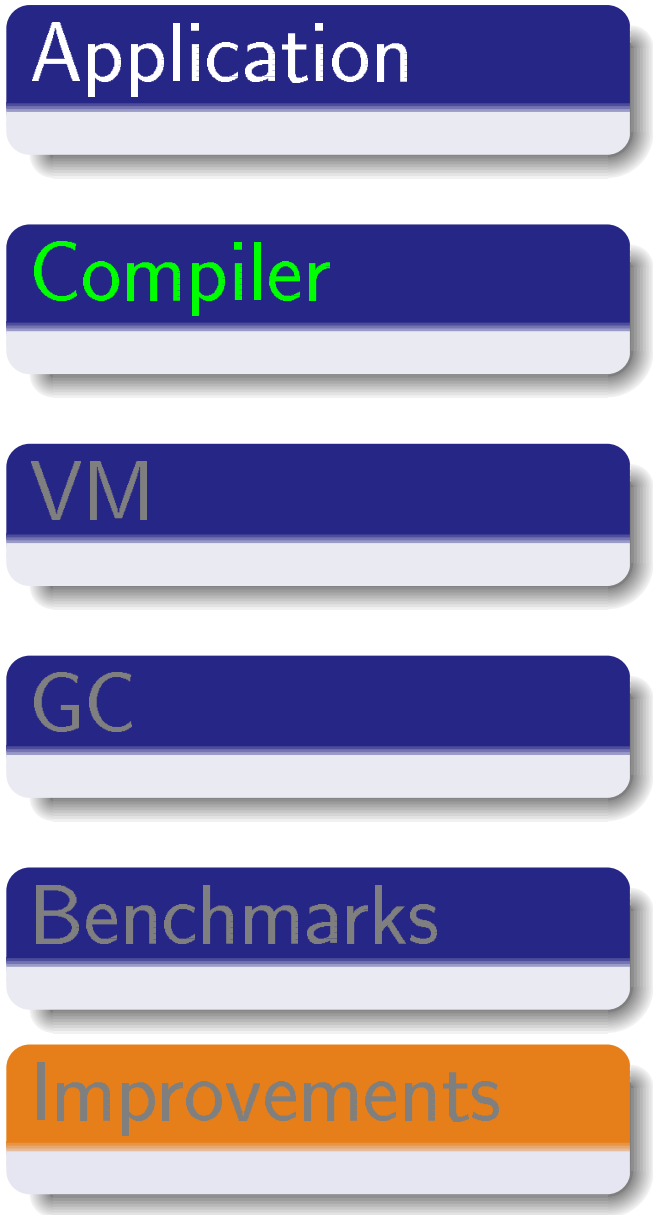
Benchmarks

Improvements

Have you ever ...

As a compiler developer

- Built a new optimization based on a neat analysis
- But, got no improvement or even slow down benchmark programs?



Have you ever ...

As a VM developer

- Applied a new technique inside a VM
- But, achieved no positive result, or only had a positive result by chance?

Application

Compiler

VM

GC

Benchmarks

Improvements

Have you ever ...

As a garbage collection (GC) developer

- Built a theoretically efficient GC algorithm
- But, the collector refused to run any faster or gave random results?

Application

Compiler

VM

GC

Benchmarks

Improvements

Have you ever ...

When measuring a set of benchmarks

- Found naughty benchmarks
- Disagreed with others, gave very strange or random results?

Application

Compiler

VM

GC

Benchmarks

Improvements

Have you ever ...

Improvements?

- Failed in reproducing the improvement of a published work
- Got a 10% improvement on a platform, but it disappeared after you got a new machine

Application

Compiler

VM

GC

Benchmarks

Improvements

Motivation

Goal

- Lots of us may have such kind of experiences
- How to understand these situations?
- Performance measurement analysis

Application

Compiler

VM

GC

Benchmarks

Improvements

Motivation

Performance measurement is difficult

- Computers are getting increasingly complex
- Many factors can affect measurement results, which are important?
- Virtual execution environments bring an extra layer and become even more challenging
- Study the relative factors in performance analysis

Motivating Example

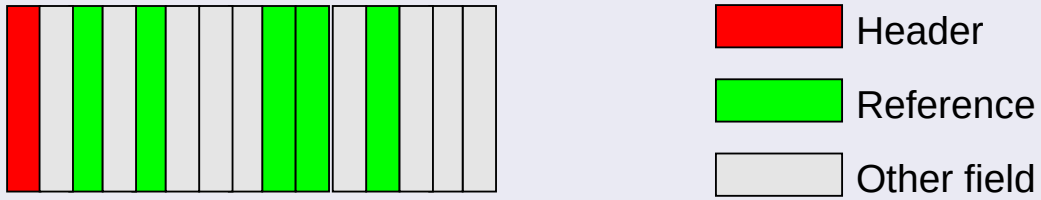
We developed a GC-related technique and observed surprising behaviors

Questions:

- What factors can impact performance?
- How large can the impact be?
- How can we explain the observed behaviors?

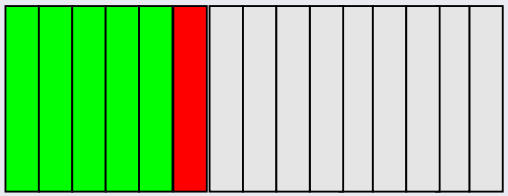
Motivating Example

Original Object Layout



References are located separately

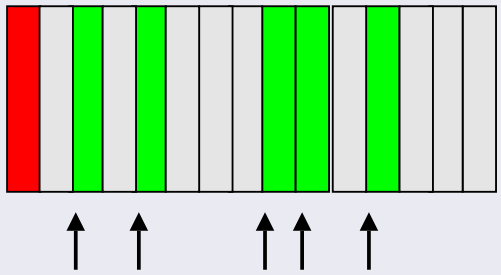
New: Reference Section (RS)

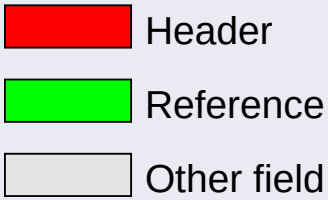


Group all references in a contiguous section

Motivating Example

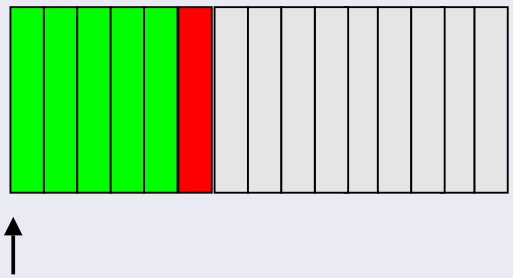
Original Reference Tracing





Get the the addresses of references one by one

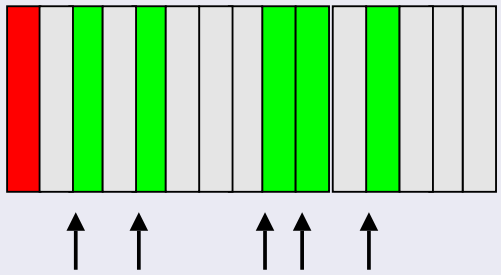
RS Reference Tracing

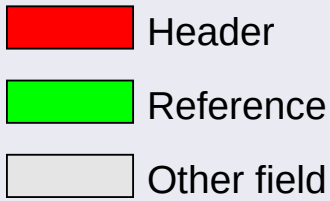


Get the first reference's address

Motivating Example

Original Reference Tracing





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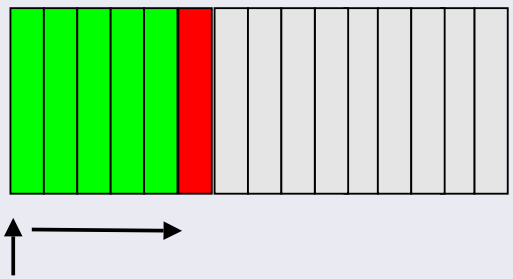
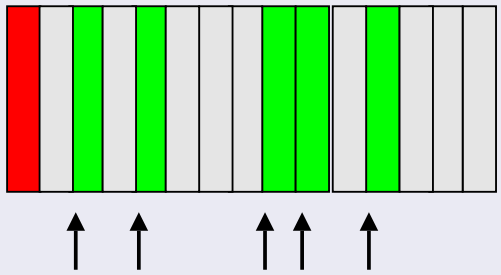
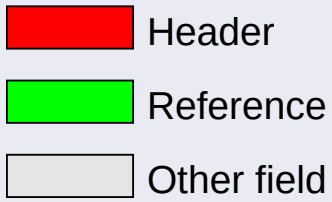


Scan the whole section immediately

Motivating Example

Original Reference Tracing





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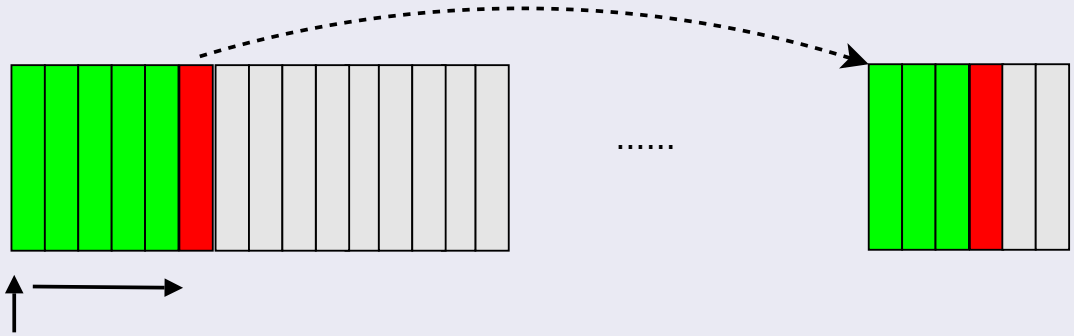
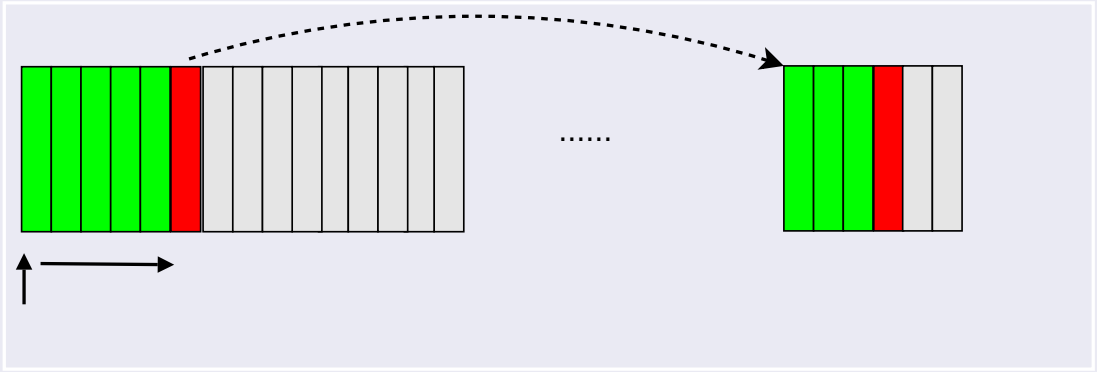


Jump to the next section

Implementation

RS Tracing Technique



- Useful for all tracing GCs
- Implemented in two JVMs

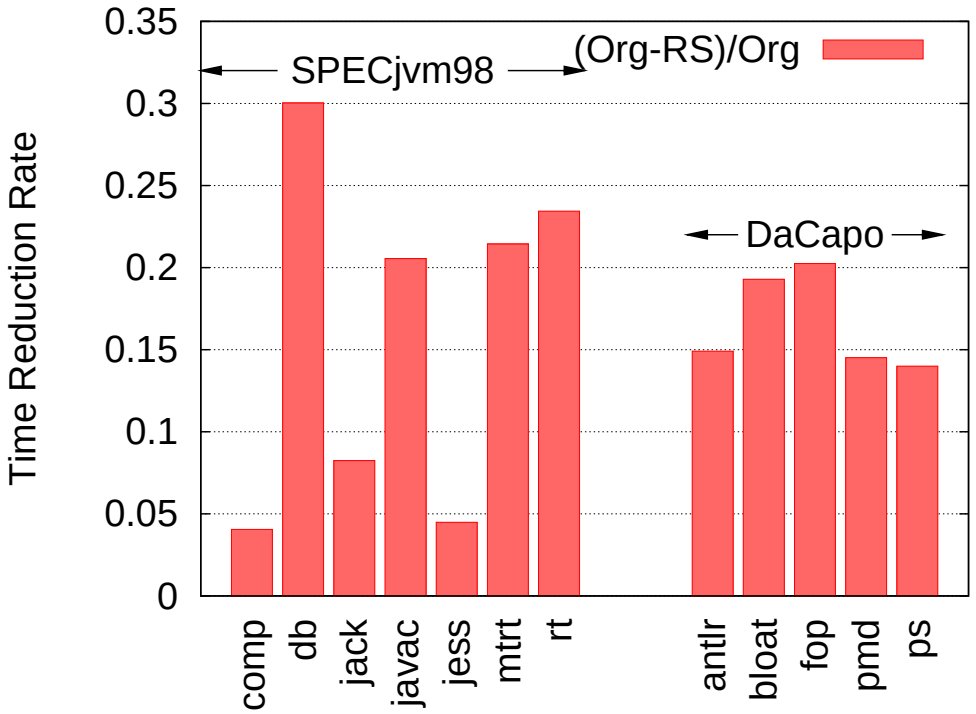
SableVM

An interpreter

Jikes RVM

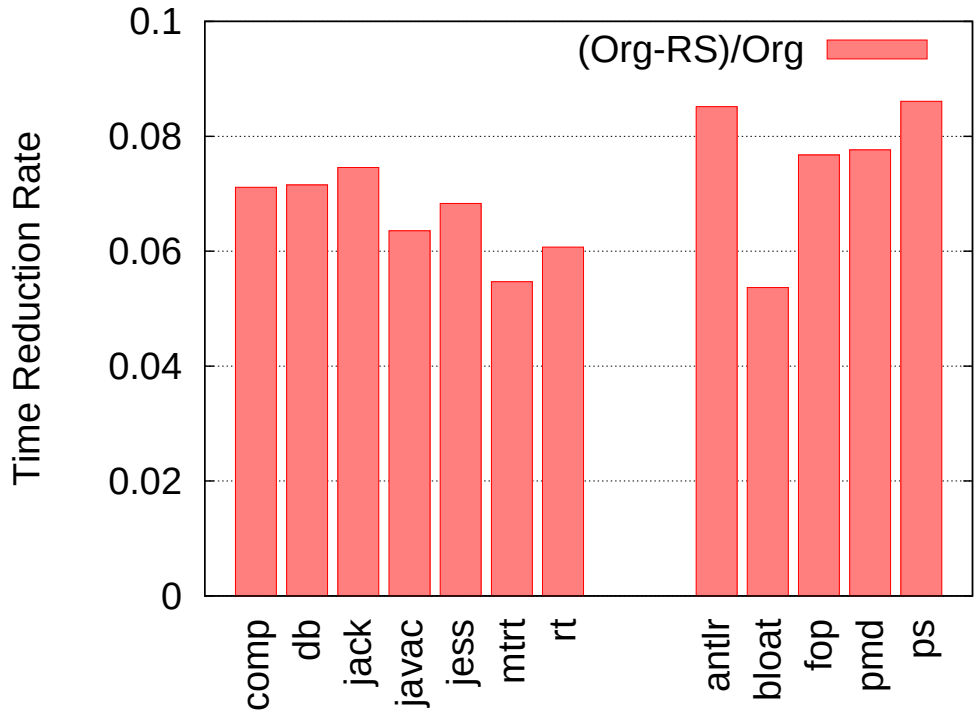
A compiler-based VM

GC Time Reduction: Semi-space



SableVM

Average saving 16.3%

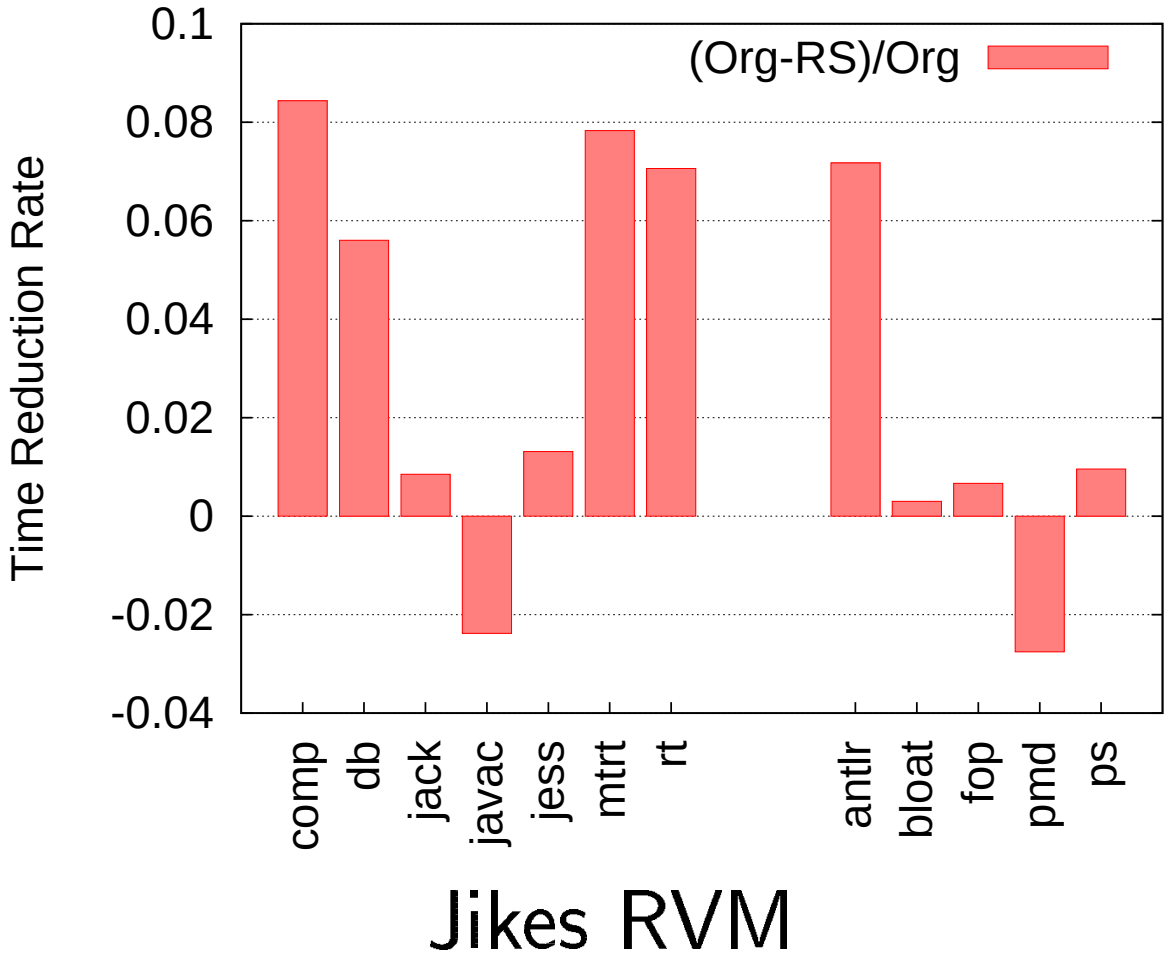


Jikes RVM

Average saving 7.1%

- Both JVMS obviously benefited on all benchmarks

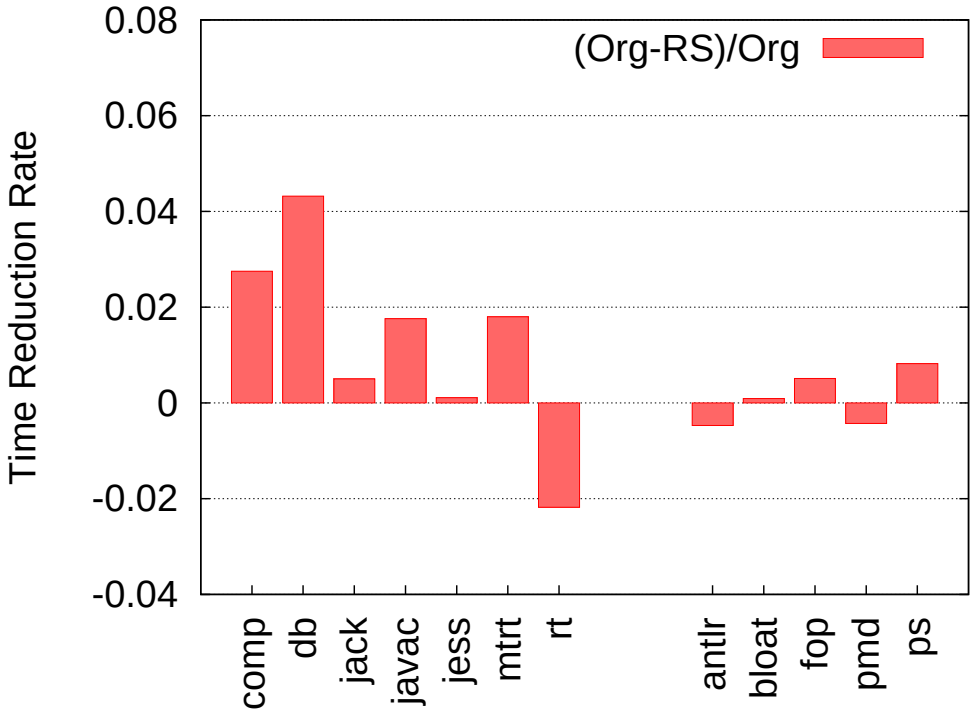
GC Time Reduction: GenMS



- **GenMS:** Generational-copying and mark-sweep
- **Less regular** results, some are **unexpected**

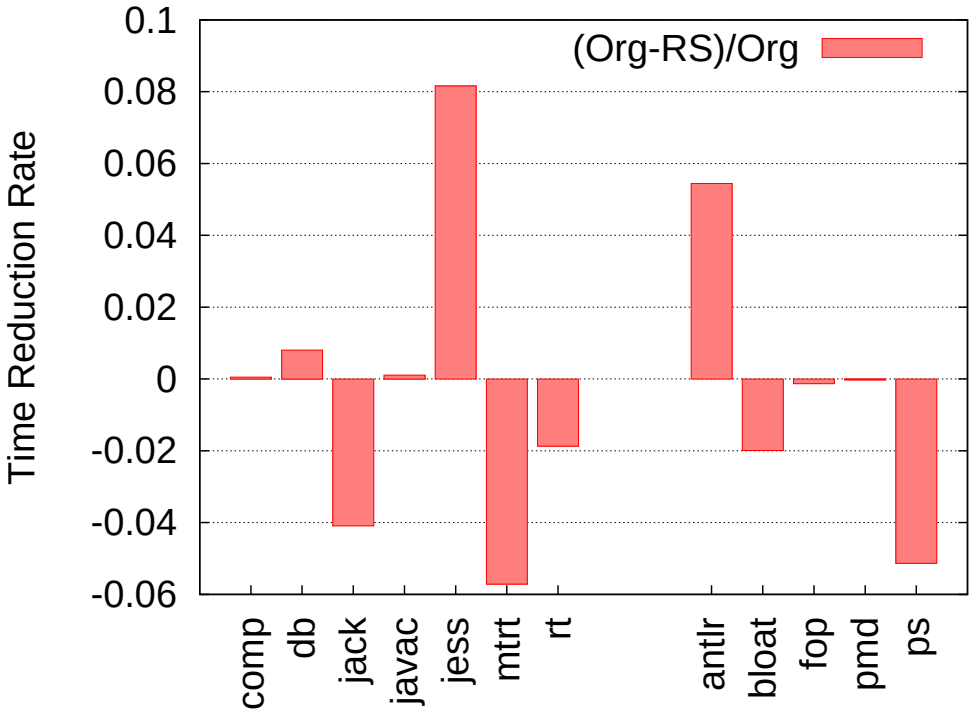
Mutator Time Reduction

Mutator Time = Whole Execution Time - GC Time



SableVM

Mysterious result

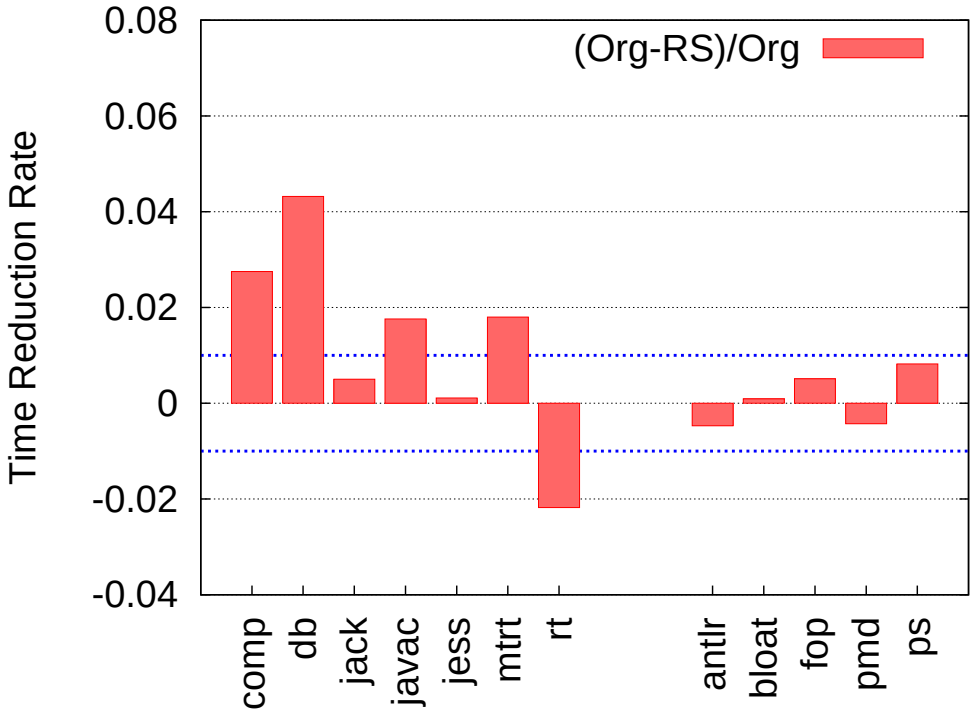


Jikes RVM

Quite **random** results

Mutator Time Reduction

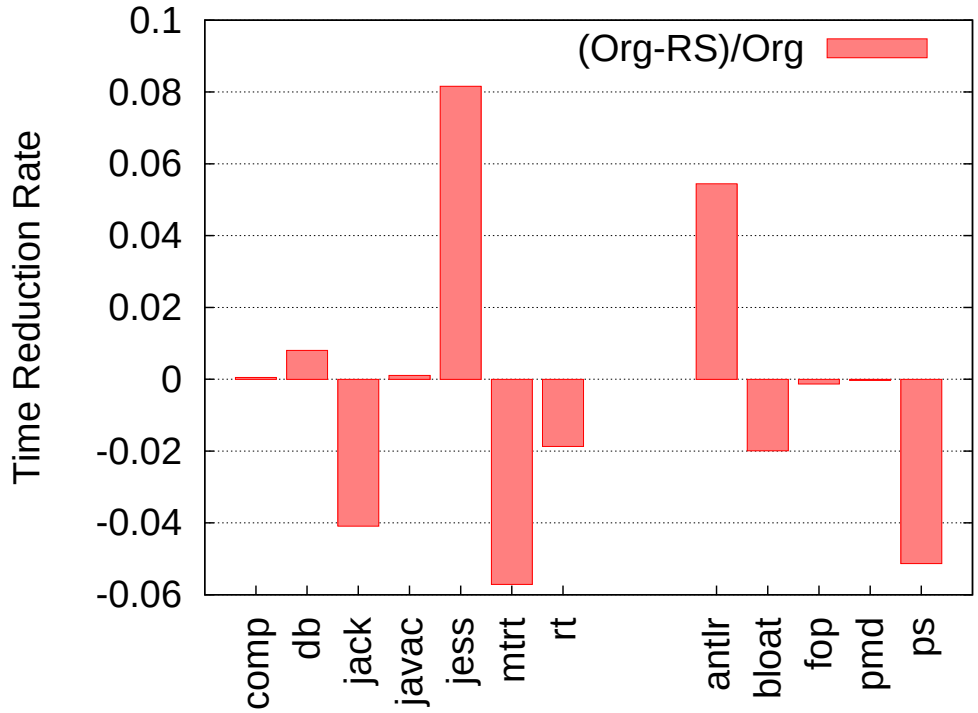
Mutator Time = Whole Execution Time - GC Time



SableVM

Mysterious result

Variation > GC time?!

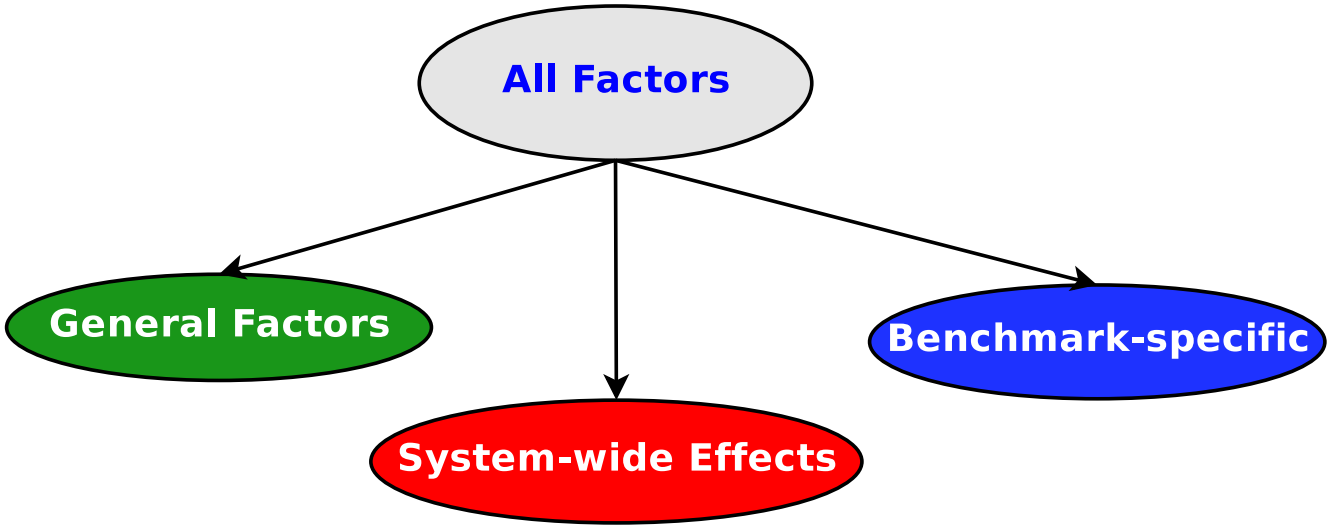


Jikes RVM

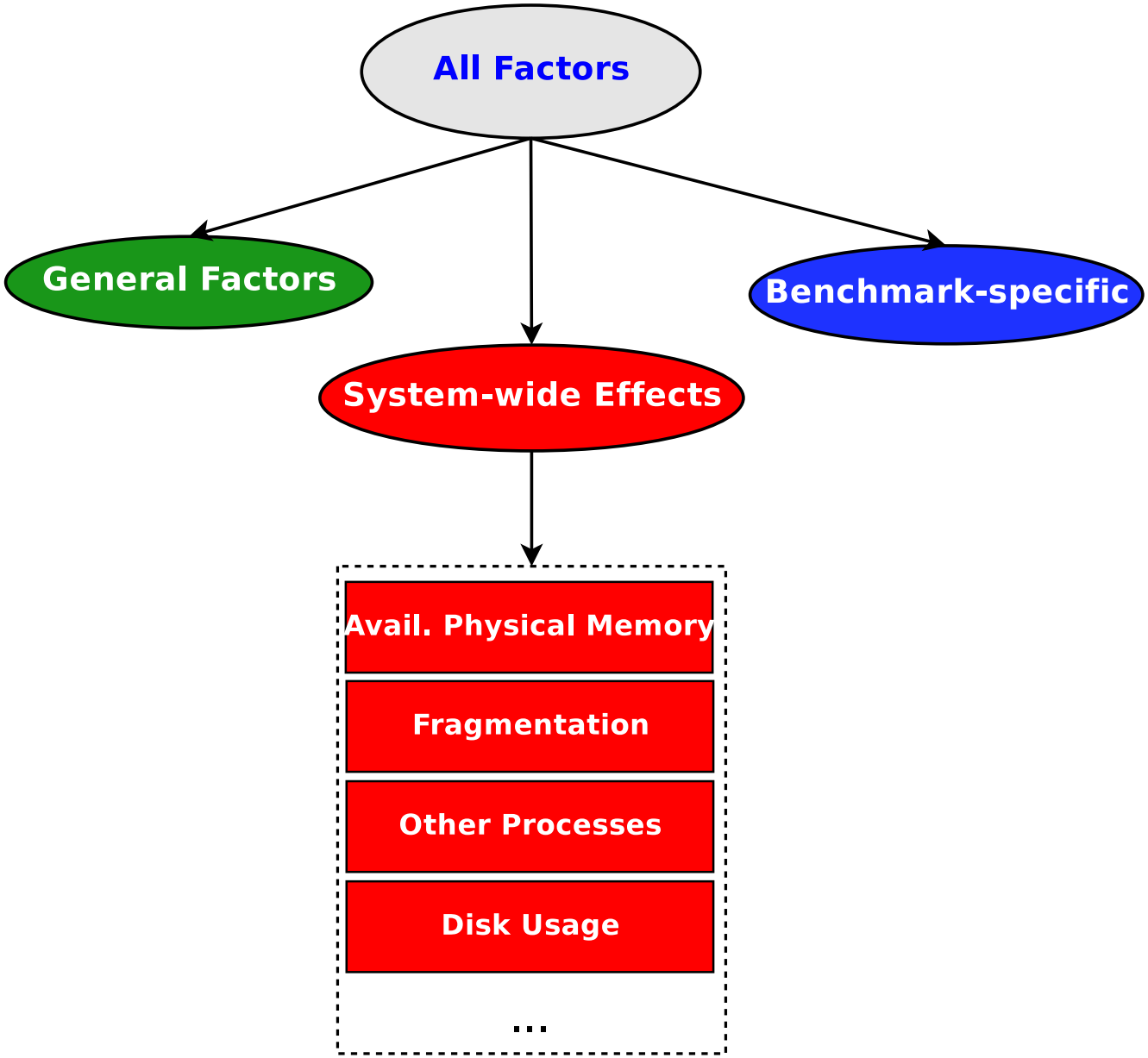
Quite **random** results

Outline

Relative Factors



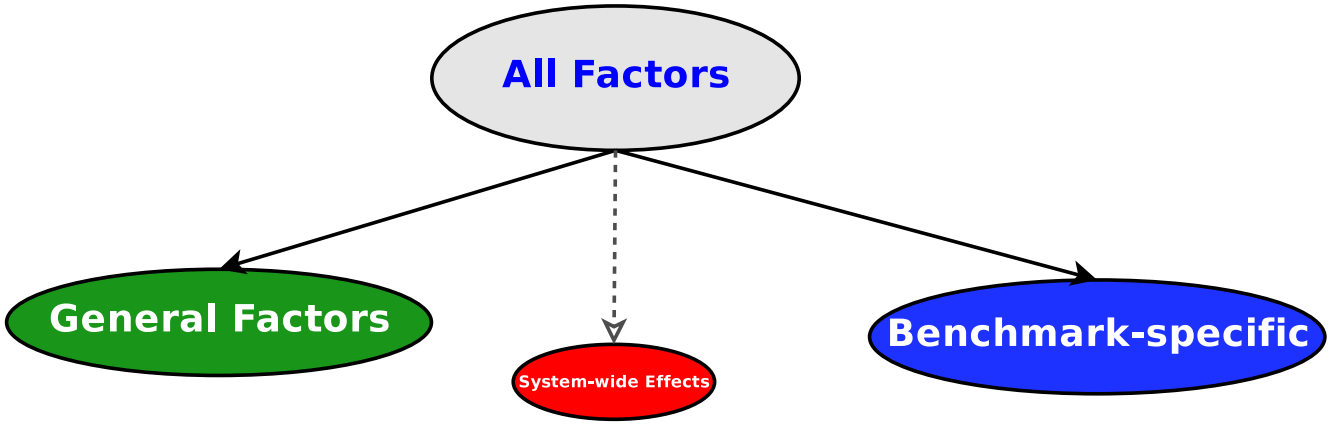
Relative Factors



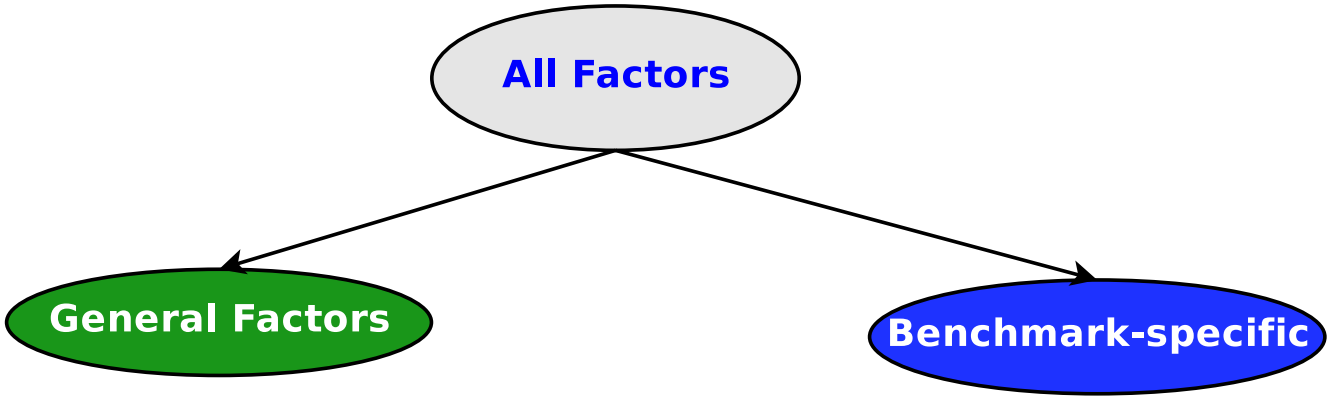
Reduce **System-wide Effect**

- Goal: Figure out the important reasons
- Reduce unnecessary noise
- Test on a **newly restarted, isolated, minimized workload** system, as most people do
- Make the **System-wide Effect** as small as possible

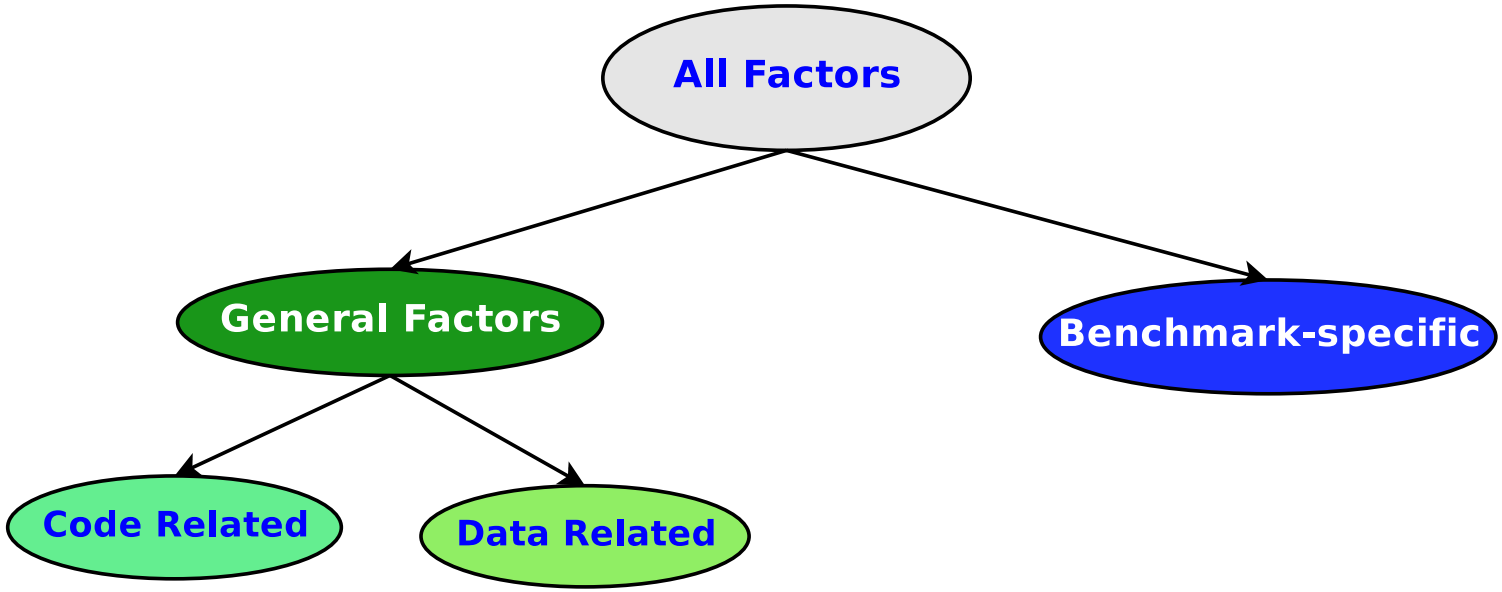
Make System-wide Effect Small



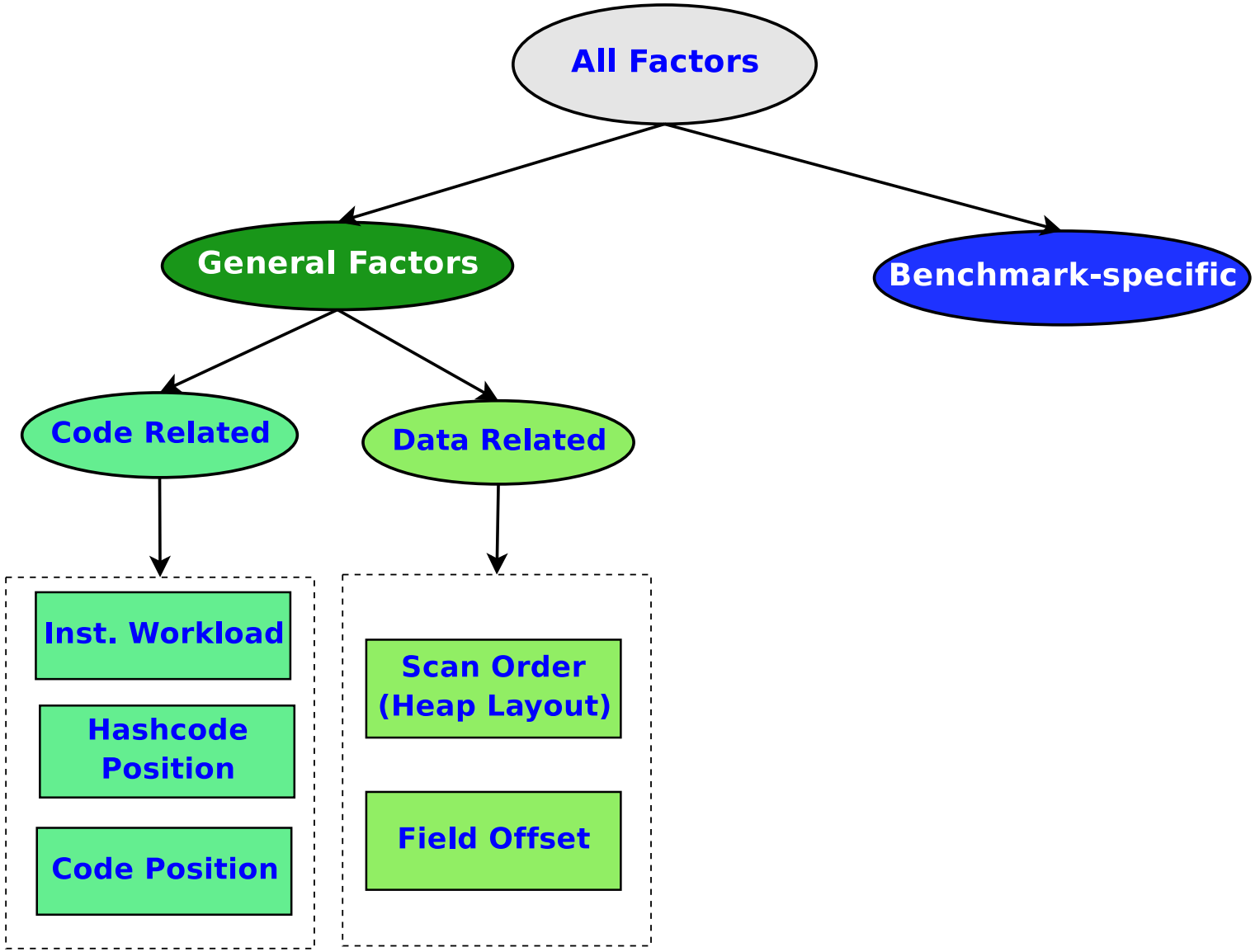
Relative Factors



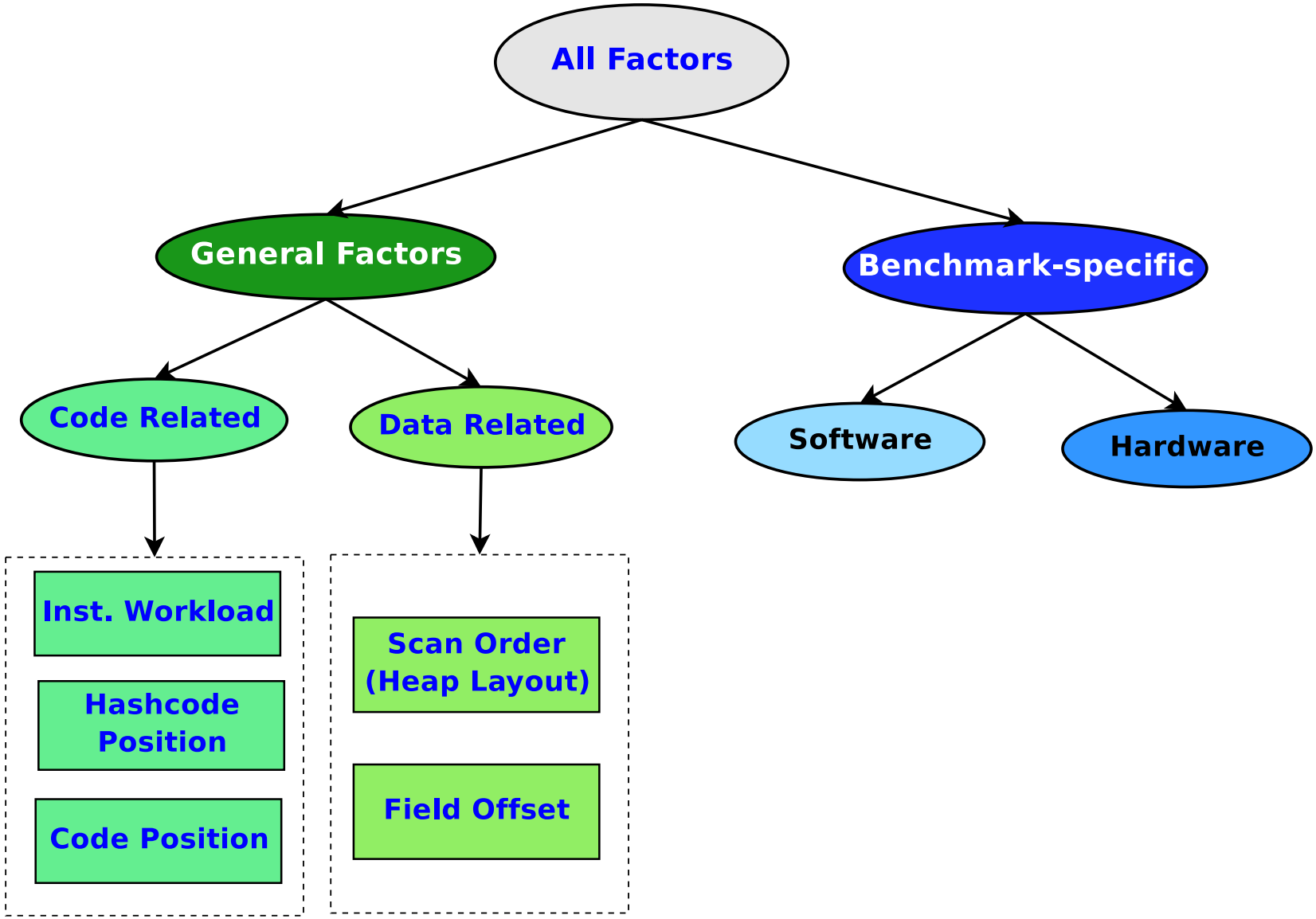
Relative Factors



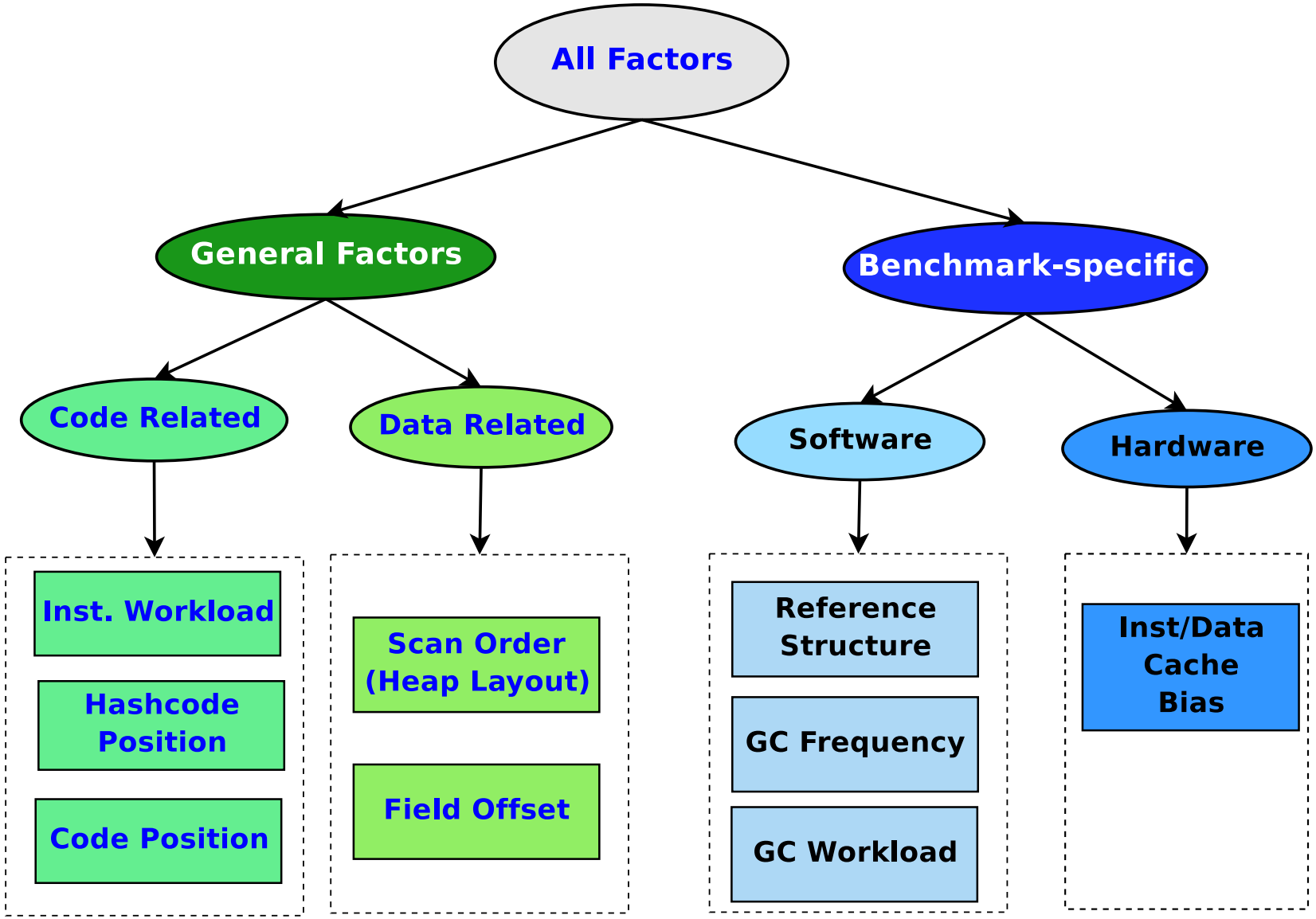
Relative Factors



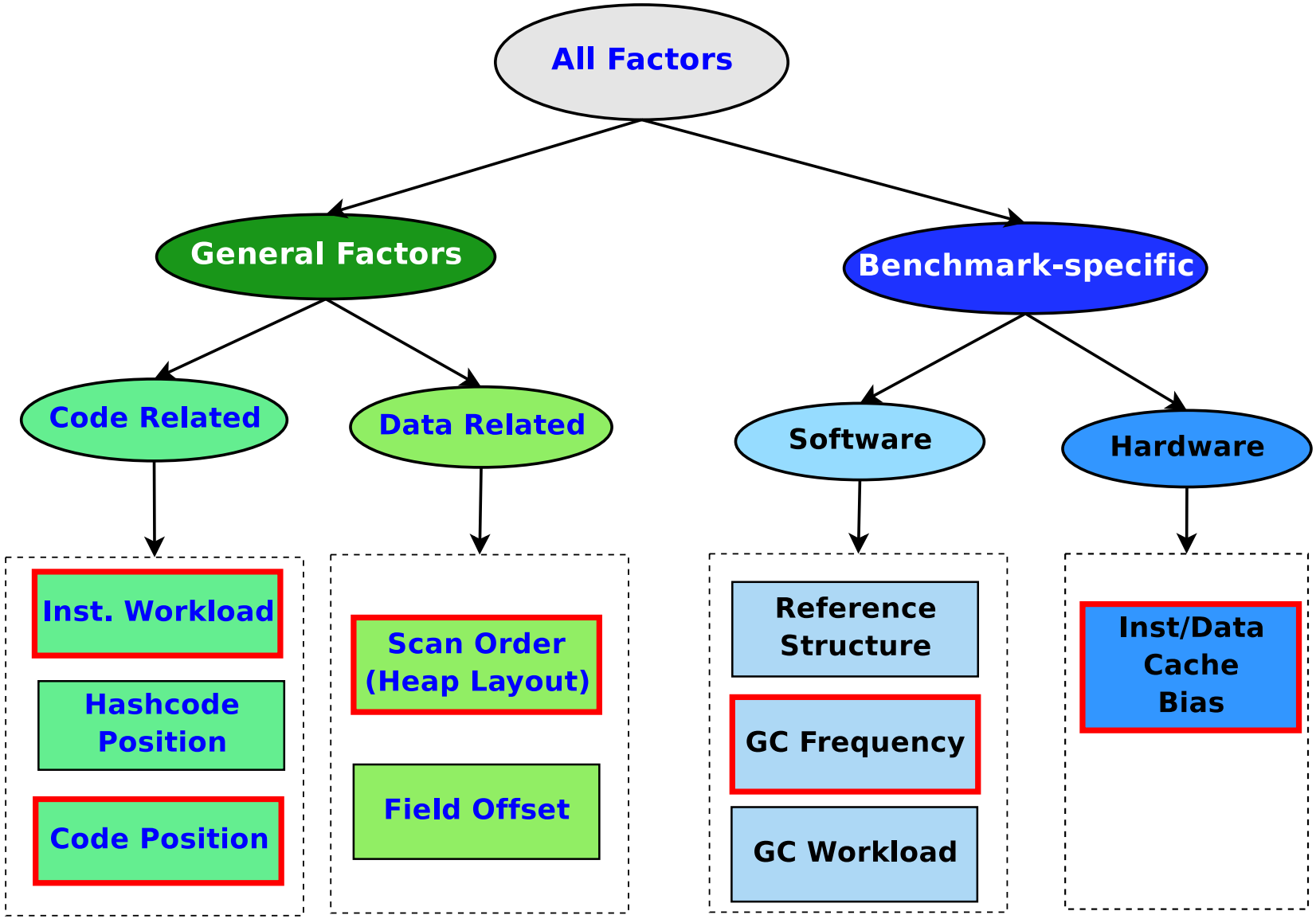
Relative Factors



Relative Factors



Relative Factors



Selected Factors

General

- Instruction
- Code Position
- Scan Order

Benchmark-specific

- GC Frequency
- Cache Bias

Outline

Factors

General

- Instruction
- Code Position
- Scan Order

Benchmark Spec.

- GC Frequency
- Cache Bias

Instruction Workload

- The number of machine instruction executed
- A fundamental factor of execution time
- Measured using hardware counters

Instruction Workload results

In GC

- Reduced up to 12 %
- $\Rightarrow$ GC speedup

In Mutator

- The variation is very small (*on average* 0.03%)
- **Instruction workload** did not cause the performance changes in mutator

Factors

General

- Instruction
- Code Position
- Scan Order

Benchmark Spec.

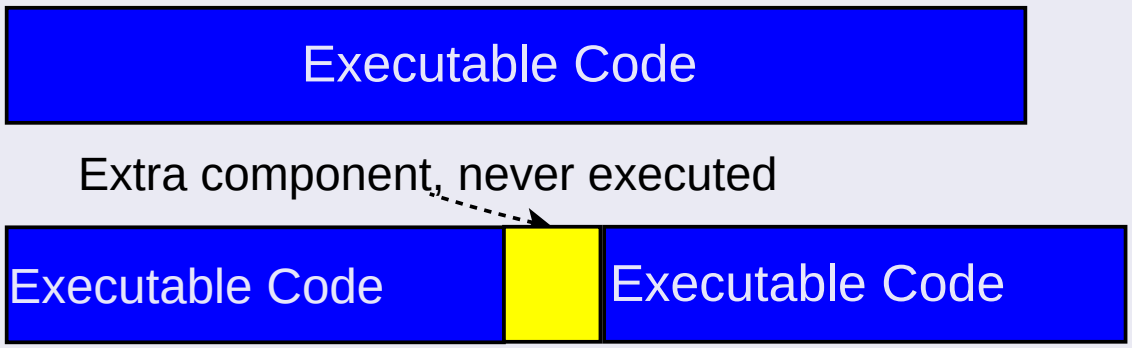
- GC Frequency
- Cache Bias

Code Position

- How code is arranged in memory
- Arrangement can affect cache performance
- How large can the impact be?
- Test by modifying the code position

Modify **Code Position**

Jikes RVM: Add an Extra Component, Never Executed

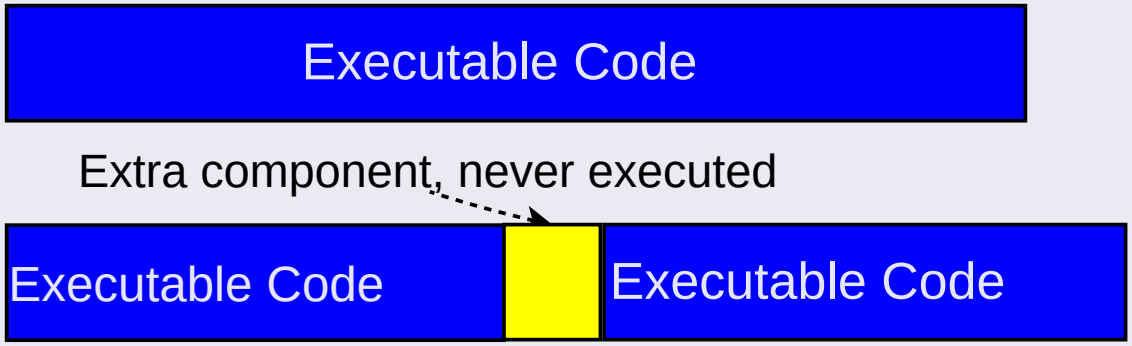


- Compare T_{org} vs T_{with_extra}
- Try different configurations

SableVM: Code Shifting

Modify **Code Position**

Jikes RVM: Add Extra Component, Never Executed



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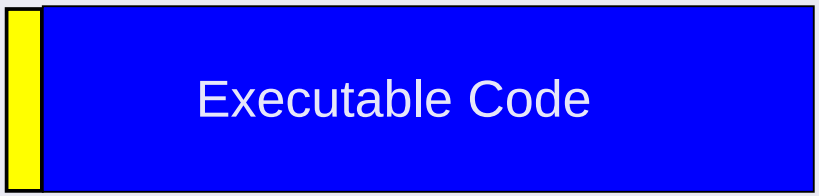
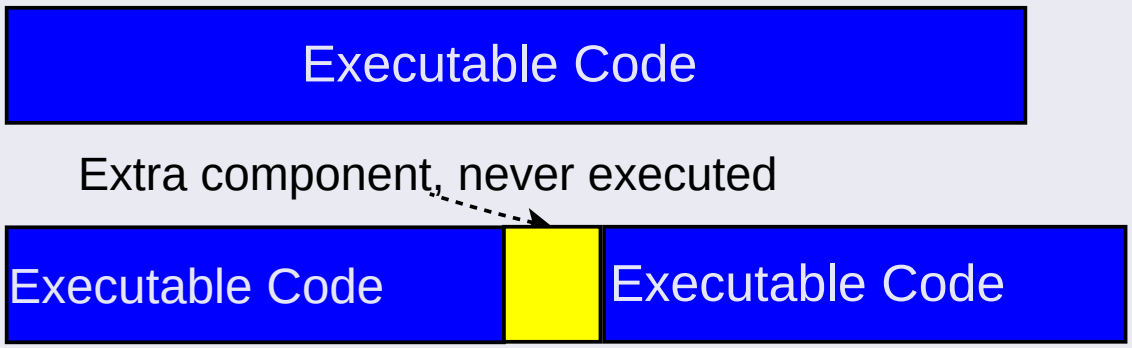
SableVM: Code Shifting



- Add empty space before the executable code
- Shift the code

Modify **Code Position**

Jikes RVM: Add Extra Component, Never Executed



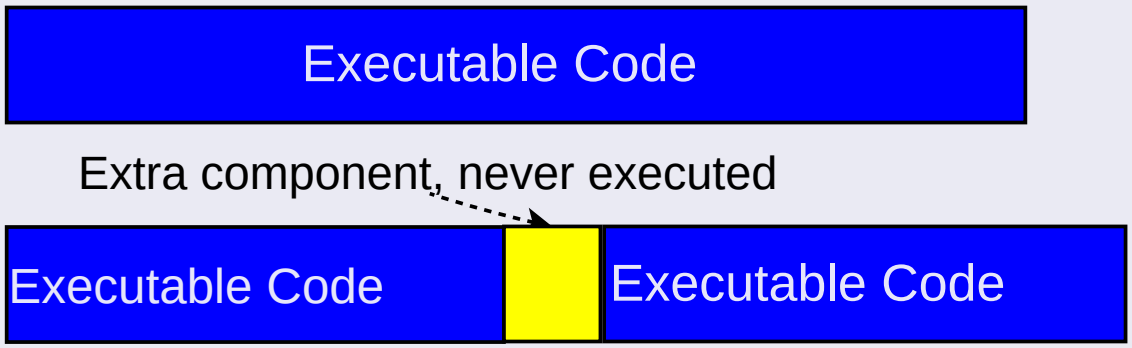
- Compare T_{org} and T_{with_extra}
- Try different configurations

SableVM: Code Shifting

- Increase the space by 4 bytes in each step

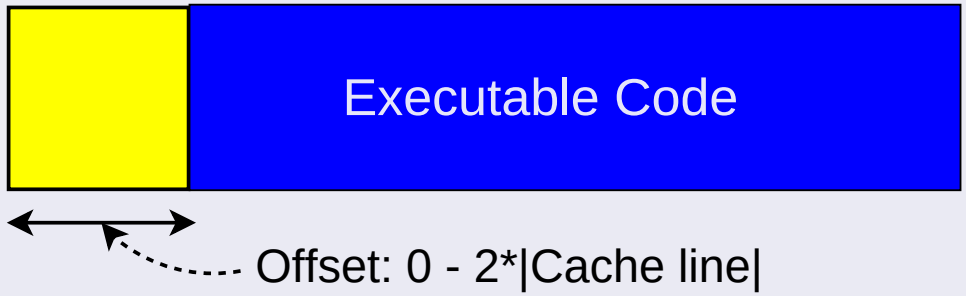
Modify **Code Position**

Jikes RVM: Add Extra Component, Never Executed



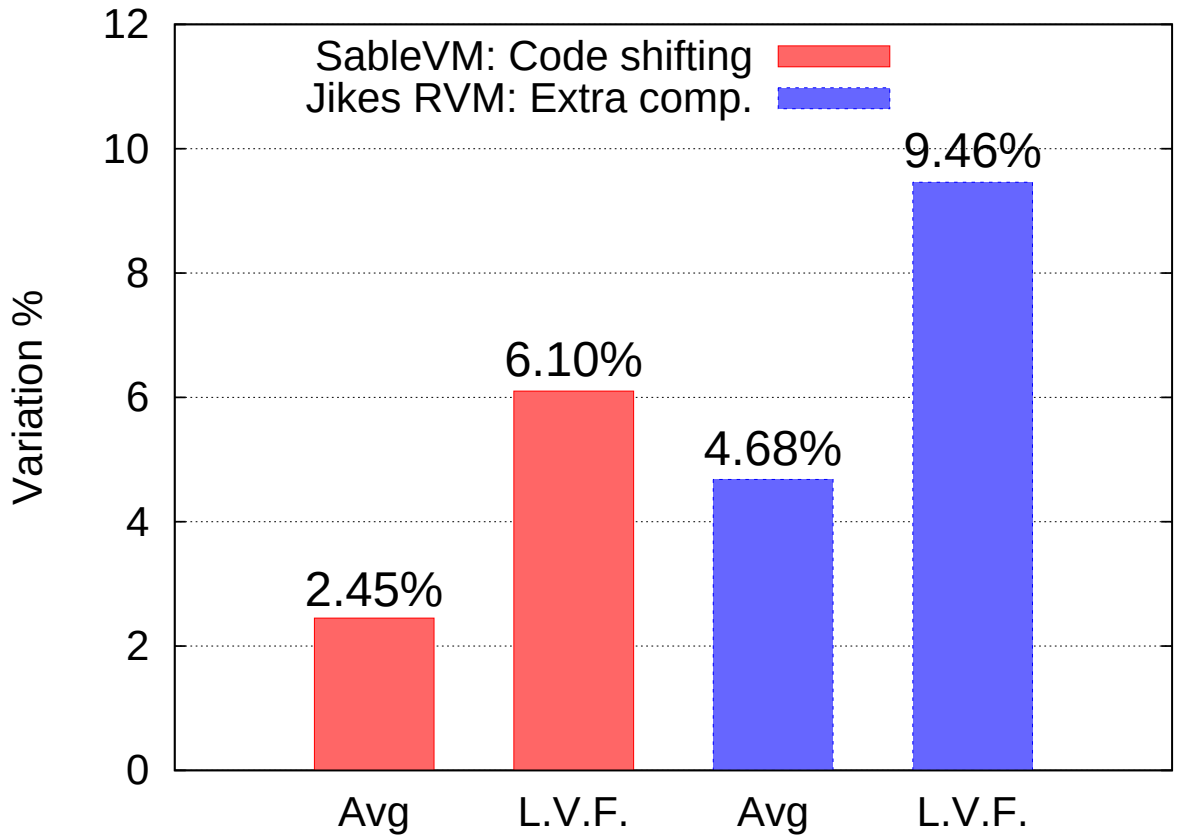
- Compare T_{org} and T_{with_extra}
- Try different configurations

SableVM: **Code Shifting**



- Obtain a set of shifted versions

Code Position Results



- **L.V.F.** for **L**argest **V**ariation **F**ound
- As large as 9.46%
- Could be even larger

- The impact of **Code position** can be **nearly 10%**
- Unexpectedly significant

Factors

General

- Instruction
- Code Position
- Scan Order

Benchmark Spec.

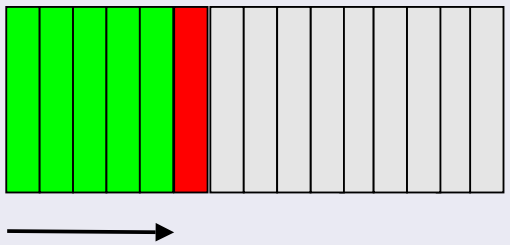
- GC Frequency
- Cache Bias

Scan Order

- Changing the scan order $\Rightarrow$ different heap layouts
- Impacts data cache performance
- We measured two scan orders

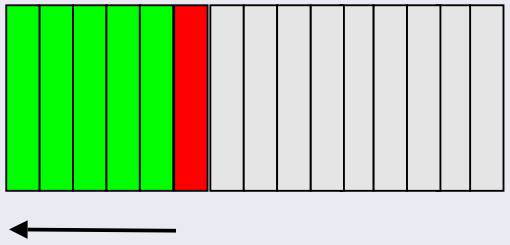
Two Scan Orders

Order 1



subclass → superclass

Order 2



superclass → subclass

Scan Order results

- Data cache performance changed
- No dominant winner

Scan Order results

Cyc/Miss	Mutator	GC
SPECjvm98	396	137
DaCapo	254	167
Average	337	150

- Low data cache misses density in mutator
- 10% in data cache miss $\not\Rightarrow$ 1% in whole execution time

- Data cache performance changed
- No dominant winner

Scan Order results

Cyc/Miss	Mutator	GC
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- Low data cache misses density in mutator
- 10% in data cache miss $\not\Rightarrow$ 1% in whole execution time

- Data cache performance changed
- No dominant winner
- Impact: **scan order** $<$ **code position**

Factors

General

- Instruction
- Code Position
- Scan Order

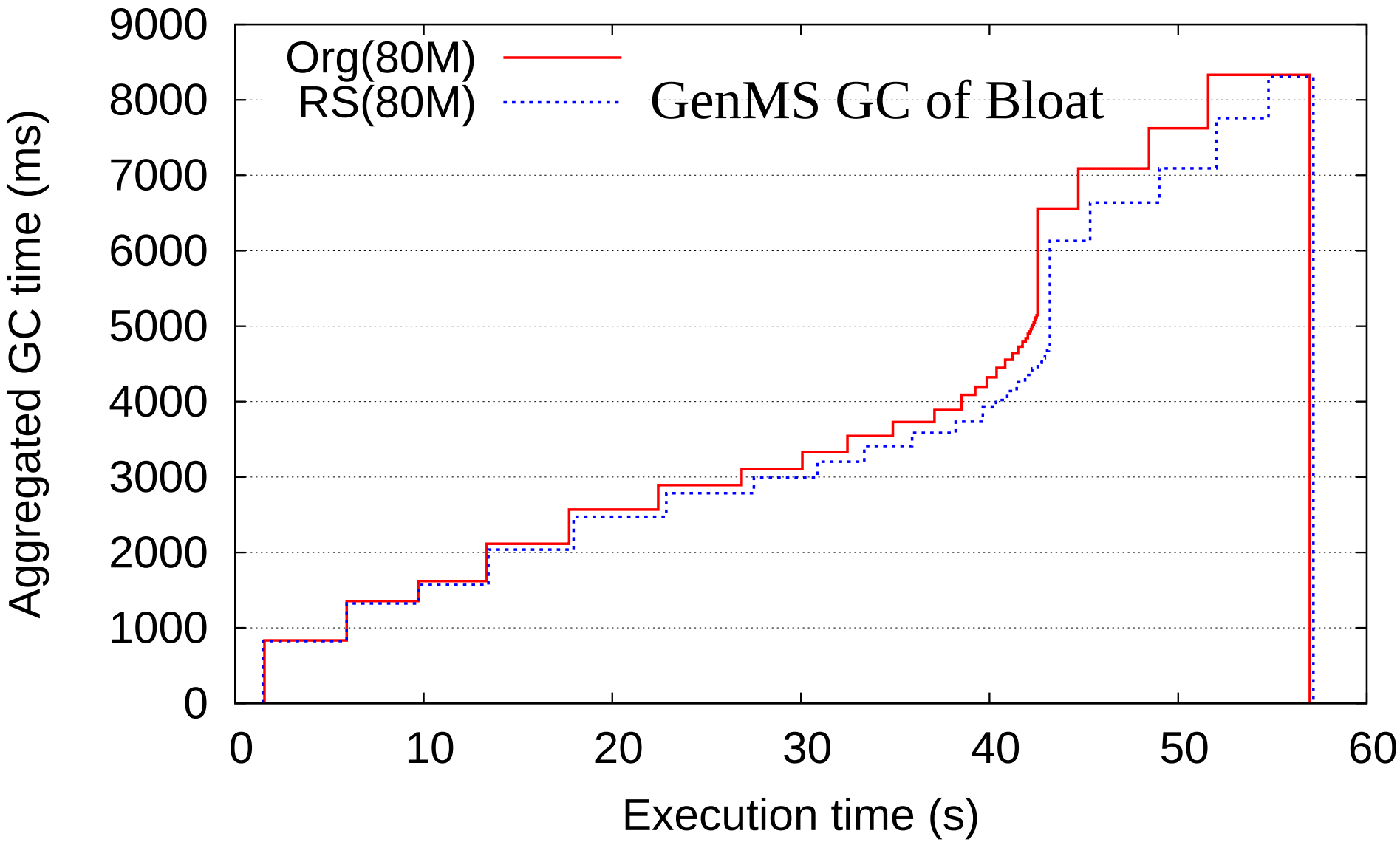
Benchmark Spec.

- GC Frequency
- Cache Bias

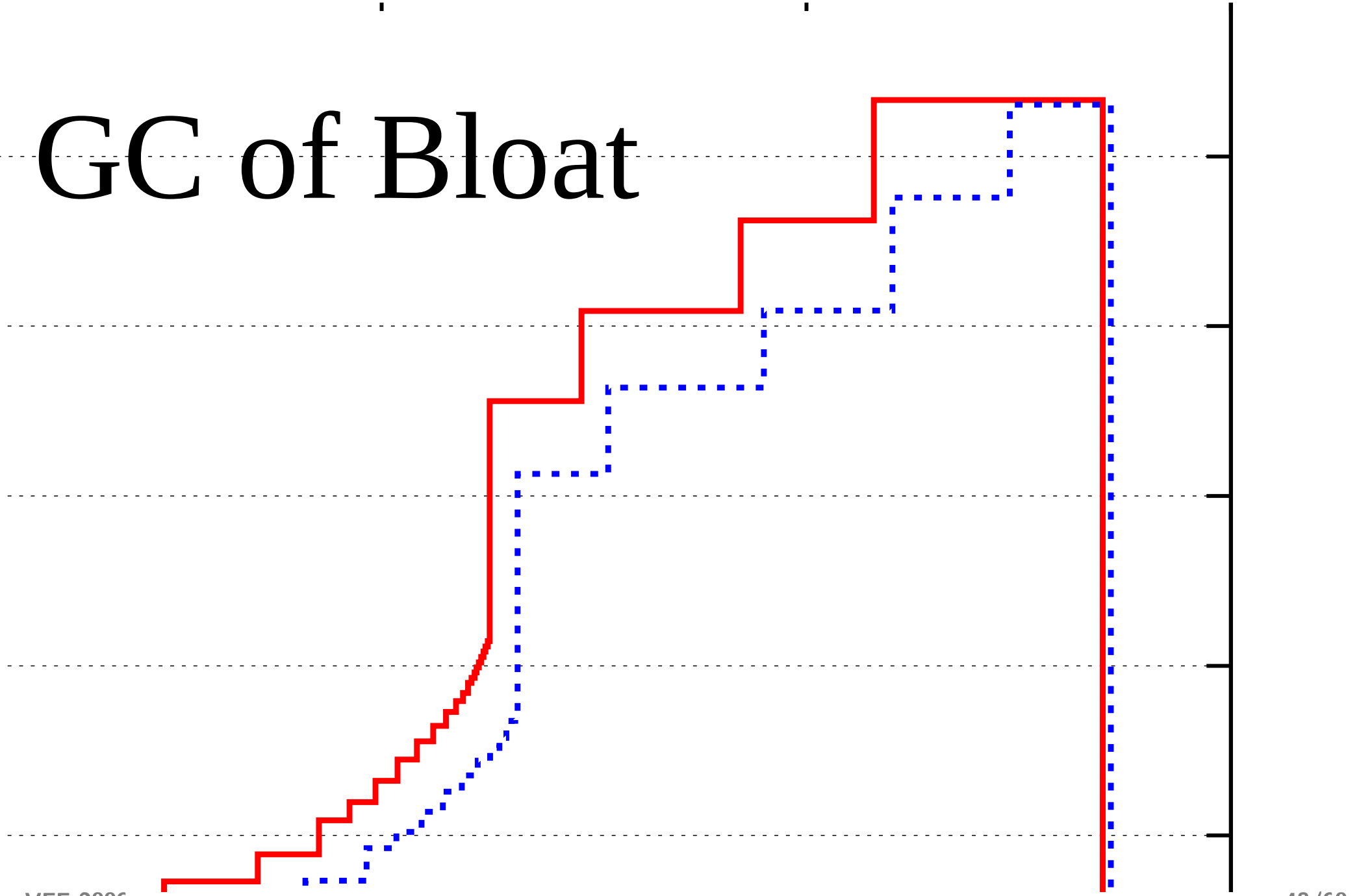
GC Frequency

- The number of GC cycles can be different
- **GenMS** GC results on benchmark BLOAT

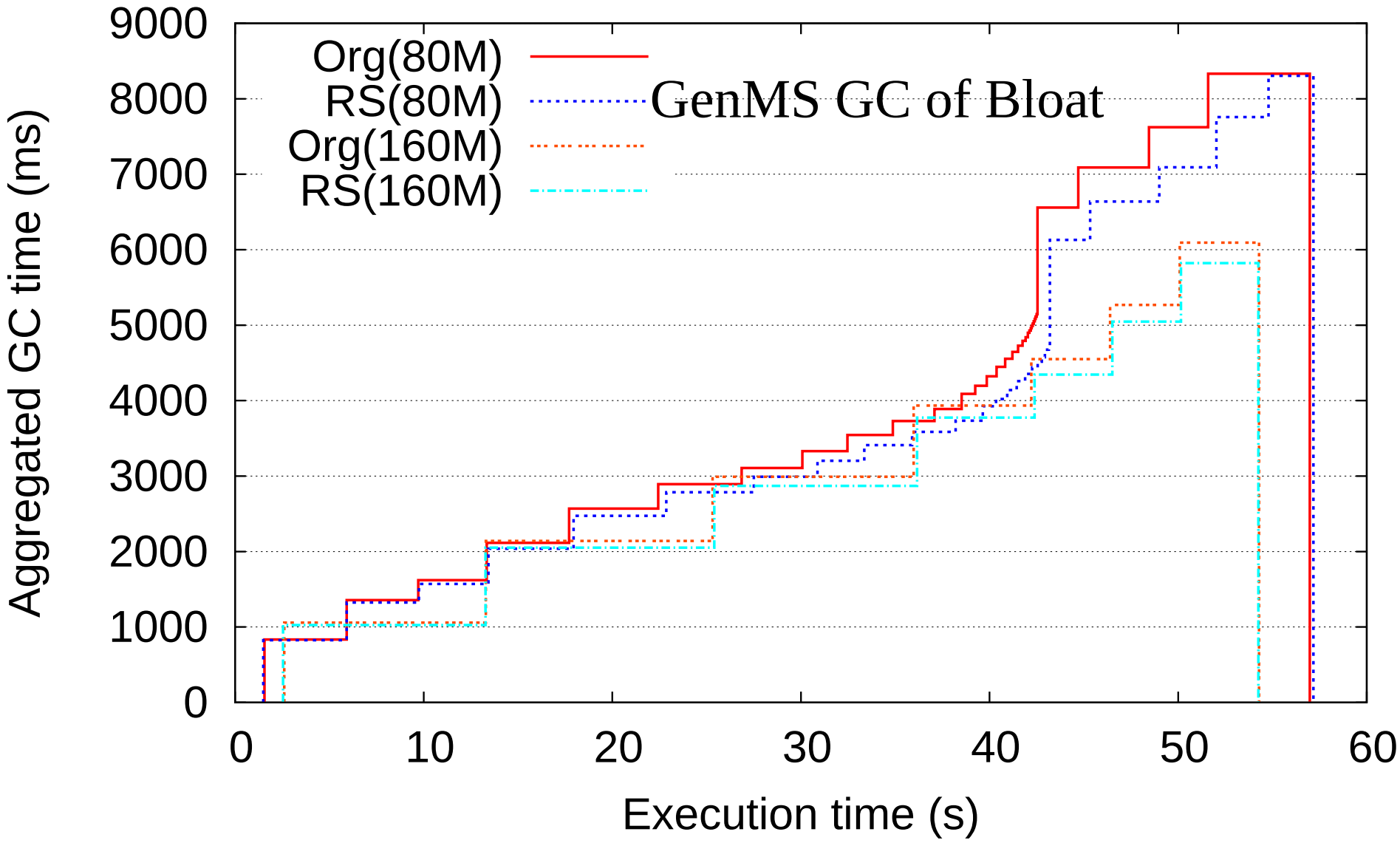
GC Frequency results



GC Frequency results



GC Frequency results



Factors

General

- Instruction
- Code Position
- Scan Order

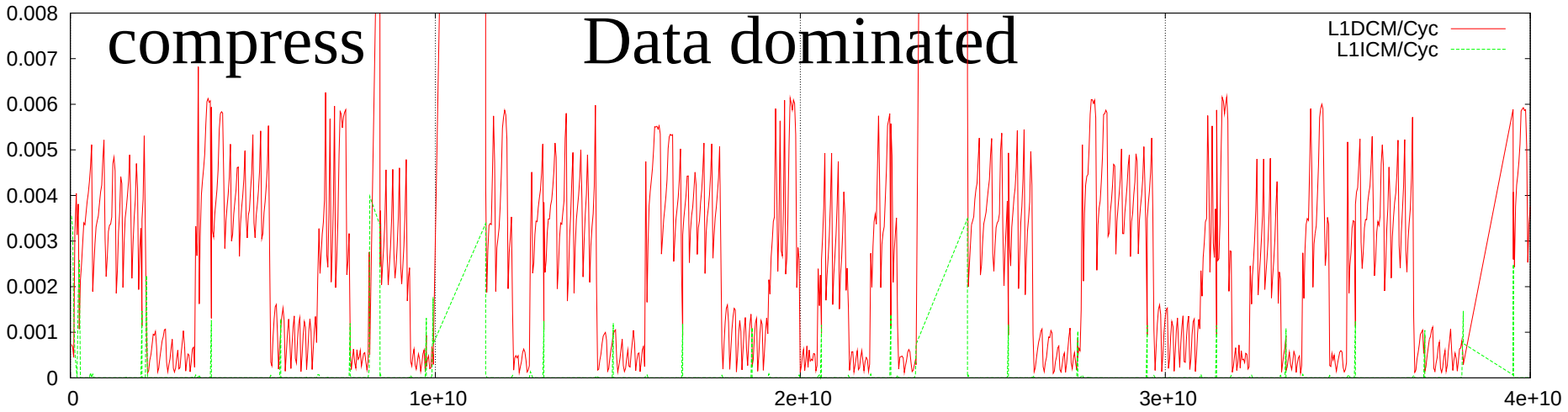
Benchmark Spec.

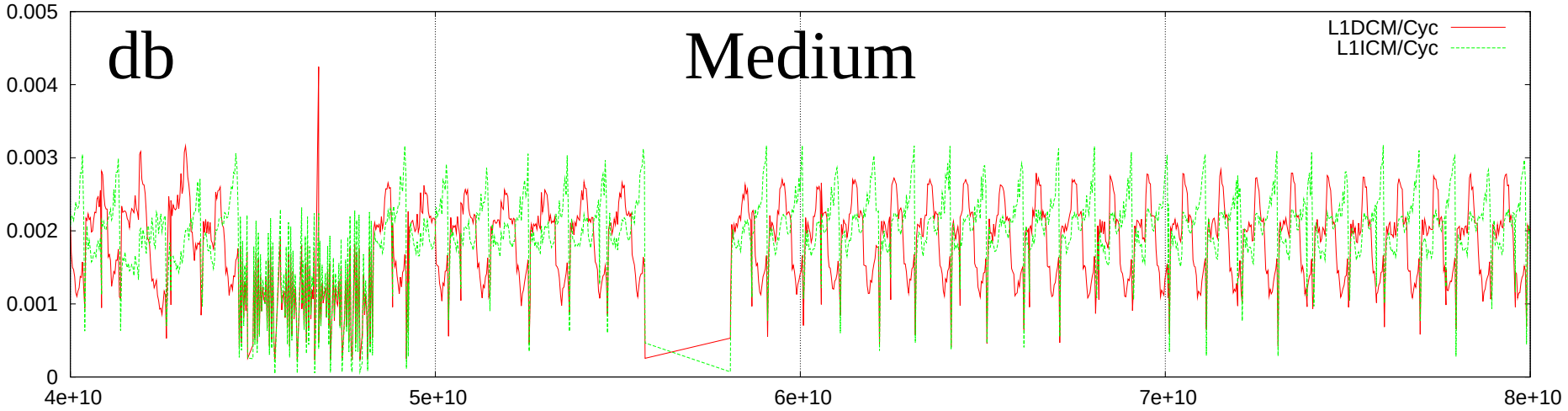
- GC Frequency
- Cache Bias

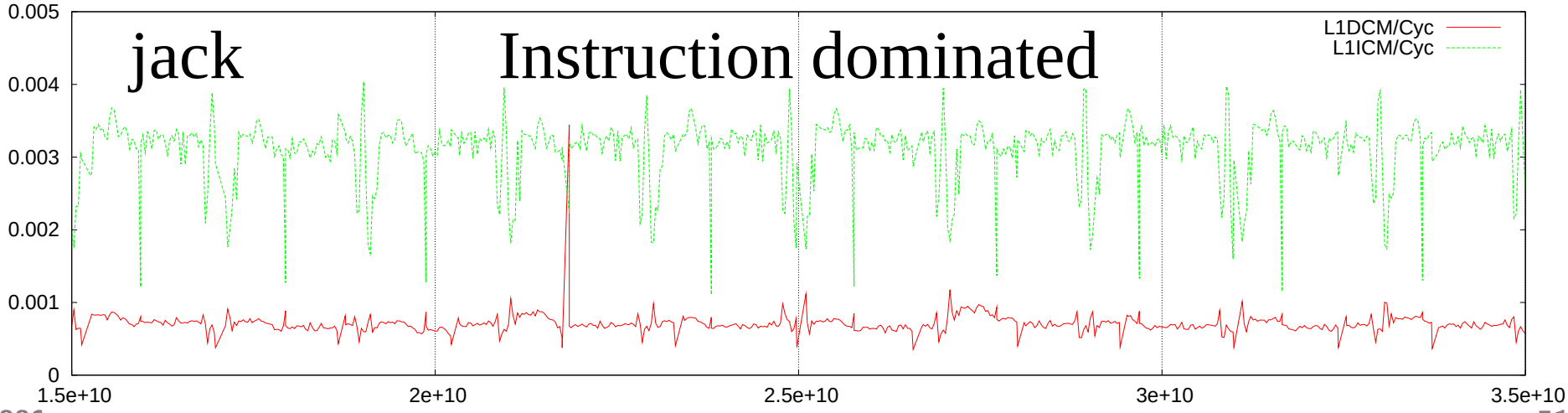
Benchmark Cache Bias

- More sensitive to the behavior of one type of cache than the other
- Cache performance graphs

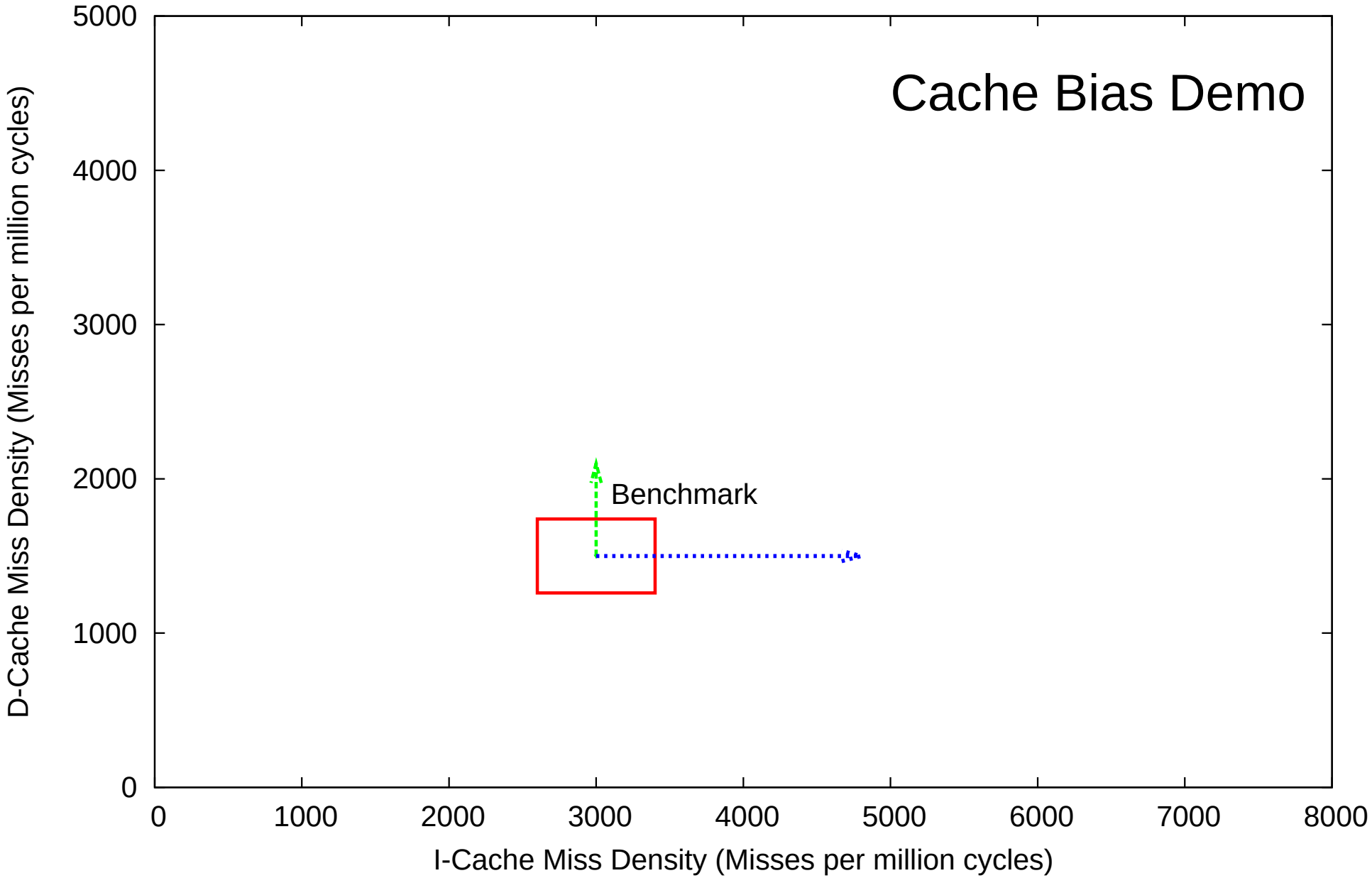
X-AXIS	Elapsed cycles
Y-AXIS	Cache misses density
Red curves	Data cache results
Green curves	Inst. cache results


compress
Data dominated
L1DCM/Cyc
L1ICM/Cyc
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
0
1e+10
2e+10
3e+10
4e+10

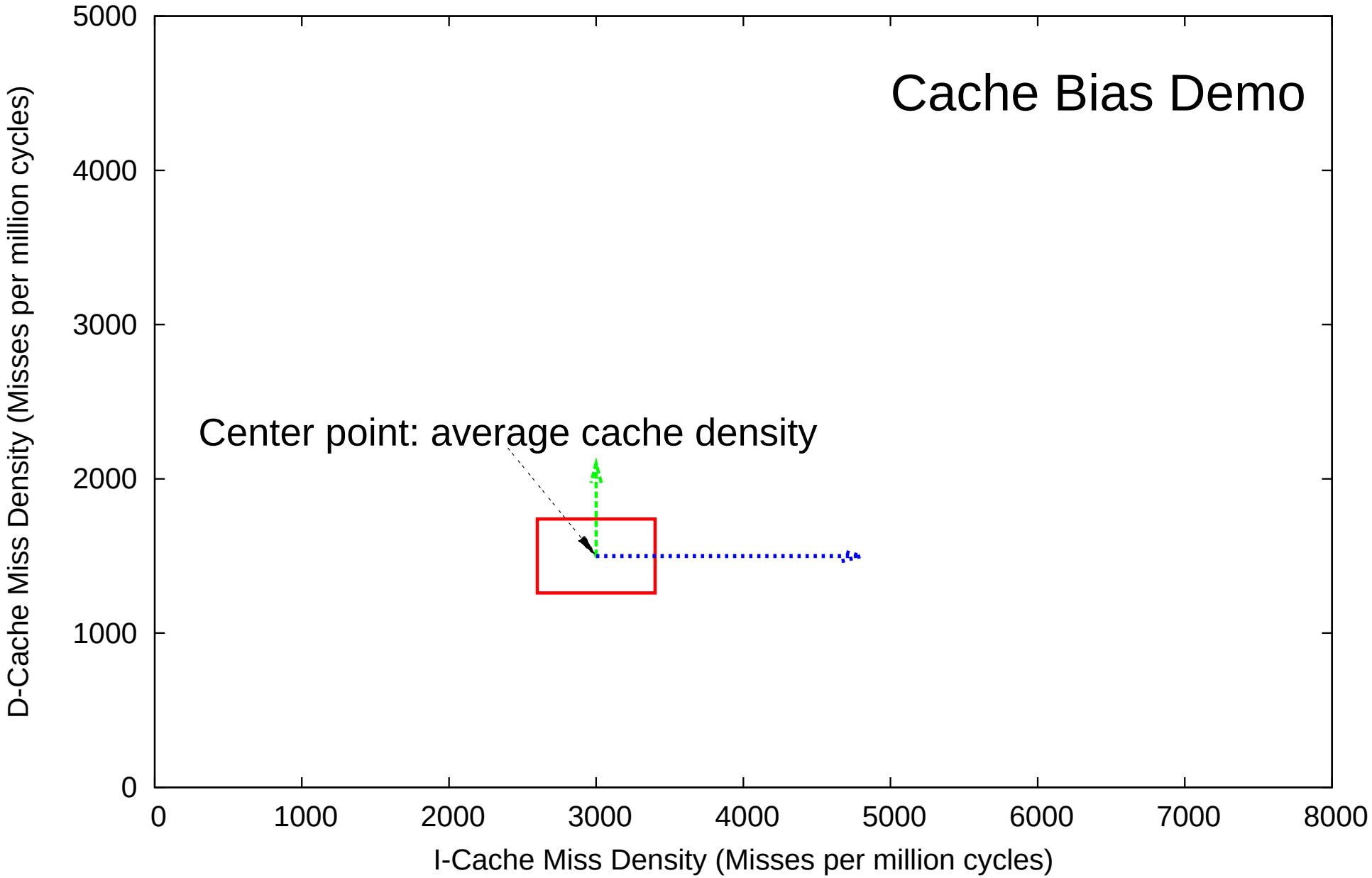

db
Medium
L1DCM/Cyc
L1ICM/Cyc
0.005
0.004
0.003
0.002
0.001
0
4e+10
5e+10
6e+10
7e+10
8e+10


jack
Instruction dominated
L1DCM/Cyc
L1ICM/Cyc
0.005
0.004
0.003
0.002
0.001
0
1.5e+10
2e+10
2.5e+10
3e+10
3.5e+10

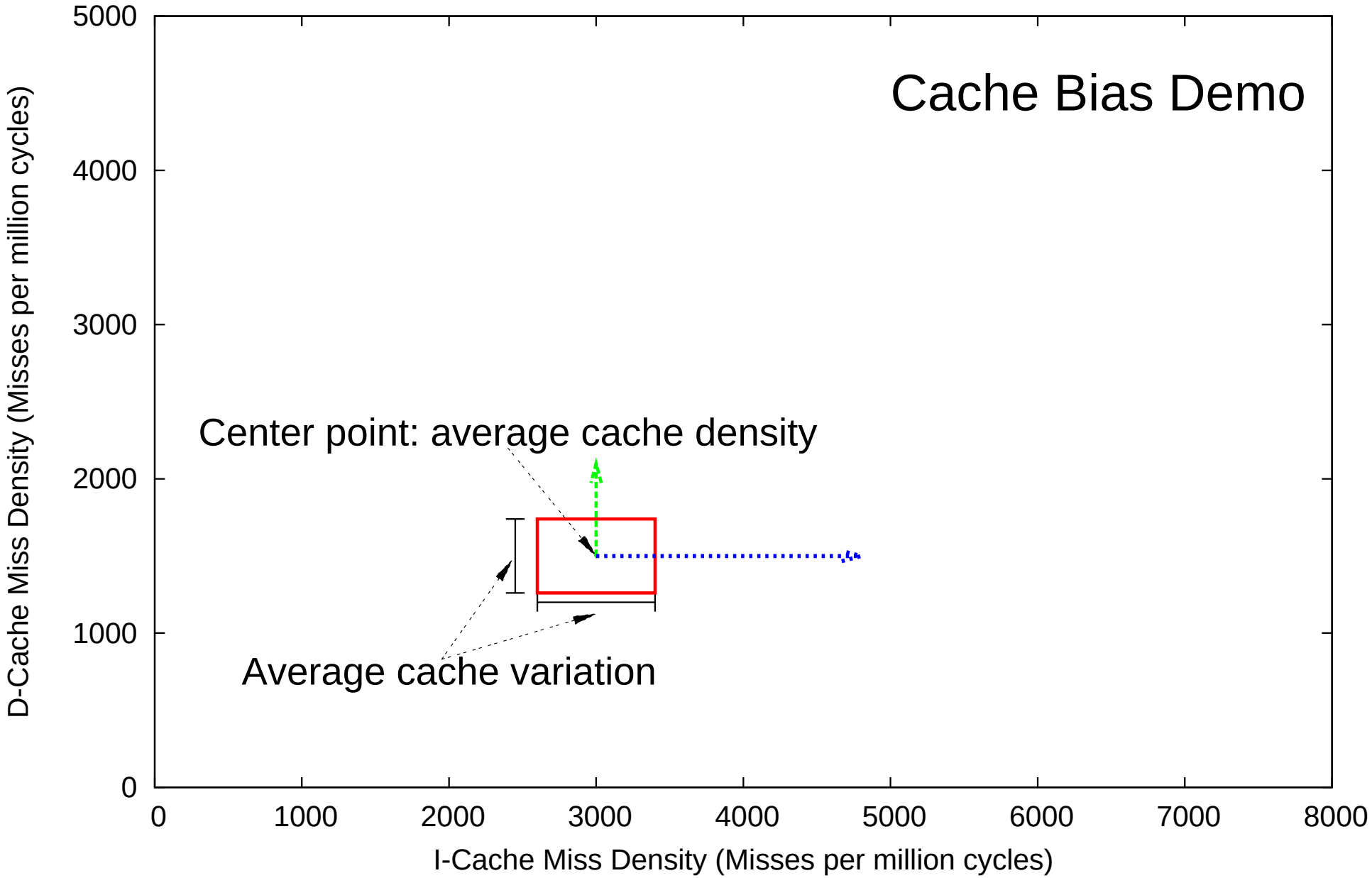
Cache Bias Graph Demo



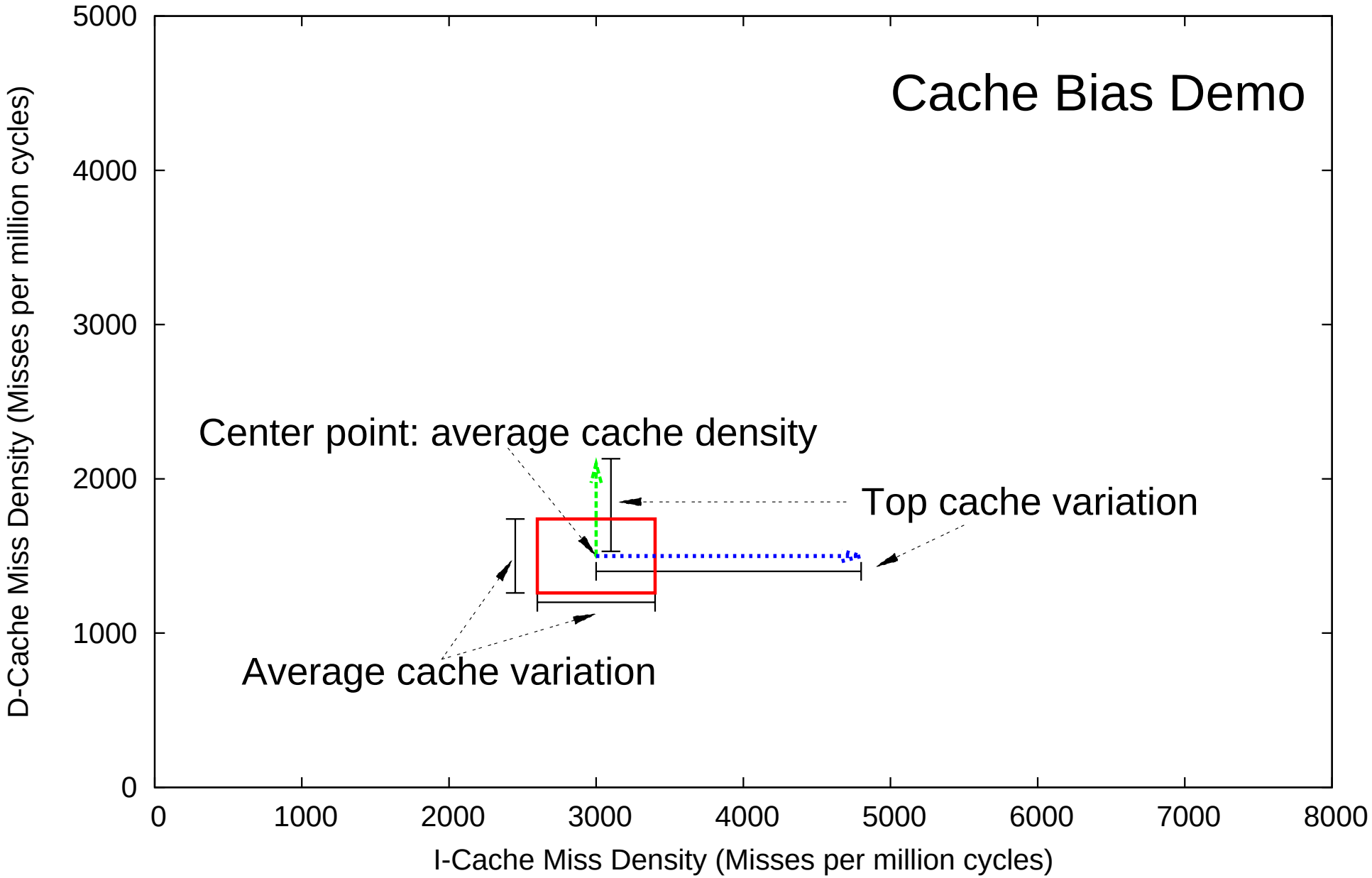
Cache Bias Graph Demo



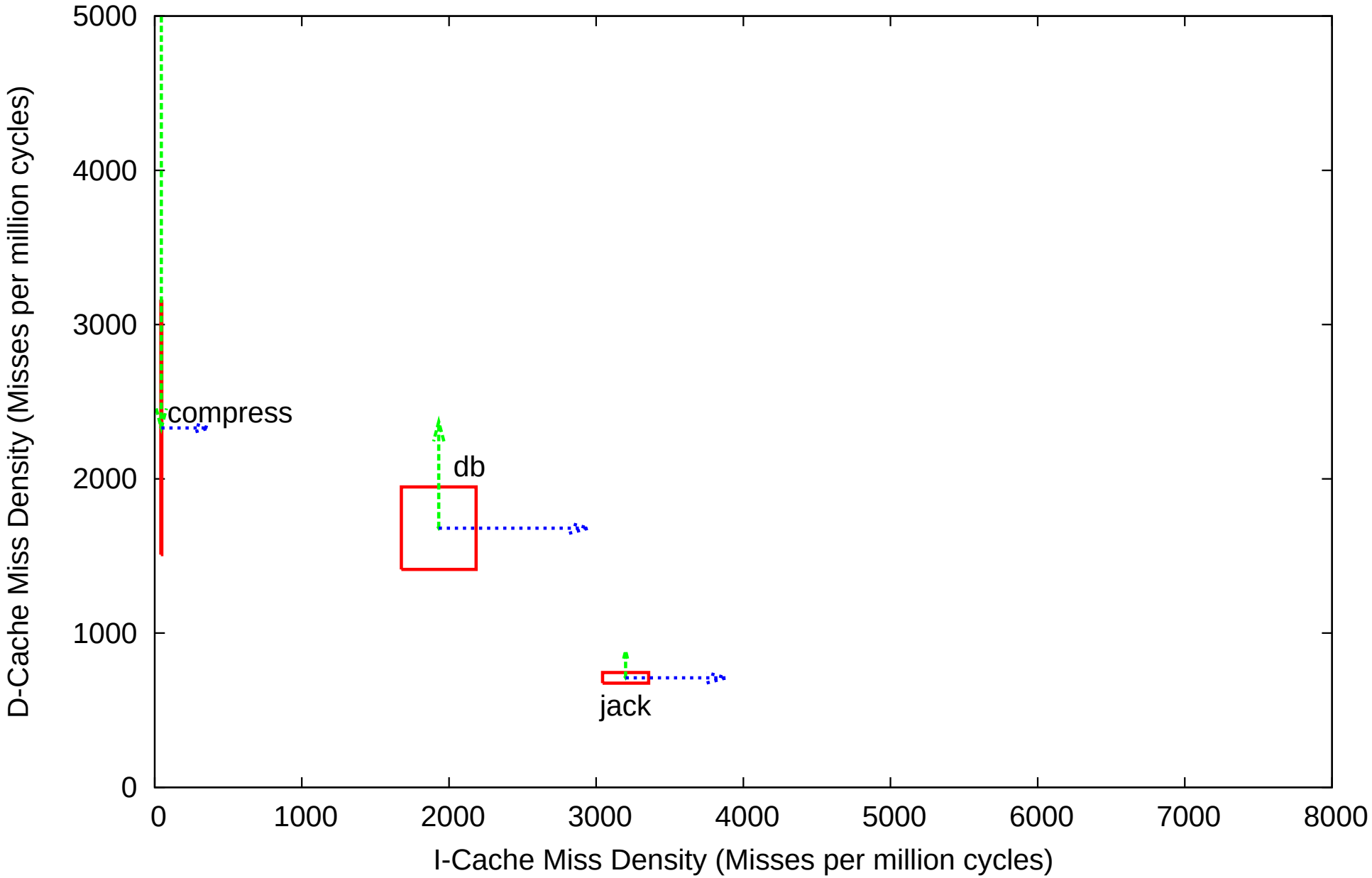
Cache Bias Graph Demo



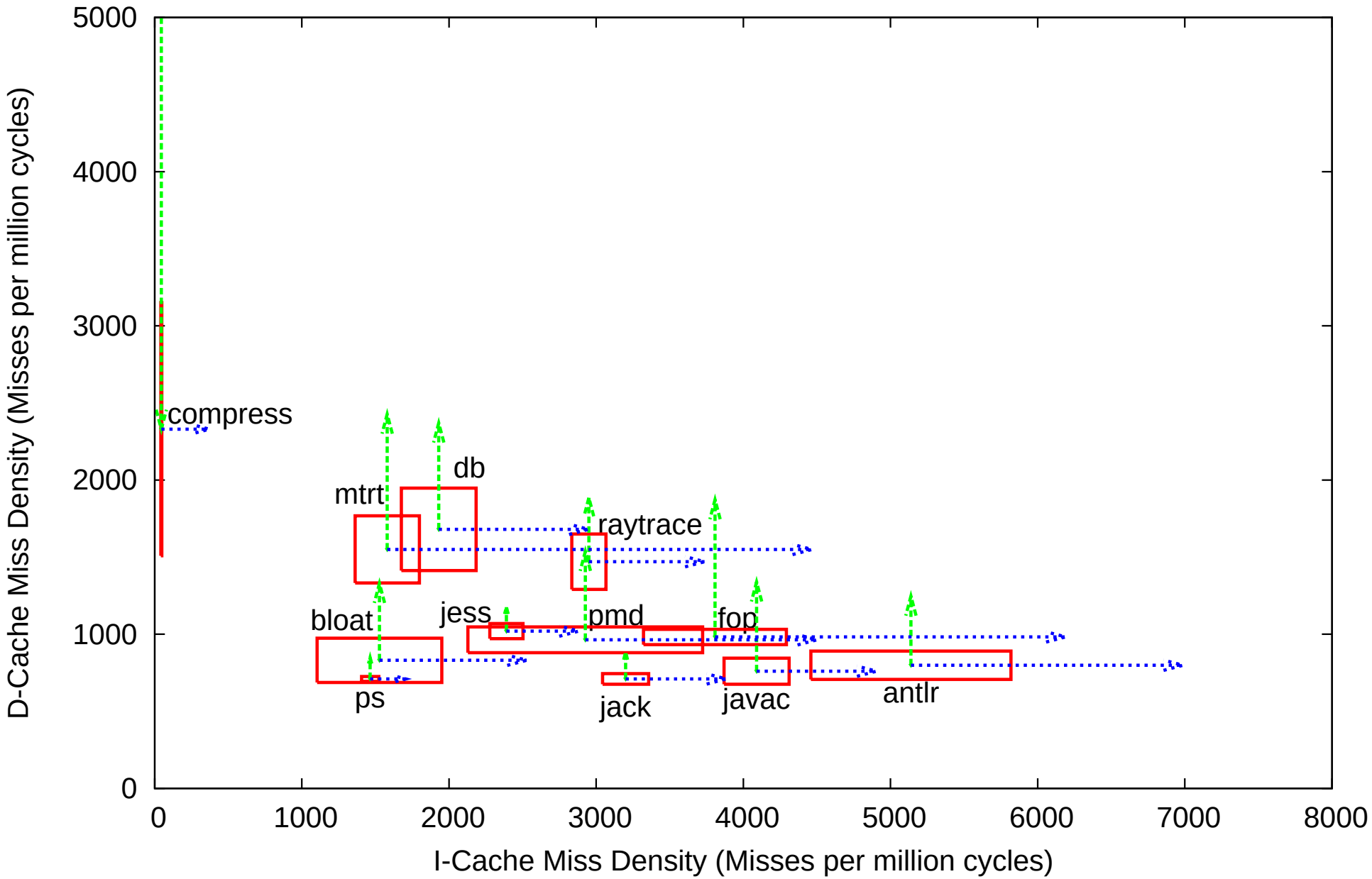
Cache Bias Graph Demo



Cache Bias


5000
4000
3000
2000
1000
0
D-Cache Miss Density (Misses per million cycles)
compress
db
jack
0
1000
2000
3000
4000
5000
6000
7000
8000
I-Cache Miss Density (Misses per million cycles)

Cache Bias


D-Cache Miss Density (Misses per million cycles)
I-Cache Miss Density (Misses per million cycles)
0
1000
2000
3000
4000
5000
6000
7000
8000
compress
mtrt
db
raytrace
bloat
jess
pmd
fop
ps
jack
javac
antlr

Conclusions

- Side-effects are significant enough to distort judgement on techniques
  - Measured influences of up to nearly 10%!
- It is necessary to do deep analysis on measurement results
- Many potential factors affect performance,
  - We estimated the importance of the factors
  - Case study: a GC optimization
- Present a general categorization of relative factors
  - Code/Data, Benchmark-specific, System-wide effects
  - Investigated relative impact of each factor

Future Work

- Code layout
  - Reduce code related "noise" $\Rightarrow$ more accurate performance measurement
  - Apply potential optimizations about code layout
- Further use of hardware data
  - Online and offline analysis on hardware data
  - Optimizations based on hardware data

Questions?

Thank you!