CMPT 473
Software Testing, Reliability and Security

Performance

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Performance & Measurement

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  - Time
  - Memory
  - Open connections
  - VM instances
  - Energy consumption
  - …

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Data Structure A vs Data Structure B

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Data Structure A vs Data Structure B

How would you approach this in a data structures course?

Performance & Measurement

- Performance assessment is deceptively hard

[Demo/Exercise]

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    2) Clear evidence
    3) Correct reasoning from evidence to claims

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    1) Clear claims
    2) Clear evidence
    3) Correct reasoning from evidence to claims
  - And yet this is challenging to get right!

Performance and Measurement

Several facets:

- Speed / Running time
  - The total time required (latency?)
- Throughput
  - Pages/Transactions per second, bytes per second
- Responsiveness
  - UI response time, server response time at peak load
- Memory Consumption
  - Peak memory consumption
- ...

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  - Design tests that specifically target performance objectives

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  - Design tests that specifically target performance objectives

How? What should the tests capture?

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    - Focus on cost of an operation in isolation
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  - *Macrobenchmarks*
    - Real world system performance

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- Assessing performance is done through benchmarking
  - *Microbenchmarks*
    - Focus on cost of an operation in isolation
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  - *Macrobenchmarks*
    - Real world system performance
  - Workloads (inputs) must be chosen carefully either way.
    - representative, pathological, scenario driven, ...

Benchmarking

- Suppose we want to run a microbenchmark

```
startTime = getCurrentTimeInSeconds();
doWorkloadOfInterest();
endTime = getCurrentTimeInSeconds();
reportResult(endTime – startTime);
```

Benchmarking

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What possible issues do you observe?

Benchmarking

- Suppose we want to run a microbenchmark

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startTime = getCurrentTimeInSeconds();
doWorkloadOfInterest();
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reportResult(endTime – startTime);
```

  - Granularity of measurement
  - Warm up effects
  - Nondeterminism
  - Size of workload
  - System interference
  - Frequency scaling?
  - Interference of other workloads?
  - Alignment?

Benchmarking

- Granularity & Units
  - Why is granularity a problem?
  - What are alternatives to `getCurrentTimeInSeconds()`?

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- Granularity & Units
  - Why is granularity a problem?
  - What are alternatives to `getCurrentTimeInSeconds()`?
  - What if I want to predict performance on a different machine?
    - Using *cycles* instead of wall clock time can be useful, but has its own limitations

Benchmarking

- Warm up time
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for (…) doWorkloadOfInterest();
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Benchmarking

- Nondeterministic behavior
  - Will `getCurrentTimeInSeconds()` always return the same number?

Why/why not?

Benchmarking

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  - Will `getCurrentTimeInSeconds()` always return the same number?
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    - Hint: The Law of Large Numbers!

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  the arithmetic mean will converge on the expected value

Is this always what you want?

Benchmarking

- A revised (informal) approach:

```
for (…) doWorkloadOfInterest();
startTime = getCurrentTimeInNanos();
for (…) doWorkloadOfInterest();
endTime = getCurrentTimeInNanos();
reportResult(endTime – startTime);
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Benchmarking

- A revised (informal) approach:

```
for (…) doWorkloadOfInterest();
startTime = getCurrentTimeInNanos();
for (…) doWorkloadOfInterest();
endTime = getCurrentTimeInNanos();
reportResult(endTime - startTime);
```

- This still does not solve everything
  - Frequency scaling?
  - Interference of other workloads?
  - Alignment?

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    - Results are often normalized against the baseline

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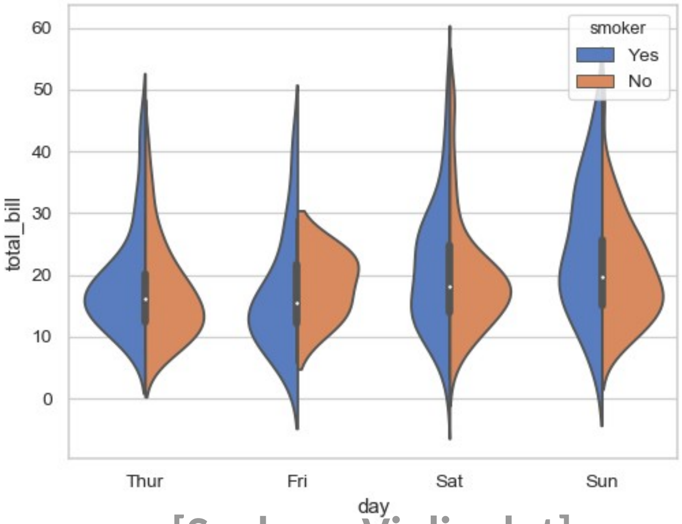
    - Show the distribution (e.g. violin plots)



[Seaborn Violinplot]

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- Now we have a benchmark, how do we interpret/report it?
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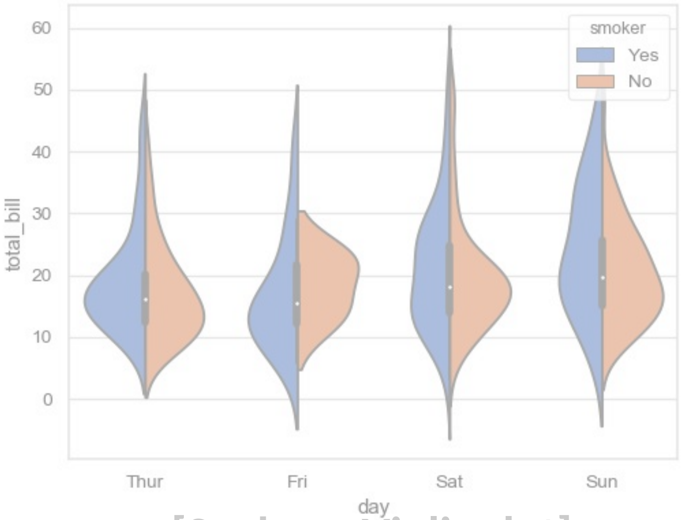
    - Show the distribution (e.g. violin plots)
    - Summarize the distribution (e.g. mean and confidence intervals, box & whisker)



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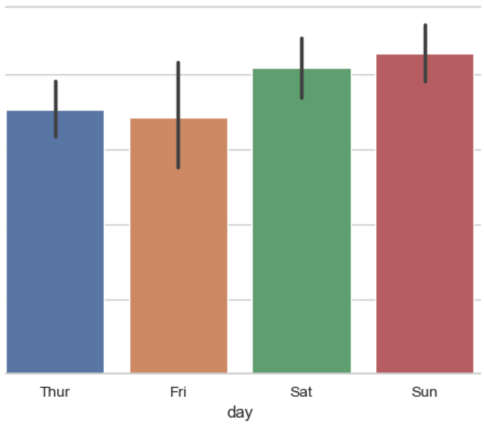
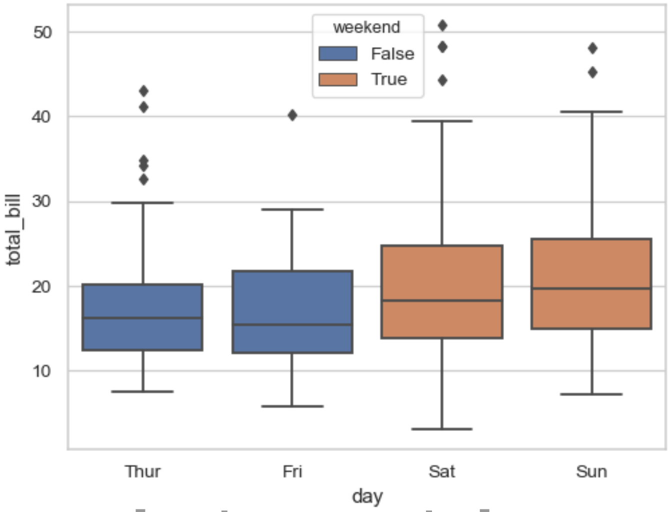


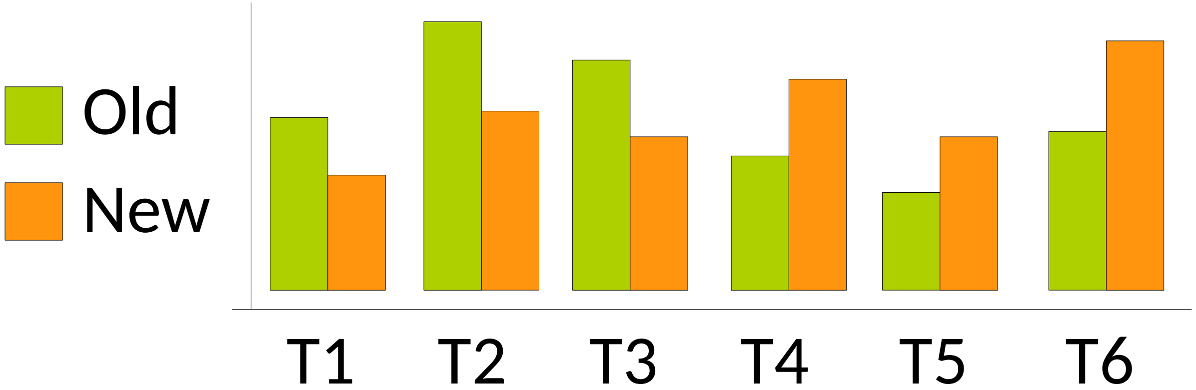
[Seaborn Barplot]



[Seaborn Boxplot]

Benchmarking

- A ***benchmark suite*** comprises multiple benchmarks



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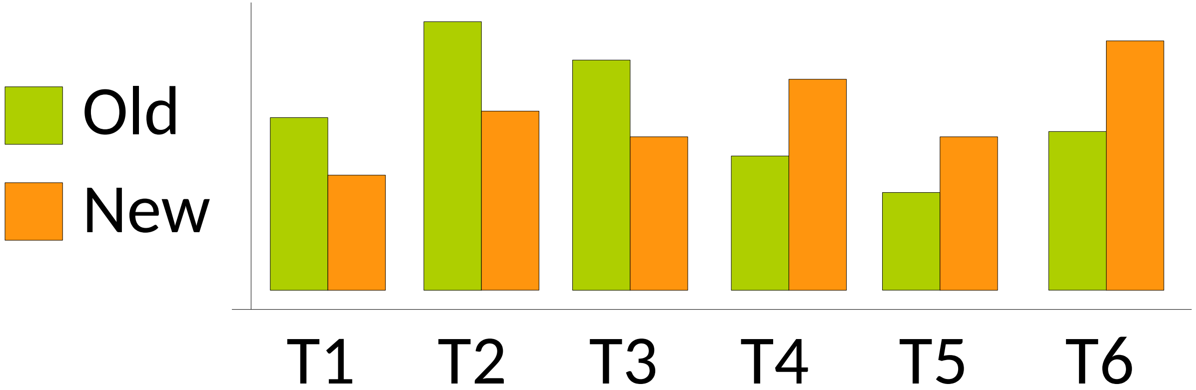

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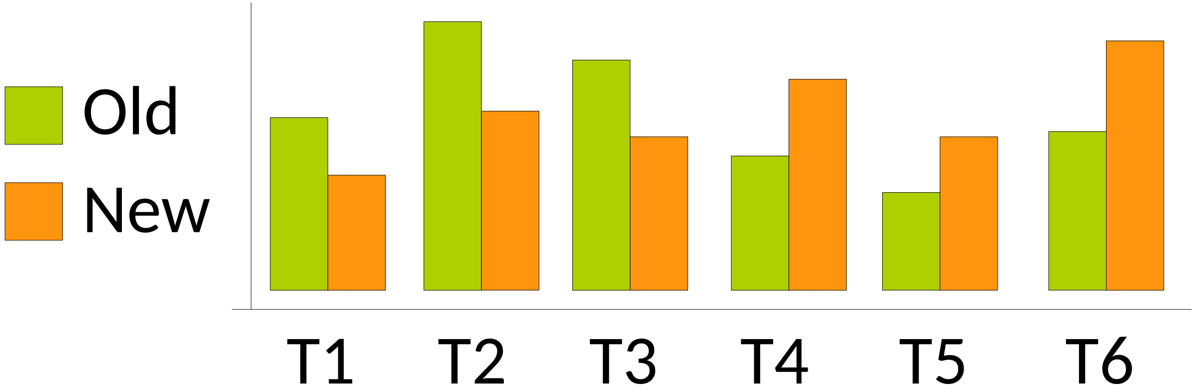
  - 2 major senarios
    - *Hypothesis testing*
      - Is solution A different than B?



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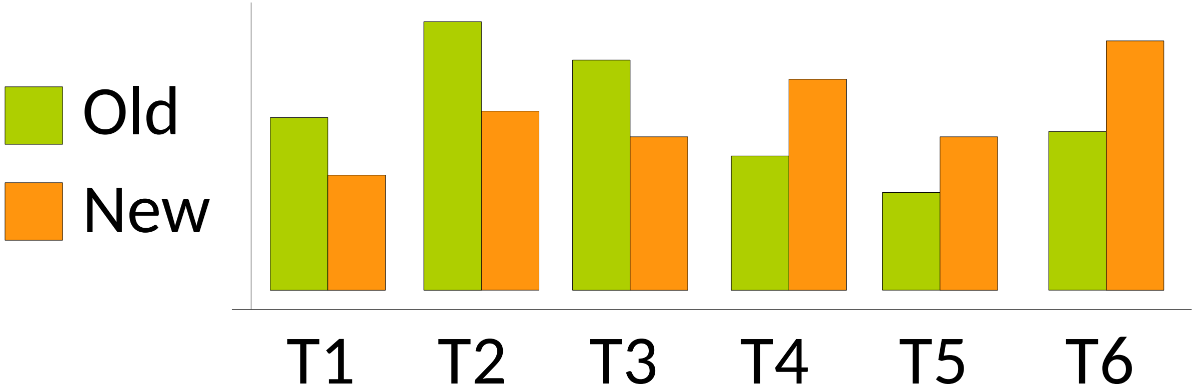

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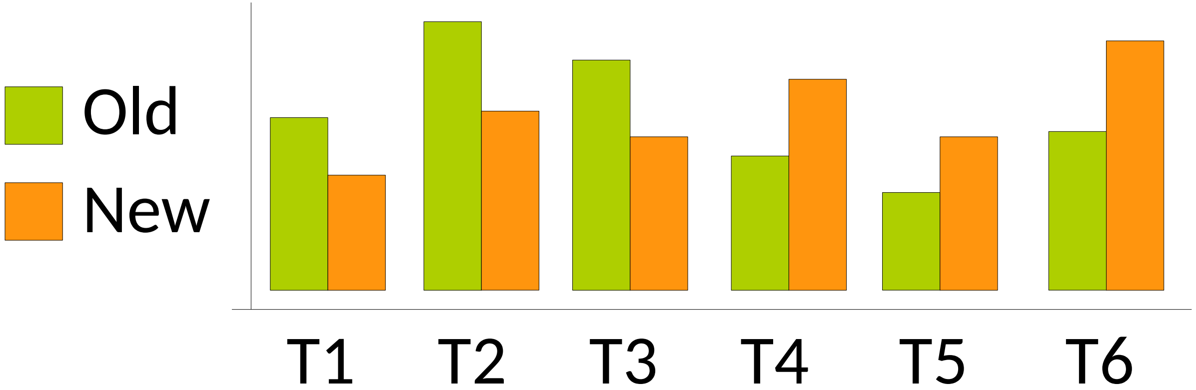

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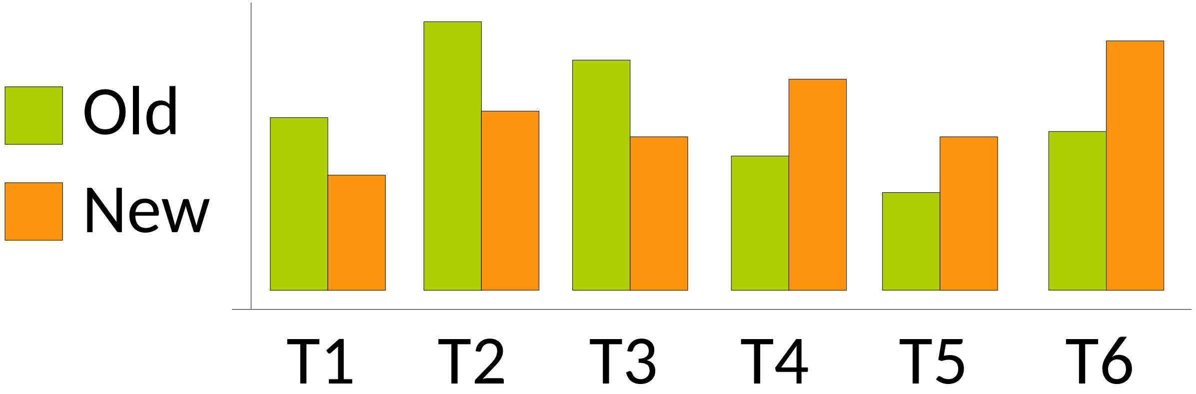

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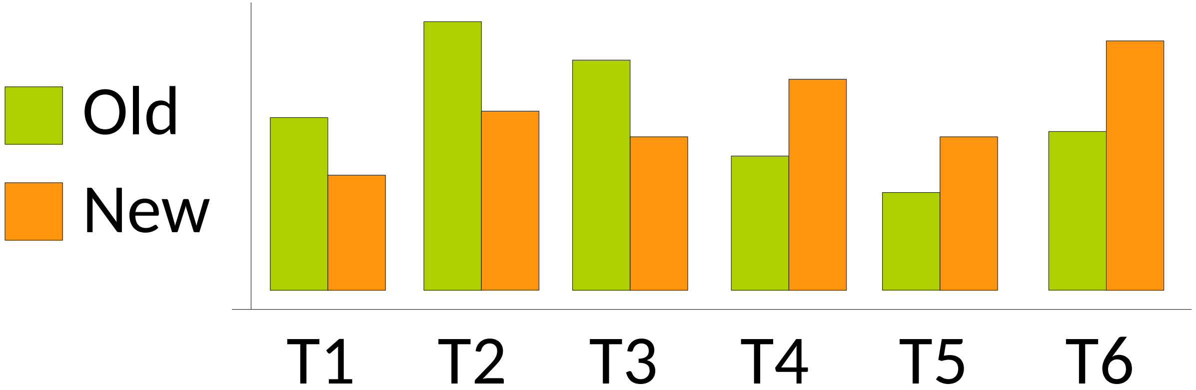
Old: ?
New: ?

$\frac{New}{Old}$: ?



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Each type means something different and has valid uses

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Handling Nondeterminism

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for (x in 0 to 4)
  times[x] = doWorkloadOfInterest();
```

E(time) = arithmean(times)

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Given tasks t1, t2, & t3 serving 40 pages each:
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CAVEAT: If the size of each workload changes, a weighted harmonic mean is required!

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Any idea why it may be useful here?
(A bit of a thought experiment)

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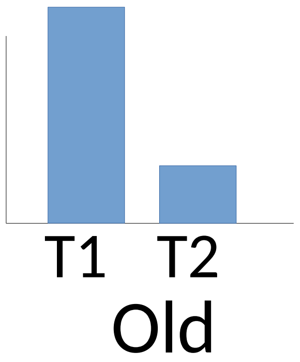

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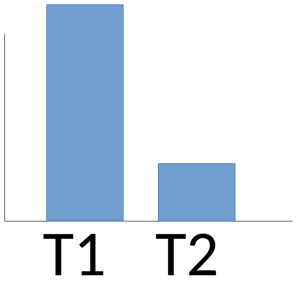
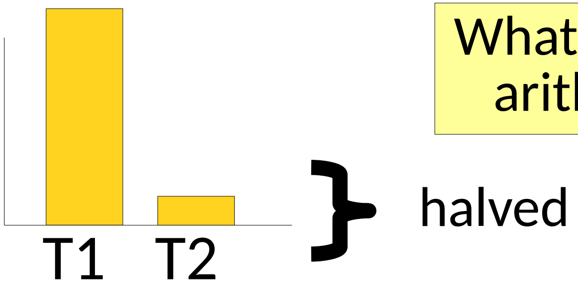


Old



New 1

What happens to the arithmetic mean?

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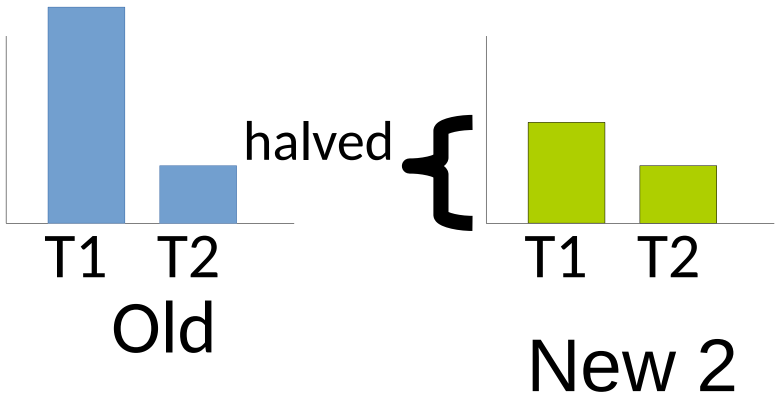

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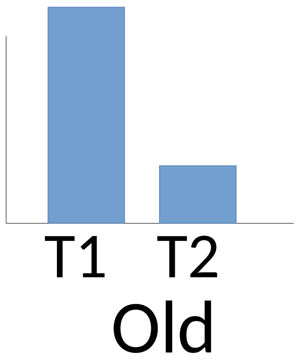

The (non) change to T1 dominates any behavior for T2!

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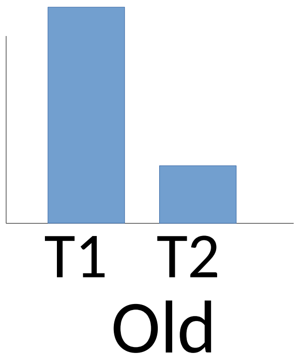

Geometric:

$$\sqrt{r_1 \times r_2}$$

Old

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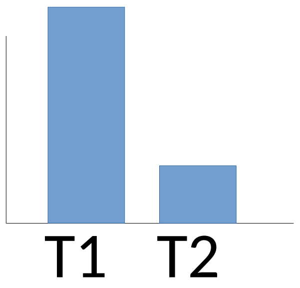

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Old

$$\sqrt{r_1 \times (\frac{1}{2} r_2)}$$

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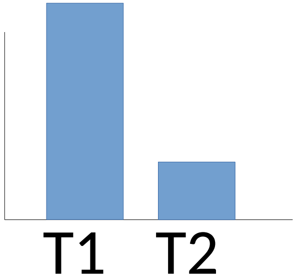

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$$\sqrt{r_1 \times (\frac{1}{2} r_2)}$$

New 1

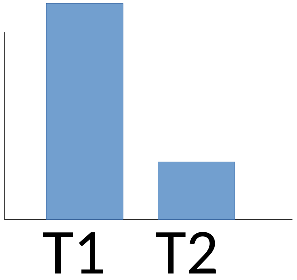
$$\sqrt{(\frac{1}{2} r_1) \times r_2}$$

New 2

Summary Statistics

- Geometric Mean
  - Good for reporting results that mean different things
  - e.g. Timing results across *many different* benchmarks

$$\sqrt[N]{\prod_{i=1}^{N} r_i}$$



Old

Geometric:

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$$\sqrt{r_1 \times (\frac{1}{2} r_2)} = \sqrt{\frac{1}{2} \times r_1 \times r_2} = \sqrt{(\frac{1}{2} r_1) \times r_2}$$

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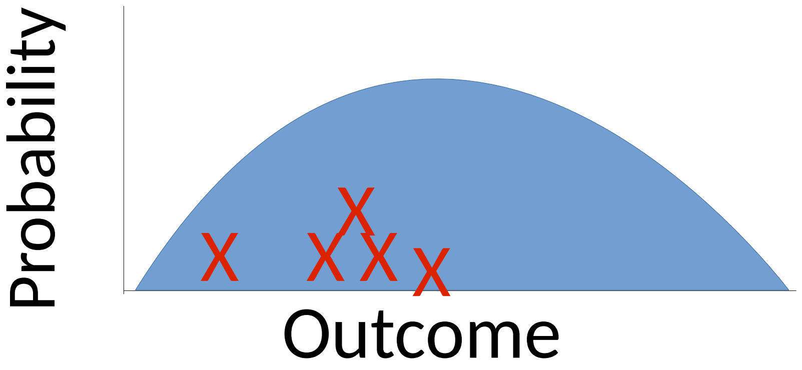
Note: It doesn't have an *intuitive* meaning!
It does provides a balanced *score* of performance.

See [Mashey 2004] for deeper insights.

Summary Statistics

- Remember the distributions
  - Measurement is inherently nondeterministic
  - Every measurement is a sample from a probability distribution



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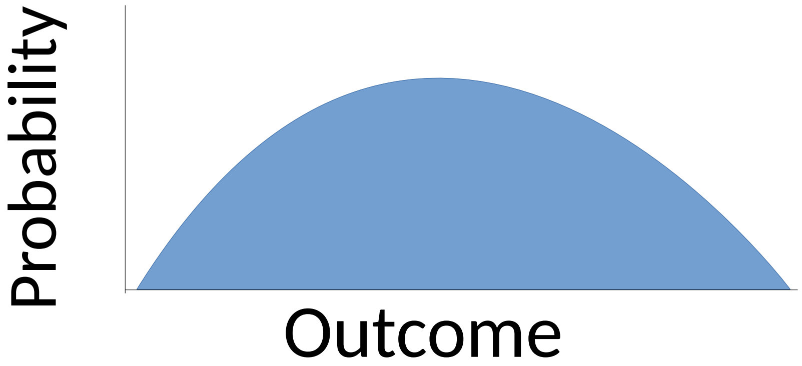

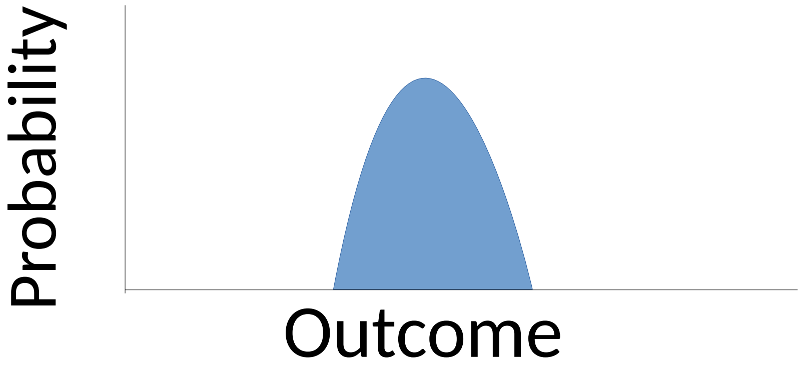

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- More rigorously, consider
  - Confidence intervals, T-tests, & ANOVA

Benchmarking

- In practice applying good benchmarking & statistics is made easier via frameworks
  - Google benchmark (C & C++)
  - Google Caliper (Java)
  - Nonius
  - Celero
  - Easybench
  - Pyperf
  - …

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events like

```
task-clock,context-switches,cpu-migrations,
page-faults,cycles,instructions,branches,
branch-misses,cache-misses,cycle_activity.stalls_total
```

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  - If all possible results are compact, just compute a table up front

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A ***uniform cost model***
throws necessary information away

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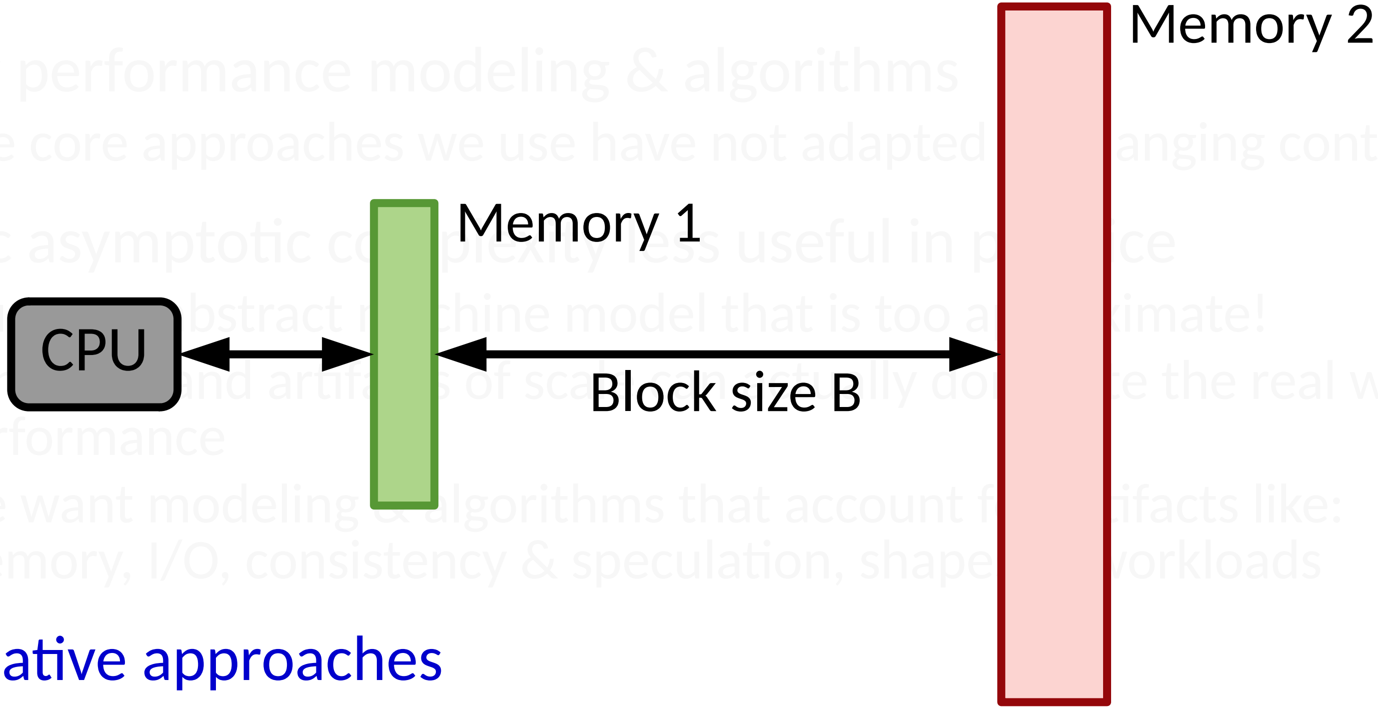

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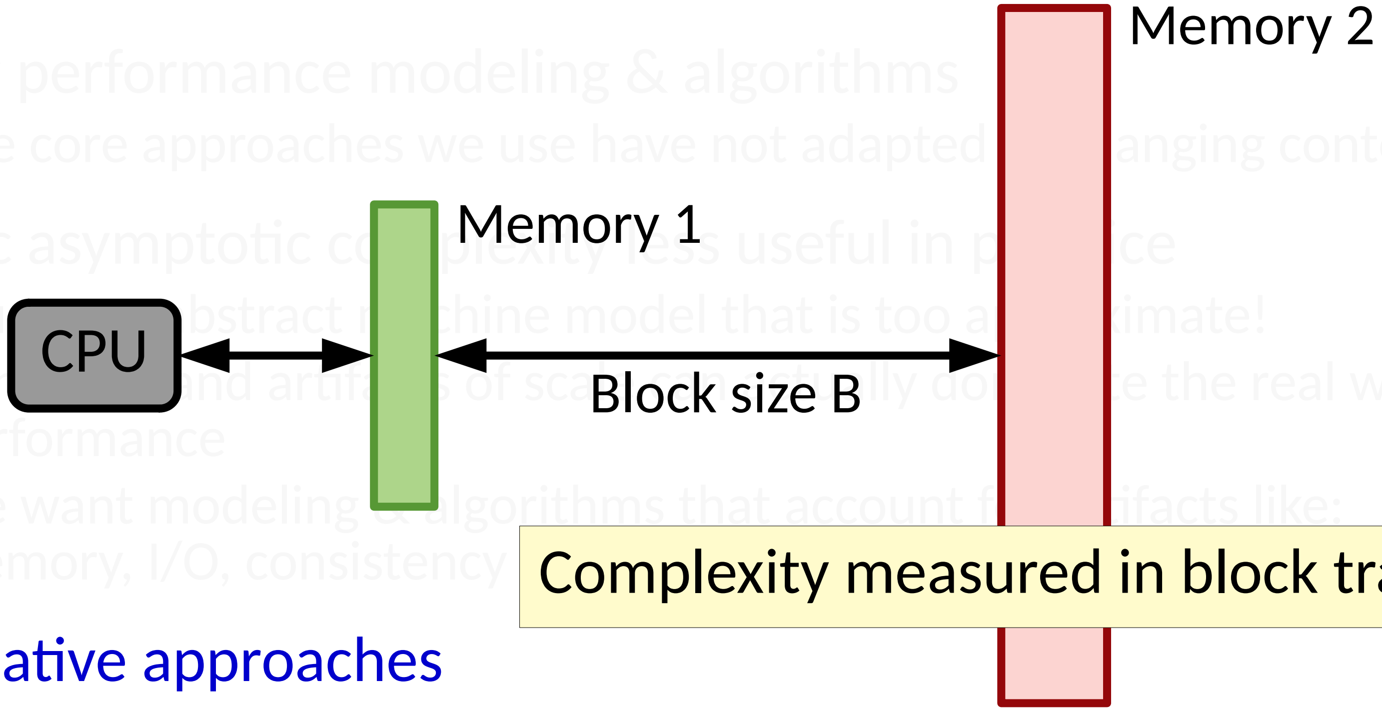

Complexity measured in block transfers

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Similar to I/O, but agnostic to block size

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  - Parameterized complexity

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- Good tooling can allow you to investigate performance well