Software Performance Engineering

Recitation 1.4

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Tuesday, Sep 23, 2025

Some due dates

- Homework 3 is released, due Sep 29, next Monday.

- Project 1 beta is due today!
- Submit your code to the GitHub repo
- Submit your writeup to **both Gradescope and your repo**

- Reach tier 20 to get at least a B grade for beta.

Beta Writeup

- A brief overview of your design.
- The general state of completeness and expected performance of your implementation.
- Any additional information that you feel would be helpful to the staff in understanding your submission.
- An acknowledgment of any help received from course staff, classmates on Piazza, or publicly available materials.

Weekly Report

- Please remember to submit your weekly report every week.
- Class contribution: 5 points towards final

- Time adjustment (starting this Friday):
  - Release: Friday morning, 10am
  - Due: next Monday evening, 5pm

Optimization tips

- What we covered in recitations so far:
  - recitation 1.1: from bit rotation to block rotation
  - recitation 1.2: in-block rotation (row-column-row algorithm)
  - recitation 1.3: divide-and-conquer approach for RCR
- Bit hacks
- Bently rules:
  - Caching
  - Precomputation
  - Sub-expression elimination
  - Loop unrolling
  - Function inlining

And so many more!

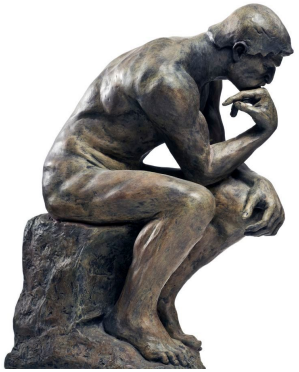
Resources

- Go to the course calendar to find all the lecture and recitation slides, and the project due dates.

Performance Engineering

Performance Engineering

think,



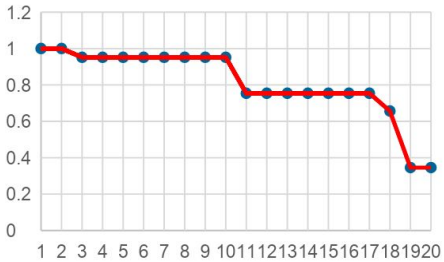
code,

run,

measure,

Basic Performance-Engineering Workflow

1. Measure the performance of Program `A`.
2. Make a change to Program `A` to produce a hopefully faster Program `A′`.
3. Measure the performance of Program `A′`.
4. If `A′` beats `A`, set `A = A′`.
5. If `A` is still not fast enough, go to Step 2.



If you can't measure performance **reliably**,
it is hard to make many small changes that add up

Example: Timing a Code for Sorting

```
#include <stdio.h>
#include <time.h>

void my_sort(double *A, int n);
void fill(double *A, int n);

int main() {
  int max = 4 * 1000 * 1000;
  int min = 1;
  int step = 20 * 1000;
  double A[max];
  struct timespec start, end;

  for (int n=min; n<max; n+=step) {
    fill(A, n);

    clock_gettime(CLOCK_MONOTONIC, &start
    my_sort(A, n);
    clock_gettime(CLOCK_MONOTONIC, &end);

    double tdiff = (end.tv_sec -
start.tv_sec)
        + 1e-9*(end.tv_nsec -
start.tv_nsec);
    printf("size %d, time %f\n", n, tdiff);
  }
  return 0;
}
```

Library for `clock_gettime()`

Sorting routine to be timed.

Auxiliary routine for filling array with random numbers.

Used by `clock_gettime()`:

```
struct timespec {
  time_t tv_sec; /* seconds */
  long tv_nsec;  /* nanoseconds */
};
```

Inspired by a study due to Sivan Toledo.

Example: Timing a Code for Sorting

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  struct timespec start, end;

  for (int n=min; n<max; n+=step) {
    fill(A, n);

    clock_gettime(CLOCK_MONOTONIC, &start);
    my_sort(A, n);
    clock_gettime(CLOCK_MONOTONIC, &end);

    double tdiff = (end.tv_sec -
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        + 1e-9*(end.tv_nsec -
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    printf("size %d, time %f\n", n, tdiff);
  }
  return 0;
}
```

Loop over arrays of increasing length.

Array randomly filled.

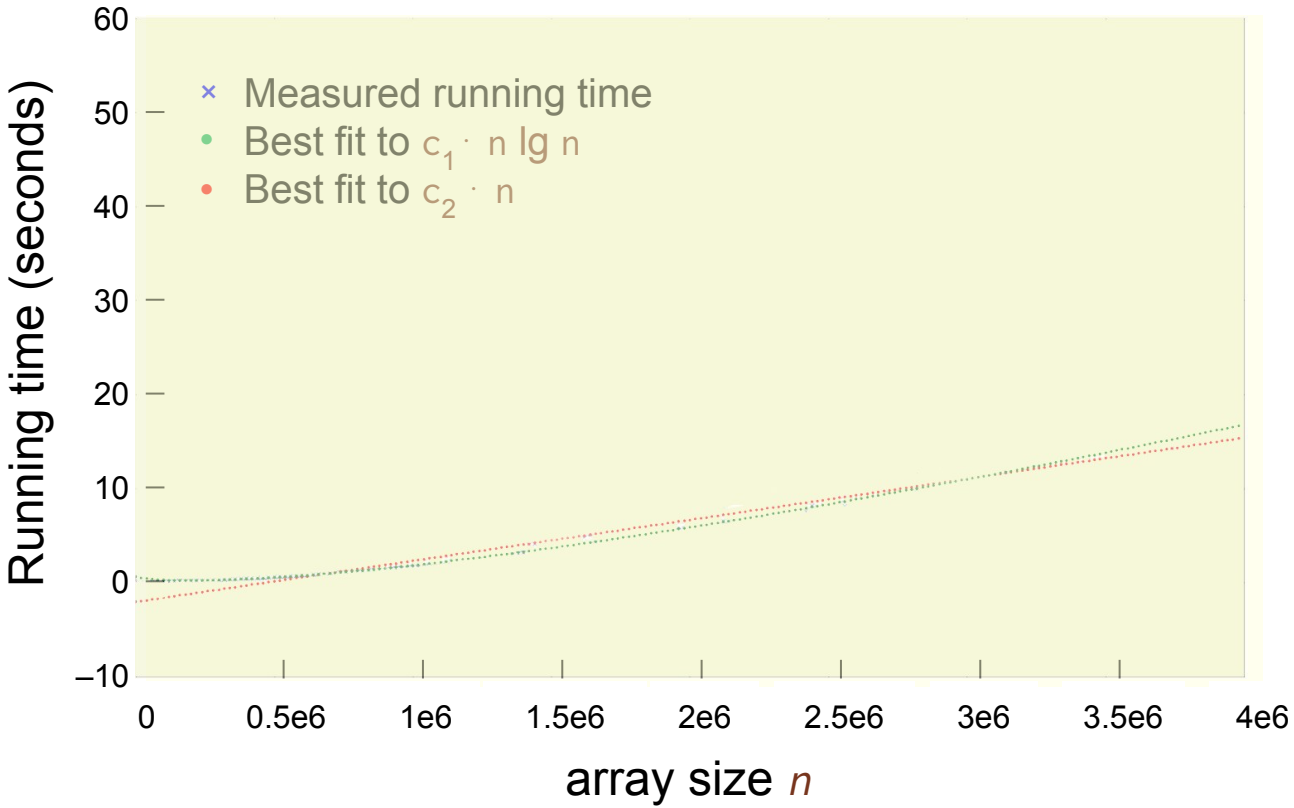
Measure time before sorting.

Sort.

Measure time after sorting.

Compute elapsed time.

Running Times for Sorting



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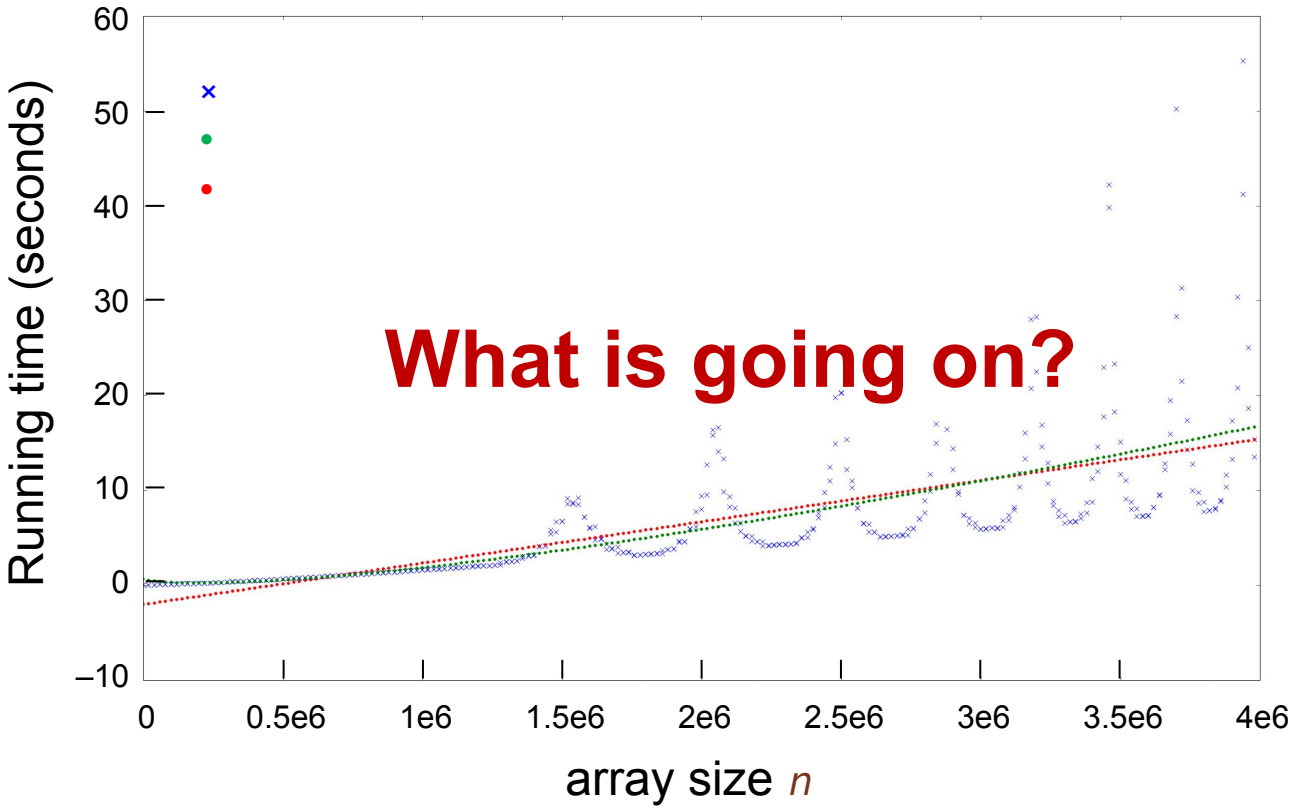

Dynamic Voltage and Frequency Scaling

DVFS is a technique to dynamically trade power for performance by **adjusting** the **clock frequency** and **supply voltage** to transistors

- Reduce operating frequency if chip is too hot or otherwise to save power.
- Reduce voltage if frequency is reduced.
- Turbo Boost increases frequency if the chip is cool.

$$\text{Power} \propto CV^2f$$

C = dynamic capacitance ≈ roughly area × activity (how many bits toggle)
V = supply voltage
f = clock frequency

Changing frequency and voltage has a cubic effect on power (and heat)

Today's Topic

How can one **reliably** measure the performance of software?

We'll start with **What Statistics and Metrics To Measure**

What Statistics and Metrics To Measure

Summary Statistics and Noise

Suppose that you measure the performance of a **deterministic program 100 times*** with the same input on a computer with some **interfering background noise**.

What statistic best represents the raw performance of the software?

- ❑ mean
- ❑ median
- ❑ maximum
- ❑ minimum

* we start it cold 100 times to eliminate any kind of caching effect from previous runs

Summary Statistics and Noise

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What statistic best represents the raw performance of the software?

- ❑ mean
- ❑ median
- ❑ maximum
- ☑ minimum

Minimum does the best at **noise rejection**, because we expect that any measurements higher than the minimum are due to noise.

Summarizing Ratios

Trial	Program A	Program A’
1	9	3
2	8	2
3	2	20
4	10	2
Mean	7.25	6.75

Summarizing Ratios

Trial	Program A	Program A'	A/A'
1	9	3	3.00
2	8	2	4.00
3	2	20	0.10
4	10	2	5.00
Mean	7.25	6.75	3.03

Conclusion

Program A' is > 3 times better than A

WRONG!

Turn the Comparison Upside-Down

Trial	Program A	Program A’	A/A’	A’/A
1	9	3	3.00	0.33
2	8	2	4.00	0.25
3	2	20	0.10	10.00
4	10	2	5.00	0.20
Mean	7.25	6.75	3.03	2.70

Paradox

A’ is 3.03x faster than A **&** A is 2.70x faster than A’

Observation

The arithmetic mean of A/A’ is **NOT** the inverse of the arithmetic mean of A’/A

Geometric Mean

Trial	Program A	Program A'	A/A'	A'/A
1	9	3	3.00	0.33
2	8	2	4.00	0.25
3	2	20	0.10	10.00
4	10	2	5.00	0.20
Mean	(a) 7.25	(a) 6.75	(g) 1.57	(g) 0.64

Formula

$$\left(\prod_{i=1}^{n} a_i\right)^{1/n} = \sqrt[n]{a_1 a_2 \cdots a_n}$$

Observation

The geometric mean of A/A' **is** the inverse of the geometric mean of A'/A

Selecting among Summary Statistics

Given server, service as many requests as possible

- Arithmetic mean
- CPU utilization

Most cloud service requests are satisfied within 100 ms

- 90th percentile
- Wall-clock time

Best game-playing AI

- Arithmetic mean
- Win rate

Fit into a machine with 100 MB of memory

- Maximum
- Memory use

Support frequent use on a mobile device

- Arithmetic mean
- Energy use or CPU utilization

Most environmentally friendly

- Arithmetic mean
- Carbon footprint

Meet a customer service-level agreement (SLA)

- Weighted combo of statistics
- Multiple metrics

Coding time before beta due!

Optimization tips

- Always take a shot if you have an idea!
- Decide for yourself: what works for others may not work for you (even an idea from a course staff!)
  - a course staff's suggestion is also not the only solution.
- It's not guaranteed that an optimization idea will actually make your code run faster.
  - if that happens, think about why.
- Take one step at a time to make debugging easier.
- Write comments, so you won't forget what you're doing or planning to do a week later.