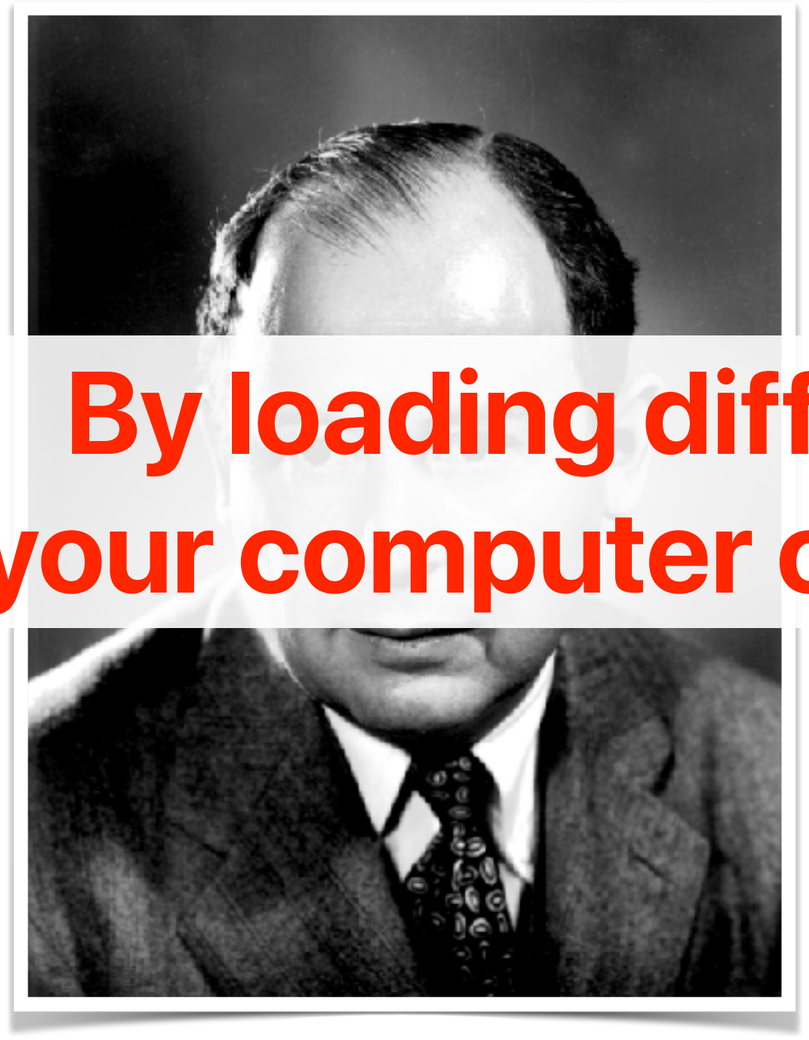
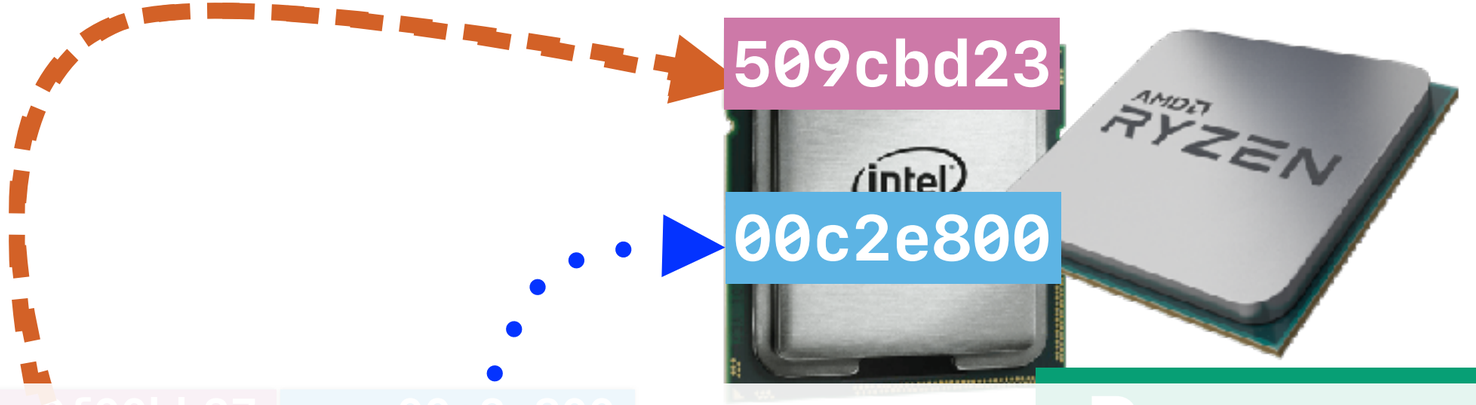
Performance (1): What matters?

Hung-Wei Tseng

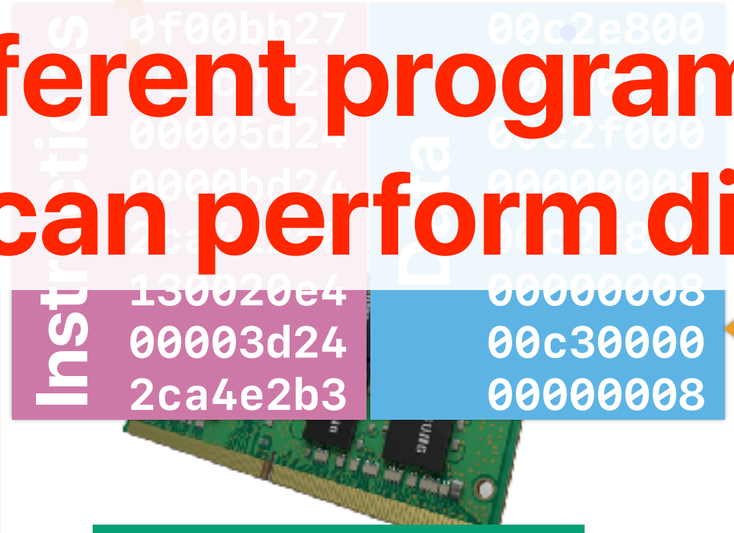
Recap: von Neumman Architecture





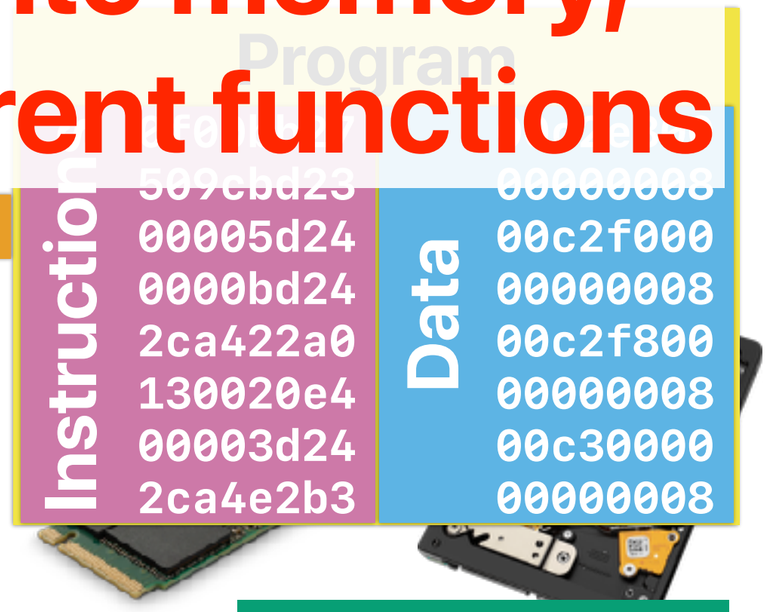
Processor

By loading different programs into memory, your computer can perform different functions



Memory

Program



Storage

Recap: Demo

```
if(option)
    std::sort(data, data + arraySize);

for (unsigned c = 0; c < arraySize*1000; ++c) {
        if (data[c%arraySize] >= INT_MAX/2)
            sum ++;
    }
}
```

$O(nlog_2n)$

$O(n)$

if option is set to 1: $O(nlog_2n)$

otherwise, O(n): $O(n)$

Best Nation

Schools in the National Univers
a full range of undergraduate r
producing groundbreaking res

To unlock full rankings, SAT/A

SUMMARY

443

Scho

Loca

Rank

Nat

Best Compute

Best Computer Science Schools

Ranked in 2022, part of Best Science S

Earning a graduate degree in computer
technology companies and colleges ar
reflects its average rating on a scale fr
institutions. Read the methodology »

UC San Diego Ranked No. 1 Public University by Washington Monthly

Campus celebrated as a leader in social mobility, research and public

Outline

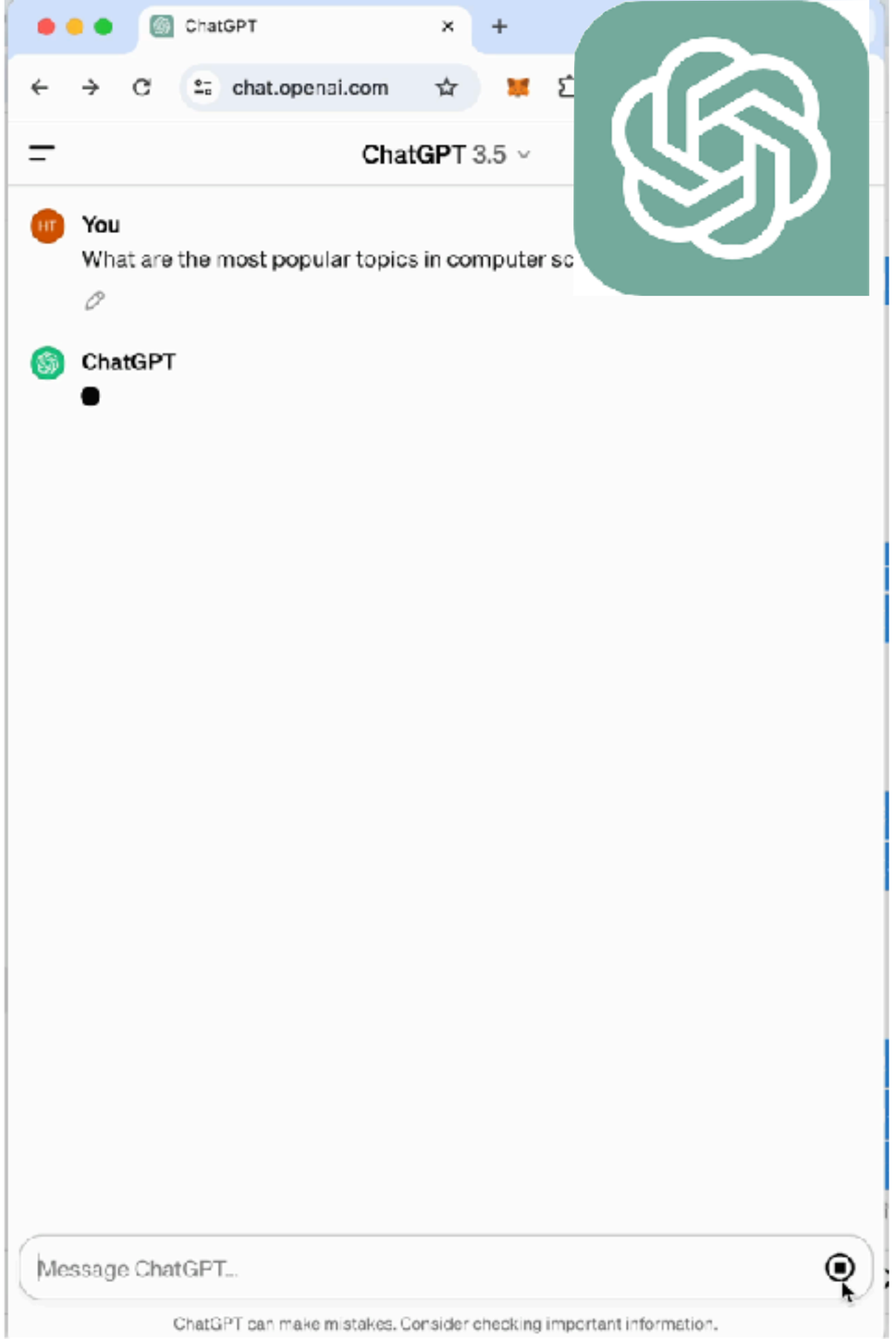
- Definition of “Performance”
- The performance equation
- What affects each factor in “Performance Equation”

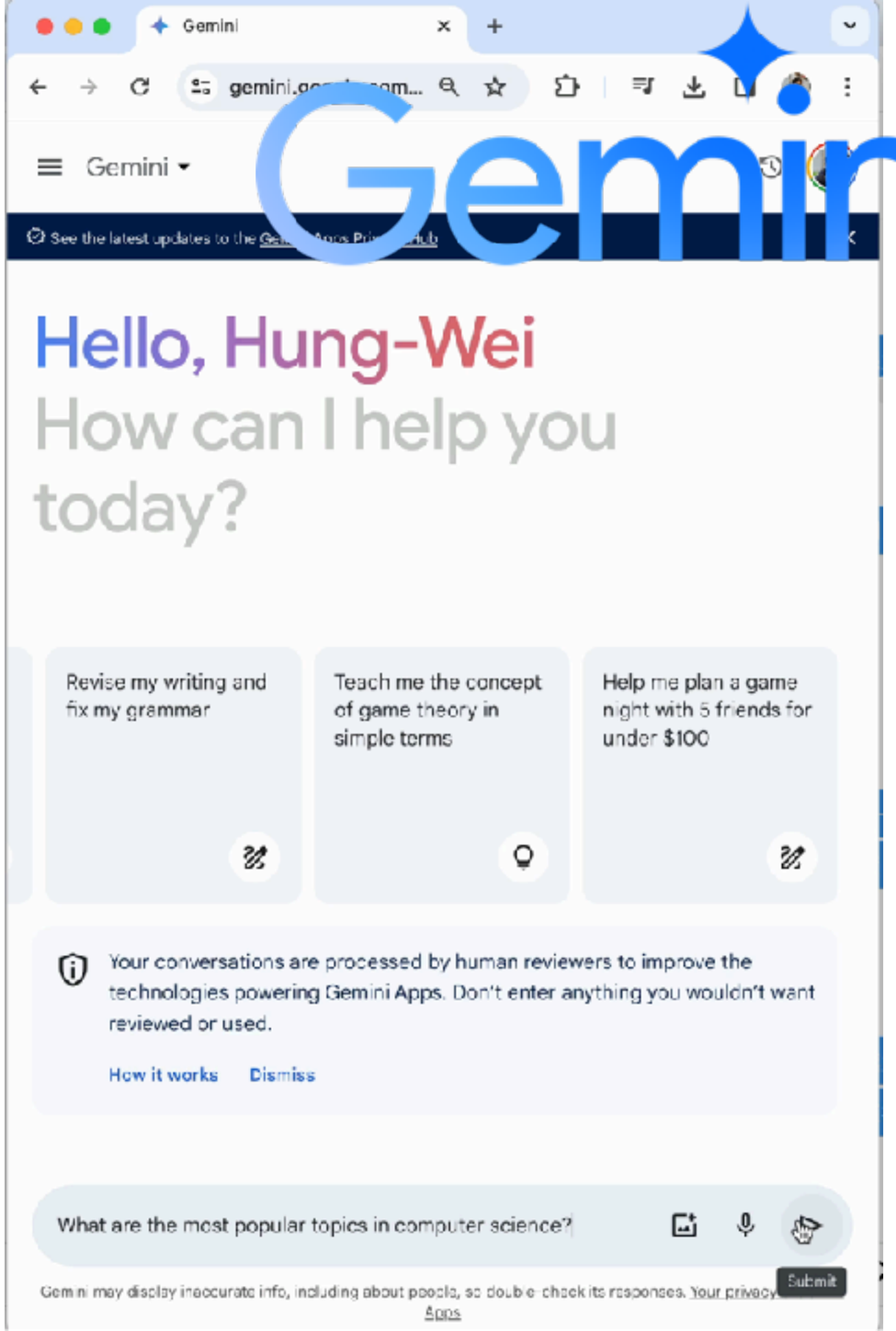
What does it really mean by “better” performance

Peer instruction

- Before the lecture — You need to complete the required **reading**
- During the lecture — I'll bring in activities to ENGAGE you in exploring your understanding of the material
  - Popup questions
  - Individual **thinking** — use polls in Zoom to express your opinion
  - Group **discussion**
    - Breakout rooms based on your residential colleges!
    - Use polls in Zoom to express your group's opinion
  - Whole-classroom **discussion** — we would like to hear from you

Read **Think** **Discuss**


ChatGPT
chat.openai.com
ChatGPT 3.5
You
What are the most popular topics in computer sc
ChatGPT
Message ChatGPT...
ChatGPT can make mistakes. Consider checking important information.


Gemini
Gemini
Hello, Hung-Wei
How can I help you today?
Revise my writing and fix my grammar
Teach me the concept of game theory in simple terms
Help me plan a game night with 5 friends for under $100
Your conversations are processed by human reviewers to improve the technologies powering Gemini Apps. Don't enter anything you wouldn't want reviewed or used.
How it works
Dismiss
What are the most popular topics in computer science?
Submit

https://www.pollev.com/hungweitseng close in 1:30

Gemini v.s. ChatGPT

- Comparing the experiments we have done with Gemini and ChatGPT, how many of the following metrics does Gemini outperforms ChatGPT?
  - ① Response time
  - ② Throughput
  - ③ End-to-end latency (i.e., total execution time)
  - ④ Quality of results
  - A. 0
  - B. 1
  - C. 2
  - D. 3
  - E. 4

Important performance metrics

- End-to-end latency — how much time the program/operation takes from the beginning to the end
- Response time — how much time the user starts to feel the program is running/finishing
- Throughput/bandwidth — the average amount of work/data can the program/system deliver within the execution time
- Energy consumption — the aggregated power during the execution time
- Cost of operation — the amount of money necessary for finishing an operation
- Quality of results — the human perception of the execution result
- Power consumption — the heat generation produced by the circuit

Important performance metrics

- End-to-end latency — how much **time** the program/operation takes from the beginning to the end
- Response time — how much **time** the user starts to feel the program is running/finishing
- Throughput/bandwidth — the average amount of work/data can the program/system deliver within the execution **time**
- Energy consumption — the aggregated power during the execution **time**
- Cost of operation — the amount of money necessary for finishing an operation (related to **time**)
- Quality of results — the human perception of the execution result
- Power consumption — the heat generation produced by the circuit

Takeaways: What matters?

- Execution time is the most essential performance metric

“Execution time” is the most important metric

Evaluating the CPU program "execution time"

- Assume that we have an application composed with a total of **5,000,000,000** instructions, in which **20%** of them are "Type-A" instructions with an average **CPI of 4** cycles, **20%** of them are "Type-B" instructions with an average **CPI of 3** cycles and the rest instructions are "Type-C" instructions with average **CPI of 1** cycle. If the processor runs at **4 GHz**, how long is the execution time?
  A. 1.25 sec
  B. 2.5 sec
  C. 3.75 sec
  D. 7.5 sec
  E. 40 sec

CPU Performance Equation

$$Performance = \frac{1}{Execution\ Time}$$

$$Execution\ Time = \frac{Instructions}{Program} \times \frac{Cycles}{Instruction} \times \frac{Seconds}{Cycle}$$

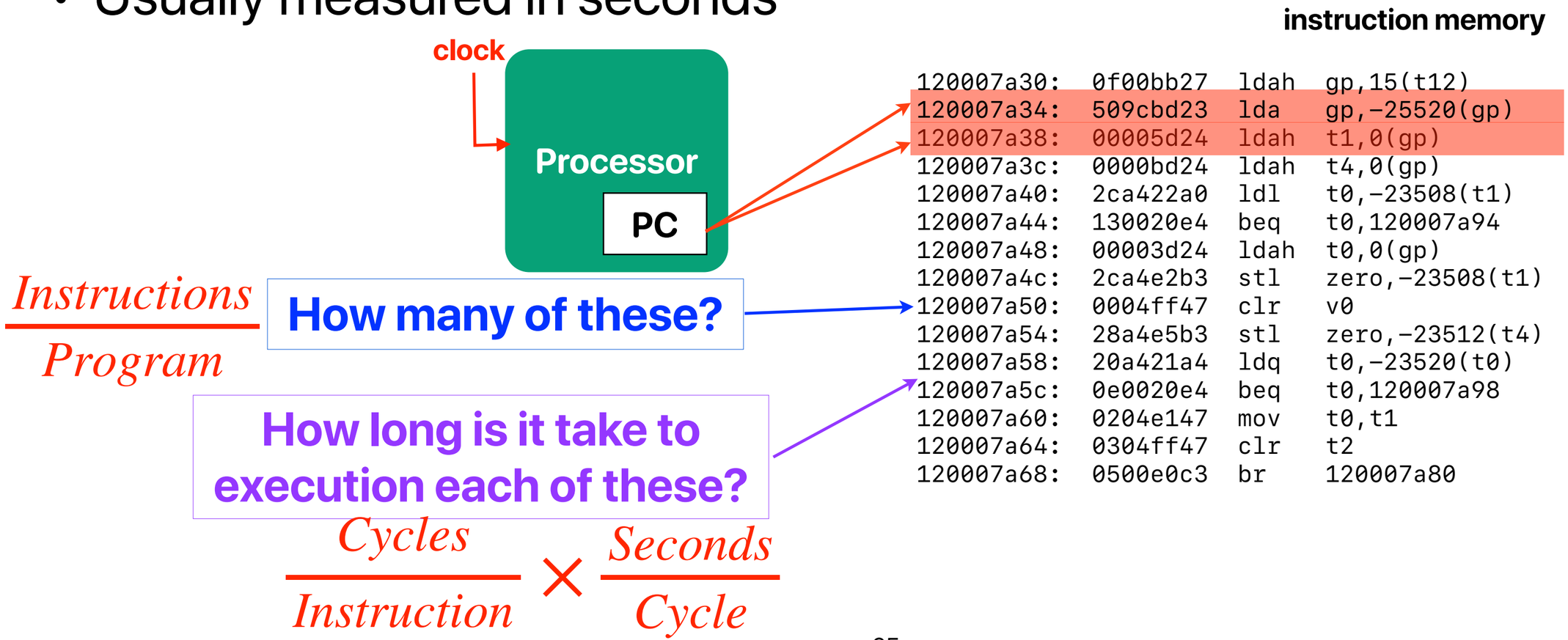
$$ET = IC \times CPI \times CT$$

$$1GHz = 10^9 Hz = \frac{1}{10^9} sec\ per\ cycle = 1\ ns\ per\ cycle$$

$$\frac{1}{Frequency(i.e., clock\ rate)}$$

Execution Time

- The simplest kind of performance
- Shorter execution time means better performance
- Usually measured in seconds



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  E. 40 sec

$$ET = IC \times CPI \times CT$$

$$ET = (5 \times 10^9) \times \underbrace{(20\% \times 4 + 20\% \times 3 + 60\% \times 1)}_{\text{average CPI}} \times \frac{1}{4 \times 10^9}\ sec = 2.5\ sec$$

Evaluating the CPU program "execution time" (2)

- Consider the following c code snippet and x86 instructions implement the code snippet

C	x86

```
for(i = 0; i < count; i++) {
    s += a[i];
}
```

```
.L3:
movslq  (%rdi), %rdx
addq    $4, %rdi
addq    %rdx, %tax
cmpq    %rcx, %rdi
jne     .L3
```

If (1) count is set to 1,000,000,000, (2) a memory instruction takes 4 cycles, (3) a branch/jump instruction takes 3 cycles, (4) other instructions takes 1 cycle on average, and (5) the processor runs at 4 GHz, how much time is it take to finish executing the code snippet?

A. 0.5 sec
B. 1 sec
C. 2.5 sec
D. 3.75 sec
E. 4 sec

Evaluating the CPU program "execution time" (2)

- Consider the following c code snippet and x86 instructions implement the code snippet

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`for(i = 0; i < count; i++) {`
`  s += a[i];`
`}`
	`.L3:`
	`movslq (%rdi), %rdx`
	`addq $4, %rdi`
	`addq %rdx, %tax`
	`cmpq %rcx, %rdi`
	`jne .L3`

If (1) count is set to 1,000,000,000, (2) a memory instruction takes 4 cycles, (3) a branch/jump instruction takes 3 cycles, (4) other instructions takes 1 cycle on average, and (5) the processor runs at 4 GHz, how much time is it take to finish executing the code snippet?

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$$ET = IC \times CPI \times CT$$

$$ET = (5 \times 10^9) \times (20\% \times 4 + 20\% \times 3 + 60\% \times 1) \times \frac{1}{4 \times 10^9}\ sec = 2.5\ sec$$

total # of dynamic instructions

average CPI

Takeaways: What matters?

- Execution time is the most essential performance metric
- The following three factors define the execution time of a program
  - Instruction count
  - Cycles per instruction
  - Cycle time

What Affects Each Factor in Performance Equation

https://www.pollev.com/hungweitseng close in 1:30

What can programmers affect?

- Performance equation consists of the following three factors
  ① IC
  ② CPI
  ③ CT

How many can a **programmer** affect?

A. 0
B. 1
C. 2
D. 3

Demo — programmer & performance

A

```
for(i = 0; i < ARRAY_SIZE; i++)
{
  for(j = 0; j < ARRAY_SIZE; j++)
  {
    c[i][j] = a[i][j]+b[i][j];
  }
}
```

B

```
for(j = 0; j < ARRAY_SIZE; j++)
{
  for(i = 0; i < ARRAY_SIZE; i++)
  {
    c[i][j] = a[i][j]+b[i][j];
  }
}
```

$O(n^2)$ **Complexity** $O(n^2)$

Instruction Count?

Clock Rate

CPI

Demo — programmer & performance

A

```
for(i = 0; i < ARRAY_SIZE; i++)
{
  for(j = 0; j < ARRAY_SIZE; j++)
  {
    c[i][j] = a[i][j]+b[i][j];
  }
}
```

B

```
for(j = 0; j < ARRAY_SIZE; j++)
{
  for(i = 0; i < ARRAY_SIZE; i++)
  {
    c[i][j] = a[i][j]+b[i][j];
  }
}
```

$O(n^2)$	**Complexity**	$O(n^2)$
Same	**Instruction Count?**	**Same**
Same	**Clock Rate**	**Same**
???	**CPI**	**???**

Use “performance counters” to figure out!

- Modern processors provides performance counters
  - instruction counts
  - cache accesses/misses
  - branch instructions/mis-predictions
- How to get their values?
  - You may use “perf stat” in linux
  - You may use Instruments —> Time Profiler on a Mac
  - Intel’s vtune — only works on Windows w/ intel processors
  - You can also create your own functions to obtain counter values

Demo — programmer & performance

A

```
for(i = 0; i < ARRAY_SIZE; i++)
{
  for(j = 0; j < ARRAY_SIZE; j++)
  {
    c[i][j] = a[i][j]+b[i][j];
  }
}
```

B

```
for(j = 0; j < ARRAY_SIZE; j++)
{
  for(i = 0; i < ARRAY_SIZE; i++)
  {
    c[i][j] = a[i][j]+b[i][j];
  }
}
```

$O(n^2)$	Complexity	$O(n^2)$
Same	Instruction Count?	Same
Same	Clock Rate	Same
Better	CPI	Worse

Demo — programmer & performance

A

```
for(i = 0; i < ARRAY_SIZE; i++)
{
  for(j = 0; j < ARRAY_SIZE; j++)
  {
    c[i][j] = a[i][j]+b[i][j];
  }
}
```

B

```
for(j = 0; j < ARRAY_SIZE; j++)
{
  for(i = 0; i < ARRAY_SIZE; i++)
  {
    c[i][j] = a[i][j]+b[i][j];
  }
}
```

How many of the following make(s) the performance different between version A & version B?

① IC

② CPI

③ CT

A. 0

B. 1

C. 2

D. 3

Programmer's impact

- By adding the "sort" in the following code snippet, what the programmer changes in the performance equation to achieve **better** performance?

```
std::sort(data, data + arraySize);

for (unsigned c = 0; c < arraySize*1000; ++c) {
    if (data[c%arraySize] >= INT_MAX/2)
        sum ++;
}
}
```

A. CPI

B. IC ← **programmer changes IC as well, but not in the positive direction**

C. CT

D. IC & CPI

E. CPI & CT

Programmers can also set the cycle time

https://software.intel.com/sites/default/files/comment/1716807/how-to-change-frequency-on-linux-pub.txt

```
==========================================
Subject: setting CPU speed on running linux system


If the OS is Linux, you can manually control the CPU speed by reading and writing some virtual files in the "/proc"

1.) Is the system capable of software CPU speed control?
If the "directory" /sys/devices/system/cpu/cpu0/cpufreq exists, speed is controllable.
-- If it does not exist, you may need to go to the BIOS and turn on EIST and any other C and P state control and vi



2.) What speed is the box set to now?
Do the following:
$ cd /sys/devices/system/cpu
$ cat ./cpu0/cpufreq/cpuinfo_max_freq
3193000
$ cat ./cpu0/cpufreq/cpuinfo_min_freq
1596000

3.) What speeds can I set to?
Do
$ cat /sys/devices/system/cpu/cpu0/cpufreq/scaling_available_frequencies
It will list highest settable to lowest; example from my NHM "Smackover" DX58SO HEDT board, I see:
3193000 3192000 3059000 2926000 2793000 2660000 2527000 2394000 2261000 2128000 1995000 1862000 1729000 159600
You can choose from among those numbers to set the "high water" mark and "low water" mark for speed.  If you set "h


4.) Show me how to set all to highest settable speed!
Use the following little sh/ksh/bash script:
$ cd /sys/devices/system/cpu  # a virtual directory made visible by device drivers
$ newSpeedTop=`awk '{print $1}' ./cpu0/cpufreq/scaling_available_frequencies`
$ newSpeedLow=$newSpeedTop  # make them the same in this example
$ for c in ./cpu[0-9]* ; do
>   echo $newSpeedTop >${c}/cpufreq/scaling_max_freq
>   echo $newSpeedLow >${c}/cpufreq/scaling_min_freq
> done
$

5.) How do I return to the default - i.e. allow machine to vary from highest to lowest?
Edit line # 3 of the script above, and re-run it.  Change the line:
$ newSpeedLow=$newSpeedTop  # make them the same in this example
```

How programmer affects performance?

- Performance equation consists of the following three factors
  1. IC
  2. CPI
  3. CT

  How many can a **programmer** affect?

  A. 0
  B. 1
  C. 2
  D. 3

Announcement

- Assignment #1 due 4/11
  - We typically give you two weeks to work on an assignment
  - We never allow late submission and we will never have deadline extension
  - We autograde everything in your assignment + unlimited submissions before the deadline = start early, receive feedback early, and get good grades
  - Due on 4/11
- Assignment #2 due on 4/18
- No reading quizzes next week — you have more time working on assignments
- Check our website for slides/grades/schedules, gradescope for quizzes/assignments, piazza for discussions
- Youtube channel for lecture recordings: https://www.youtube.com/c/ProfUsagi/playlists

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