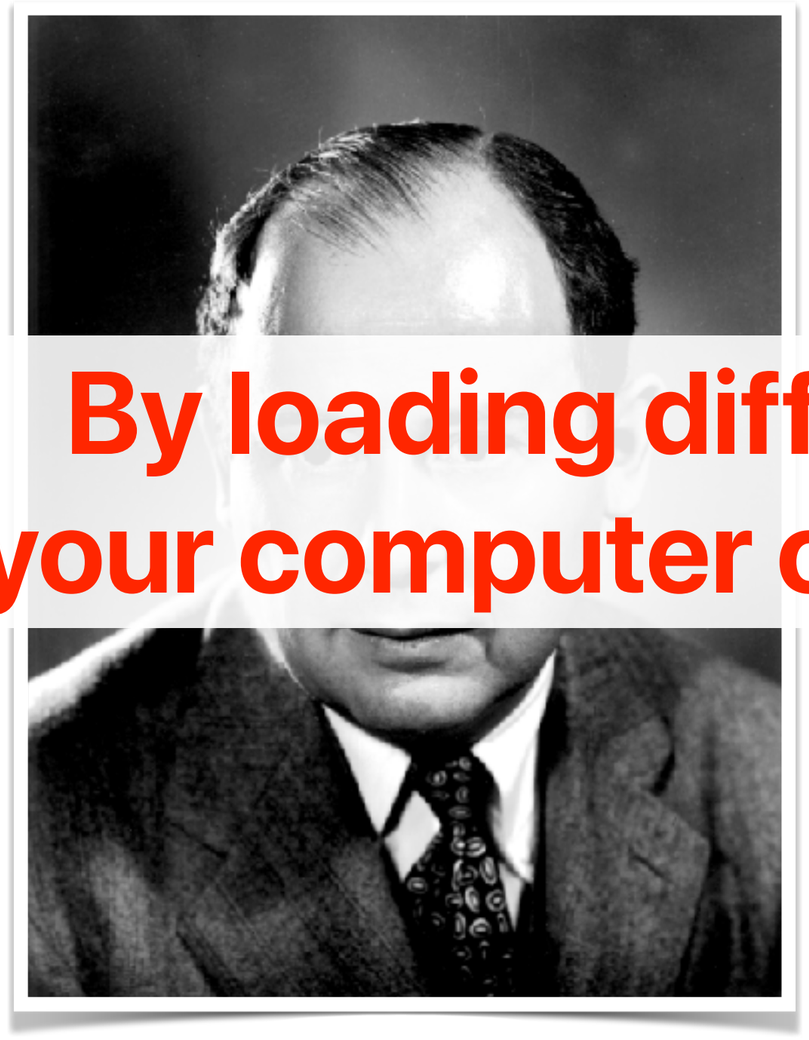
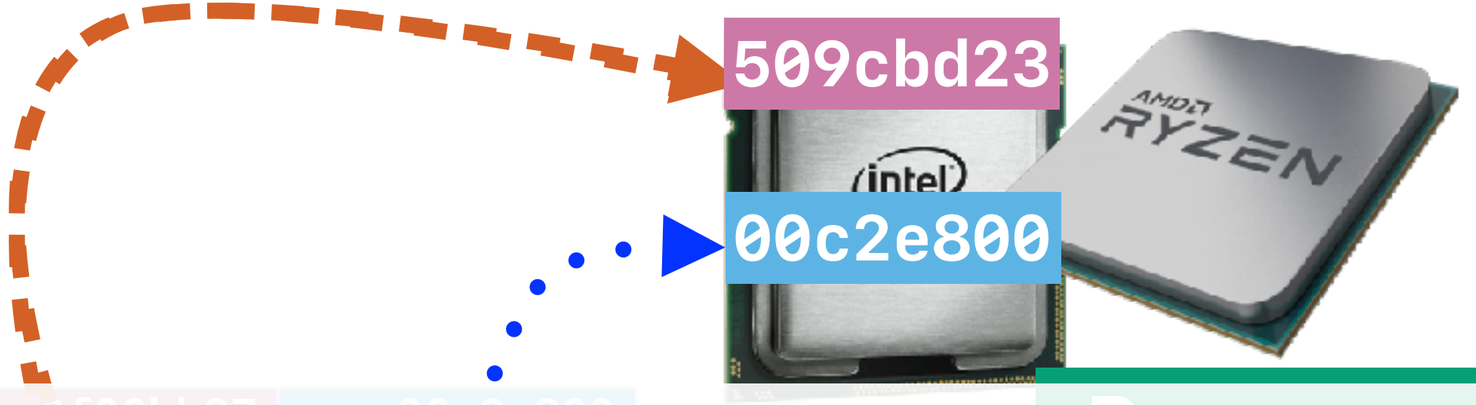
Performance (I): The Basics

Hung-Wei Tseng

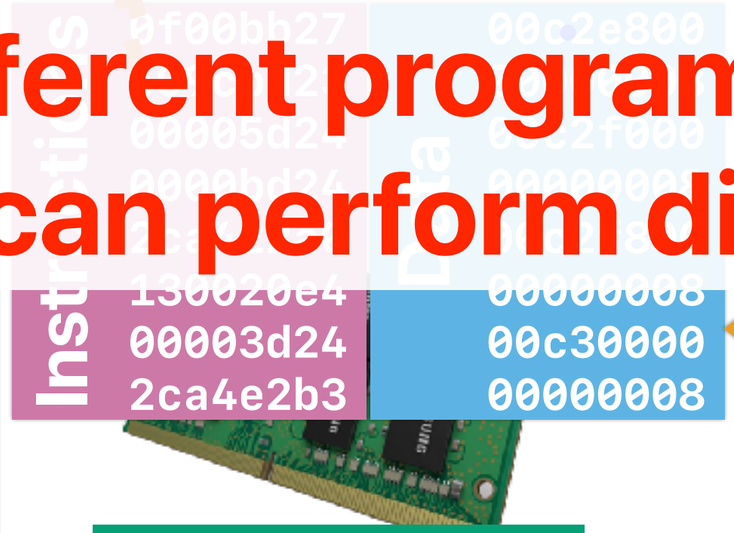
Recap: von Neumman Architecture





Processor

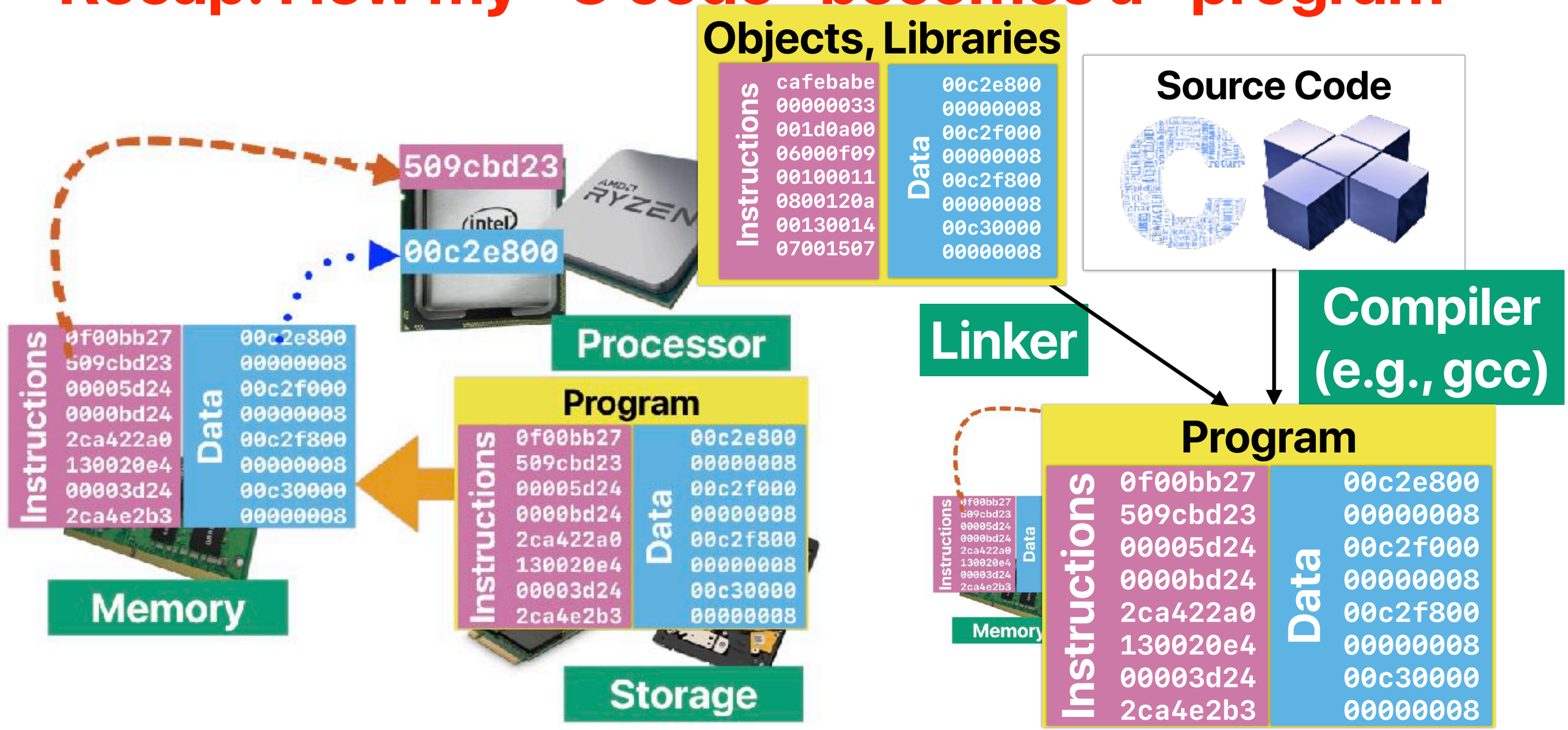
By loading different programs into memory, your computer can perform different functions



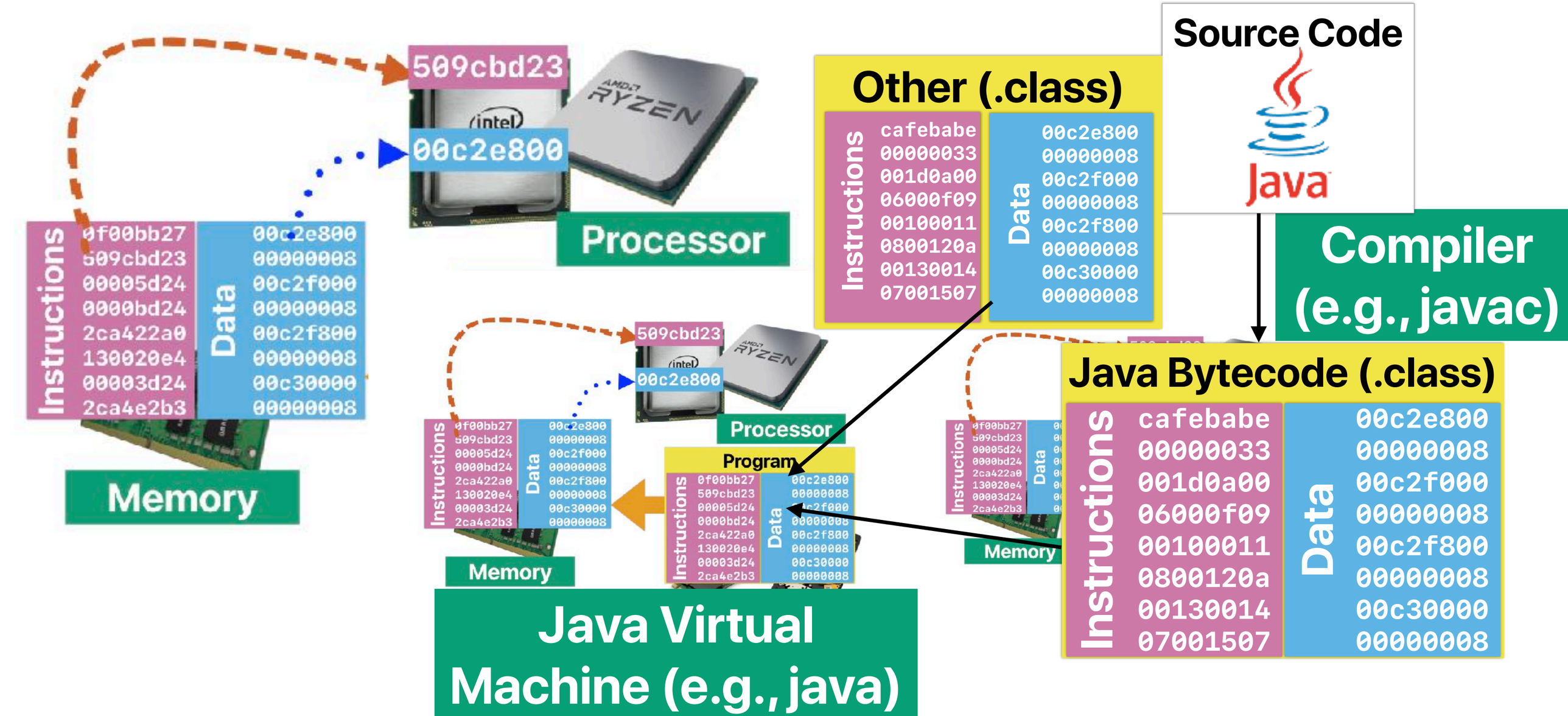
Memory

Storage

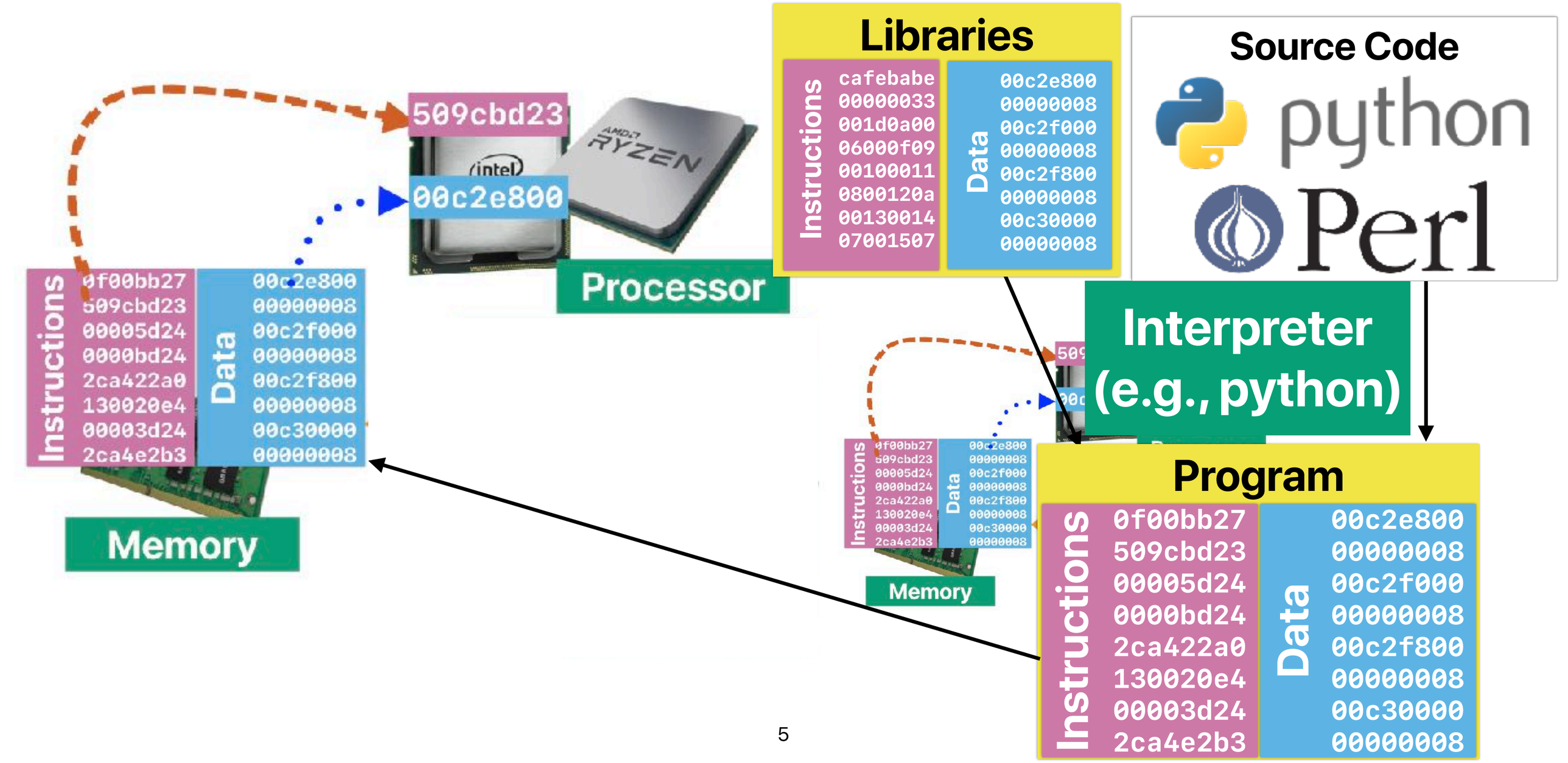
Recap: How my "C code" becomes a "program"



Recap: How my "Java code" becomes a "program"



Recap: How my "Python code" becomes a "program"



Outline

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

Definition of “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**

Now, make sure you login to Poll Everywhere (through the App or the website) with UCRNetID

Now, you have at least 90 seconds to answer the question!

CPU Performance Equation (X)

- Assume that we have an application composed with a total of **5000000000** instructions, in which **20%** of them are "Type-A" instructions with an average **CPI of 8** cycles, **20%** of them are "Type-B" instructions with an average **CPI of 4** cycles and **the rest** instructions are "Type-C" instructions with average **CPI of 1** cycle. If the processor runs at **3 GHz**, how long is the execution time?
  A. 3.67 sec
  B. 5 sec
  C. 6.67 sec
  D. 15 sec
  E. 45 sec

Now, it’s time to discuss with your surroundings (with masks on) — and make sure you vote again after the discussion!

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CPU Performance Equation

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

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

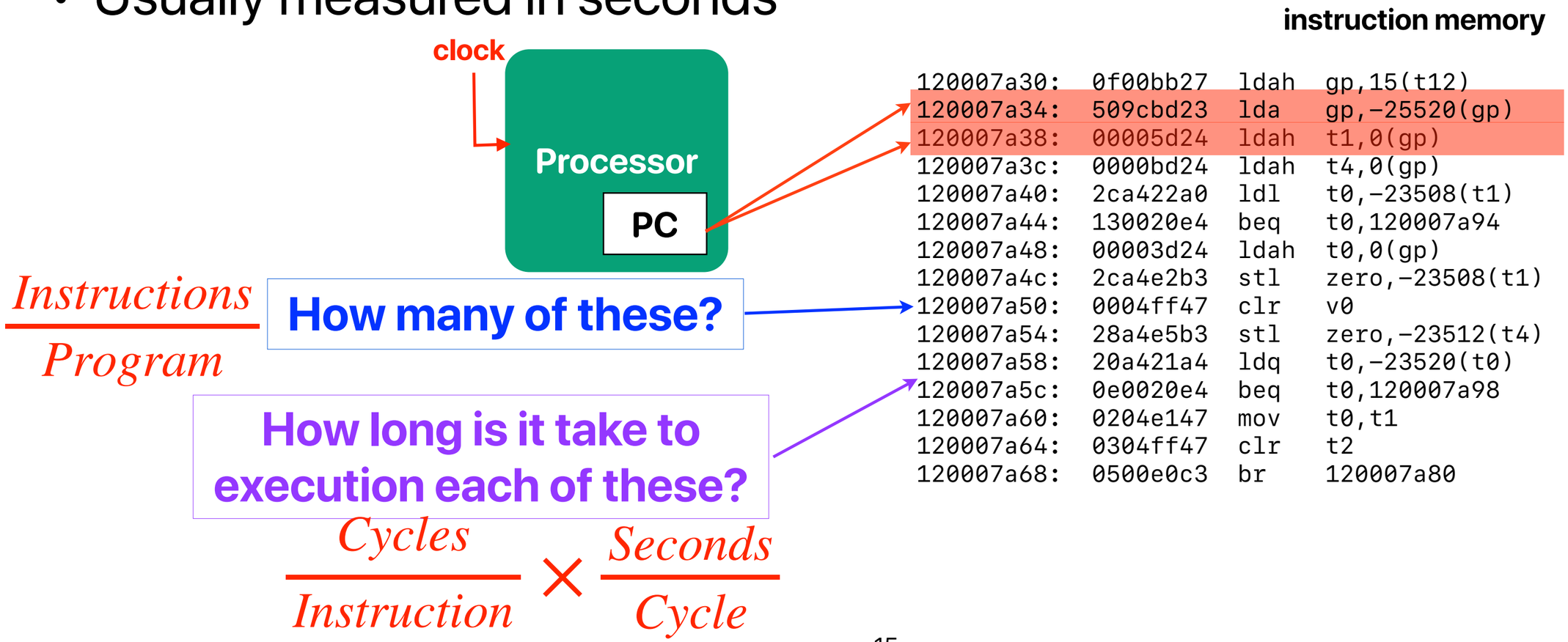
$$ET = IC \times CPI \times CT$$

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

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

Execution Time

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



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D. 15 sec
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$$ET = (5 \times 10^9) \times \underbrace{(20\% \times 8 + 20\% \times 4 + 60\% \times 1)}_{\textbf{average CPI}} \times \frac{1}{3 \times 10^{-9}} sec = 5$$

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

Speedup of Y over X

- Consider the same program on the following two machines, X and Y. By how much Y is faster than X?

	Clock Rate	Instructions	Percentage of Type-A	CPI of Type-A	Percentage of Type-B	CPI of Type-B	Percentage of Type-C	CPI of Type-C
Machine X	3 GHz	5000000000	20%	8	20%	4	60%	1
Machine Y	5 GHz	5000000000	20%	13	20%	4	60%	1

A. 0.2
B. 0.25
C. 0.8
D. 1.25
E. No changes

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D. 1.25
E. No changes

Speedup

- The relative performance between two machines, X and Y. Y is n times faster than X

$$n = \frac{Execution\ Time_X}{Execution\ Time_Y}$$

- The speedup of Y over X

$$Speedup = \frac{Execution\ Time_X}{Execution\ Time_Y}$$

Speedup of Y over X

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A. 0.2
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$$ET_Y = (5 \times 10^9) \times (20\% \times 13 + 20\% \times 4 + 60\% \times 1) \times \frac{1}{5 \times 10^{-9}} sec = 4$$

$$Speedup = \frac{Execution\ Time_X}{Execution\ Time_Y}$$

$$= \frac{5}{4} = 1.25$$

What Affects Each Factor in Performance Equation

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

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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

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for(i = 0; i < ARRAY_SIZE; i++)
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for(j = 0; j < ARRAY_SIZE; j++)
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```

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

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for(j = 0; j < ARRAY_SIZE; j++)
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  for(i = 0; i < ARRAY_SIZE; i++)
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  }
}
```

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

Demo — programmer & performance

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```
for(j = 0; j < ARRAY_SIZE; j++)
{
  for(i = 0; i < ARRAY_SIZE; i++)
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  }
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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
C. CT
D. IC & CPI
E. CPI & CT

Programmer's impact

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A. CPI
B. IC
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
```

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  2. CPI
  3. CT

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Announcement

- Reading quiz due next Monday before the lecture
  - We will drop two of your least performing reading quizzes
  - You have two shots, both unlimited time
- Check our website for slides, eLearn for quizzes/assignments, piazza for discussions
- Youtube channel for lecture recordings: https://www.youtube.com/c/ProfUsagi/playlists