File System Trace Replay Methods Through the Lens of Metrology

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Very popular but ...

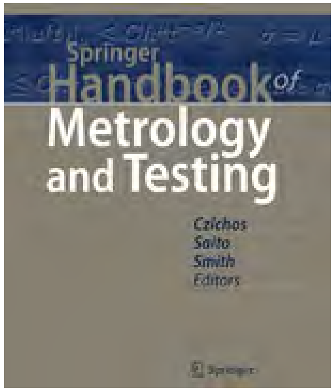
- Many ad hoc trace replay tools – no description about their design and implementation
    - Impossible to reproduce results.

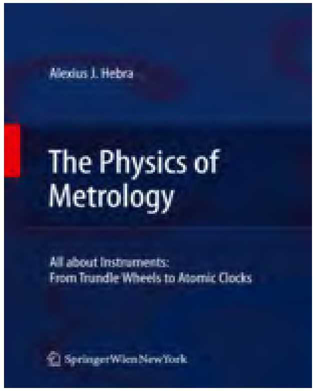
"How to do this accurately is still an open question, and the best we can do right now is take results with a degree of skepticism" - Traeger, A., Zadok, E., Joukov, N., & Wright, C. P. (2008). A nine year study of file system and storage benchmarking. *ACM Transactions on Storage (TOS)*

Before creating new methods, how good are current trace based methods?

Our take

A metrology case study

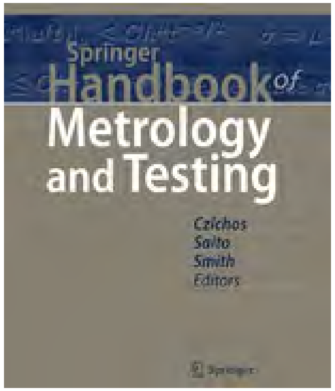


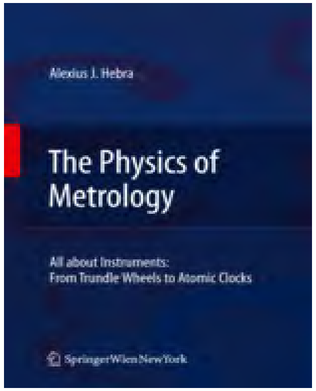


Our take

A metrology case study

Single-laboratory





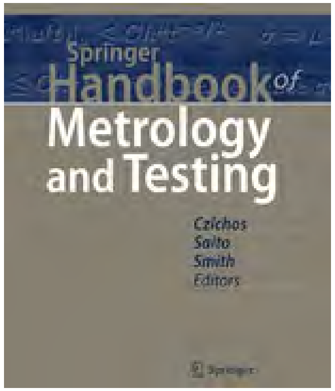
Our take

A metrology case study

Single-laboratory

Inter-laboratories

Different operators
Different instruments
Different environment



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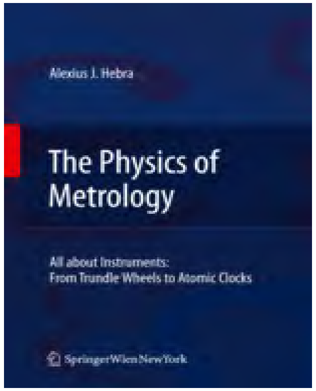

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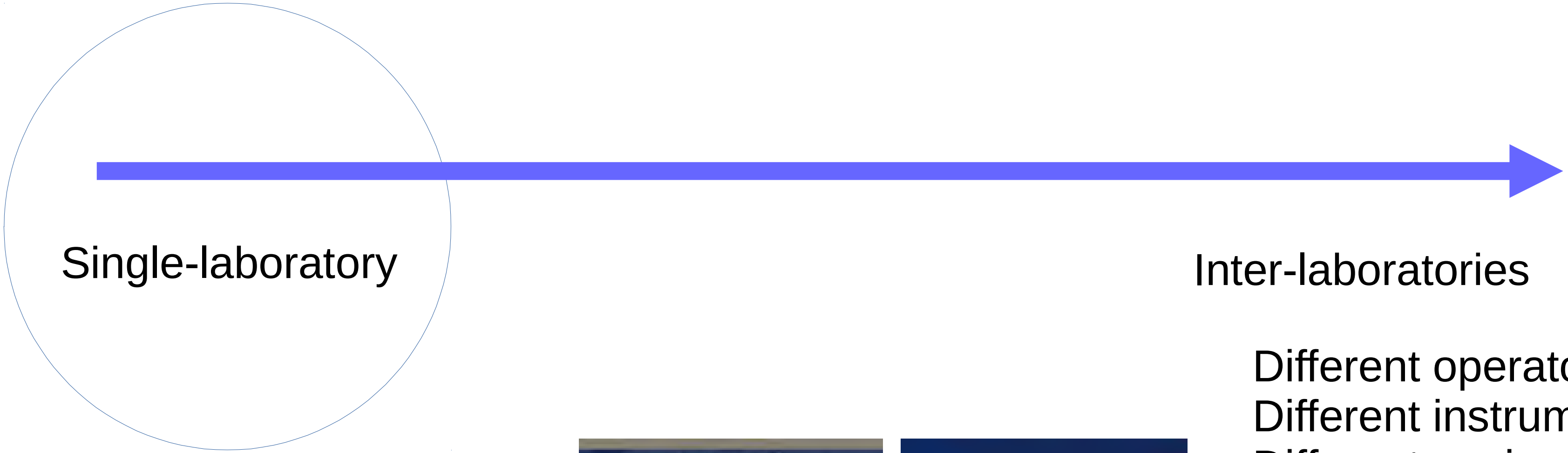
Our take

A metrology case study



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Inter-laboratories

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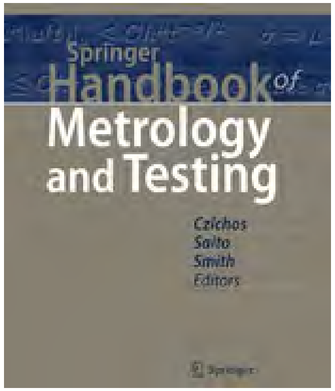

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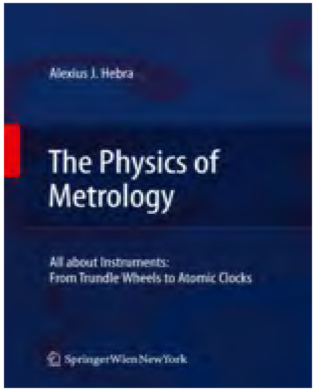

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Single-lab testing

1. Define the measurand
   - The quantity intended to be measured
2. Specify the measurement procedure
3. Identify the uncertainty sources
4. Conduct the measurement characterization
   - In terms of bias, precision, sensitivity, resolution, etc.
5. Perform the calibration (or mitigation of measurement errors)
6. Calculate the measurement uncertainty
   - An interval **[y – u, y + u]** within the true value of measurand **y** are expected to be.

Measurand

File system response time

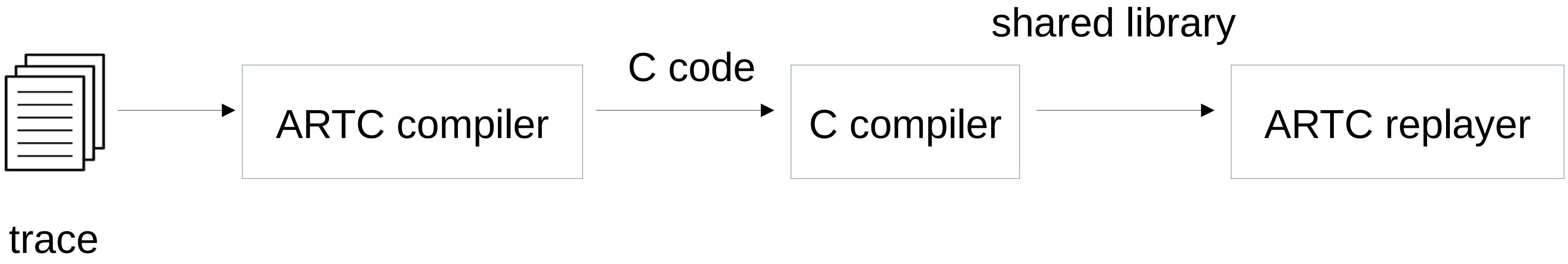
Measurement procedure

Instruments

- ARTC replayer (compilation-based)
- TBBT replayer (event-based)

1. *Weiss, Zev, et al*. **"Root: Replaying multithreaded traces with resource-oriented ordering."** SOSP. ACM, 2013.
2. Zhu, Ningning, Jiawu Chen, and Tzi-Cker Chiueh. **"TBBT: scalable and accurate trace replay for file server evaluation."** FAST,2005.

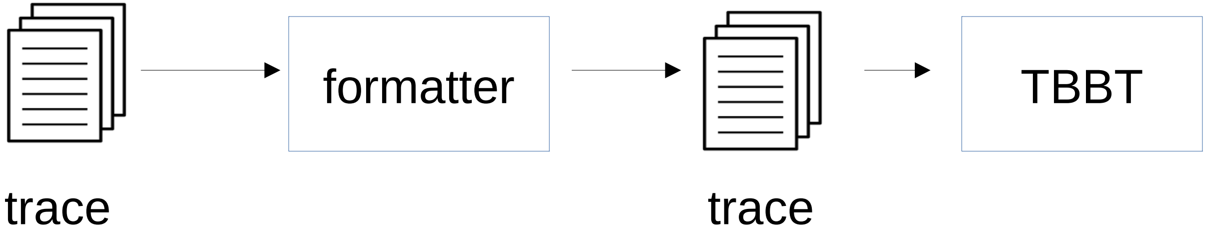
ARTC Replayer



1. *Weiss, Zev, et al*. **"Root: Replaying multithreaded traces with resource-oriented ordering."** SOSP. ACM, 2013.

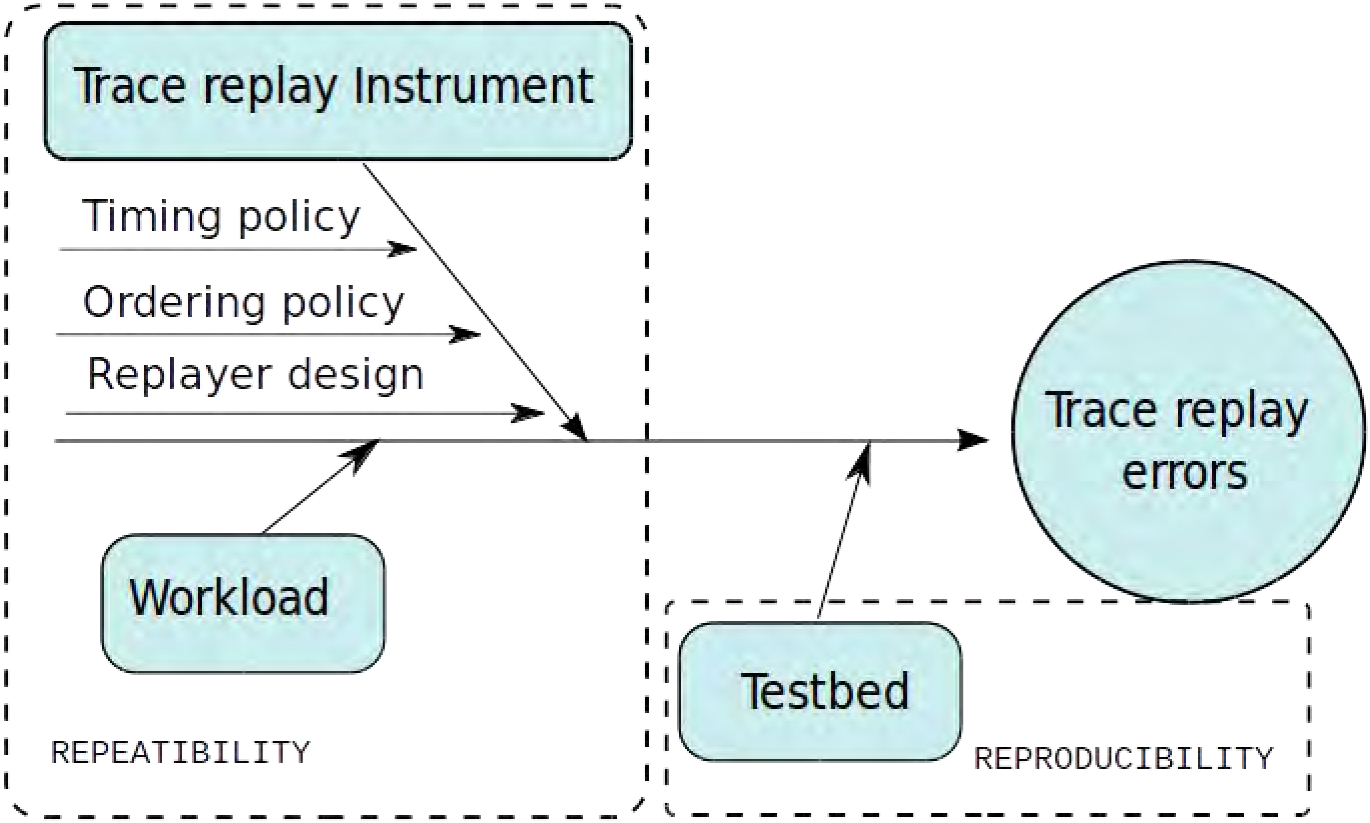
TBBT Replayer

Based on TBBT design, running as a real time process to be less **sensitive**

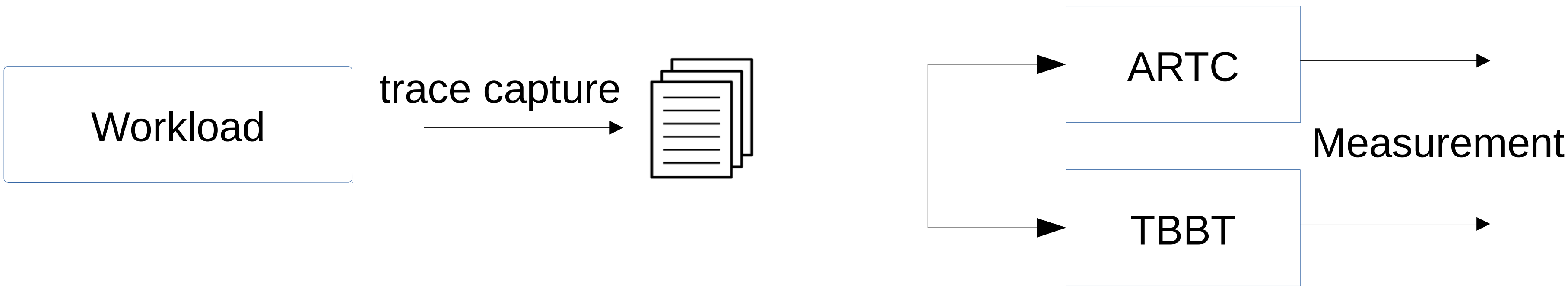


1. Zhu, Ningning, Jiawu Chen, and Tzi-Cker Chiueh. **"TBBT: scalable and accurate trace replay for file server evaluation."** FAST,2005.
2. Tarihi, Mojtaba, Hossein Asadi, and Hamid Sarbazi-Azad. **"DiskAccel: Accelerating Disk-Based Experiments by Representative Sampling."** SIGMETRICS , 2015.

Uncertainty sources



Characterization



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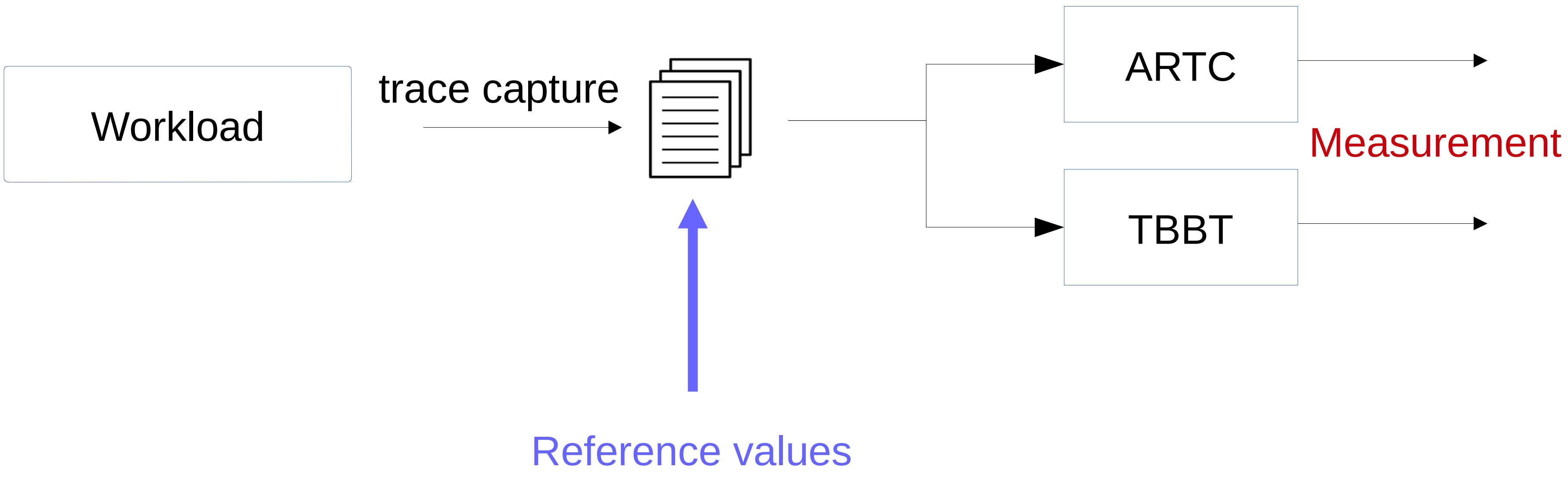
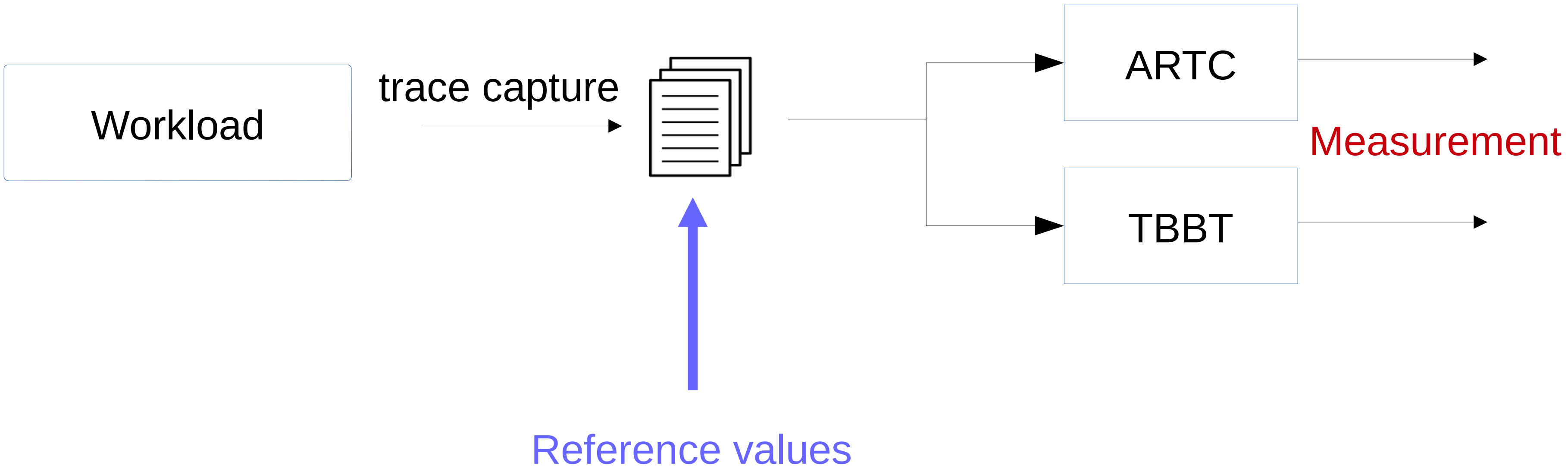


Characterization

- Microbenchmark (5k ops, 4k chunks, [1-4] threads)
  - Random read (RR), Random write (RW)
  - Sequential read (SR), Sequential write (SW)
- Filebench fileserver workload



Workload

trace capture

ARTC

TBBT

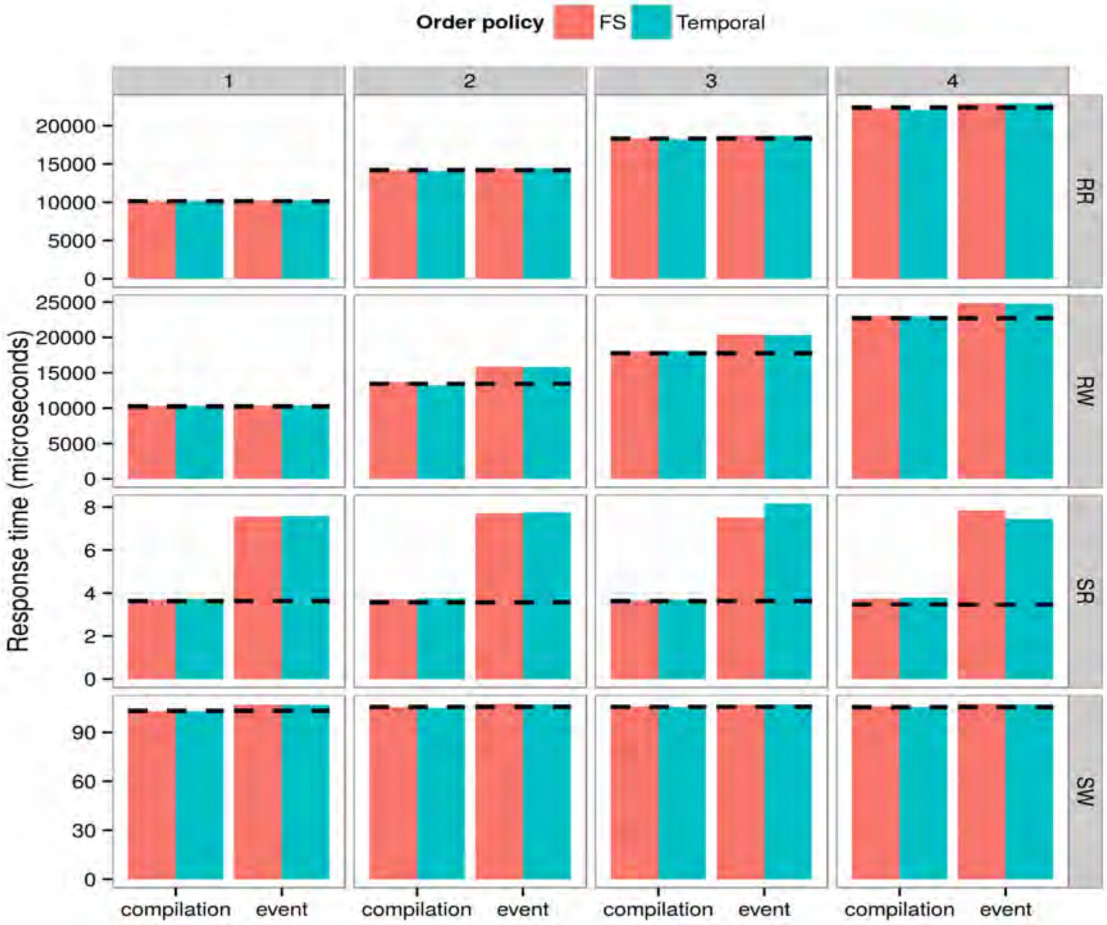
Measurement

Reference values

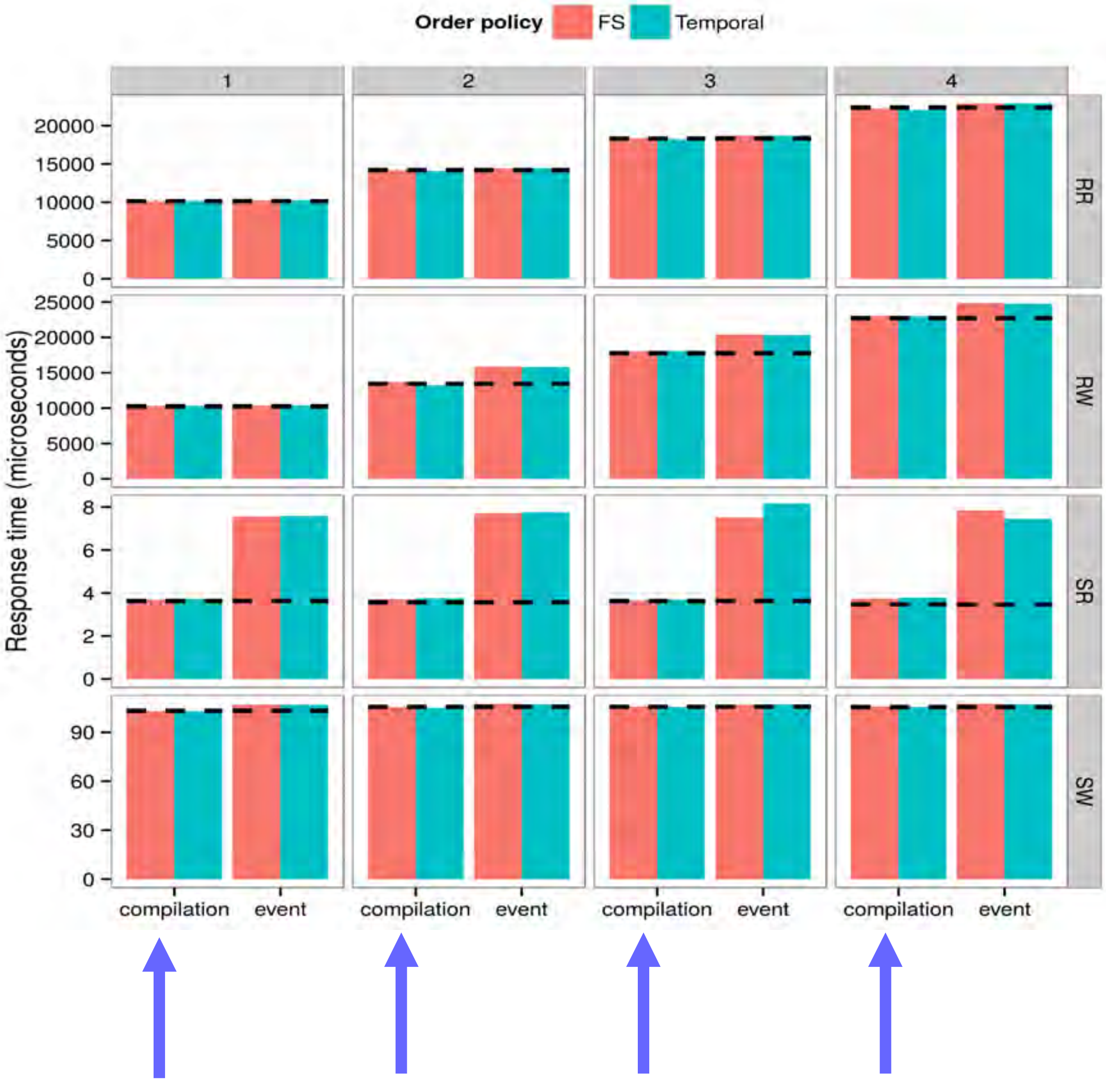
Characterization

Microbenchmark

Bias characterization



Bias characterization



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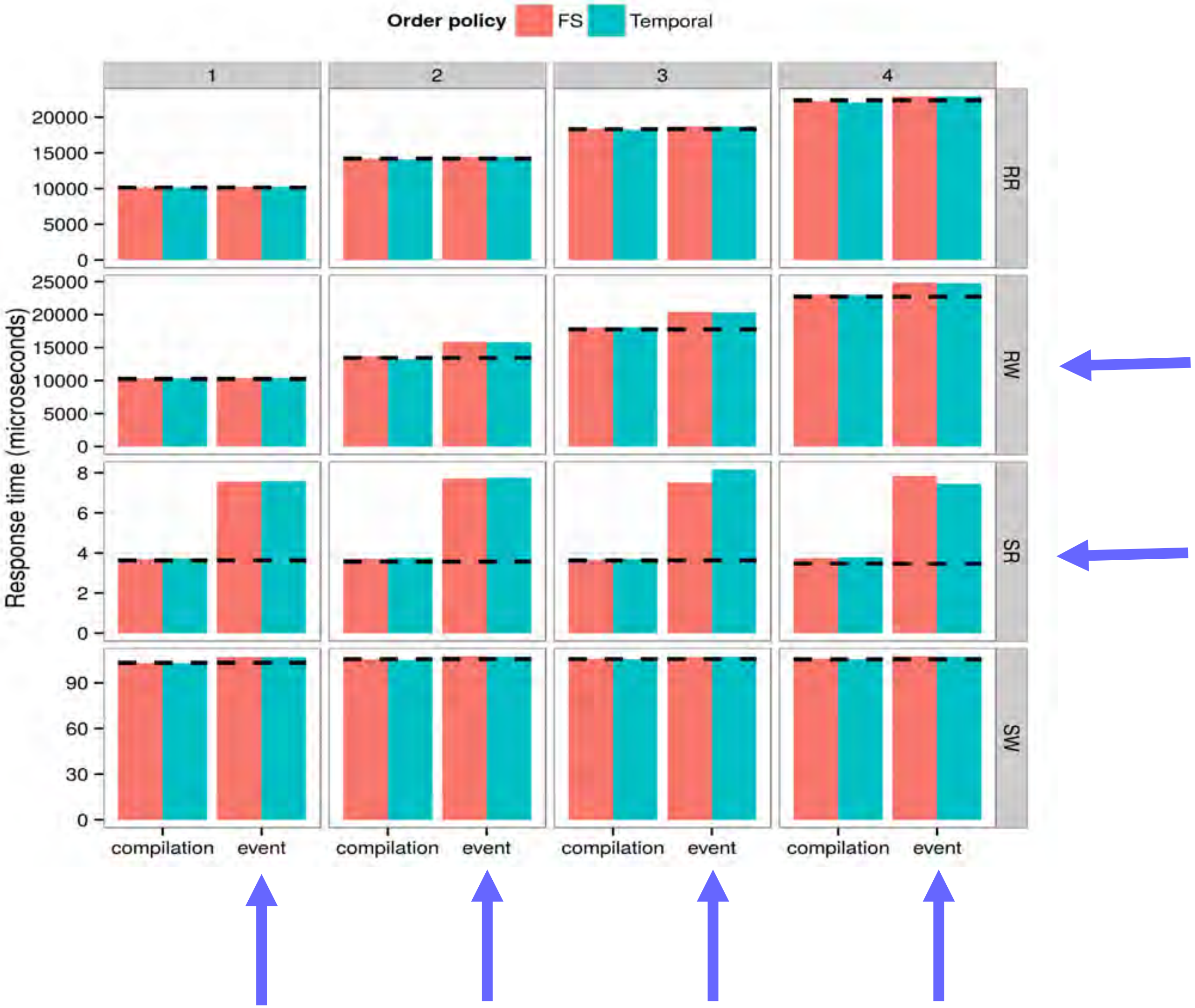
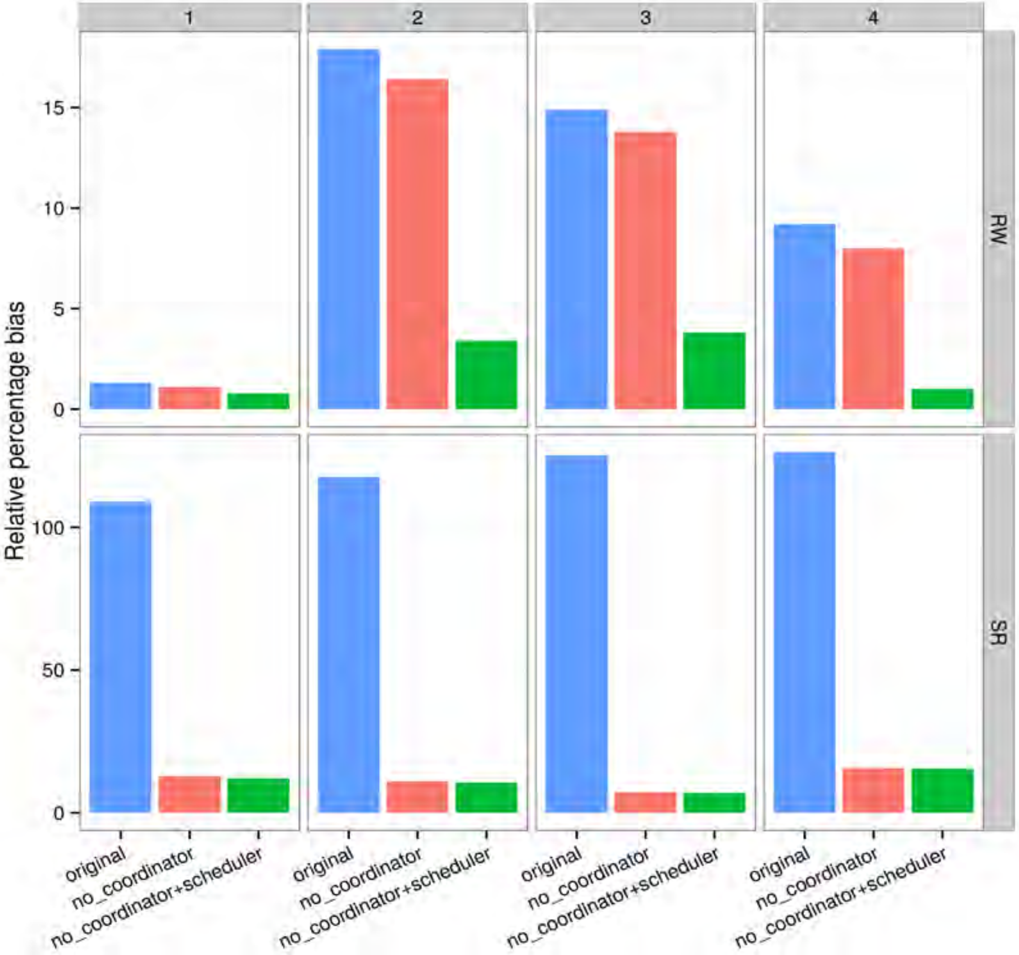
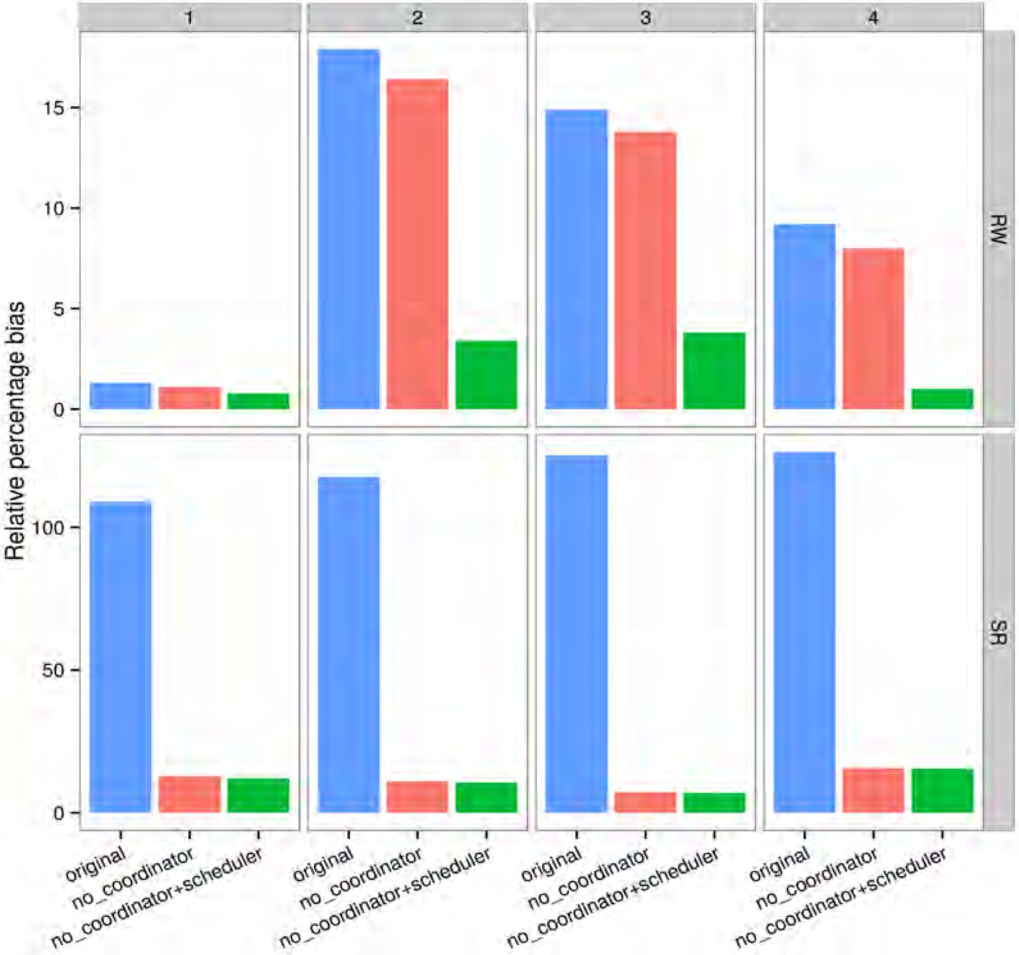


TBBT improvements



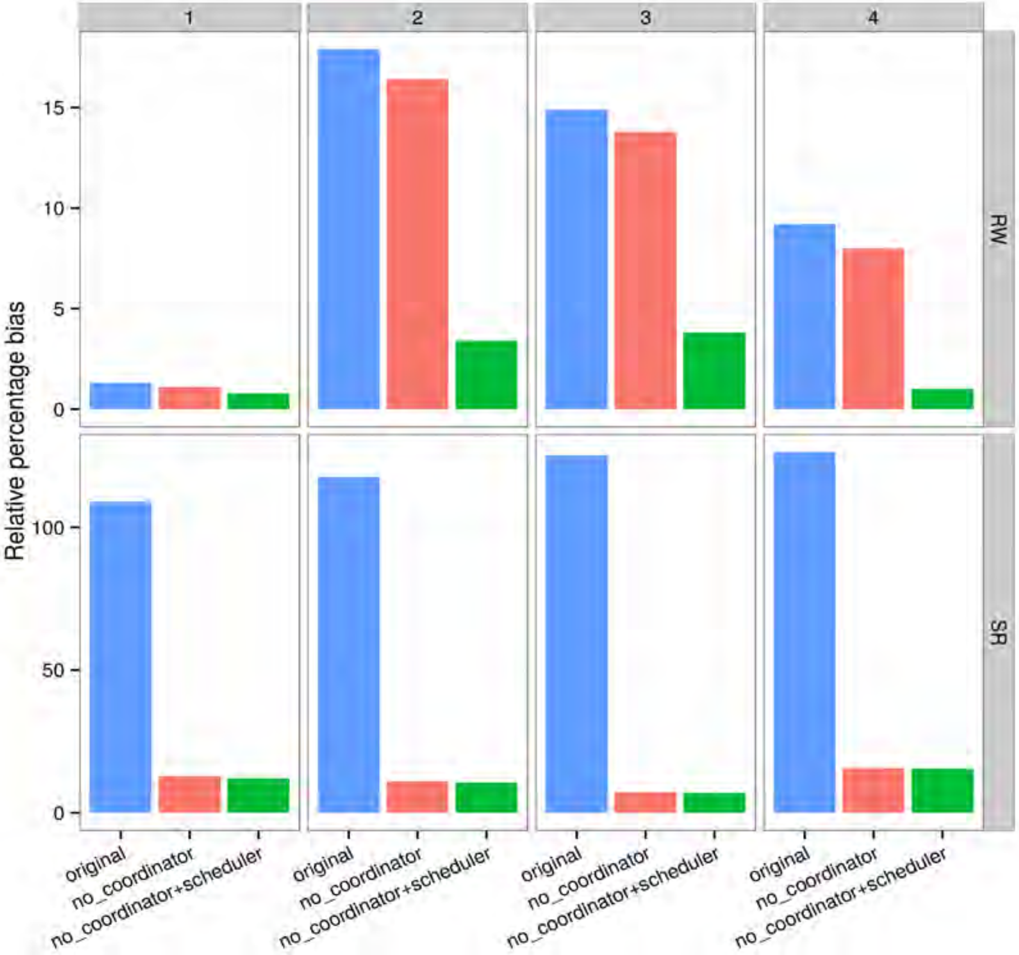
TBBT improvements



TBBT coordinator overhead

TBBT coordinator overhead

TBBT improvements



TBBT coordinator overhead

Real time scheduler

TBBT coordinator overhead

Uncertainty

Workload	TBBT	ARTC
Random read	22579.0 ± 2.4% (22891.6 ± 4.8%)	22243.5 ± 1.8%
Random write	22946.1 ± 3.2% (24807.6 ± 18%)	23076.0 ± 4.1%
Sequential read	4.0 ± 32.9% (7.8 ± 253%)	3.7 ± 18.6%
Sequential write	105.6 ± 1.3% (107.7 ± 4.2%)	105.8 ± 0.6%

Uncertainty

Before TBBT improvements ARTC is a clear winner

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Uncertainty

TBBT improvements are affective

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Uncertainty

How to choose between replayers?

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Characterization

Filebench fileserver workload

Characterization

Filebench fileserver workload

- 4 threads
- creat, delete, append, read, write, stat
- variable file sizes
- Wholefile read and write

Uncertainty

	TBBT	ARTC	Reference
Read	20.73 ± 118.27%	27.21 ± 92.72%	50.72
Write	50.45 ± 79.81%	69.79 ± 33.79%	83.95

Uncertainty

	TBBT	ARTC	Reference
Read	20.73 ± 118.27%	27.21 ± 92.72%	50.72
Write	50.45 ± 79.81%	69.79 ± 33.79%	83.95

Replayed response time appears better than reference

TBBT and ARTC memory footprints are smaller than filebench footprint, thus more cache hits

Uncertainty

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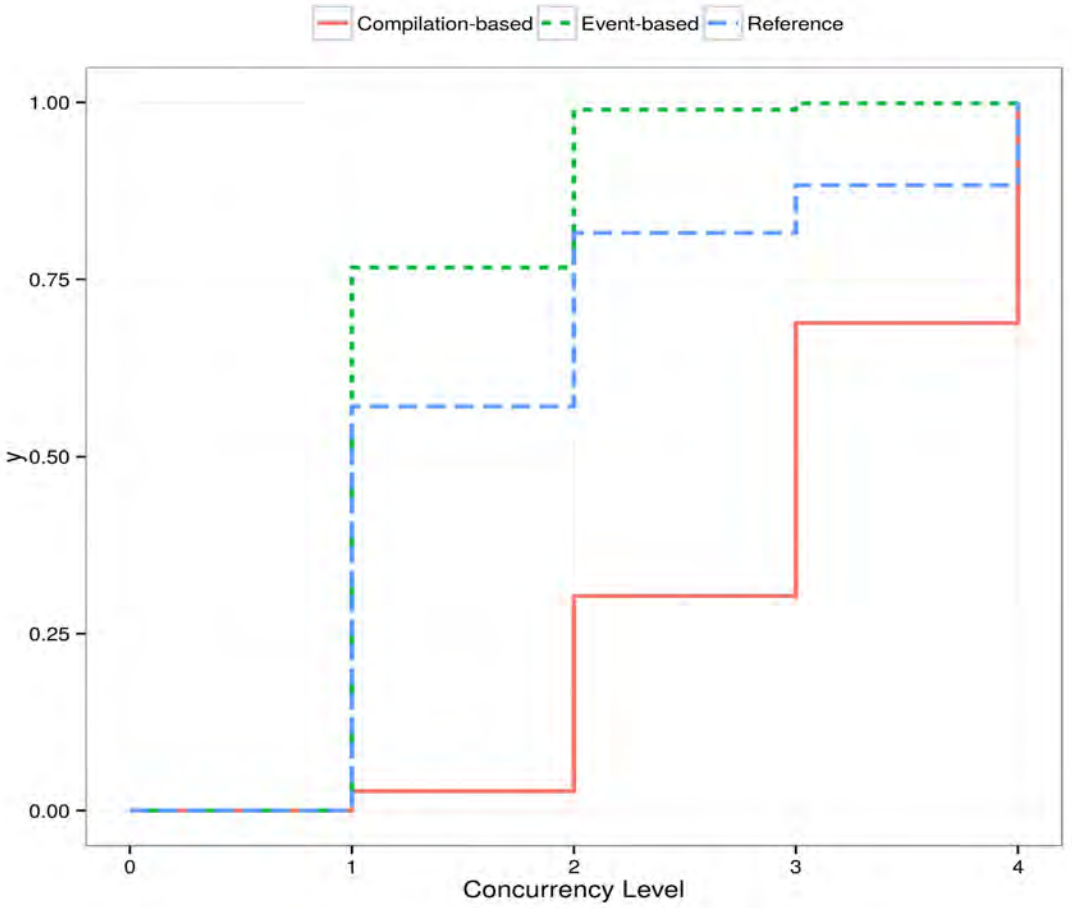
TBBT response time appears better than ARTC response time

Uncertainty

Replayers are not able to match captured workload concurrency



Conclusions

Metrology can help:

- Choosing the best instrument for the job (based on the measurement uncertainty)
    - The TBBT replayer, in some cases, is equivalent to the ARTC replayer.
- Improving tools and best practices
    - Event-based replayer needs improvement
    - Changes in OS scheduler policy may affect sensitive metrics.
- Spotting uncertainty sources
    - Differences in experimental environment, such as the amount of available memory, are likely to hurt reproducibility.