First Day of CSE142: Computer Architecture: Software Perspective (2023 Summer Session II)

Prof. Usagi a.k.a.
Hung-Wei Tseng

Before we get there ...

What's your name?

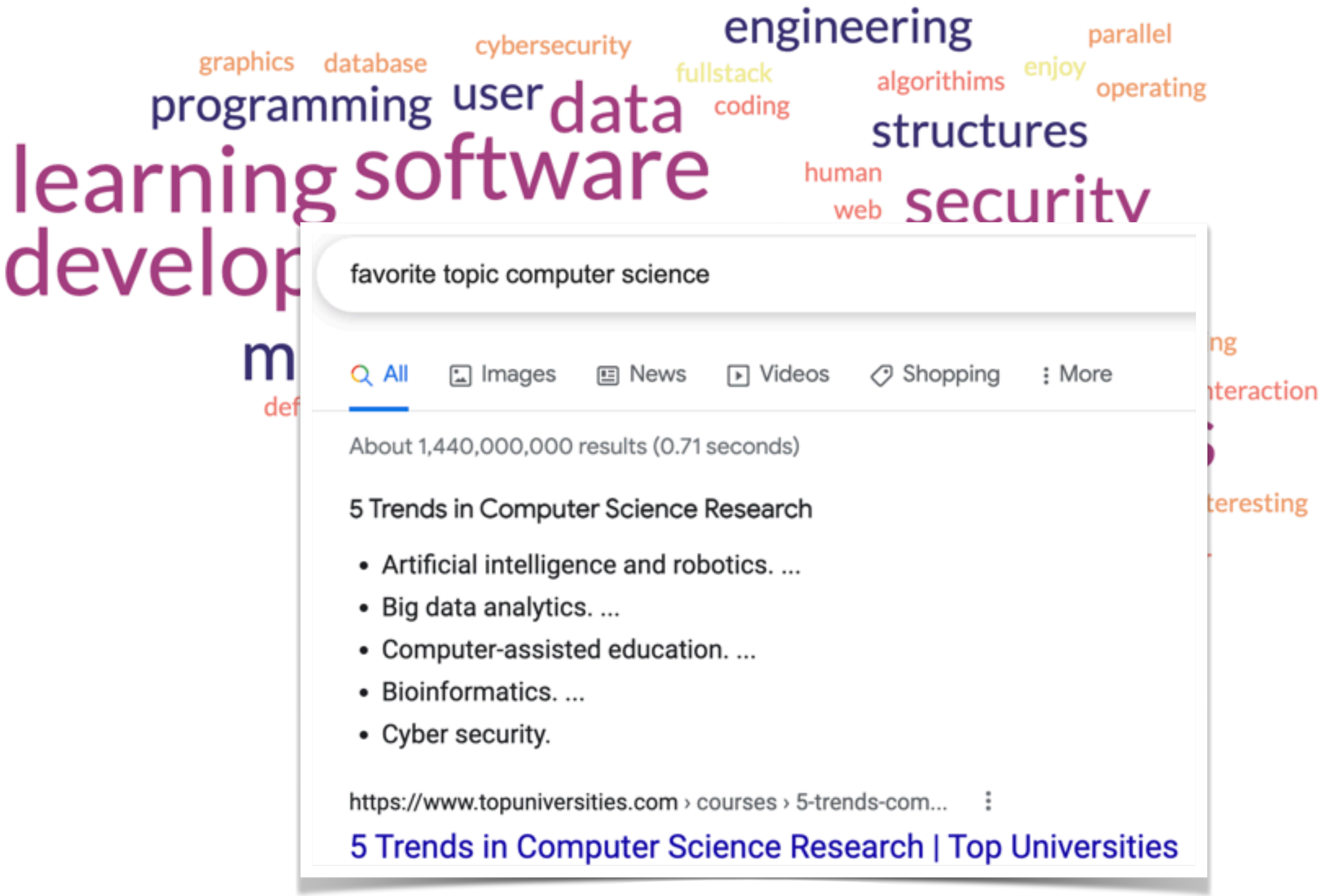
Background music: Before I Get There/ Songwriter(s):Bronze Radio Return, Chris Henderson/Performed by Bronze Radio Return

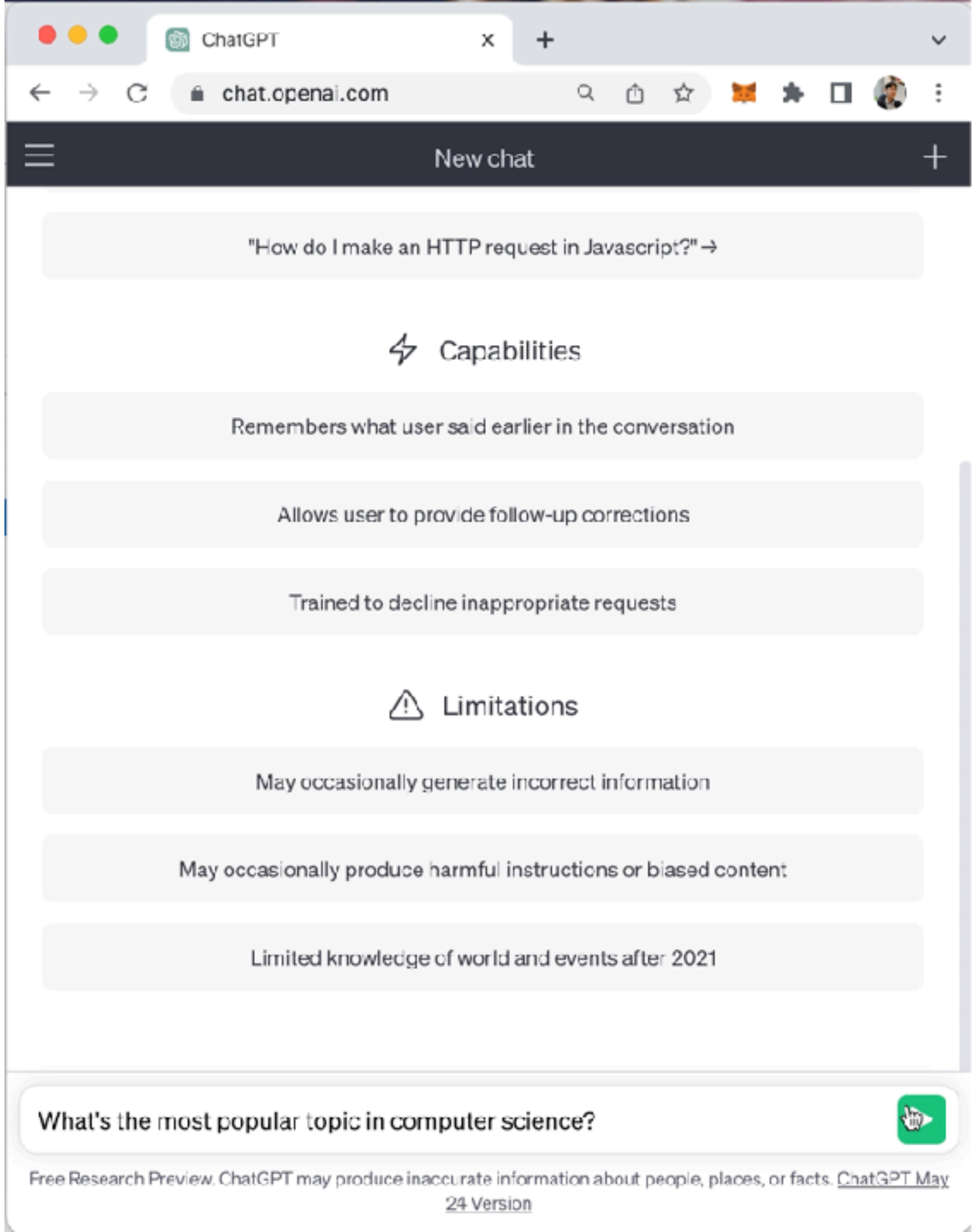
Instructor — Hung-Wei Tseng

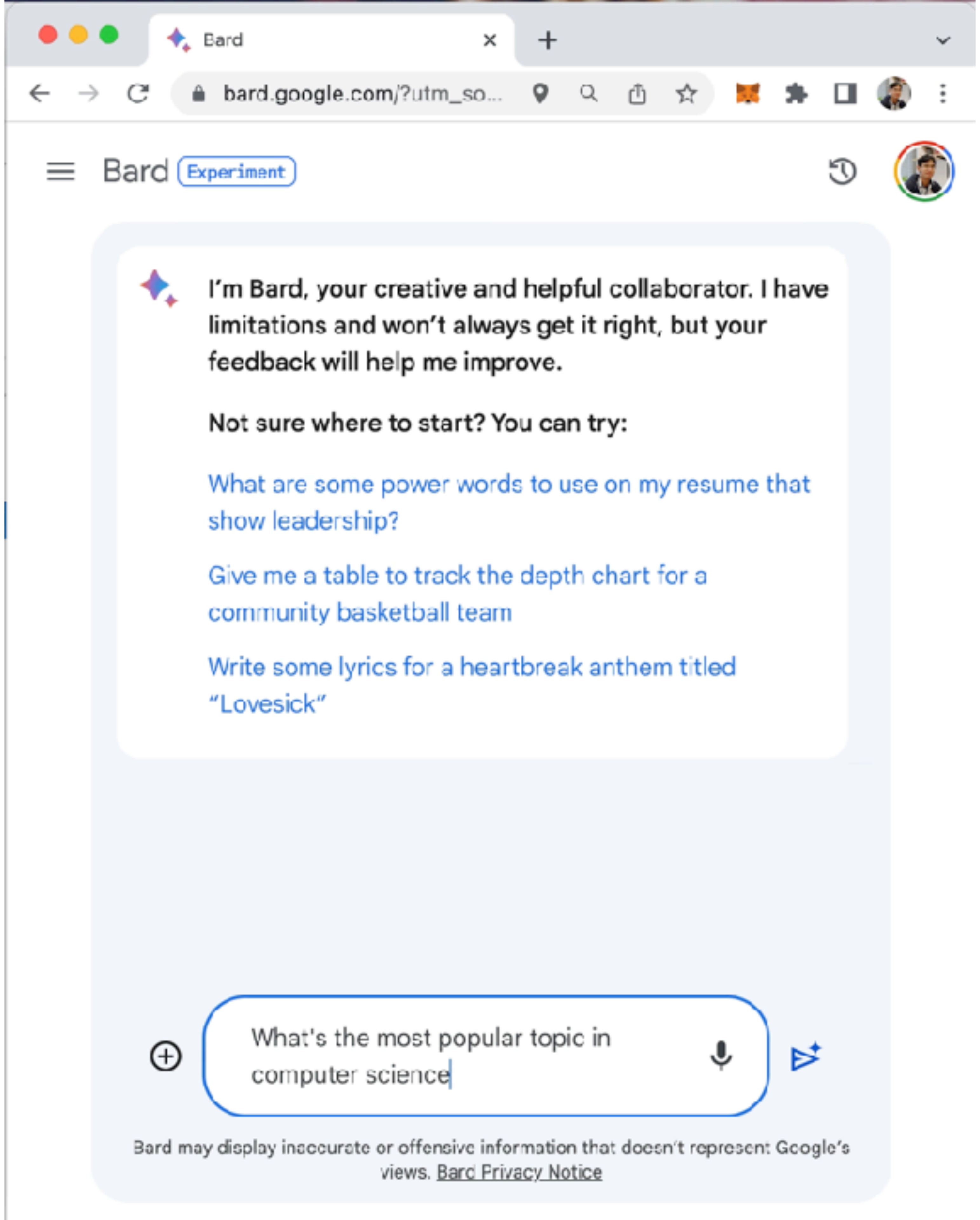
- Associate Professor @ UC Riverside, 05/2019—
- Website: https://intra.engr.ucr.edu/~htseng/
- E-mail: htseng @ ucsd.edu
- Visiting Researcher @ Google, 01/2023—03/2023
  - Working for TensorFlow Lite
- PhD in **Computer Science**, University of California, San Diego, 2014
- Research Interests
  - General-purpose computing on AI/ML/NN accelerators
  - Intelligent storage devices & near-data processing
  - Or anything else fun — we have an OpenUVR project recently
- Fun fact: Hung-Wei was once considering a career path as a singer but went back to academia due to the unsuccessful trial

Before we get there ...

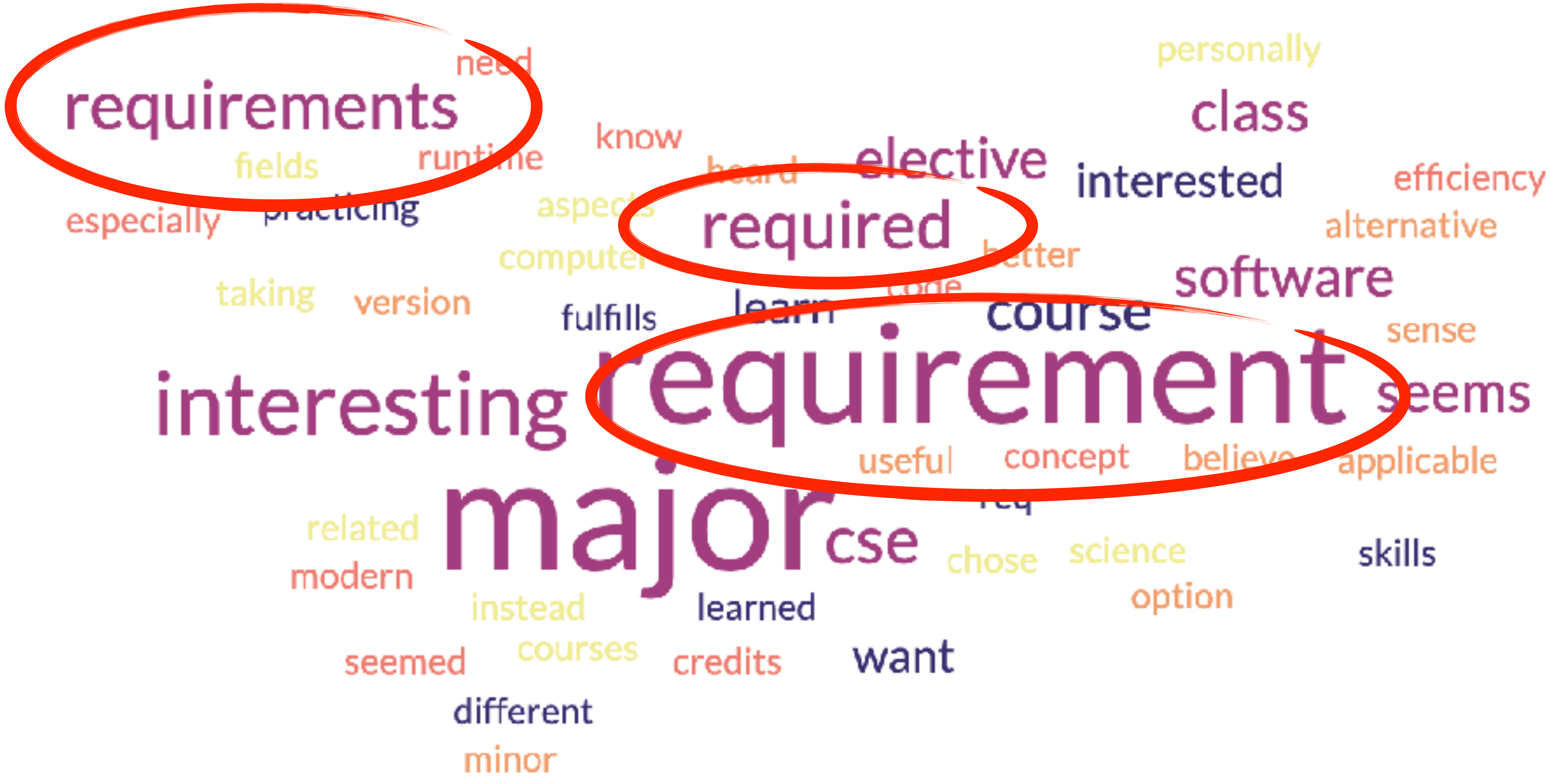
What's your name?




ChatGPT
chat.openai.com
New chat
"How do I make an HTTP request in Javascript?" →
Capabilities
Remembers what user said earlier in the conversation
Allows user to provide follow-up corrections
Trained to decline inappropriate requests
Limitations
May occasionally generate incorrect information
May occasionally produce harmful instructions or biased content
Limited knowledge of world and events after 2021
What's the most popular topic in computer science?
Free Research Preview. ChatGPT may produce inaccurate information about people, places, or facts. ChatGPT May 24 Version


Bard
bard.google.com/?utm_so...
Bard Experiment
I'm Bard, your creative and helpful collaborator. I have limitations and won't always get it right, but your feedback will help me improve.
Not sure where to start? You can try:
What are some power words to use on my resume that show leadership?
Give me a table to track the depth chart for a community basketball team
Write some lyrics for a heartbreak anthem titled "Lovesick"
What's the most popular topic in computer science
Bard may display inaccurate or offensive information that doesn't represent Google's views. Bard Privacy Notice

Before we get there …



What's your name?

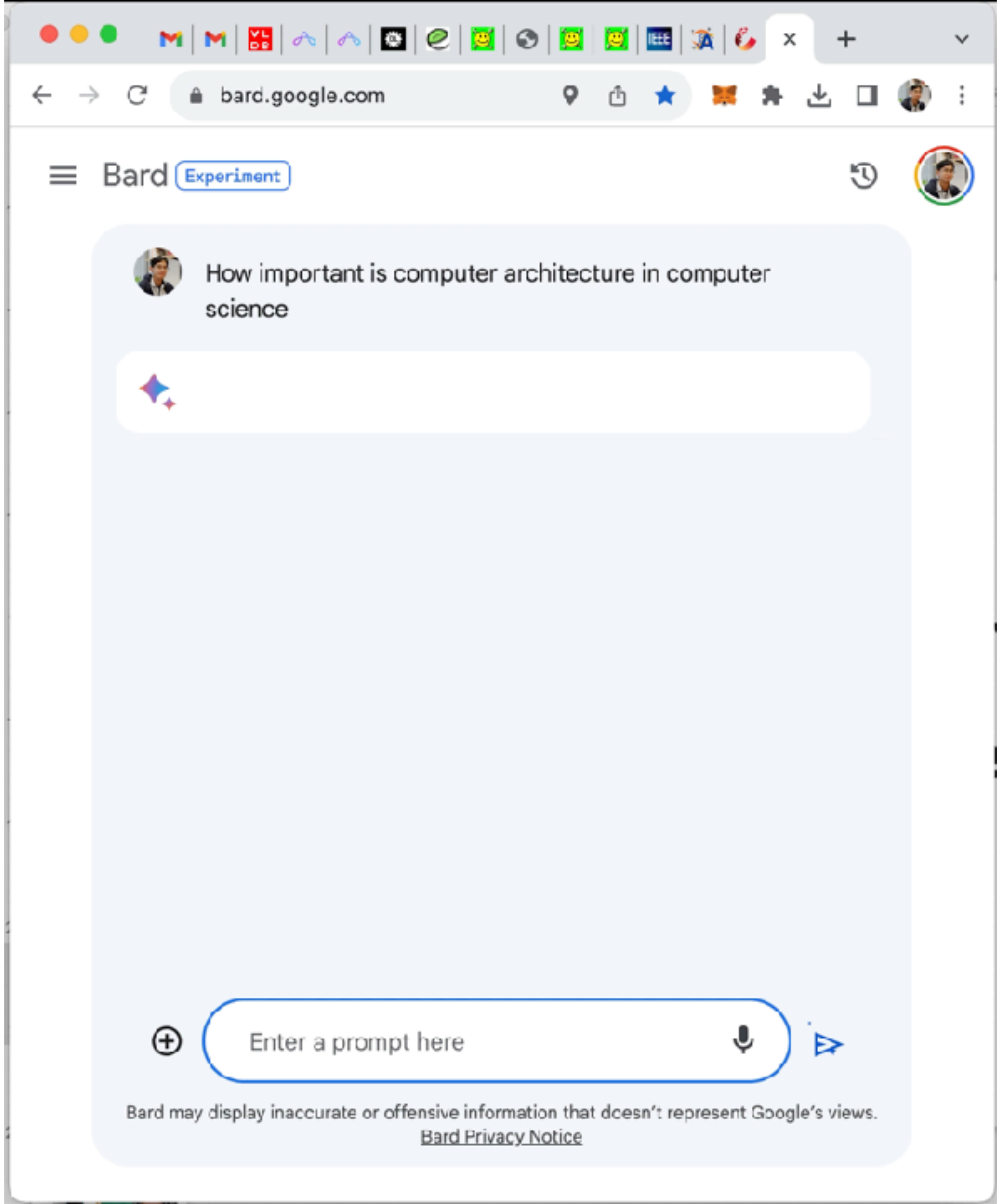
What do you care as a computer scientist?

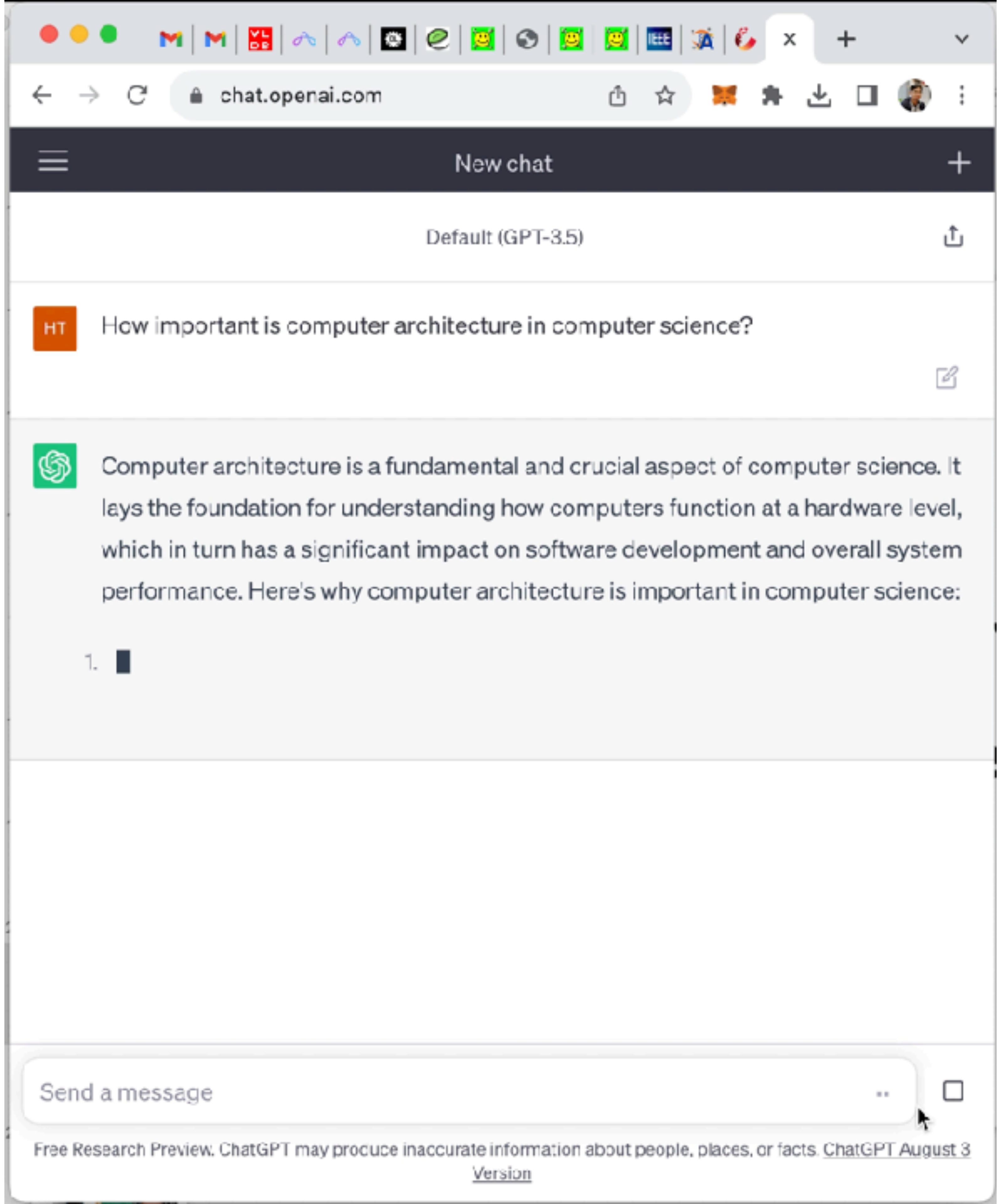
Algorithms
Data Structures
Software Engineering
Computer Architecture
Programming Languages
User Interfaces

What's computer architecture?

The manner in which the components of a computer or computer system are organized and integrated

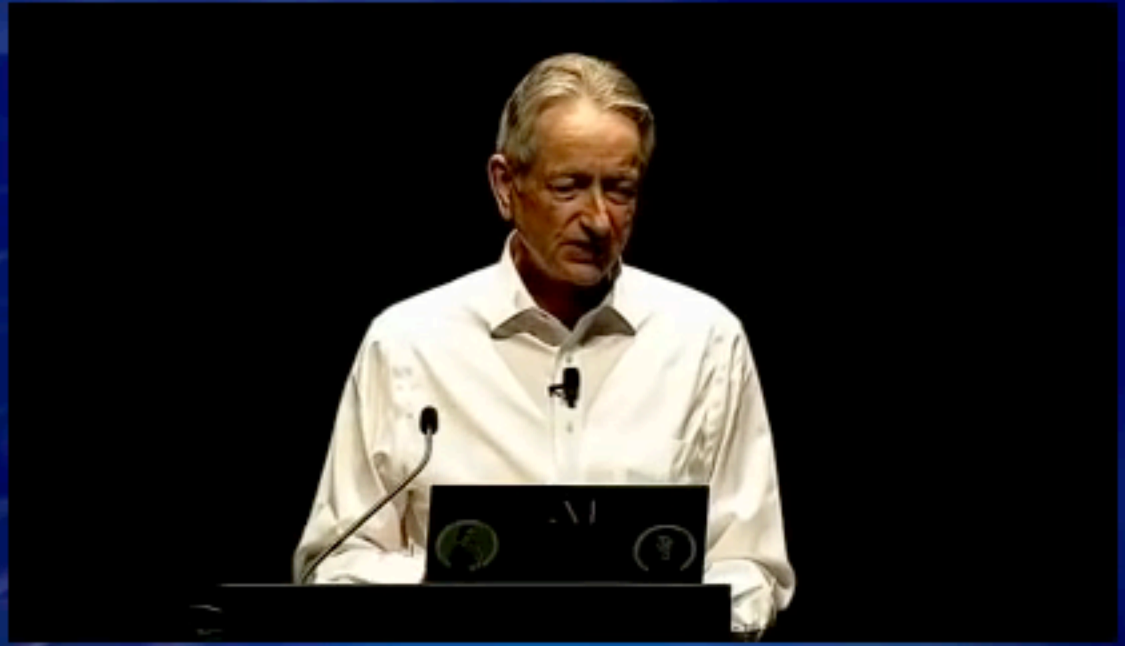
Computer Architects — Hidden Figures

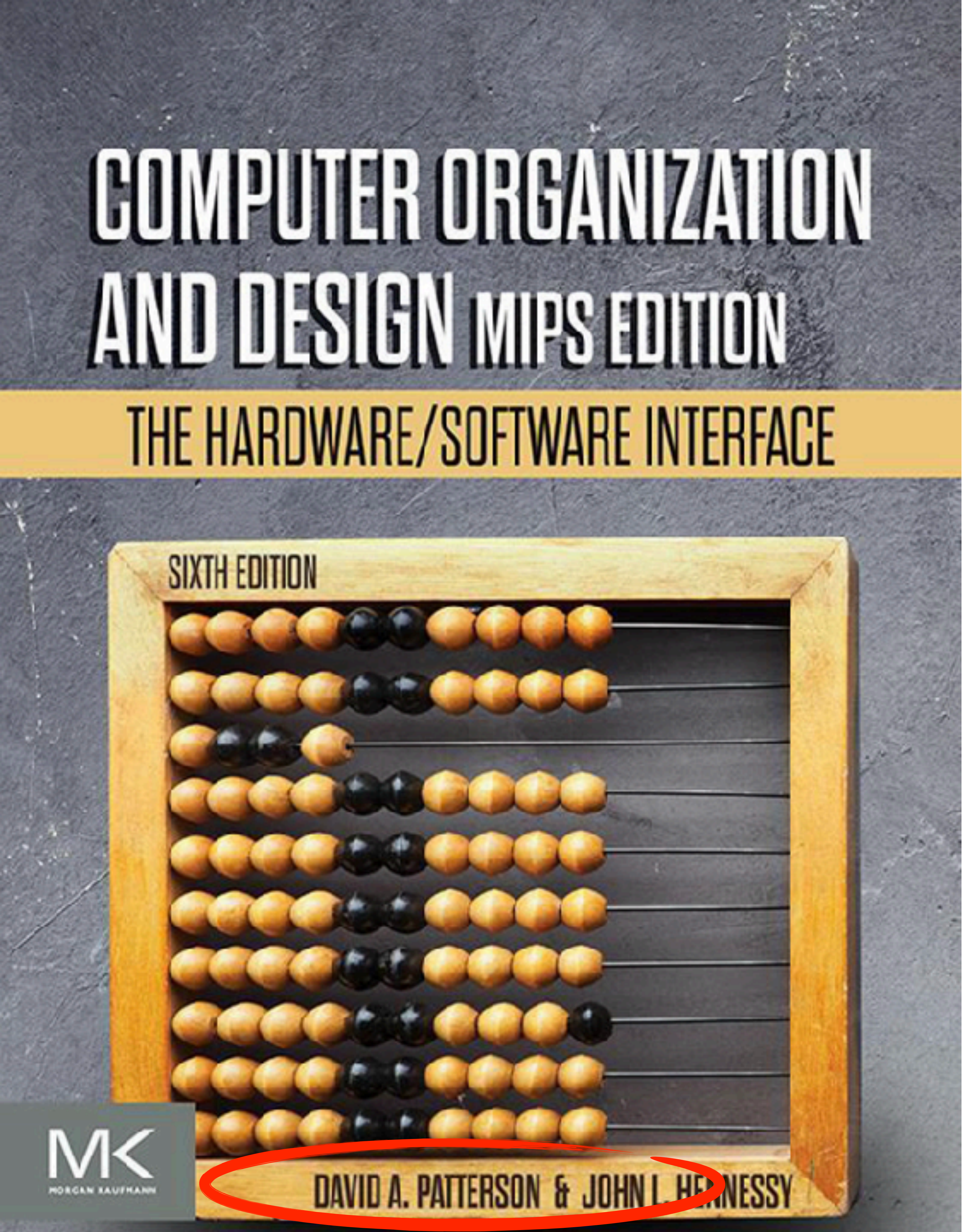

bard.google.com
Bard Experiment
How important is computer architecture in computer science
Enter a prompt here
Bard may display inaccurate or offensive information that doesn't represent Google's views.
Bard Privacy Notice


chat.openai.com
New chat
Default (GPT-3.5)
HT
How important is computer architecture in computer science?
Computer architecture is a fundamental and crucial aspect of computer science. It lays the foundation for understanding how computers function at a hardware level, which in turn has a significant impact on software development and overall system performance. Here's why computer architecture is important in computer science:
1.
Send a message
Free Research Preview. ChatGPT may produce inaccurate information about people, places, or facts. ChatGPT August 3 Version

The return of backpropagation

- Between 2005 and 2009 researchers (in Canada!) made several technical advances that enabled backpropagation to work better in feed-forward nets.
  - Unsupervised pre-training; random dropout of units; rectified linear units.
  - The technical details of these advances are very important to the researchers but they are not the main message.
  - The main message is that backpropagation now works amazingly well if you have two things:
    - a lot of labeled data
    - a lot of convenient compute power (*e.g.* GPUs)





Computer Architecture

Enables

Deep Learning

Why should I care about “Computer Architecture”

Demo

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

for (unsigned c = 0; c < arraySize*1000; ++c) {
    int t = std::rand();

    (data[c%arraySize] >= t)
            sum ++;
    }
}
```

$O(nlog_2n)$

$O(n)$

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

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

Demo (2) — quick sort v.s. bitonic sort on GPU

Quick Sort

$$O(nlog_2n)$$

Bitonic Sort

$$O(nlog_2^2n)$$

```
void BitonicSort() {

    int i,j,k;

    for (k=2; k<=N; k=2*k) {
        for (j=k>>1; j>0; j=j>>1) {
            for (i=0; i<N; i++) {
                int ij=i^j;
                if ((ij)>i) {
                    if ((i&k)==0 && a[i] > a[ij])
                        exchange(i,ij);
                    if ((i&k)!=0 && a[i] < a[ij])
                        exchange(i,ij);
                }
            }
        }
    }
}
```

? ? ? ?

Thinking about the washlet

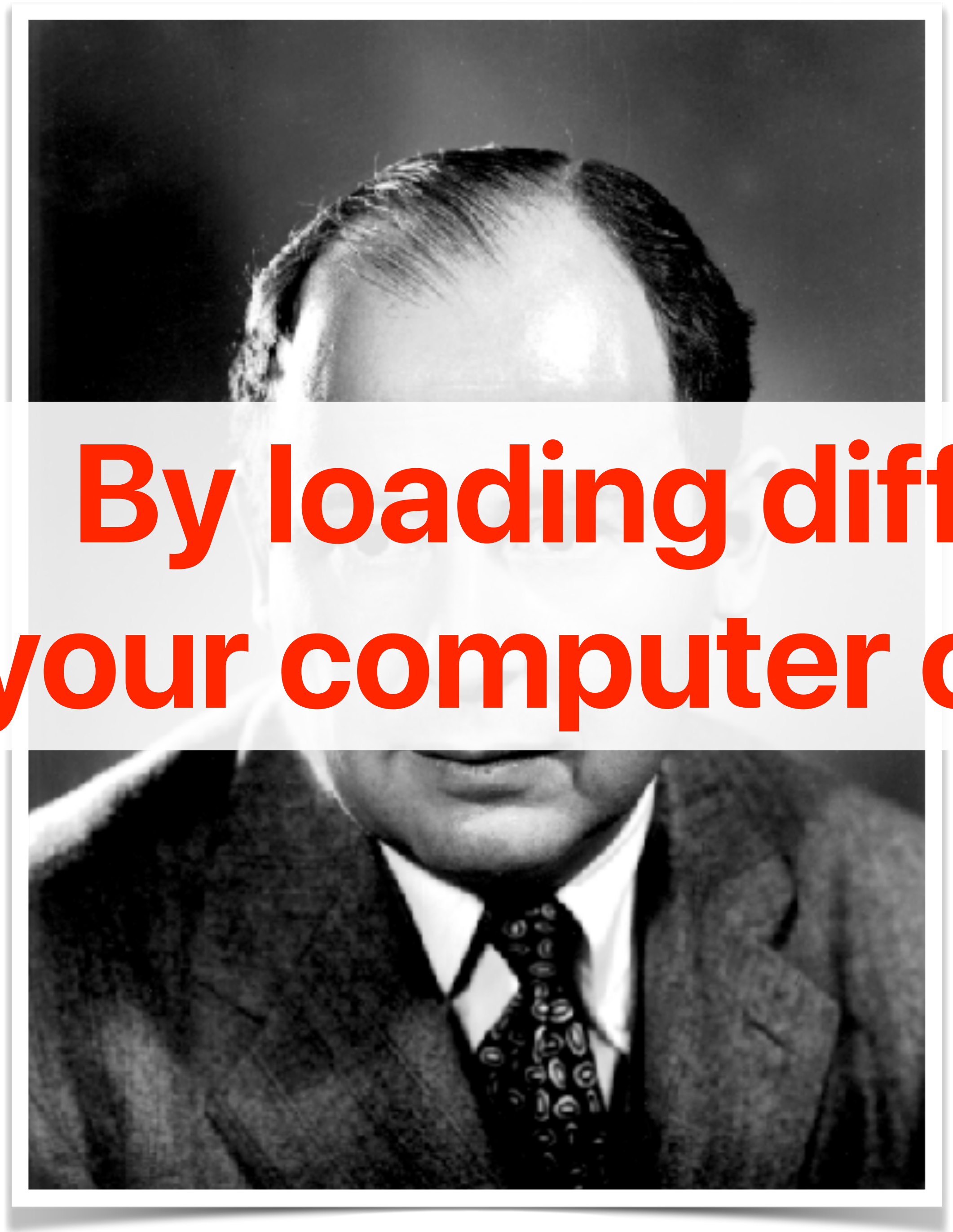
Or a Tesla

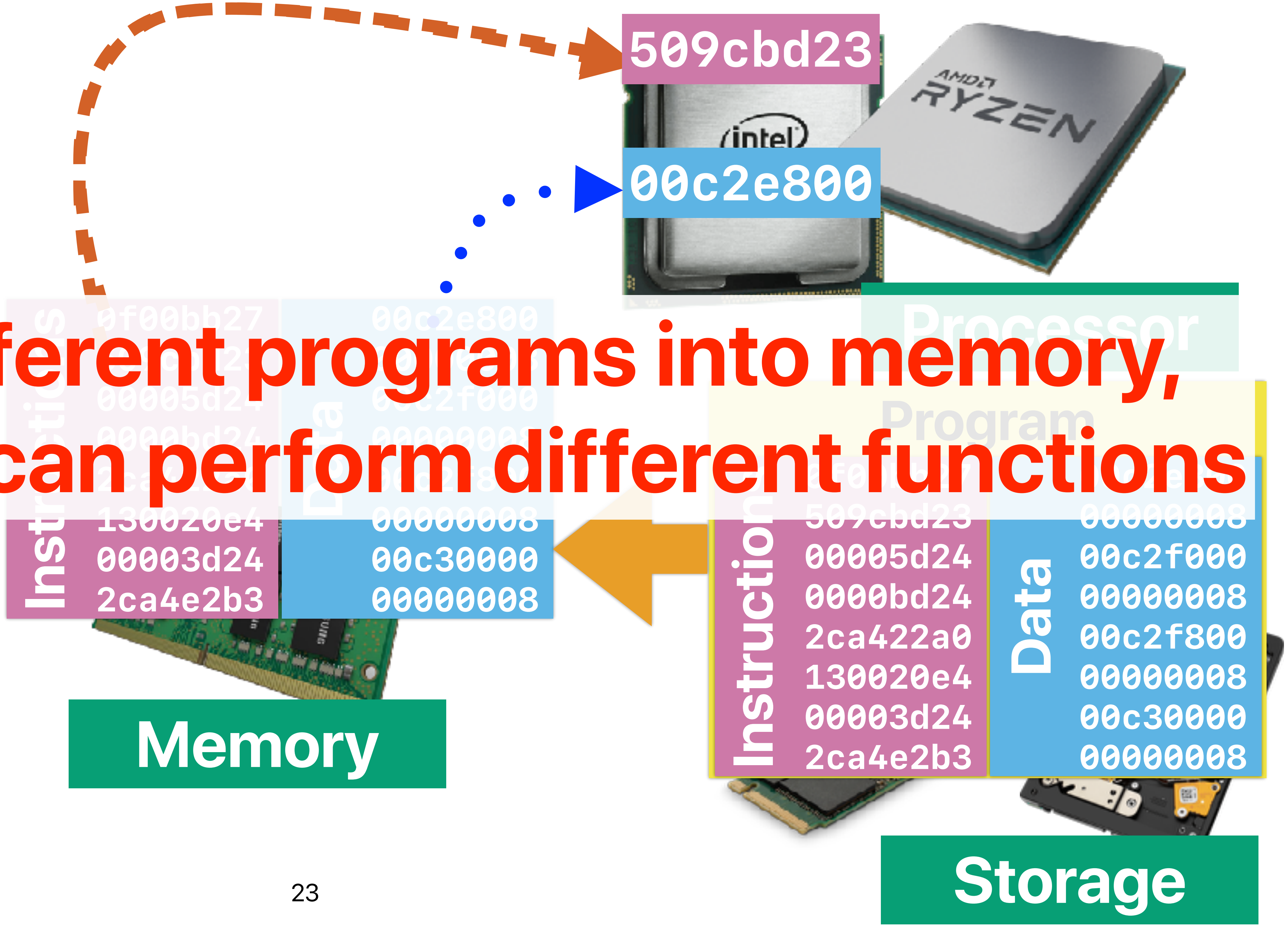
3:00

How does a computer execute your code?

Big Picture: the Von Neumann Architecture

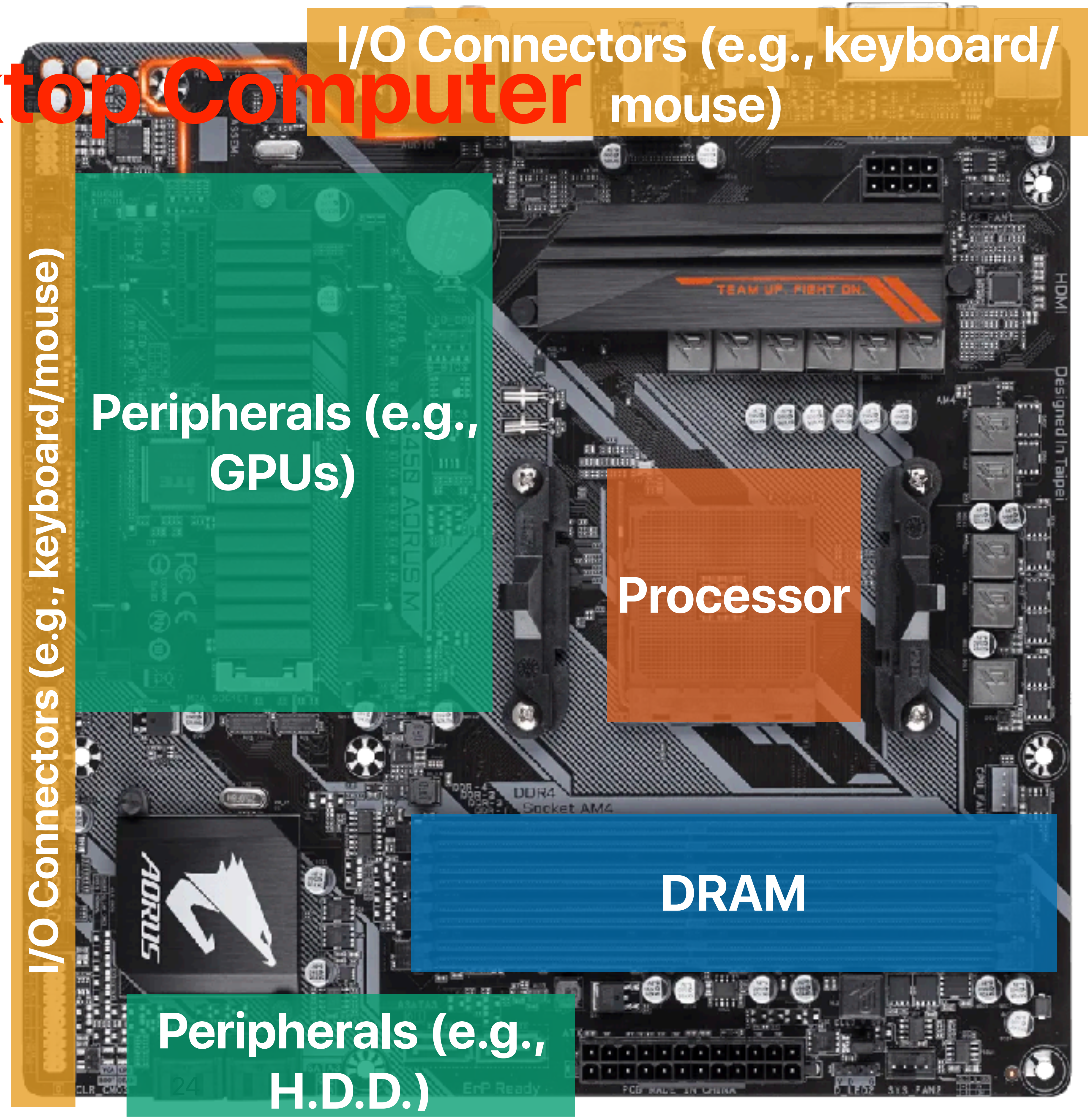
von Neumman Architecture



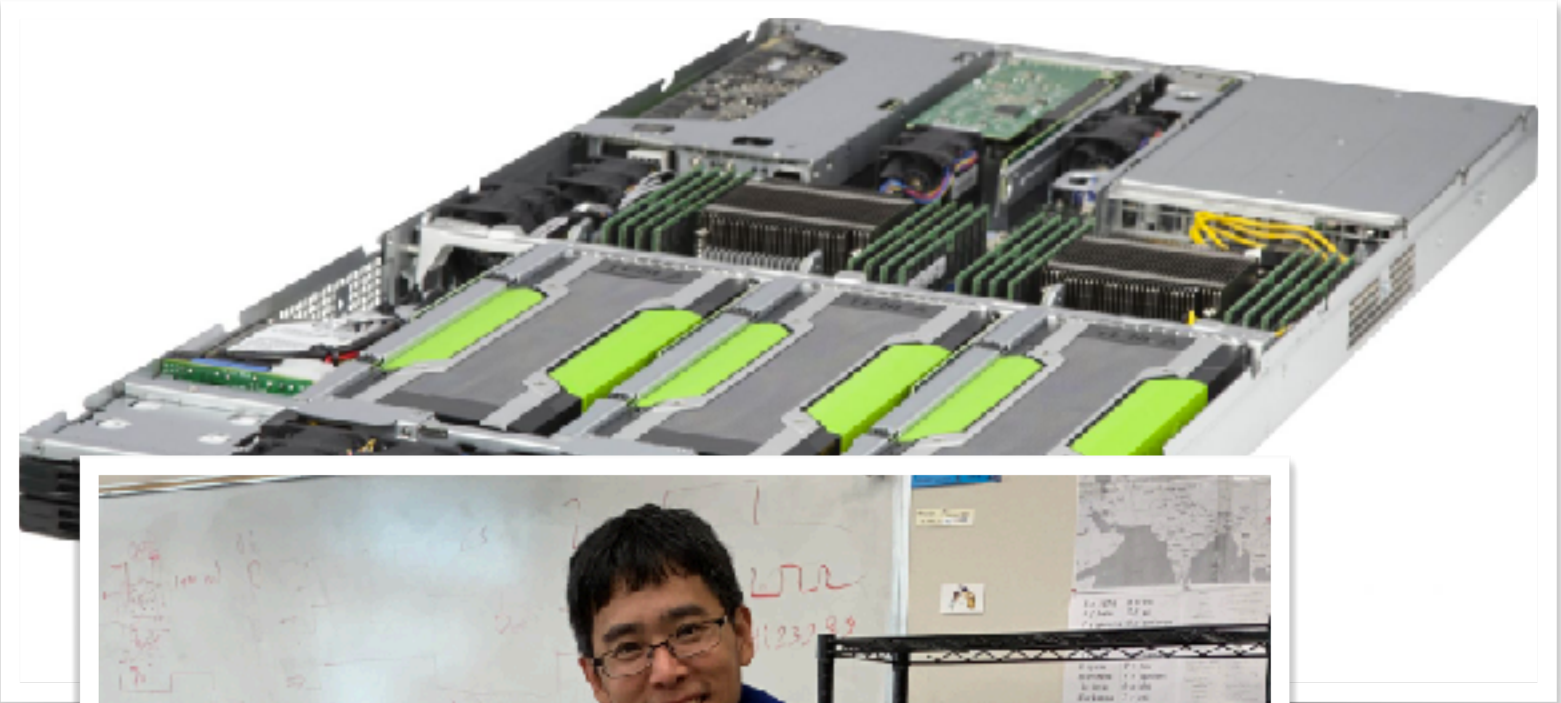


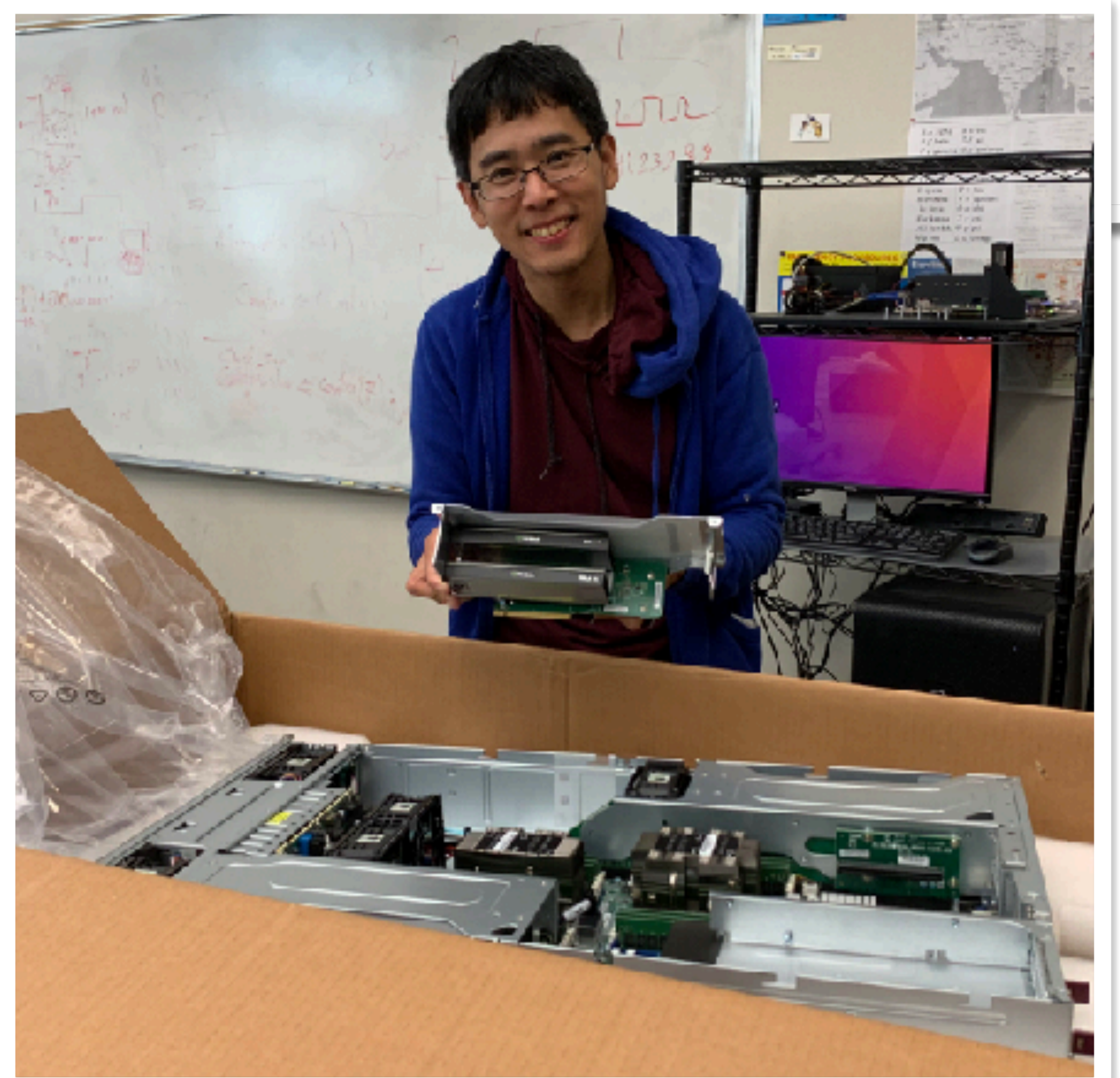
By loading different programs into memory, your computer can perform different functions

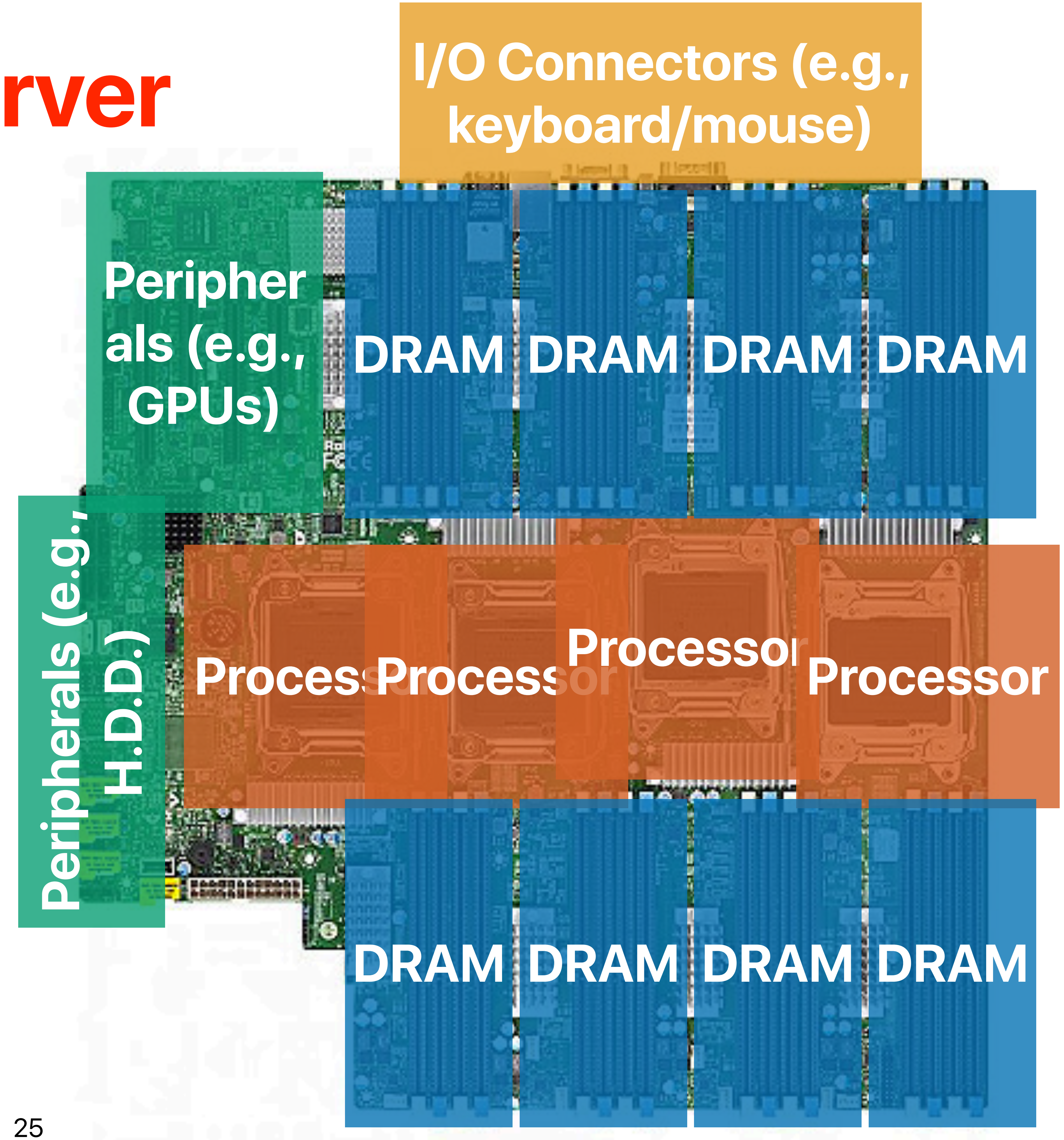
Desktop Computer



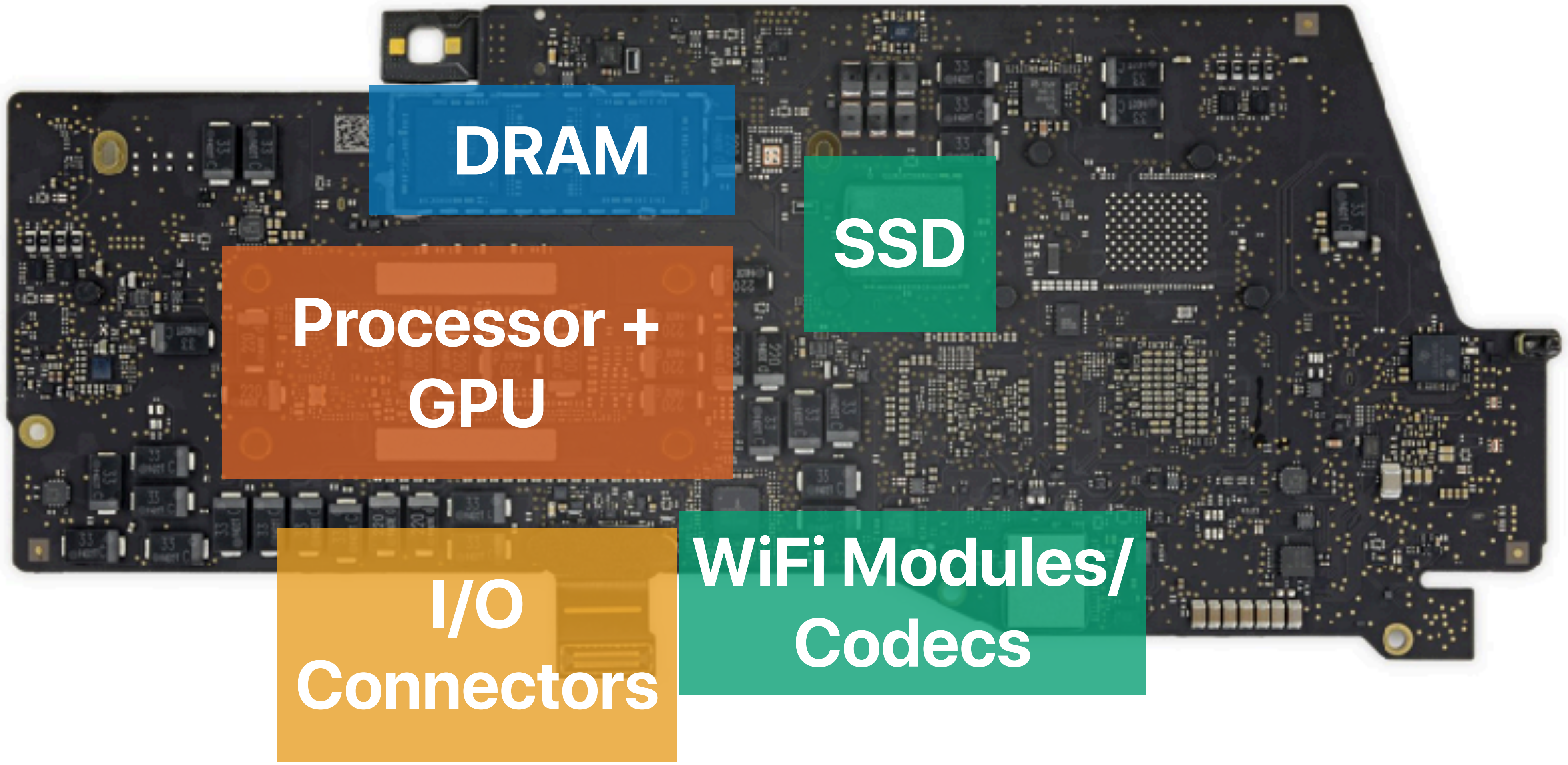
Server





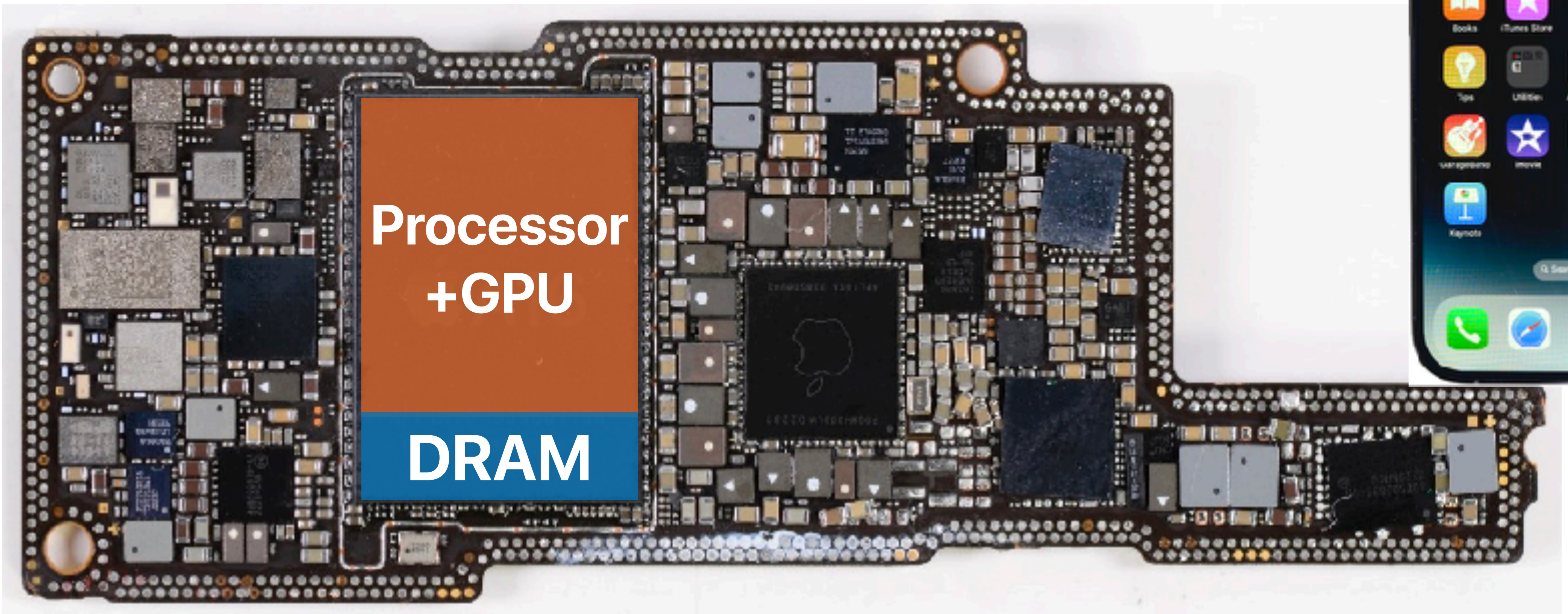

I/O Connectors (e.g., keyboard/mouse)
Peripherals (e.g., GPUs)
Peripherals (e.g., H.D.D.)
DRAM
DRAM
DRAM
DRAM
Processor
Processor
Processor
Processor
DRAM
DRAM
DRAM
DRAM

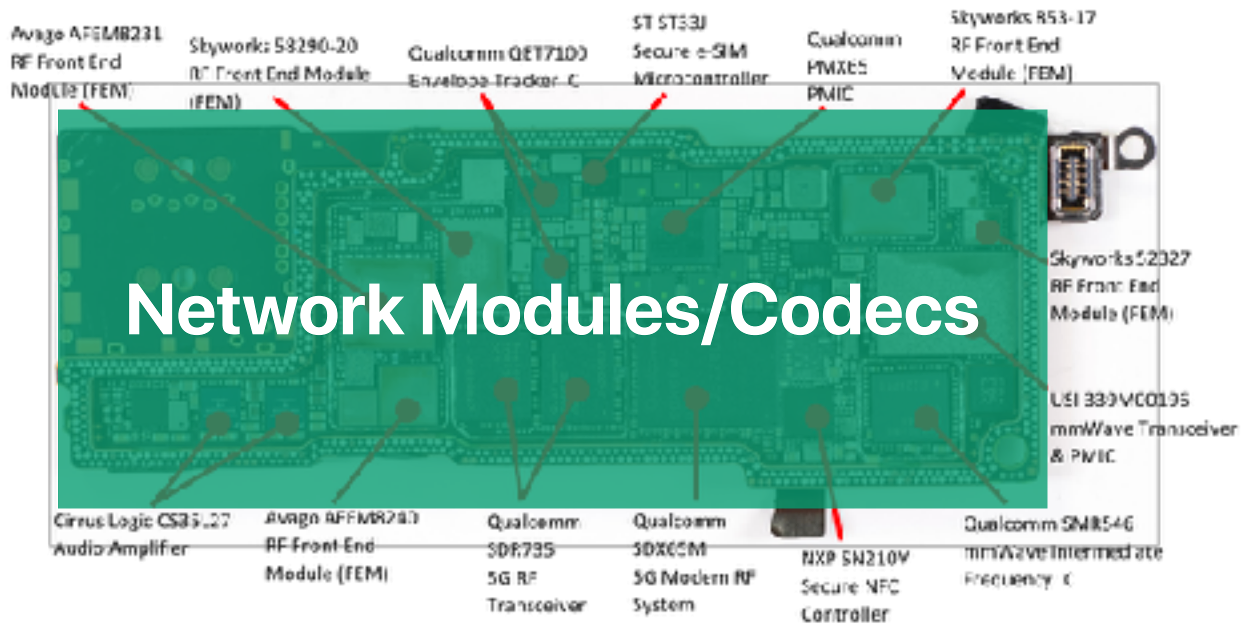
MacBook Pro 13"

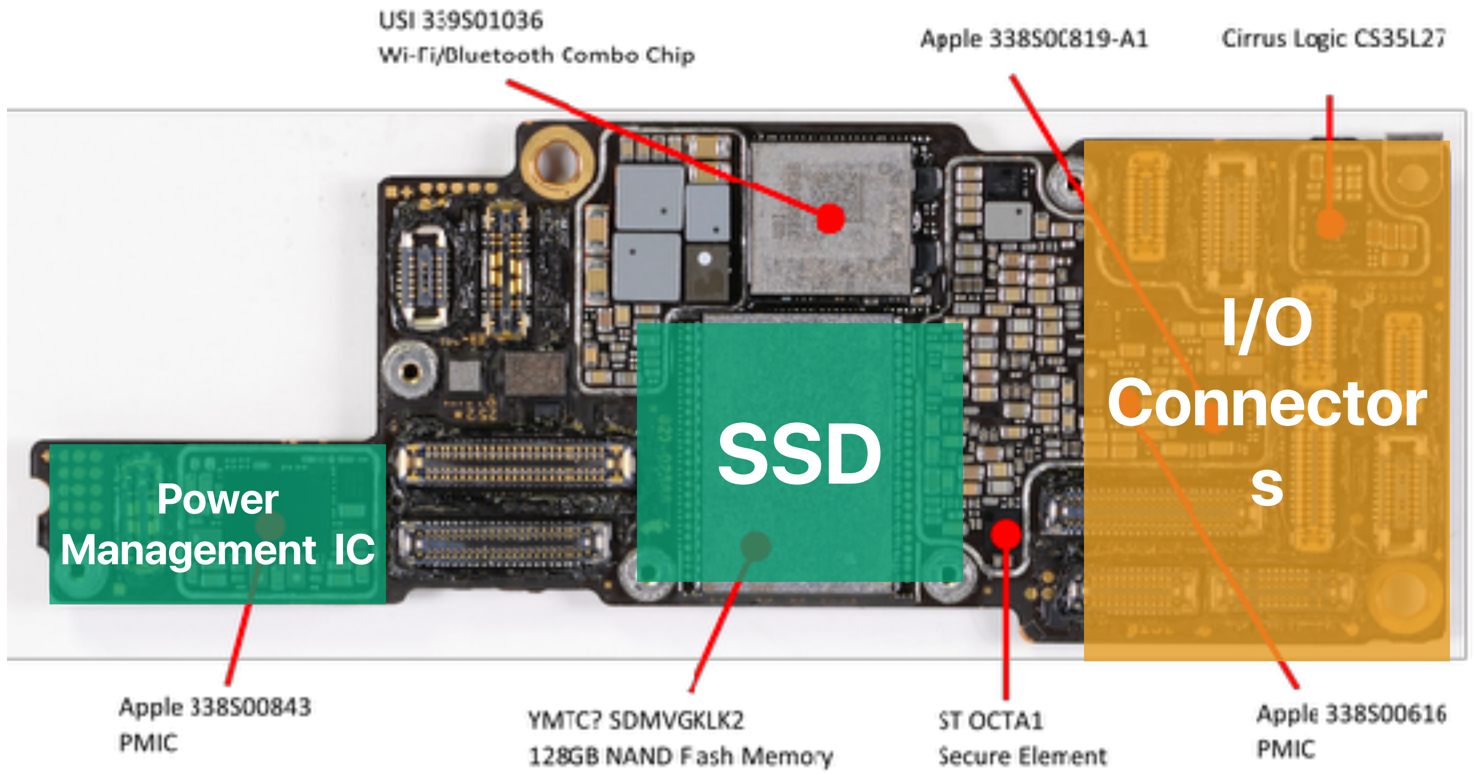


https://unitedlex.com/insights/apple-iphone-14-pro-teardown-report/

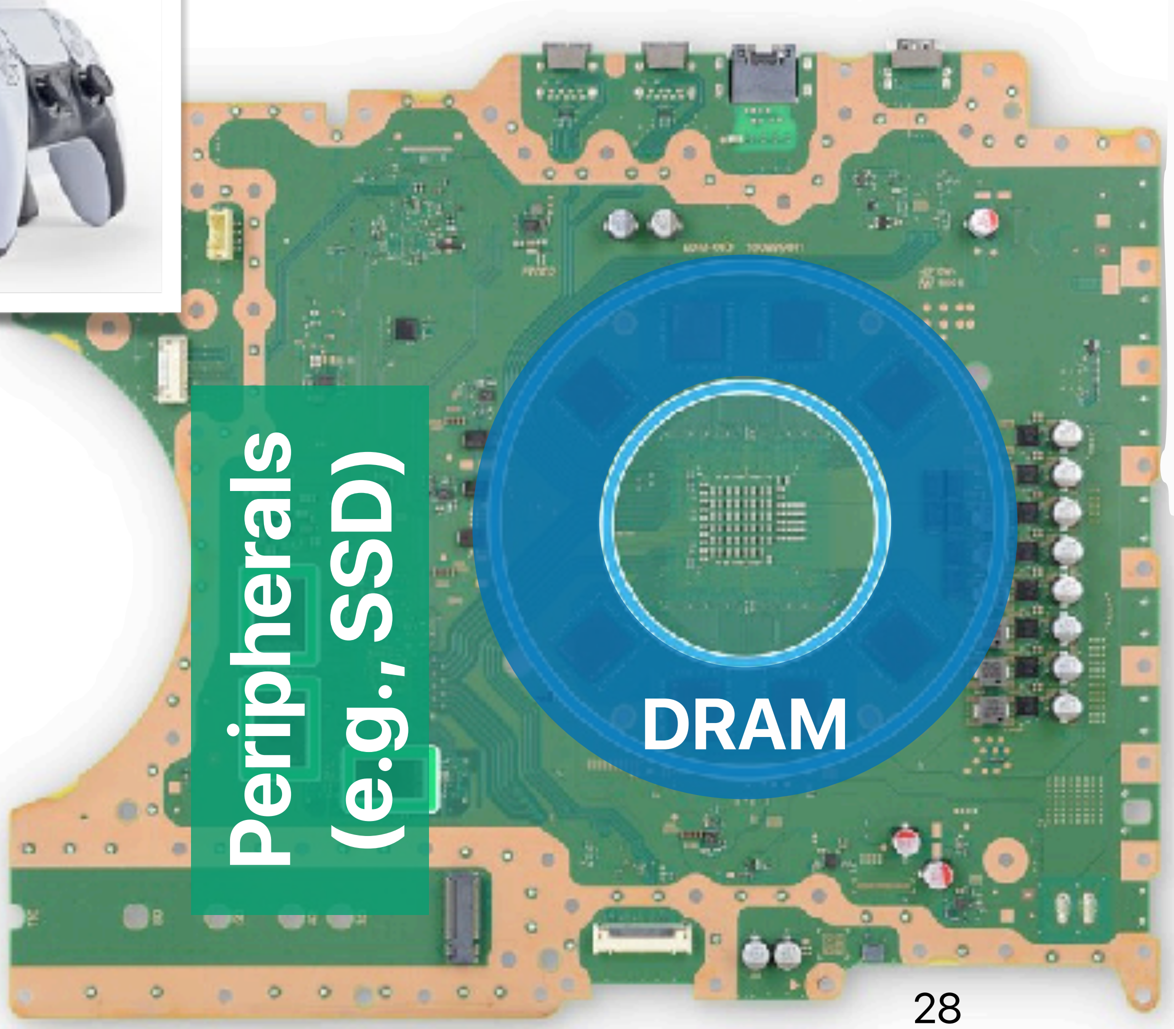
iPhone 14 Pro

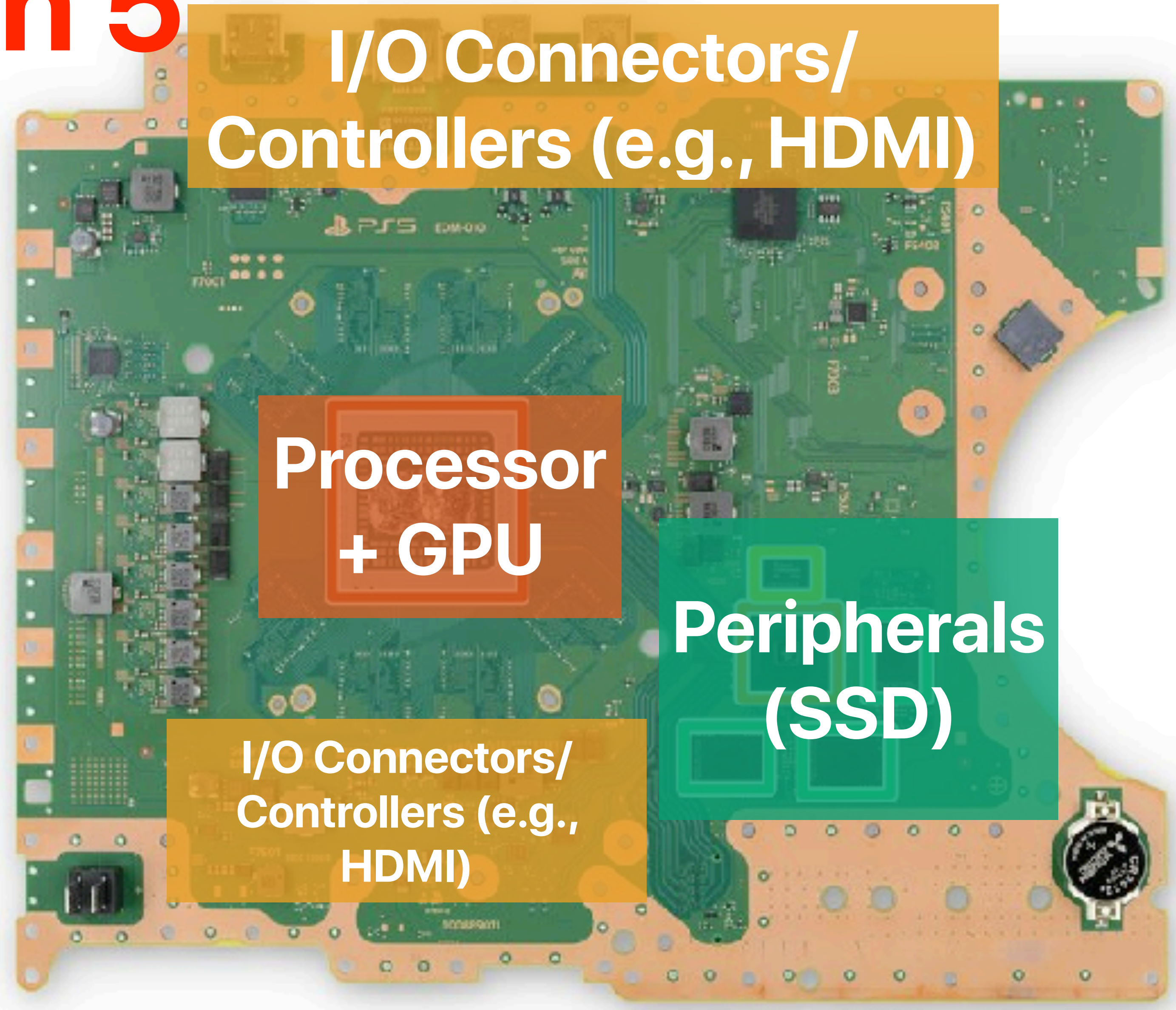




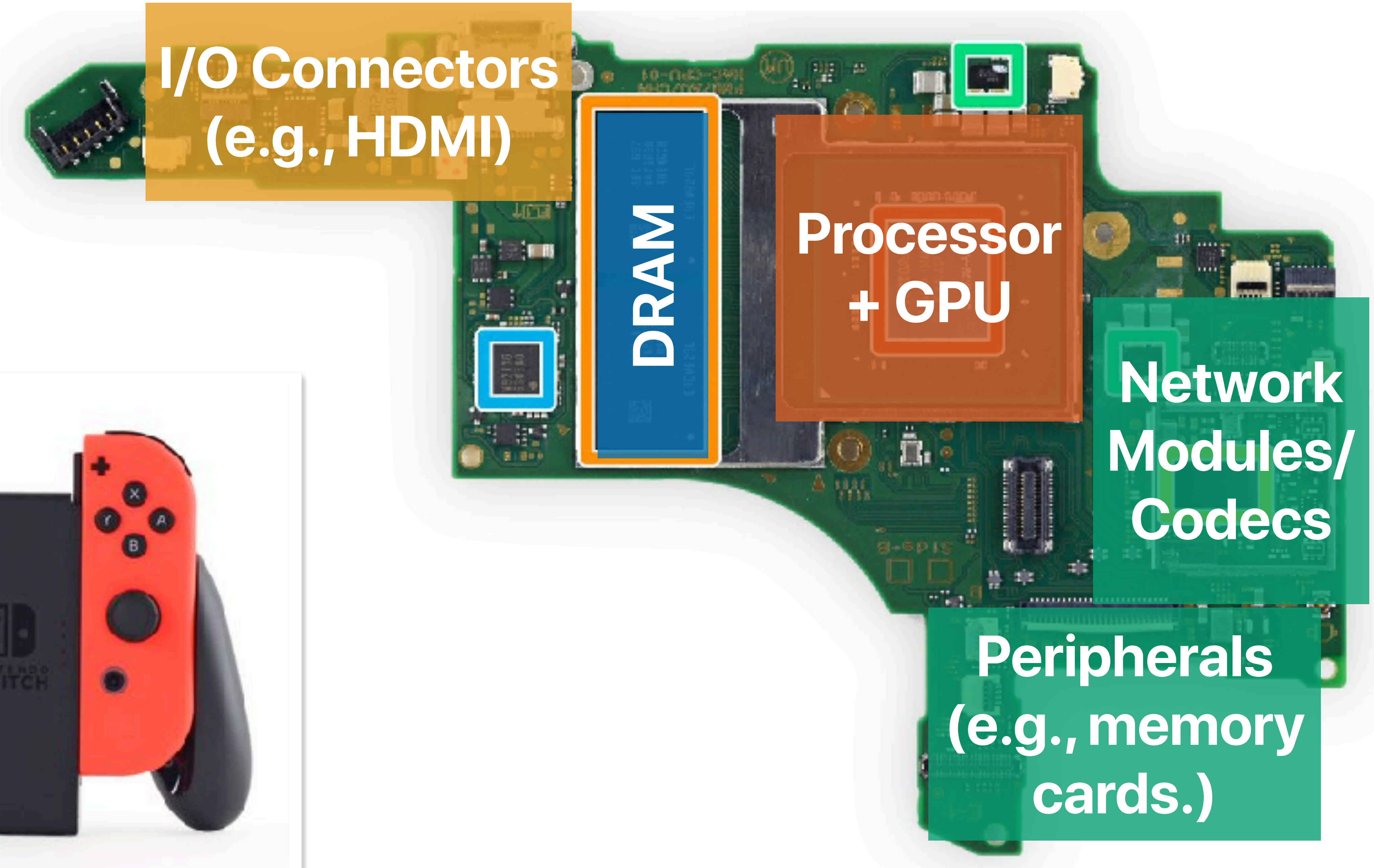


Play Station 5

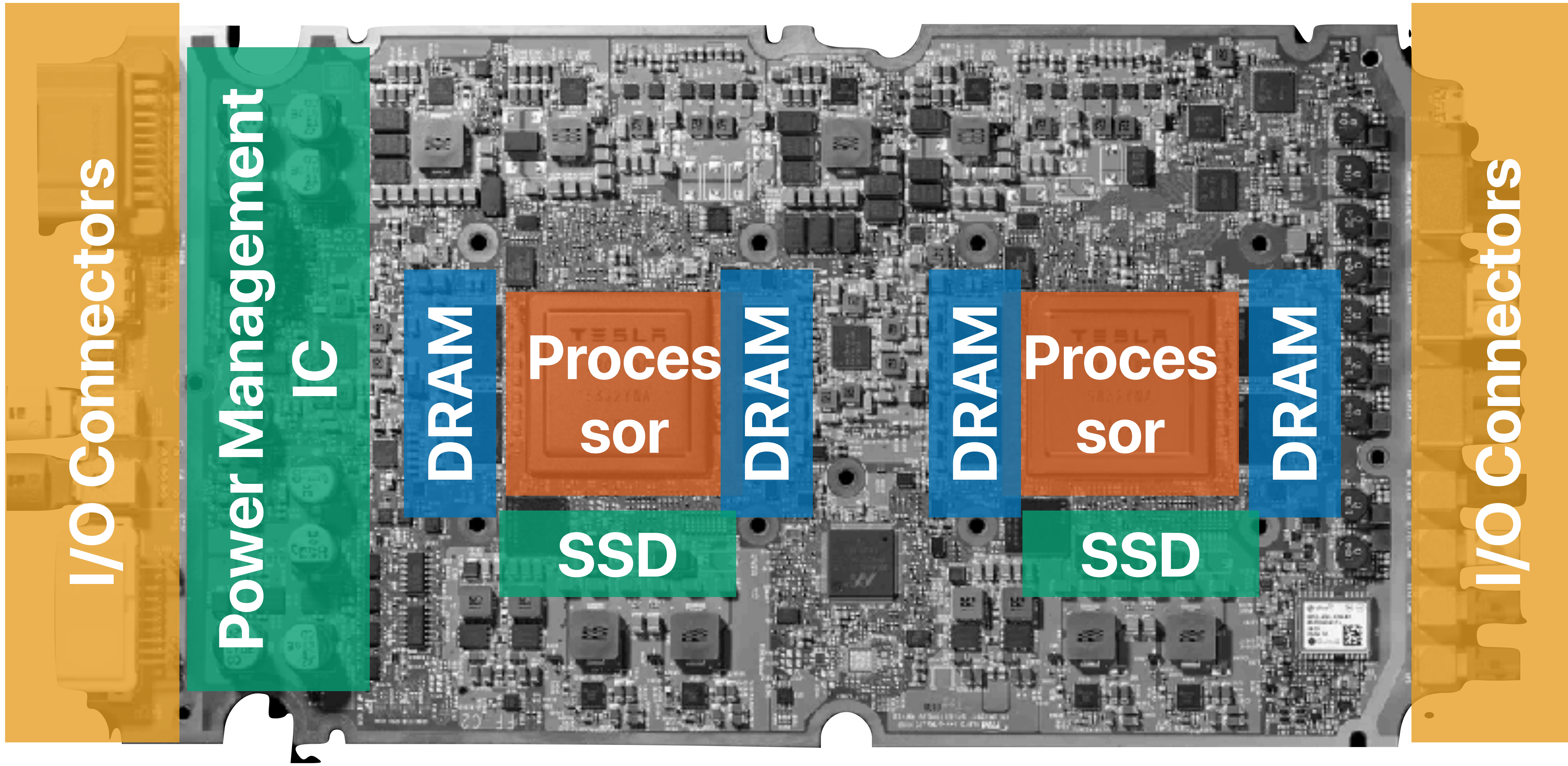




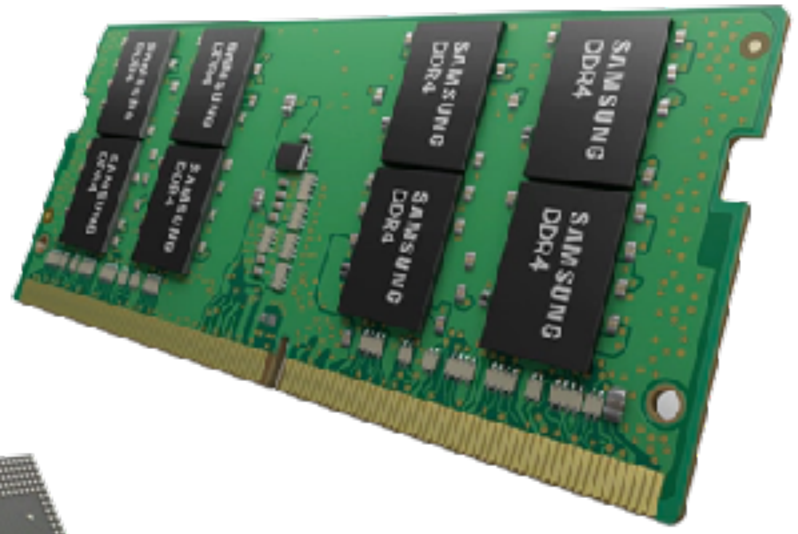
Nintendo Switch



Tesla Model 3

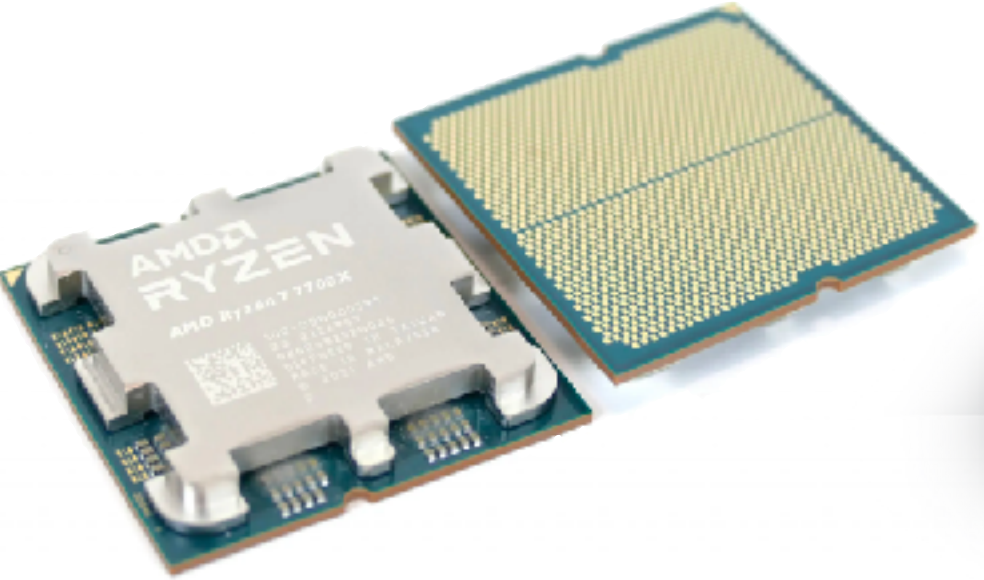


Processors and memory modules are everywhere!



Processors

Memory



Processors & Memory are every where!

The program = Instructions + Data

You may use “objdump” to see the content of a program!

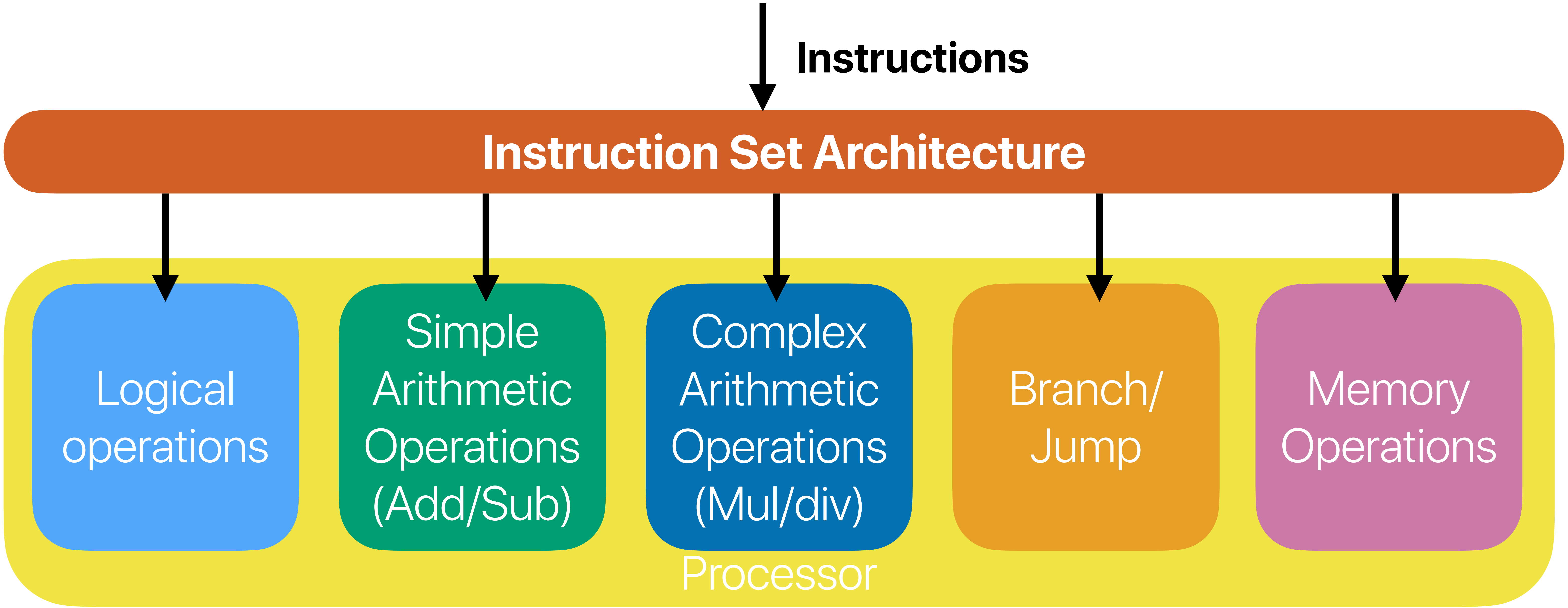
```
simple.o:     file format elf64-x86-64

Contents of section .text:
 0000 f30f1efa 554889e5 c745f800 000000c7  ....UH...E......
 0010 45fc0000 0000c745 f8000000 00eb1e8b  E......E........
 0020 45f84898 488d1485 00000000 488d0500  E.H.H.......H...
 0030 0000008b 04020145 fc8345f8 01837df8  .......E..E...}.
 0040 137edcb8 00000000 5dc3               .~......].
Contents of section .data:
 0000 01000000 02000000 03000000 04000000  ................
 0010 05000000 06000000 07000000 08000000  ................
 0020 09000000 0a000000 01000000 02000000  ................
 0030 03000000 04000000 05000000 06000000  ................
 0040 07000000 08000000 09000000 0a000000  ................
Contents of section .comment:
 0000 00474343 3a202855 62756e74 7520392e  .GCC: (Ubuntu 9.
 0010 342e302d 31756275 6e747531 7e32302e  4.0-1ubuntu1~20.
 0020 30342e31 2920392e 342e3000           04.1) 9.4.0.
Contents of section .note.gnu.property:
 0000 04000000 10000000 05000000 474e5500  ............GNU.
 0010 020000c0 04000000 03000000 00000000  ................
Contents of section .eh_frame:
 0000 14000000 00000000 017a5200 01781001  .........zR..x..
 0010 1b0c0708 90010000 1c000000 1c000000  ................
 0020 00000000 4a000000 00450e10 8602430d  ....J....E....C.
 0030 0602410c 07080000                    ..A.....
```

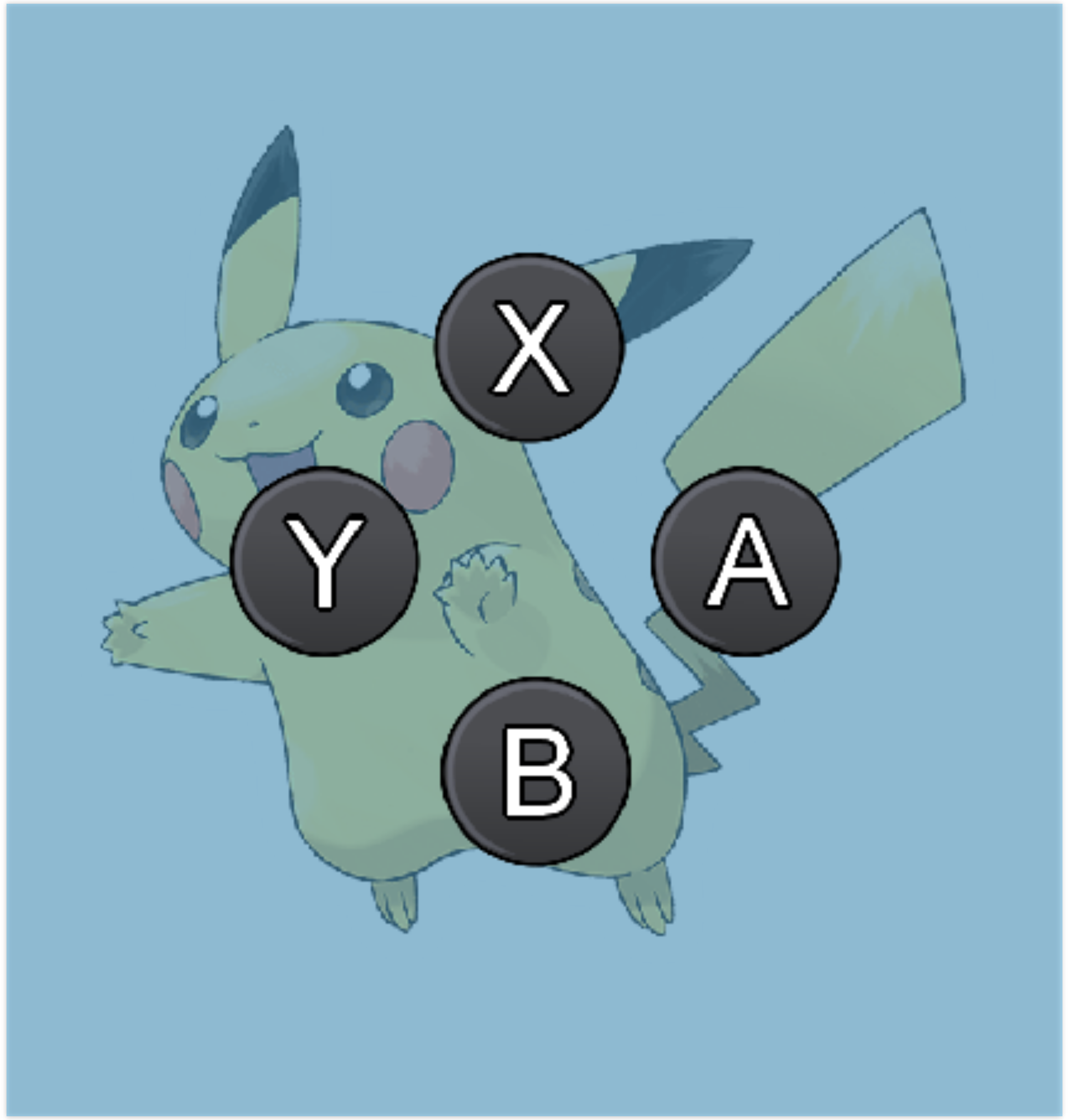
Instructions

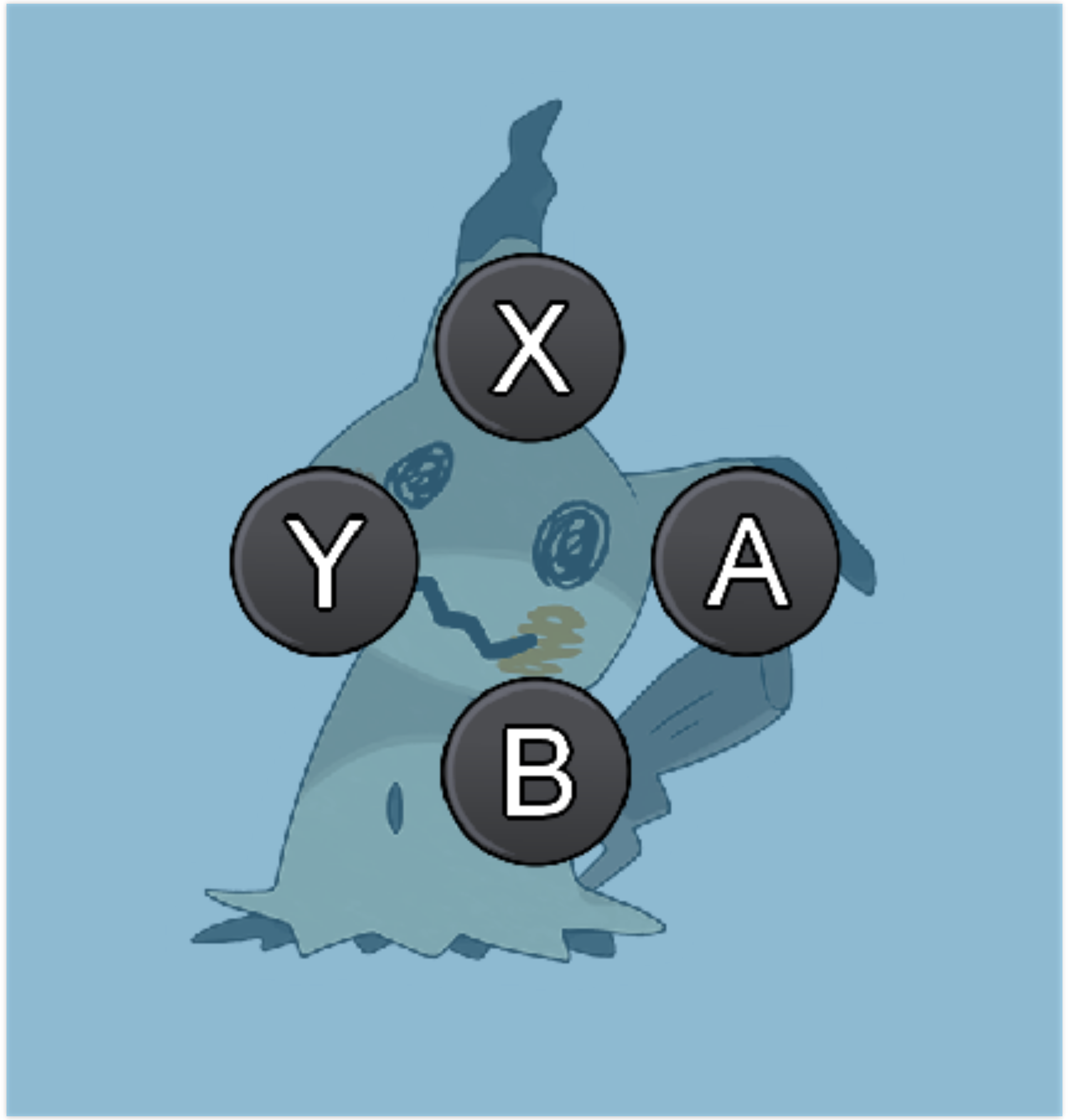
Data

Microprocessor — a collection of functional units



ISA — the “abstraction” of processor features





Most of time, I don't program at this level...

```
simple.o:     file format elf64-x86-64

Contents of section .text:
 0000 f30f1efa 554889e5 c745f800 000000c7  ....UH...E......
 0010 45fc0000 0000c745 f8000000 00eb1e8b  E......E........
 0020 45f84898 488d1485 00000000 488d0500  E.H.H.......H...
 0030 0000008b 04020145 fc8345f8 01837df8  .......E..E...}.
 0040 137edcb8 00000000 5dc3               .~......].
Contents of section .data:
 0000 01000000 02000000 03000000 04000000  ................
 0010 05000000 06000000 07000000 08000000  ................
 0020 09000000 0a000000 01000000 02000000  ................
 0030 03000000 04000000 05000000 06000000  ................
 0040 07000000 08000000 09000000 0a000000  ................
Contents of section .comment:
 0000 00474343 3a202855 62756e74 7520392e  .GCC: (Ubuntu 9.
 0010 342e302d 31756275 6e747531 7e32302e  4.0-1ubuntu1~20.
 0020 30342e31 2920392e 342e3000           04.1) 9.4.0.
Contents of section .note.gnu.property:
 0000 04000000 10000000 05000000 474e5500  ............GNU.
 0010 020000c0 04000000 03000000 00000000  ................
Contents of section .eh_frame:
 0000 14000000 00000000 017a5200 01781001  .........zR..x..
 0010 1b0c0708 90010000 1c000000 1c000000  ................
 0020 00000000 4a000000 00450e10 8602430d  ....J....E....C.
 0030 0602410c 07080000                    ..A.....
```

Start with this simple program in C

```
int A[] =
{1,2,3,4,5,6,7,8,9,10,1,2,3,4
,5,6,7,8,9,10};
```

Compiler

```
Contents of section .data:
 0000 01000000 02000000 03000000 04000000
 0010 05000000 06000000 07000000 08000000
 0020 09000000 0a000000 01000000 02000000
 0030 03000000 04000000 05000000 06000000
 0040 07000000 08000000 09000000 0a000000
```

Data

control flow operations

logical operations

```
int main()
{
    int i=0, sum=0;
    for(i = 0; i < 20; i++)
    {
        sum += A[i];
    }
    return 0;
}
```

memory access

arithmetic operations

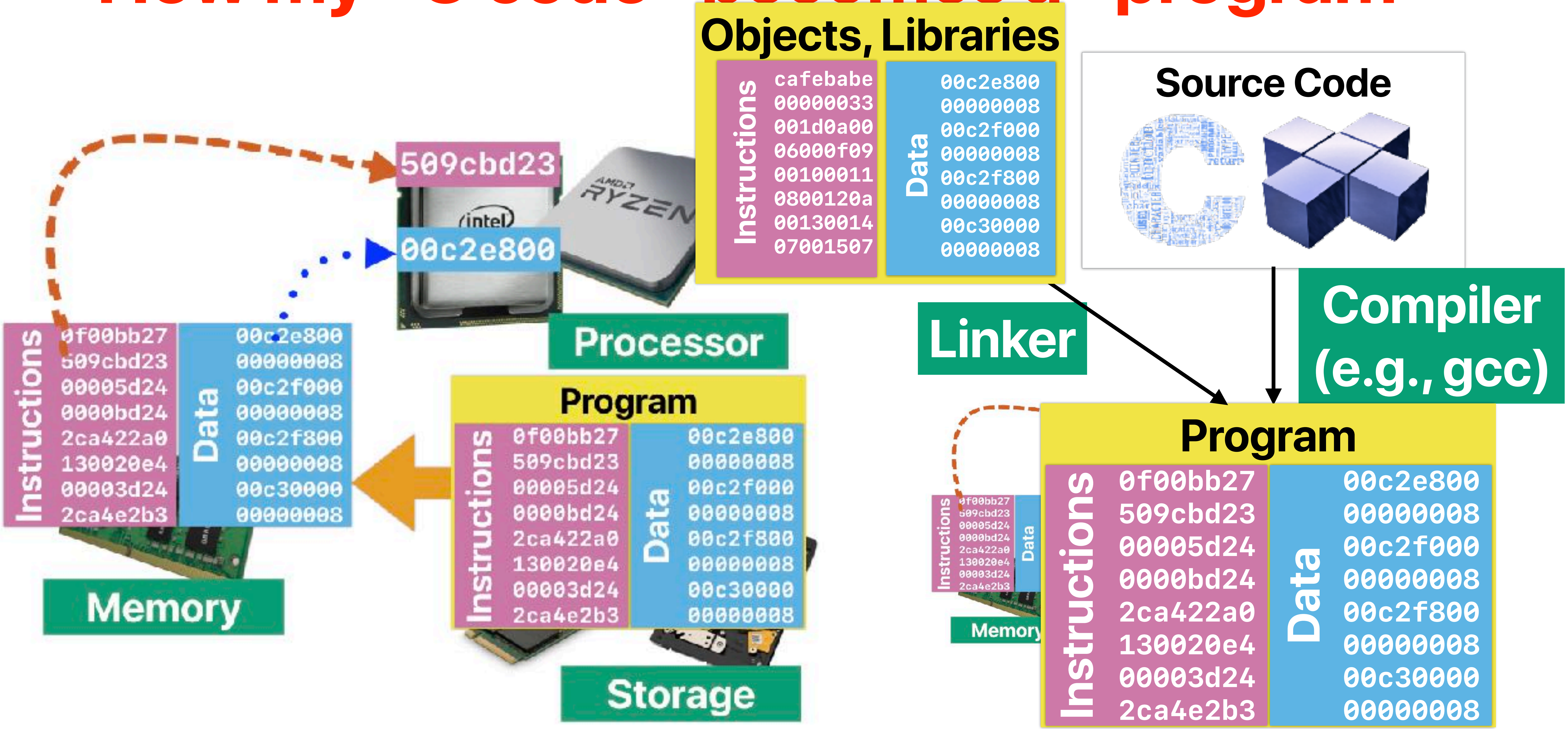
```
main:
.LFB0:
        endbr64
        pushq   %rbp
        movq    %rsp, %rbp
        movl    $0, -8(%rbp)
        movl    $0, -4(%rbp)
        movl    $0, -8(%rbp)
        jmp     .L2
.L3:
        movl    -8(%rbp), %eax
        cltq
        leaq    0(,%rax,4), %rdx
        leaq    A(%rip), %rax
        movl    (%rdx,%rax),
%eax
        addl    %eax, -4(%rbp)
        addl    $1, -8(%rbp)
.L2:
        cmpl    $19, -8(%rbp)
        jle     .L3
        movl    $0, %eax
        popq    %rbp
        ret
```

Compiler

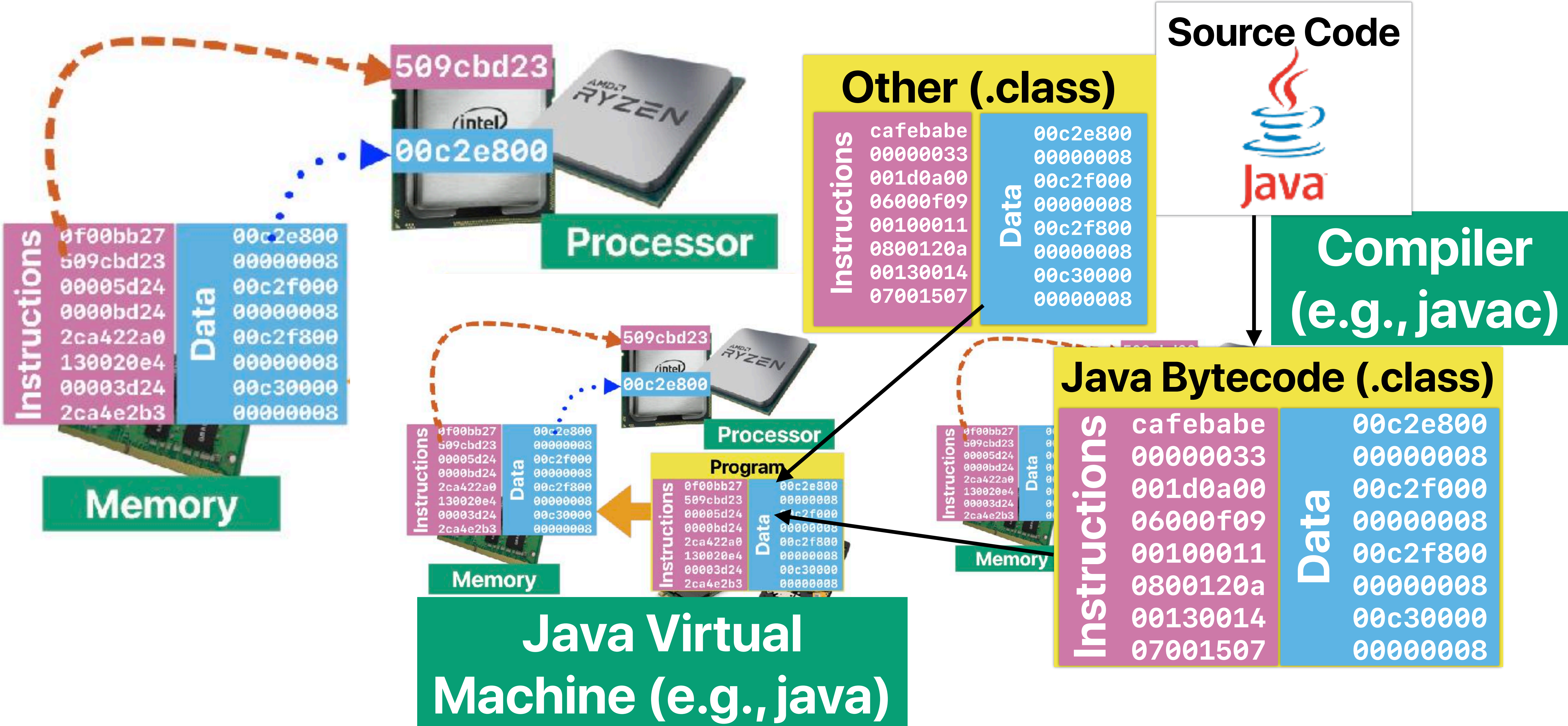
```
Contents of section .text:
 0000 f30f1efa 554889e5 c745f800 000000c7
 0010 45fc0000 0000c745 f8000000 00eb1e8b
 0020 45f84898 488d1485 00000000 488d0500
 0030 0000008b 04020145 fc8345f8 01837df8
 0040 137edcb8 00000000 5dc3
```

Instructions

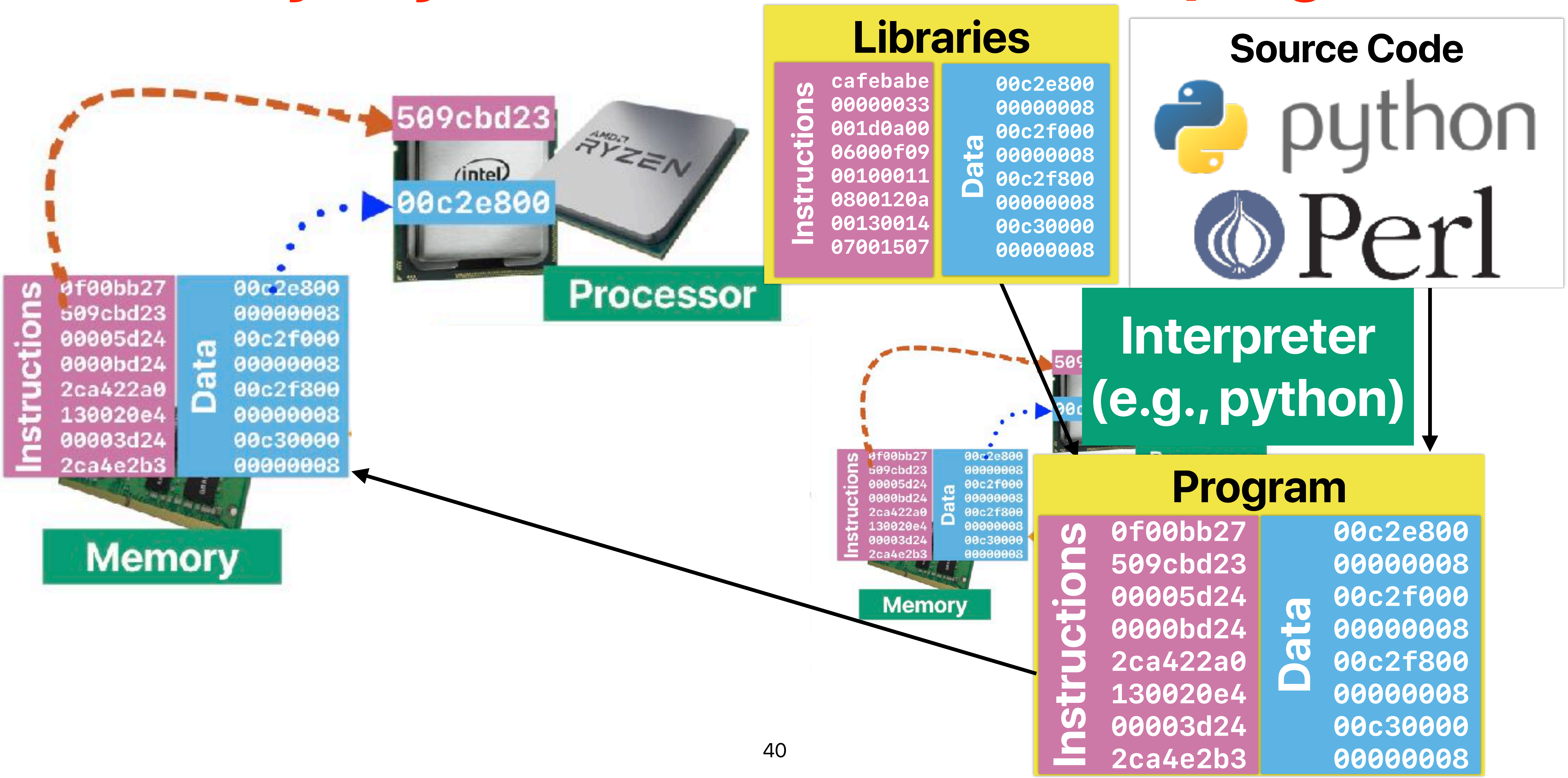
How my "C code" becomes a "program"



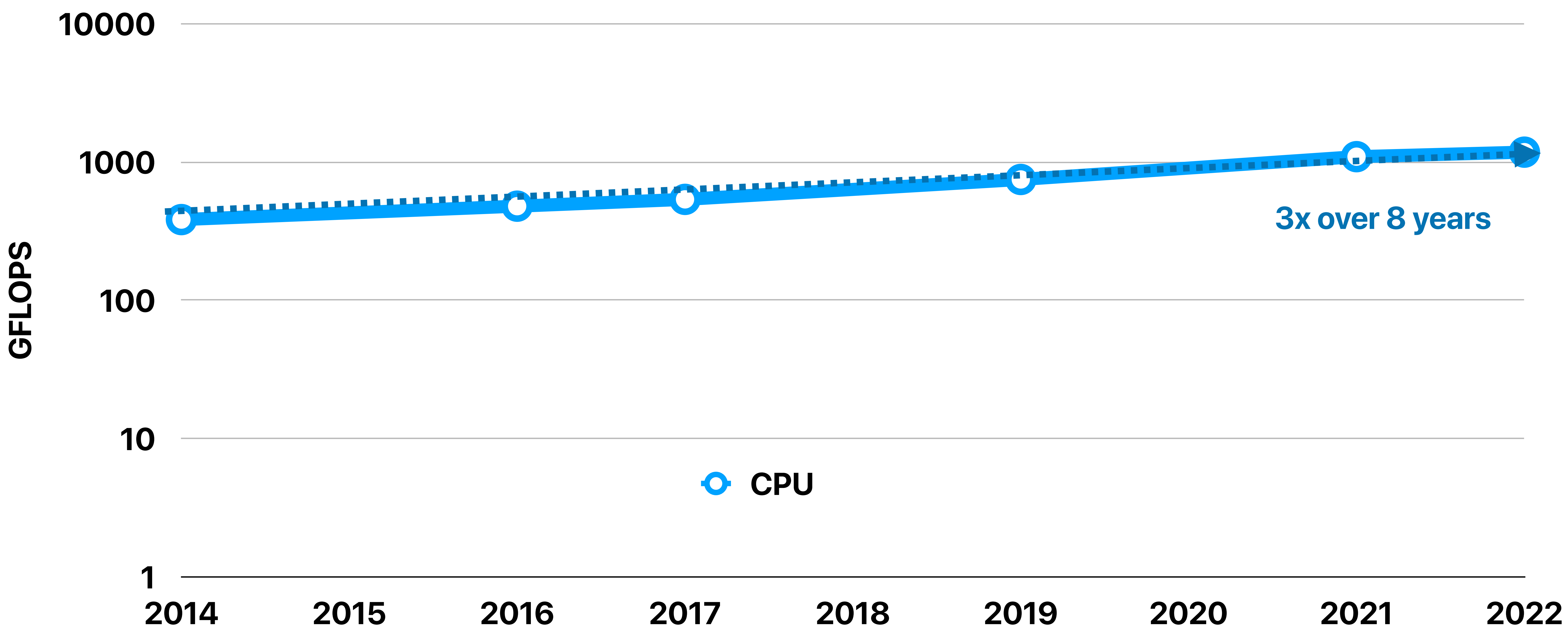
How my “Java code” becomes a “program”



How my "Python code" becomes a "program"



Processor performance does not improve anymore



Challenges of von Neumann Architecture

Moore's Law[1]

- The number of transistors we can build in a fixed area of silicon doubles every 12 ~ 24 months.

Moore's Law[1]

Present and future

By integrated electronics, I mean ... technologies which are referred to ... tronics today as well as any additi... result in electronics functions suppli... as irreducible units. These technolo... i...

to miniaturize electronics equipment ... creasingly complex electronic functi... space with minimum weight. Sever... evolved, including microassembly ... individual components, thin-film s... semiconductor integrated circuits.

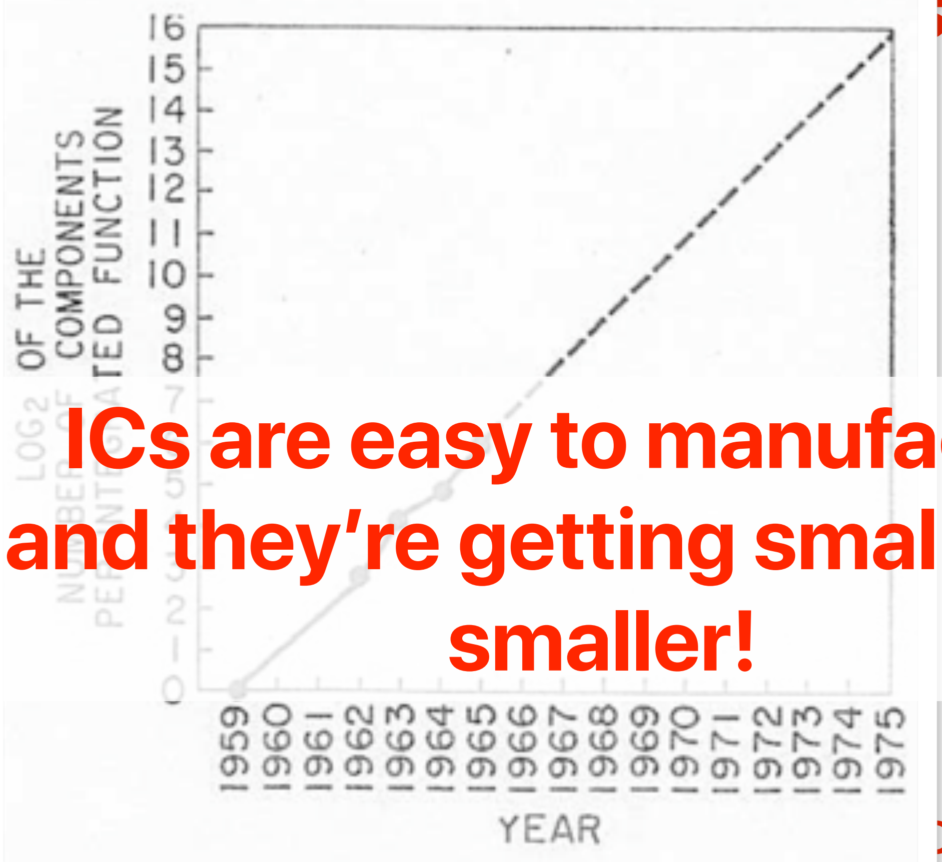
ICs are increasingly p...

The establishment

Integrated electronics is established ... or nev... and v... vable ... llo, fo... he reli... that ... ilure as the...

Increasing the yield

There is no fundamental obstacle to achieving device yields of 100%. At present, packaging costs so far exceed the cost of the semiconductor structure itself that there is no incentive to improve yields, but they can be raised as high as is economically justified. No barrier exists comparable to the thermodynamic equilibrium considerations



ICs are easy to manufacture and they're getting smaller and smaller!

Reliability coun...

In almost e... demonstrated h... level of production—low compared to that of discrete components—it offers reduced systems cost, and in many systems improved performance has been realized.

ICs are more reliable

Linear circuitry

Integration will not change linear systems as radically as digital systems. Still, a considerable degree of integration will be achieved with linear circuits. The lack of large-value capacitors and ... in integrated electronics in the linear area.

ICs are widely applicable

Heat problem

Will it be possible to remove the heat generated by tens of thousands of components in a single silicon chip?

Heat is a solvable issue

...stablish...

Moore's Law is the most impo... historic...

Two-mil squares

With the dimensional tolerances already being employed in integrated circuits, isolated high-performance transistors can be built on centers two thousandths of an inch apart. Such a two-mil square can also contain several kilohms of resistance o...

ICs are small

Day of reckoning

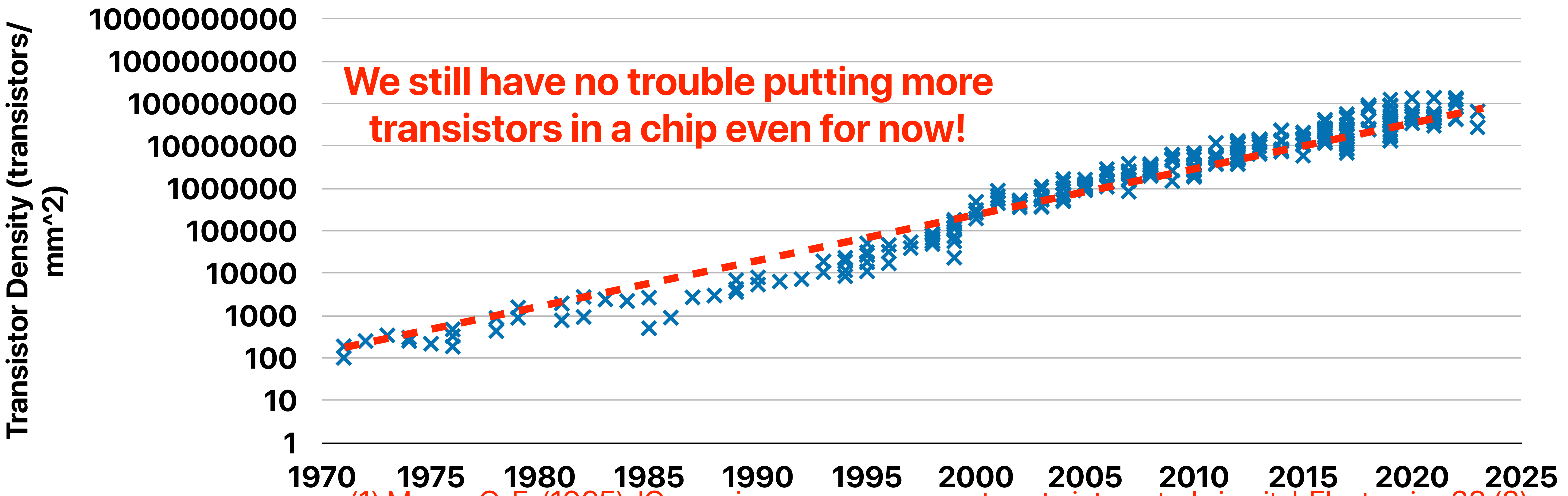
Clearly, we will be able to build such component-crammed equipment. Next, we ask under what circumstances we should do it. The total cost of making a particular system function must be minimized. To do so, we could amortize the engineering over several identical items, or evolve flexible techniques for the engineering of large functions so that no disproportionate expense need be borne by a particular array. Perhaps newly devised design automation procedures could translate from ... any special engineering.

Designing ICs can be easy

(1) Mo... ...omponents onto integrated circuits', Electronics 38 (8) .

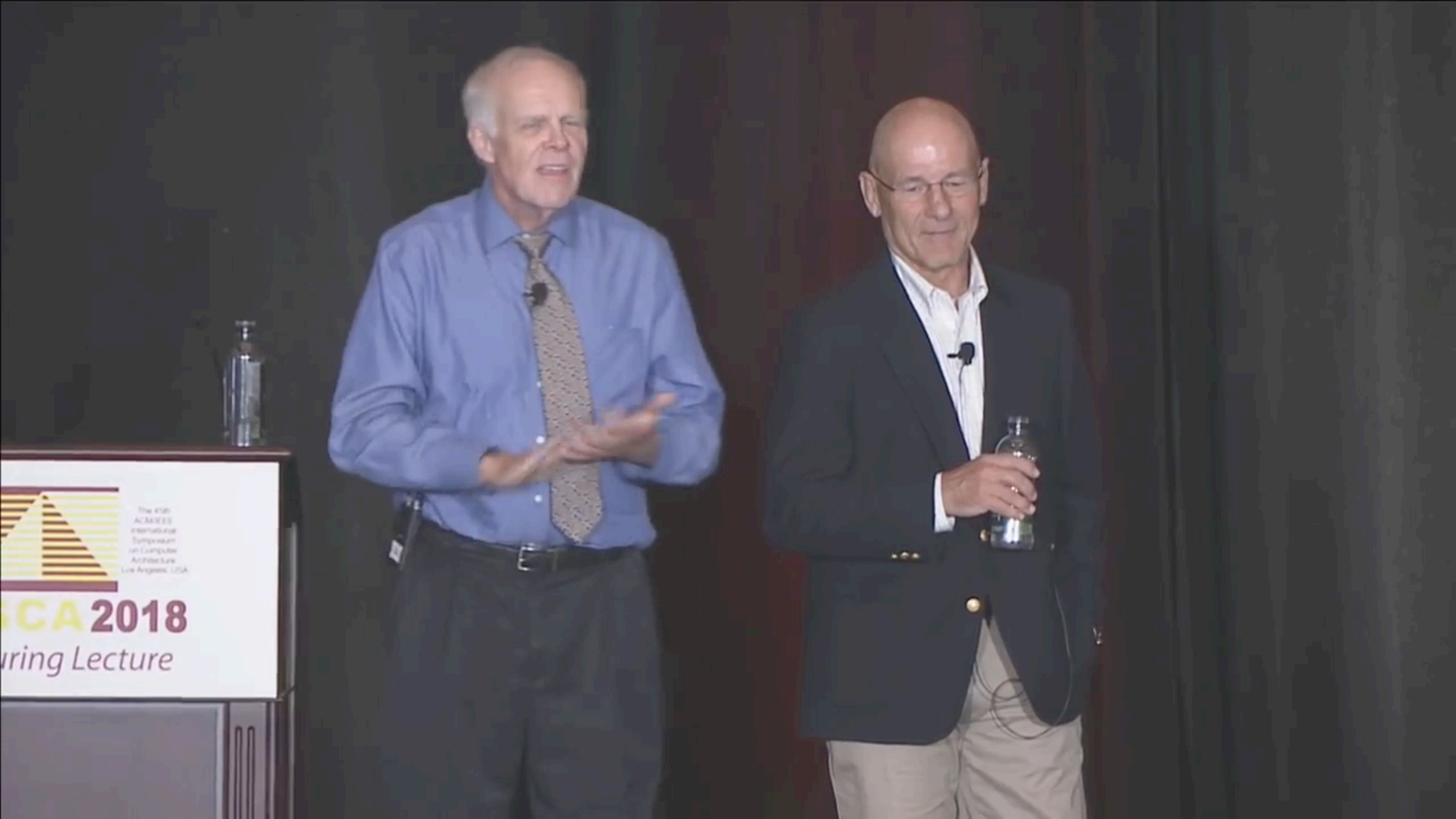
Moore's Law[1]

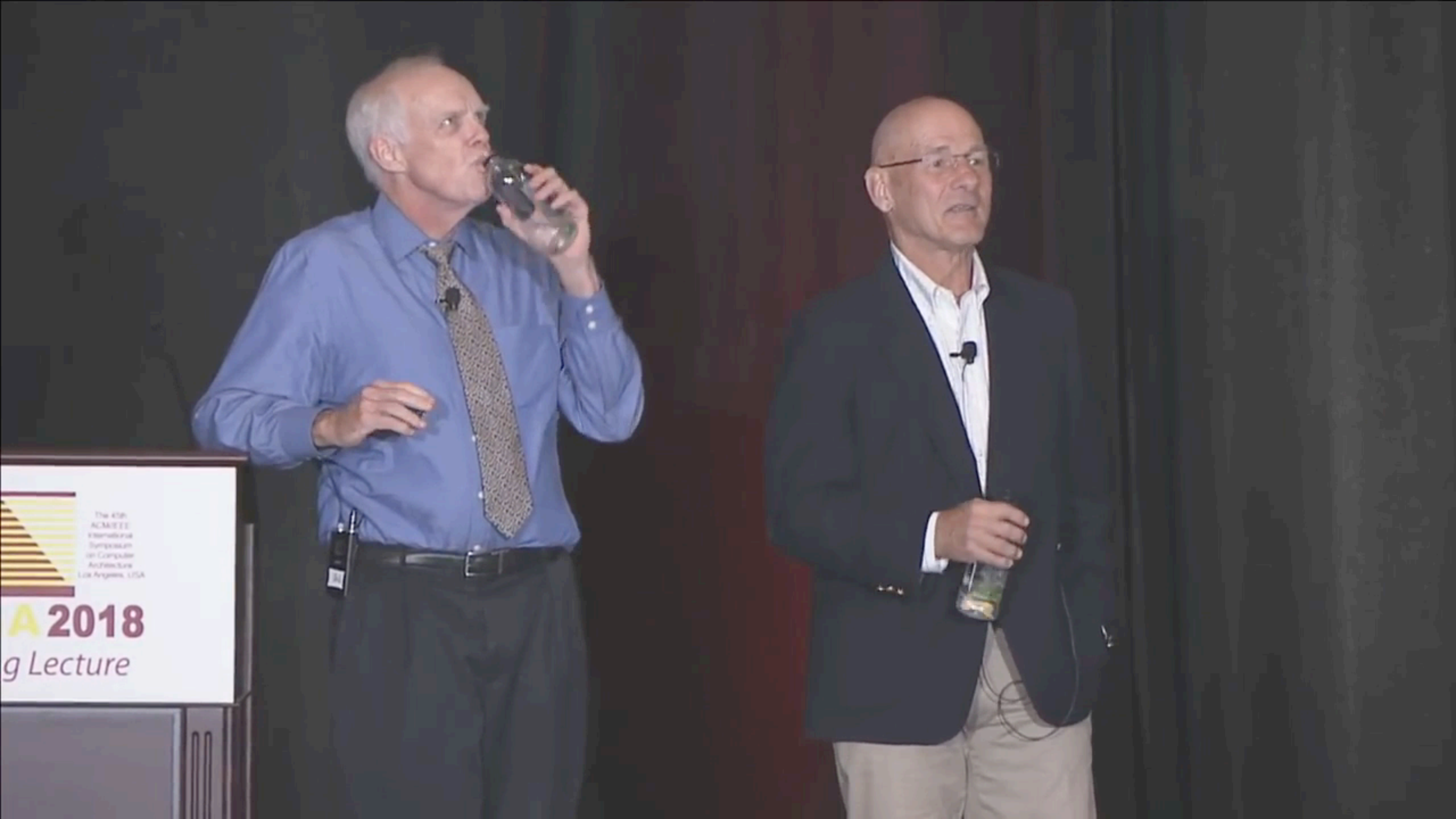
- The number of transistors we can build in a fixed area of silicon doubles every 12 ~ 24 months.
- Moore's Law "was" the most important driver for historic CPU performance gains



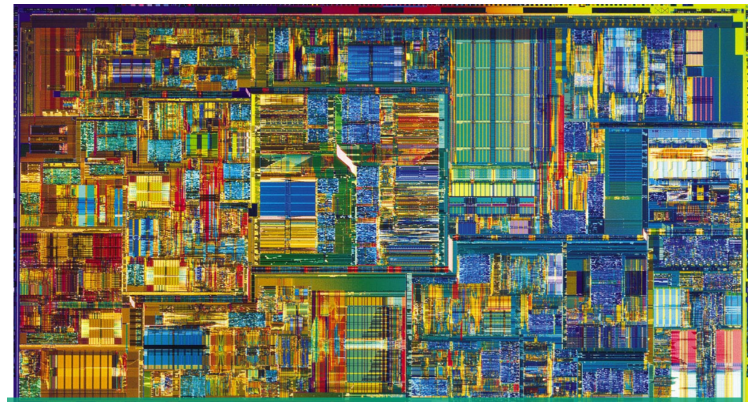
(1) Moore, G. E. (1965), 'Cramming more components onto integrated circuits', Electronics 38 (8) .

Plot based on https://en.wikipedia.org/wiki/Transistor_count by Hung-Wei Tseng

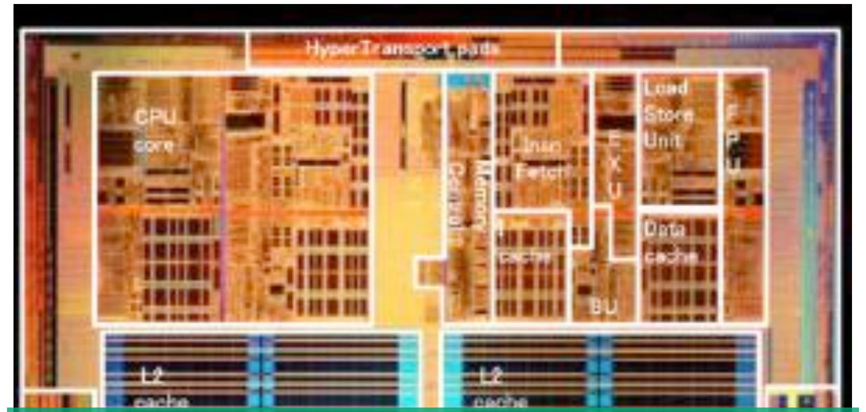

SCA2018
uring Lecture


The 45th ACM/IEEE International Symposium on Computer Architecture Los Angeles, USA
A 2018
g Lecture

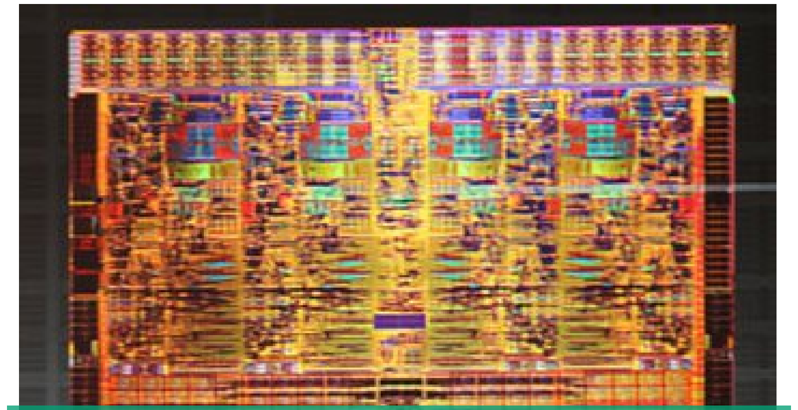
Multicore processors



Intel P4
(2000)
1 core

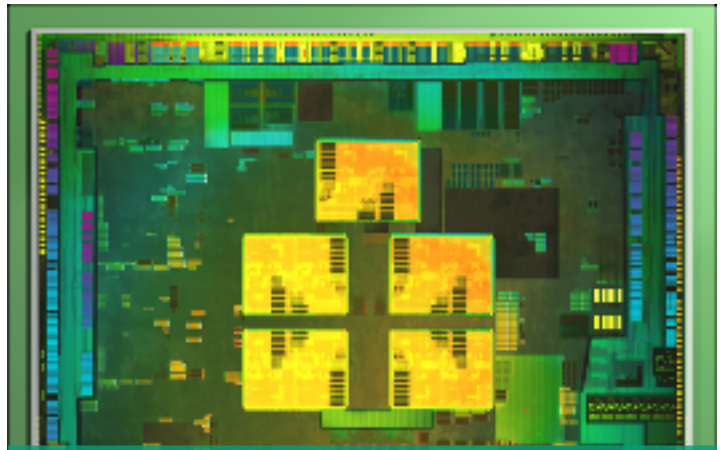


AMD Athlon 64 X2
(2005)
2 cores

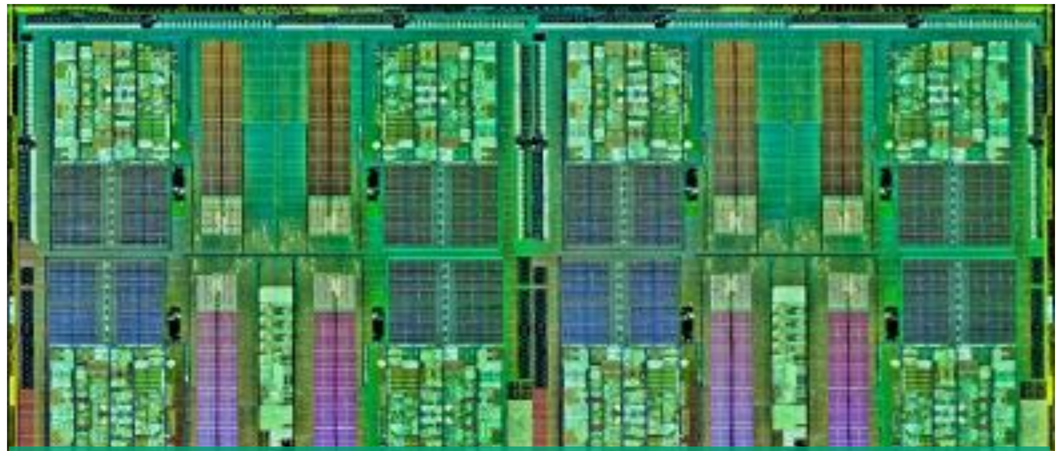


Intel Nahalem
(2010)
4 cores

SPARC T3
(2010)
16 cores

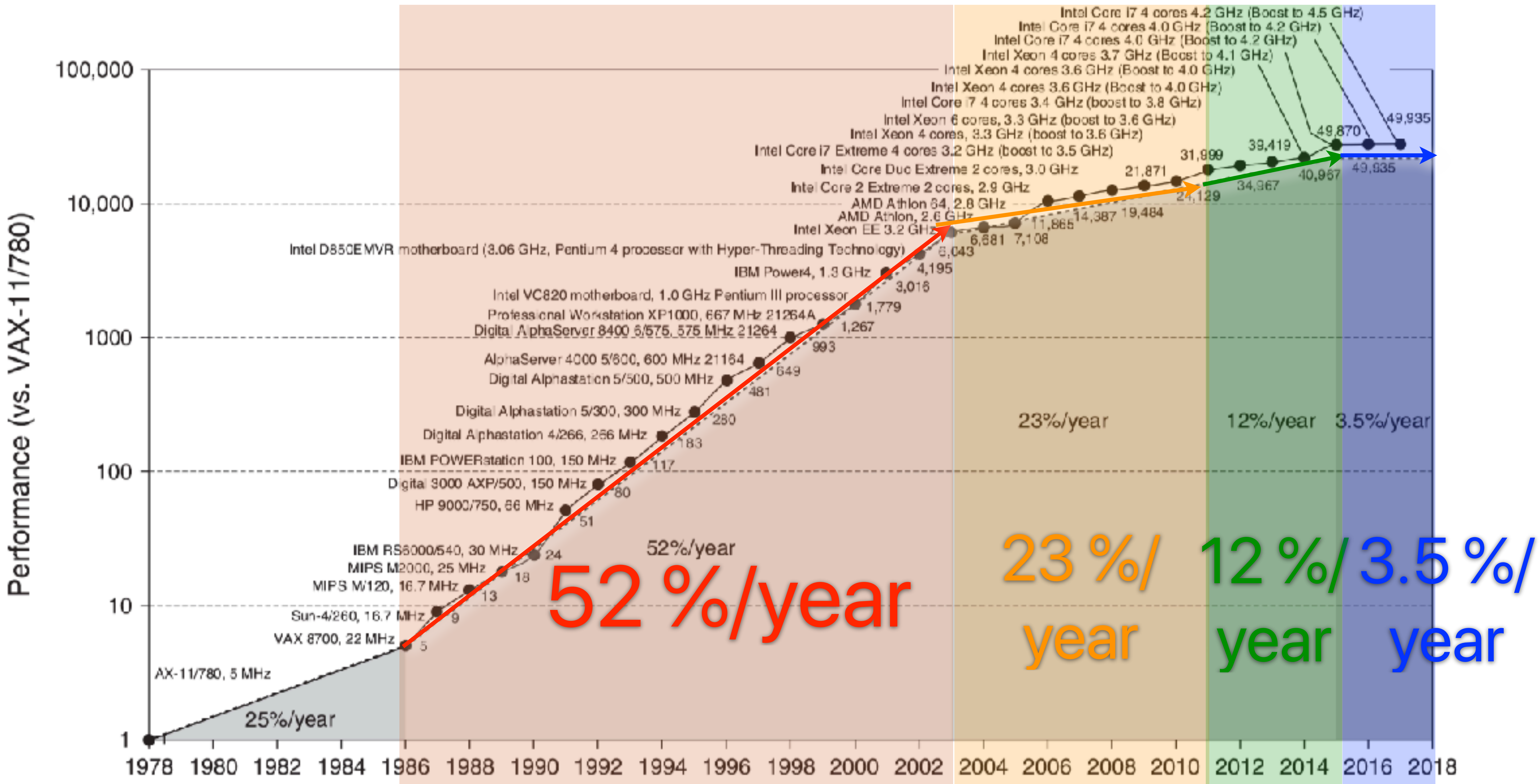


Nvidia Tegra 3
(2011)
5 cores

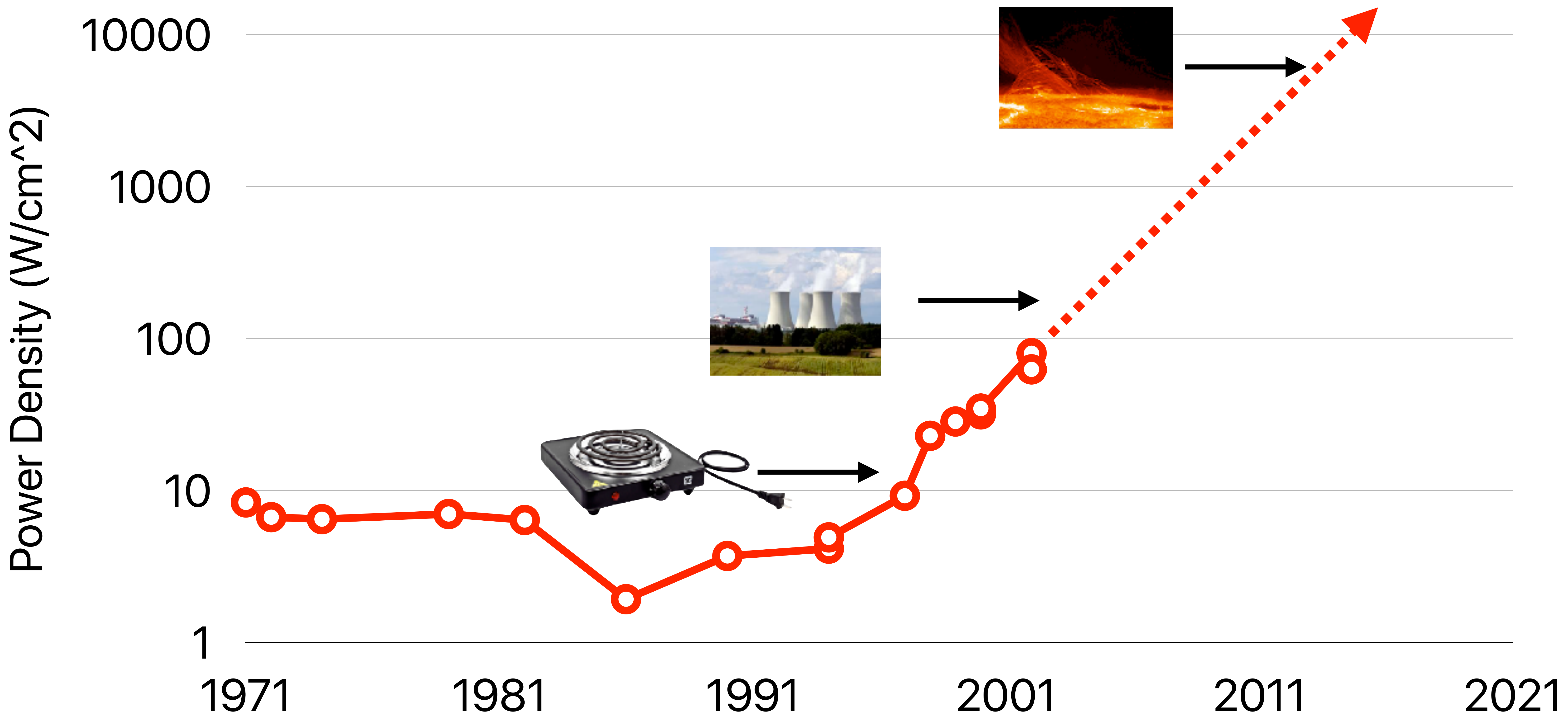


AMD Zambezi
(2011)
16 cores

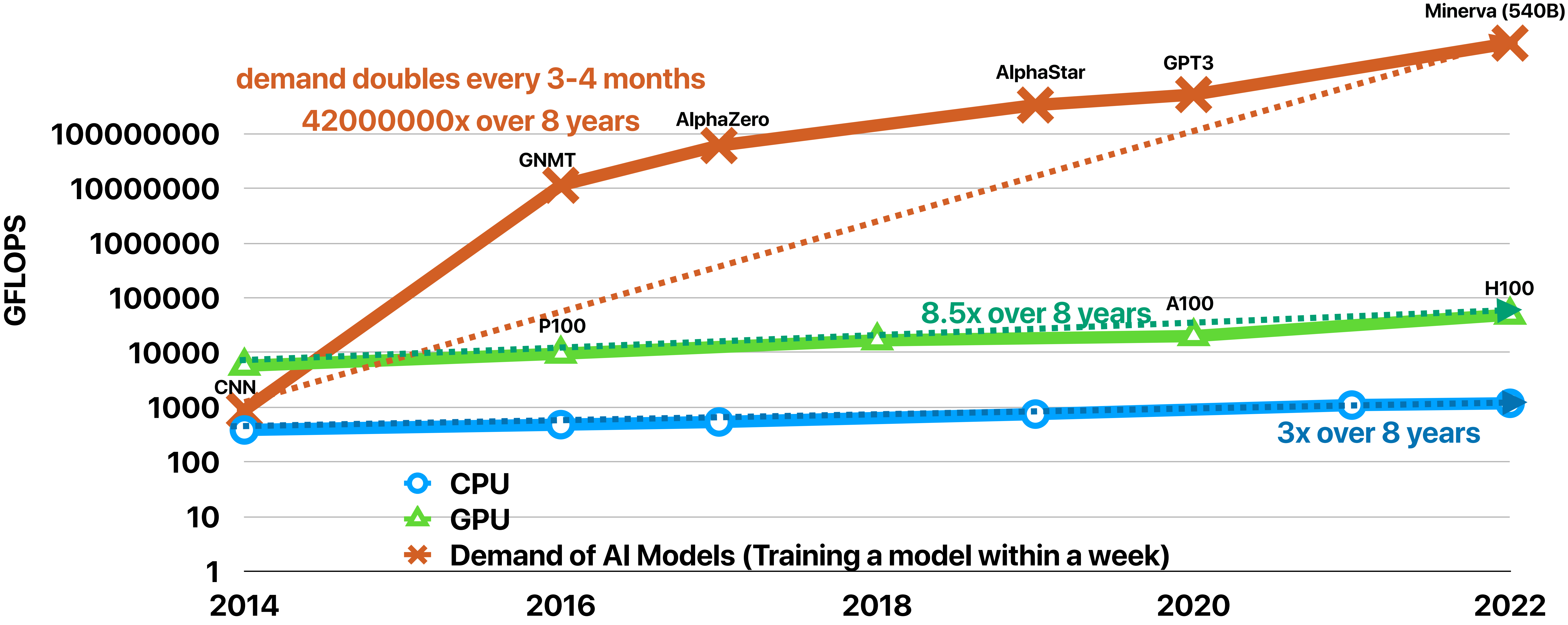
CPU performance does not scale with Moore's Law



Power Density of Processors

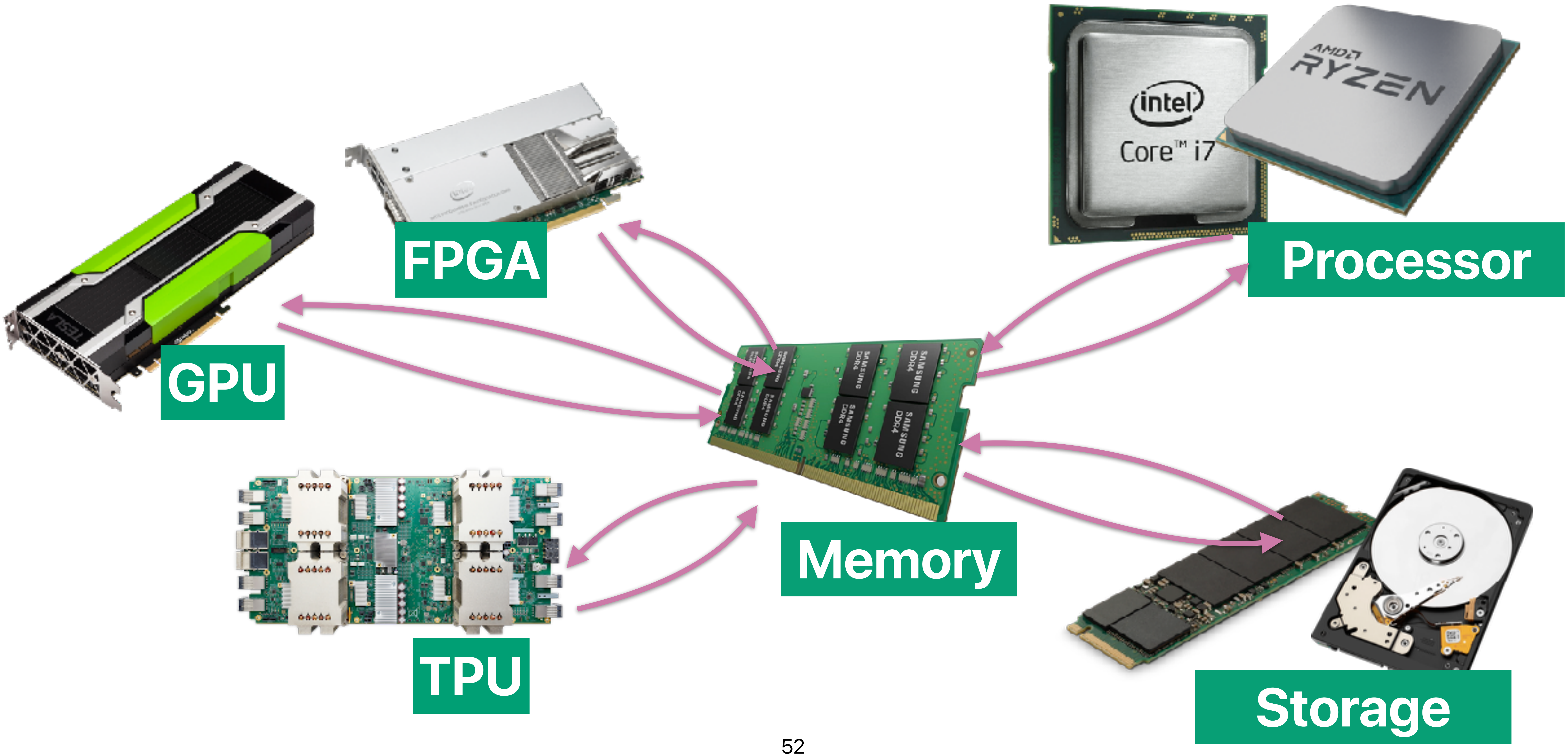


Mis-matching AI/ML demand and general-purpose processing

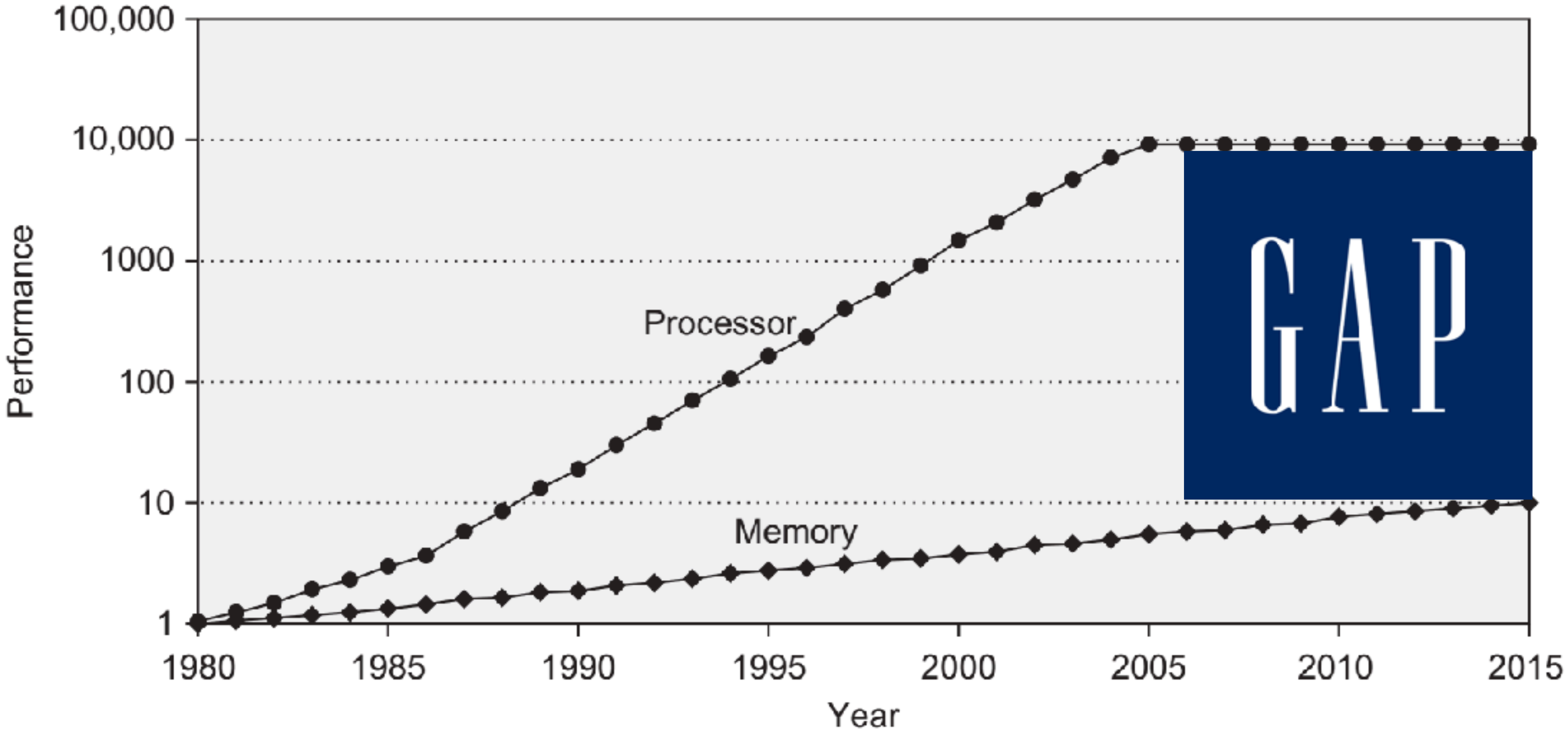


https://ourworldindata.org/grapher/artificial-intelligence-training-computation

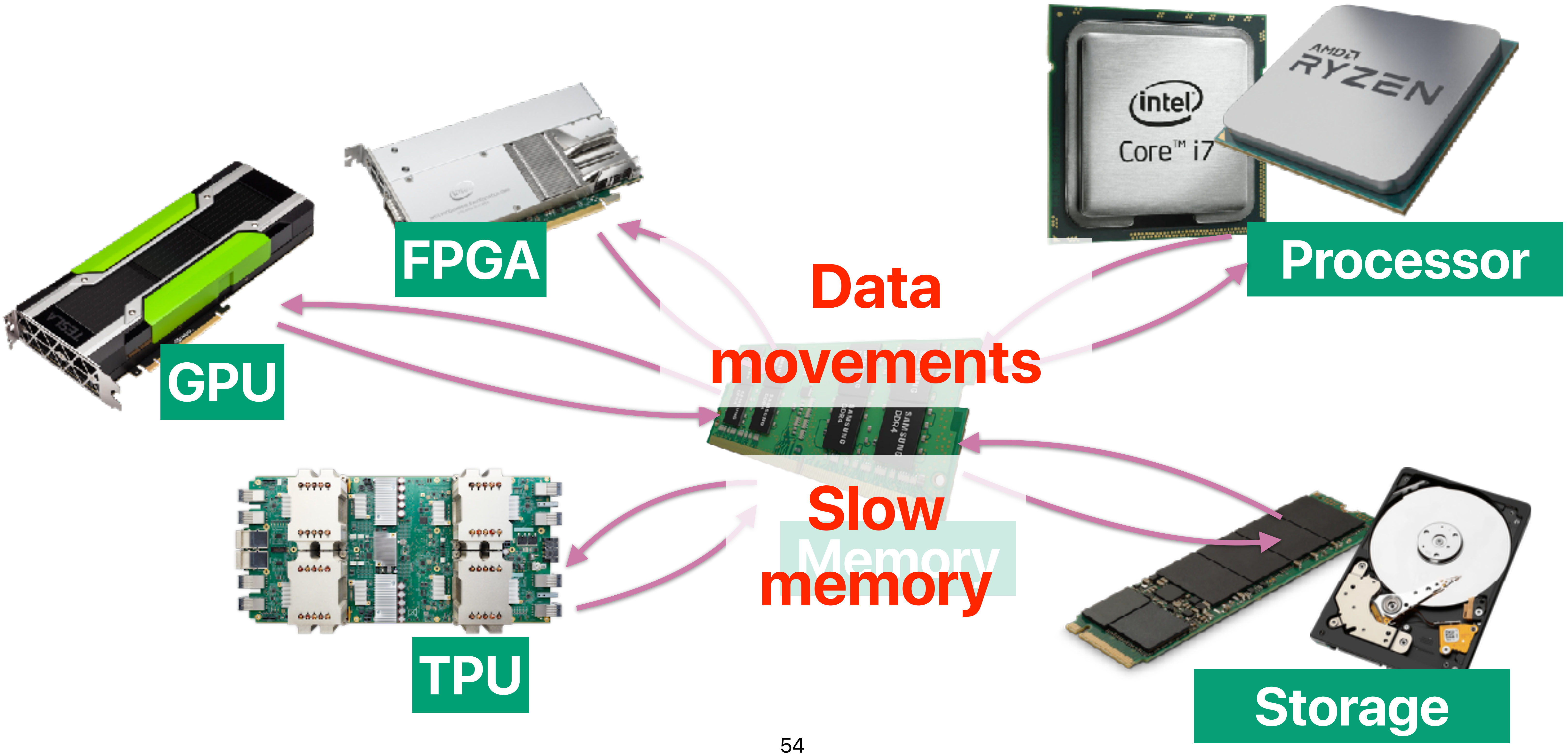
Heterogeneous Computer Architecture



Performance gap between Processor/Memory



Heterogeneous Computer Architecture



What’s going to be in the class?

Heterogeneous Computer Architecture

Performance

- Performance measurement
- What affects performance
- Amdahl's Law
- Metrics

Memory

- Memory hierarchy
- Hardware optimizations
- Software optimizations

Processor

- Pipelining
- OoO Execution
- Branch predictions
- Software optimizations

Parallelism

- Parallel hardware
- Thread-level
- Data-level
- Accelerators
- Software optimizations

Tentative Schedule

Topic	Reading	Reading	Slides (Preview)	Slides (Release)	Due
08/07/2023	Introduction: the Big Picture of Computers	1.1-1.5, 2.1 – 2.5, 2.12, 2.14, 2.17, 2.18, 2.19, 2.20, 2.21			
08/08/2023	Performance: What affects performance?	1.6, 1.8 & 1.11			-_Reading quiz for 1.6, 1.8 and 1.10
08/09/2023	Performance (II)				
08/10/2023	Performance (III)				-_Assignment #1 due 8/11 midnight
08/14/2023	Memory Hierarchy	5.1 – 5.3			-_Reading quiz for 5.1-5.3
08/15/2023	Memory Hierarchy (II)				
08/16/2023	Memory Hierarchy (III)	5.4, 5.8			-_Reading quiz for 5.4 and 5.7-5.8
08/17/2023	Memory Hierarchy (IV)	5.7			-_Assignment #2 due 8/15 midnight
08/21/2023	Midterm				
08/22/2023	Virtual Memory				
08/23/2023	Pipeline Processors	4.1-4.3, 4.6			-_Reading quiz for 4.1-4.3, 4.6 and 4.9
08/24/2023	Pipelined processors (II)	4.9			-_Assignment #3 ue 8/25 midnight
08/28/2023	Pipelined processors (III)	4.8			-_Reading quiz for 4.8 and 4.11
08/29/2023	Pipelined processors (IV)	4.11			
08/30/2023	Parallelism (I): ILP				-_Reading quiz for 6.1-6.7
08/31/2023	Parallelism (II): TLP				-_Assignment #4 due 9/1 midnight
09/04/2023	Parallelism (III): CMP				
09/05/2023	Parallelism (IV): SIMD and DSA	6[illegible]			
09/06/2023	The Golden Age of Computer Architecture				
09/07/2023	Final Review				Assignment #5 due 9/7 midnight
09/08/2	Final Exam (5p-6p)				

Performance

Memory

Processor

Parallelism

You need to complete the reading of assigned reading materials

Subject to change

Check due dates here

Learning eXperience

We're back in-person (still supporting online)

fortune.com/2023/03/07/google-sundar-pichai-staff-office-ghost-towns-microsoft-cloud/

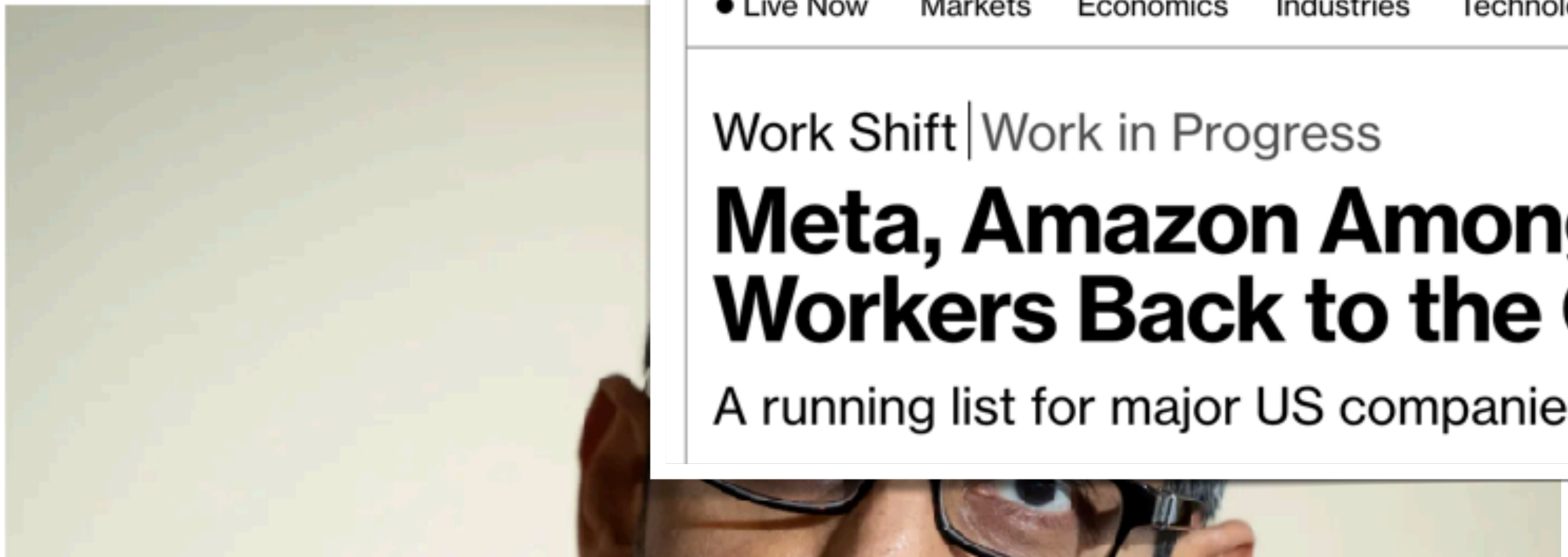
NE RANKINGS MAGAZINE NEWSLETTERS PODCASTS MORE SEARCH SIGN IN

TECH · GOOGLE

Google boss Sundar Pichai says staff are bemoaning office ghost towns—'It's just not a nice experience'

BY CHRISTIAAN HETZNER

March 7, 2023 at 4:56 AM PST



Bloomberg US Edition Sign In

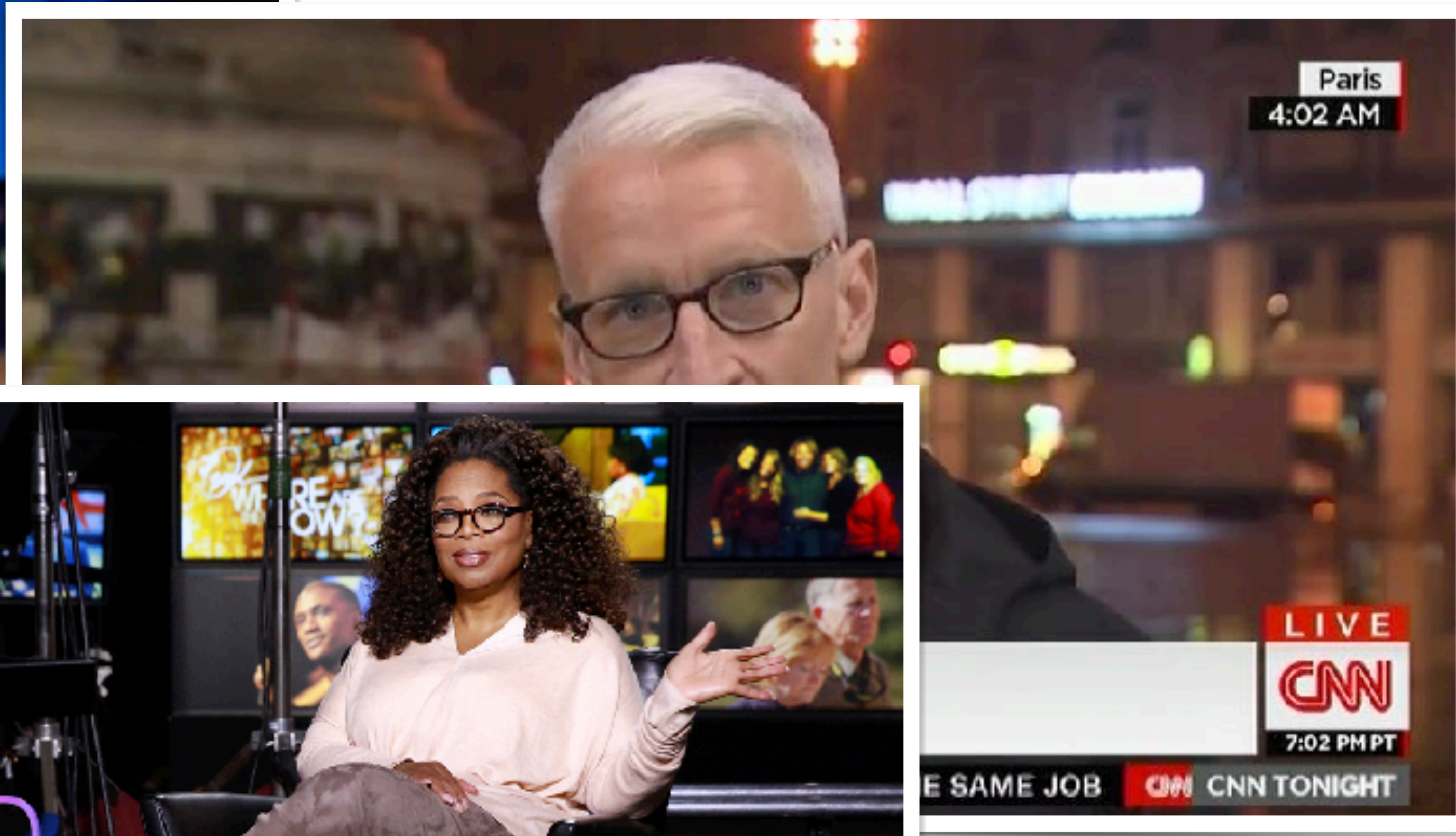
Live Now Markets Economics Industries Technology Politics Wealth Pursuits Opinion Businessweek

Work Shift | Work in Progress

Meta, Amazon Among Firms Calling Workers Back to the Office in 2023

A running list for major US companies' return-to-office mandates in 2023

Most lectures today …



I expect the lecture to be...

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 your clicker to express your opinion
  - Group discussion — **discuss** with your surroundings and use your clicker to express your group's opinion
  - Whole-classroom **discussion** — we would like to hear from you

Read **Think** **Discuss**

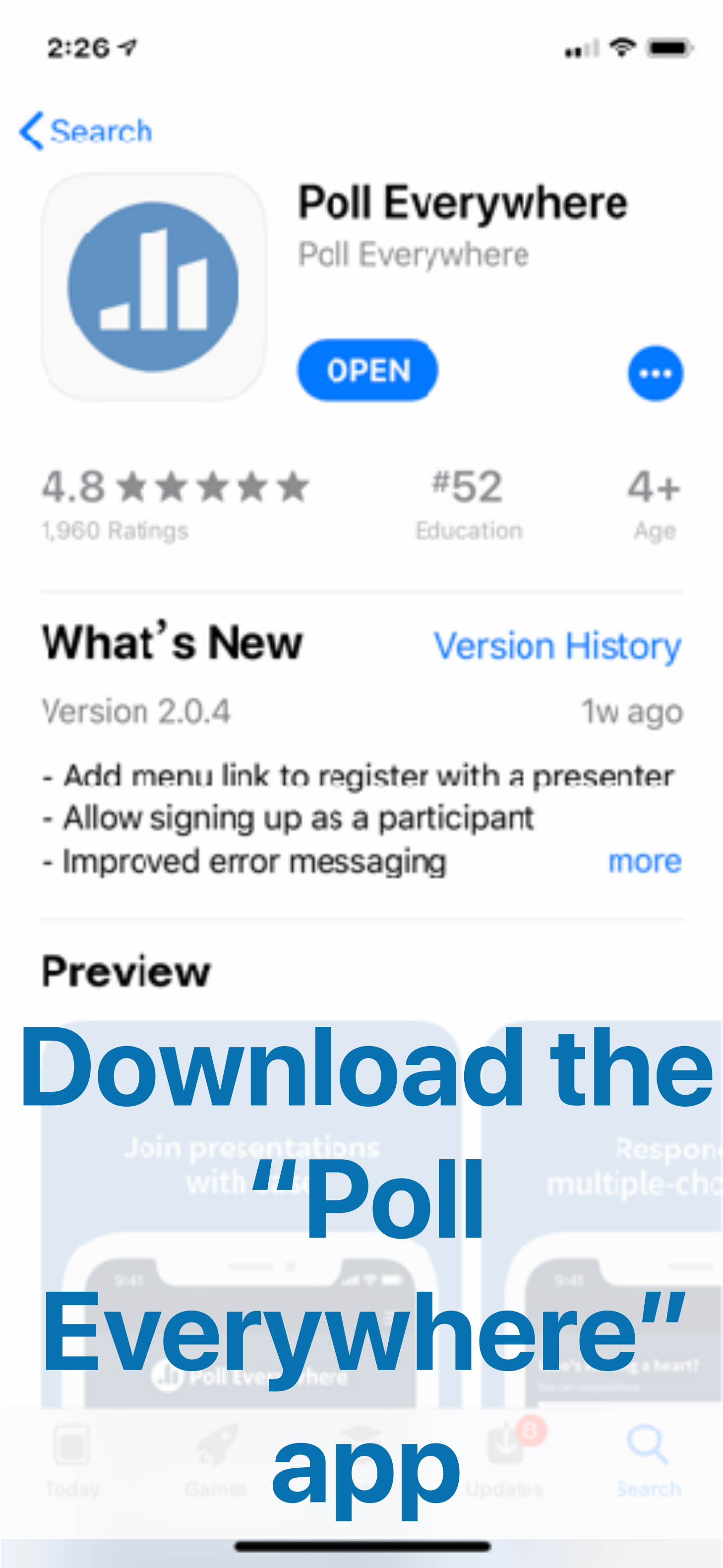
Before lectures: reading quizzes

- We need to prepare you for peer instruction activities and discussions!
- Reading assignments from
  - Computer Organization and Design MIPS Edition: The Hardware/Software Interface 6th Edition
    by John Hennessy and David Patterson
  - Or other assigned materials
- Reading quizzes:
  - On Canvas
  - Due before the lecture, usually twice a week. Check the schedule on our webpage
  - You will have two chances. We take the average
  - No time limitation until the deadline
  - No make up reading quizzes — we will drop probably your lowest two at least

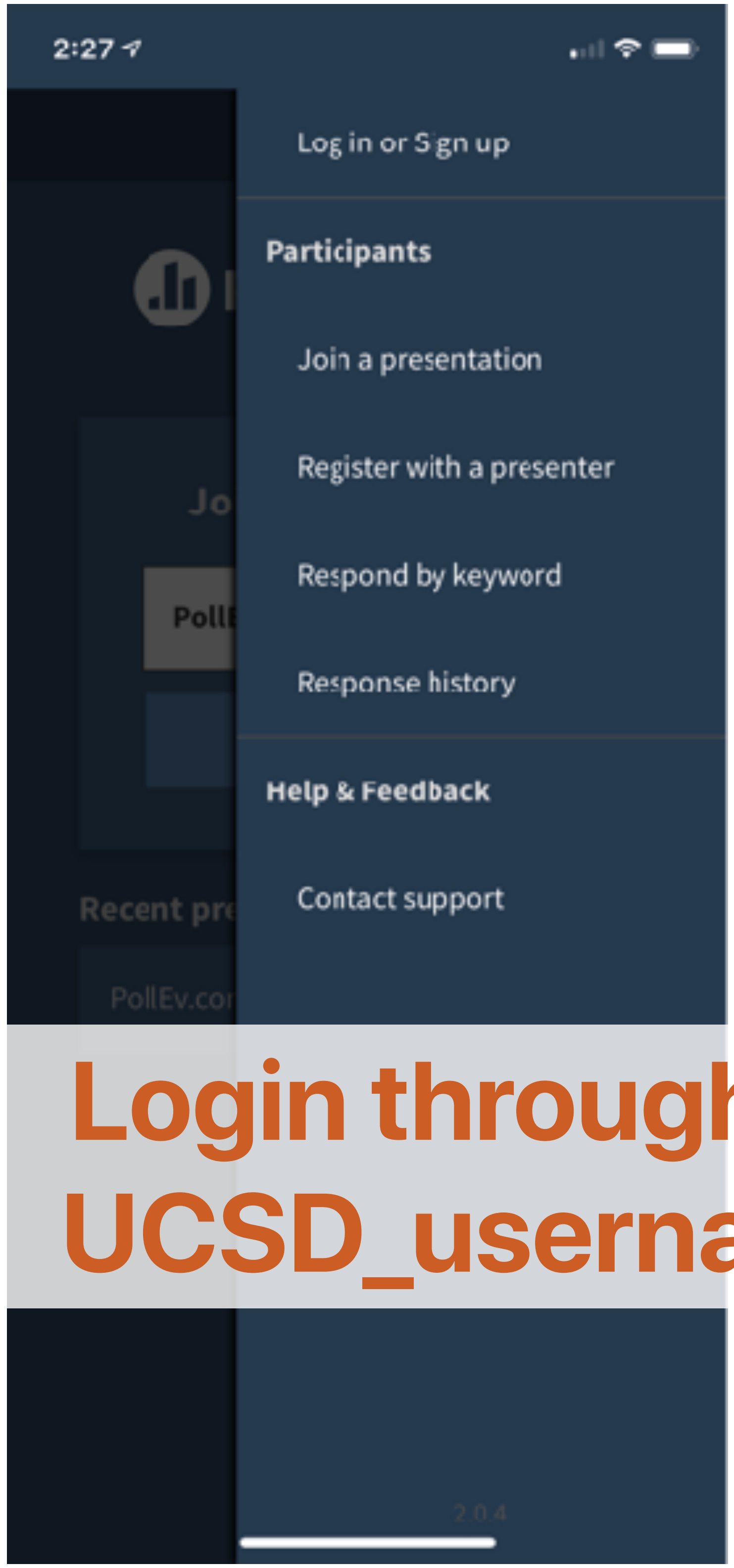
Peer instruction

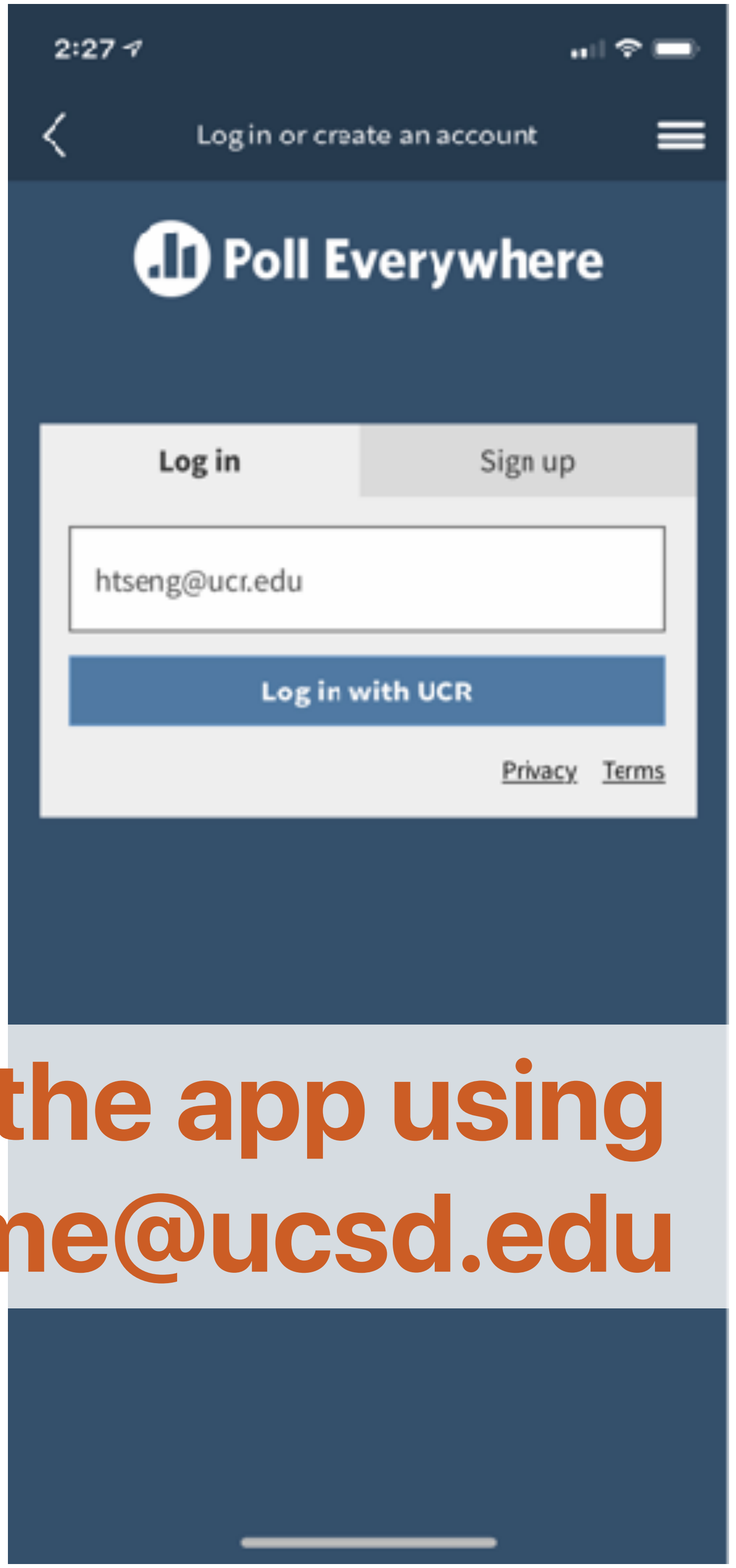
- I'll bring in activities to ENGAGE you in exploring your understanding of the material
  - Let you practice
  - Bring out misconceptions
  - Let us LEARN from each other about difficult parts.
- You will be GET CREDIT for your efforts to learn in class
  - By answering questions with **Poll Everywhere**
  - Answer **50%** of the **clicker questions** in class, get 10% of your final grade
    - Typically more than 50% of questions are individual thinking questions as individual thinking comes first
    - If you don't feel comfortable to talk with others, you can still get full credits if you made choices on all individual thinking questions

About the time of the Lecture — Setup Poll Everywhere

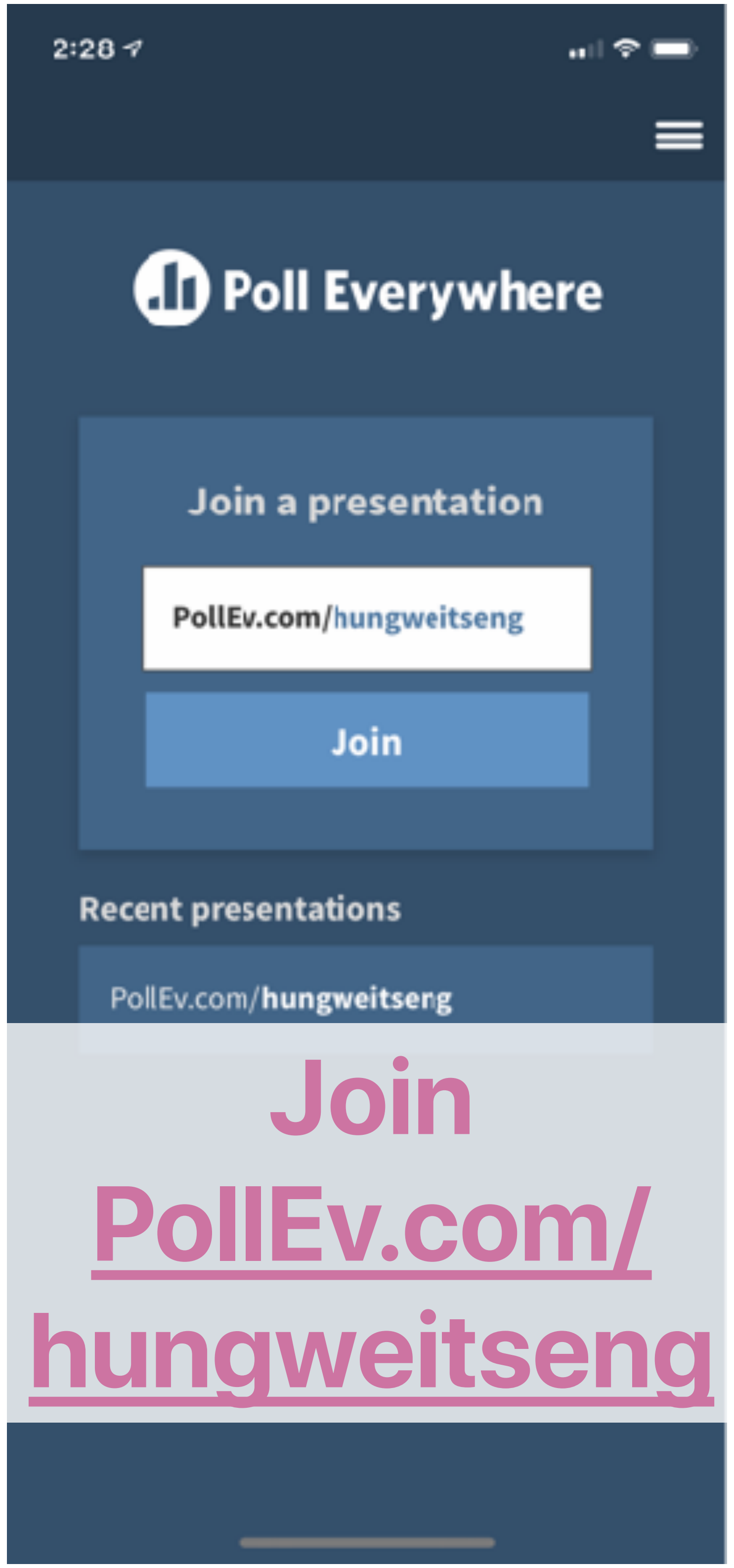


Download the "Poll Everywhere" app





Login through the app using UCSD_username@ucsd.edu



Join PollEv.com/hungweitseng

Grading Breakdown

	In-person session	Online session
Reading Quizzes	15% Drop lowest 2	15% Drop lowest 2
Participation	10% Answer 50% in-lecture questions	
Assignments	20% Drop lowest 1	20% Drop lowest 1
Midterm	20% In-person version test — closed book	30% Online version test — open book
Final	35% In-person version test — closed book	35% Online version test — open book

Assignments

- Assigned on Wednesdays, due on **Fridays 11:59p**
- The best way to prepare the examines
- Use templates in jupyter notebook format
- Submit through gradescope
  - **We do not accept scanned handwritten ones**
  - Only PDF version made from the jupyter notebook template
  - You have to click the GitHub classroom link to begin with (will post the link of each assignment on the course webpage once released)
  - You may use the escalab.org/datahub service to finish your assignment

Logistics

Instructor — Hung-Wei Tseng

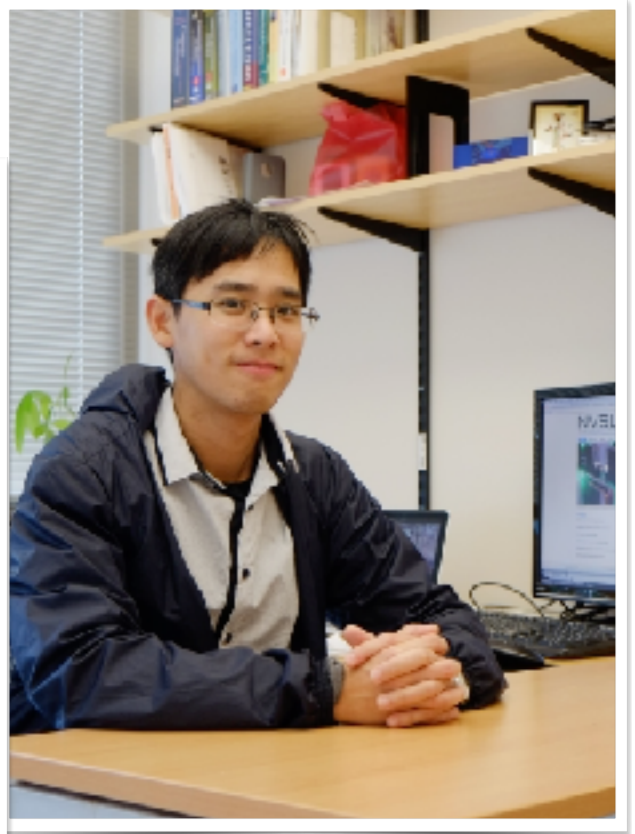
- Associate Professor @ UC Riverside, 05/2019—
- Website: https://intra.engr.ucr.edu/~htseng/
- E-mail: htseng @ ucsd.edu
- Visiting Researcher @ Google, 01/2023—03/2023
  - Working for TensorFlow Lite
- PhD in **Computer Science**, University of California, San Diego, 2014
- Research Interests
  - General-purpose computing on AI/ML/NN accelerators
  - Intelligent storage devices & near-data processing
  - Or anything else fun — we have an OpenUVR project recently
- Fun fact: Hung-Wei was once considering a career path as a singer but went back to academia due to the unsuccessful trial

UC RIVERSIDE

Google

TensorFlow

UC San Diego



Teaching Assistants

Leon Li

- Office hours: Th 10a-12p on Zoom
- E-mail: xul065 @ ucsd.edu
- https://ucsd.zoom.us/j/95484637243
- Fun fact: I'm an avid payment geek and play the real-world churning game to rack up points for free travel.

Jerry Ho

- Office hours: M 4p-6p on Zoom
- E-mail: chh009 @ ucsd.edu
- https://ucsd.zoom.us/j/95484637243
- Fun fact: He won Third Place in Section 1 of San Diego Go Tournament 2023… with 1-2 record.

Discussion sessions

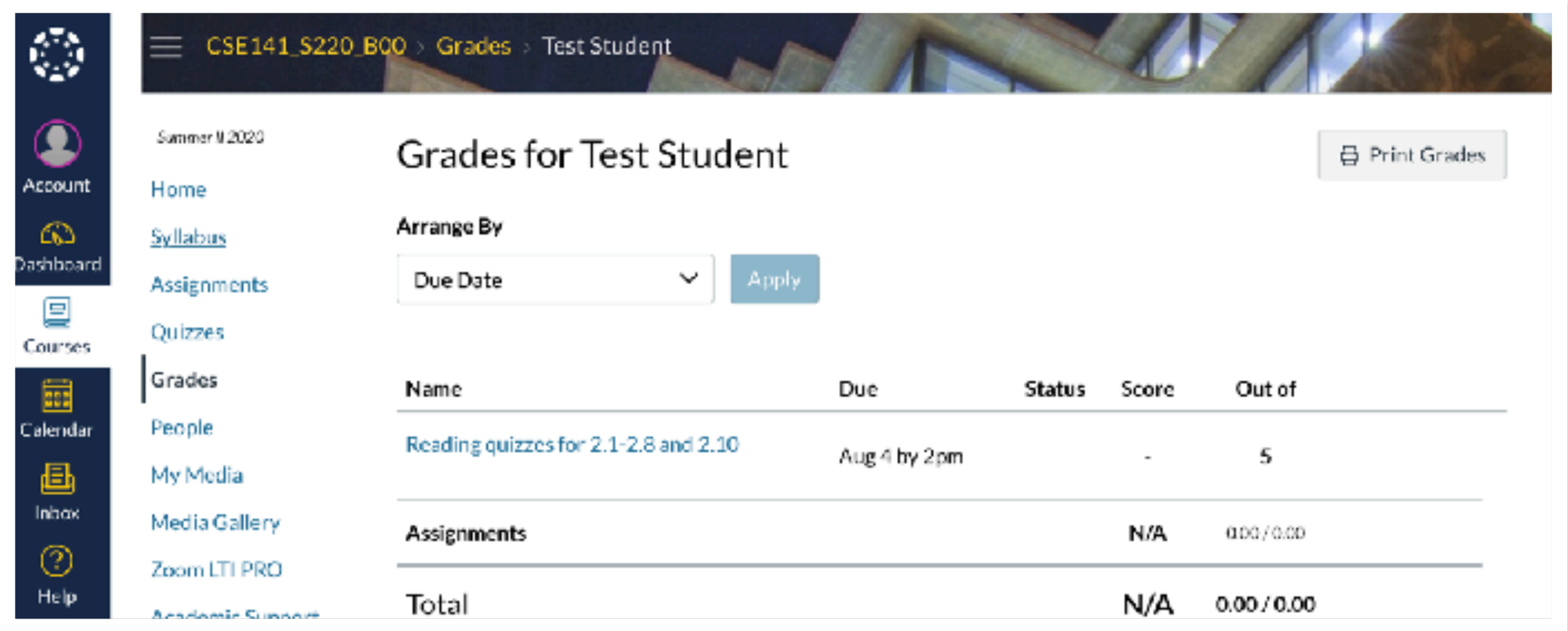
- Wednesday 4p-5p Pepper Canyon Hall
- Covers hints for your assignments
- Highly recommended

The website

- Calendar
- Schedule
- Slides
  - Preview — for the ease of note taking
  - Release — the actual slides

Grading

- You can see your grades on Canvas.



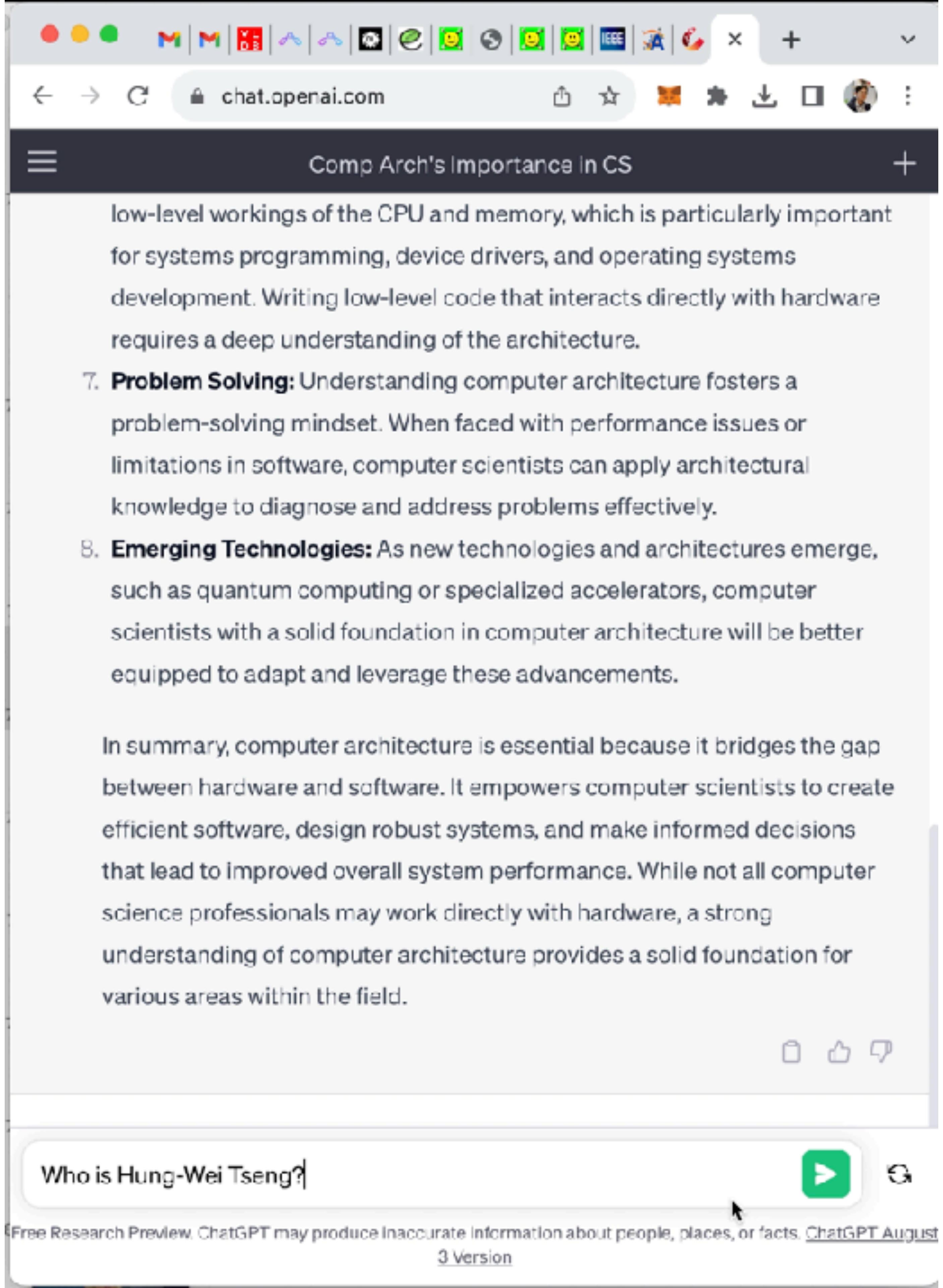
- Errors in grading
  - If you feel there has been an error in how an assignment or test was graded, you have one week from when the assignment is return to bring it to our attention. You must submit (via email to the instructor and the appropriate TAs) a written description of the problem. Neither I nor the TAs will discuss regrades without receiving an email from you about it first.
- For arithmetic errors (adding up points etc.)
  - you do not need to submit anything in writing, but the one week limit still applies.

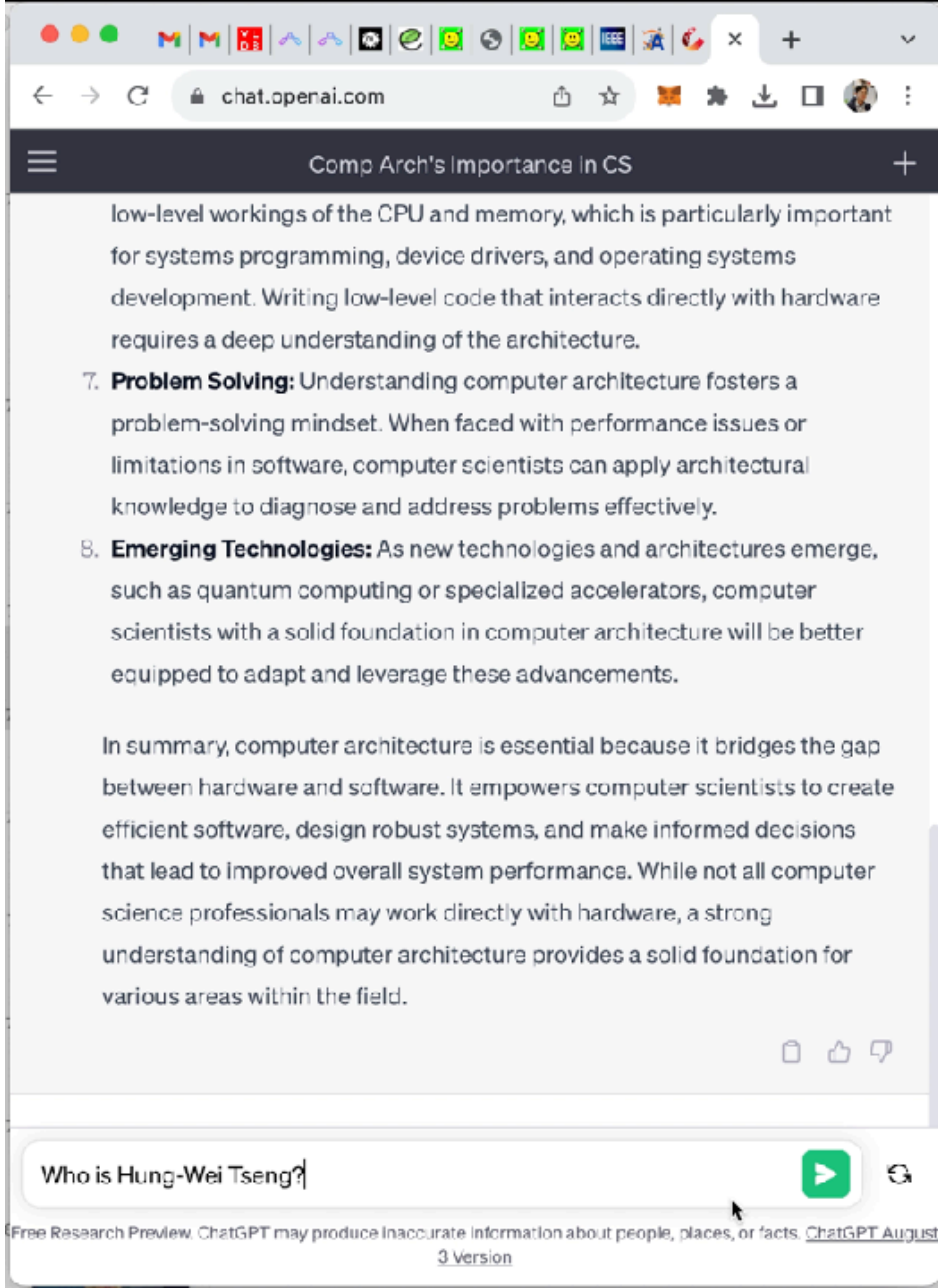
Summary of course resources

- Lectures:
  - In-person @ WLH 2205
  - Live on **Zoom** — please check your e-mail/Canvas for the link
  - Live on **Youtube** (you cannot participate): https://www.youtube.com/profusagi
  - Repository on **Youtube**: https://www.youtube.com/profusagi
- Schedule, slides on **course webpage**: https://www.escalab.org/classes/cse142-2023su
- Discussion on **piazza**: https://piazza.com/class/lkwy1ccytqc3ct/
- Reading quizzes, grading on **Canvas**: https://canvas.ucsd.edu/courses/48362
- Assignments through **gradescope**: https://www.gradescope.com/courses/564382
- Office Hours & Locations https://calendar.google.com/calendar/embed?src=c_373ea7ba1adb25dcb44c3a3d1cb62af934f7601955381cdc89116d91596ba4af%40group.calendar.google.com

Academic Honesty

- Don’t cheat.
  - Cheating on a test will get you an F in the class and no option to drop, and a visit with your college dean.
  - Cheating on homework means you don’t have to turn them in any more, but you don’t get points either. You will also take at least 25% penalty on the exam grades.
- Copying solutions of the internet or a solutions manual is cheating
  - They are incorrect sometimes
- Review the UCSD student handbook
- When in doubt, ask.


chat.openai.com
Comp Arch's Importance in CS
low-level workings of the CPU and memory, which is particularly important for systems programming, device drivers, and operating systems development. Writing low-level code that interacts directly with hardware requires a deep understanding of the architecture.
7. Problem Solving: Understanding computer architecture fosters a problem-solving mindset. When faced with performance issues or limitations in software, computer scientists can apply architectural knowledge to diagnose and address problems effectively.
8. Emerging Technologies: As new technologies and architectures emerge, such as quantum computing or specialized accelerators, computer scientists with a solid foundation in computer architecture will be better equipped to adapt and leverage these advancements.
In summary, computer architecture is essential because it bridges the gap between hardware and software. It empowers computer scientists to create efficient software, design robust systems, and make informed decisions that lead to improved overall system performance. While not all computer science professionals may work directly with hardware, a strong understanding of computer architecture provides a solid foundation for various areas within the field.
Who is Hung-Wei Tseng?
Free Research Preview. ChatGPT may produce inaccurate information about people, places, or facts. ChatGPT August 3 Version


chat.openai.com
Comp Arch's Importance in CS
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Who is Hung-Wei Tseng?
Free Research Preview. ChatGPT may produce inaccurate information about people, places, or facts. ChatGPT August 3 Version

Hey, I need help...

- Is question 3 on the homework asking for execution time or speedup
  - piazza
- I'm lost on the homework – I don't know what speedup or execution time are...
  - Office Hours (maybe discussion)
- I need to turn in the homework late
  - No late homework (you get to drop one)

Hey, I need help… (part 2)

- I’m going to miss class
  - Sorry to miss you! Please watch my youtube channel! https://www.youtube.com/profusagi
- In-depth class concept question (e.g., what’s the difference between pass-by-value vs. pass-by-reference)
  - Class or Discussion (possibly piazza)
- I can’t get into canvas
  - E-mail Academic Services (ACMS) if you can't log in. Private piazza post if waitlisted and can't see course.
- I can’t login to escalab.org/datahub
  - E-mail Hung-Wei

Hey, I need help... (part 3)

- "I'm sick...."
  - Can miss 20% of classes and drop two assignments. Issues impacting Midterm and Final require exceptional circumstances, e-mail professor
- Disability
  - E-mail paperwork from campus disability services to the Prof. by the end of week 2.

Why…

- Do I really need the textbook
  - Again, we need to prepare you for lectures
  - Textbook helps to make sure we're all on the same page when we talk about something
- Why do we use so many different resources…
  - Gradescope does not allow multiple trials of reading quizzes…
  - Canvas' discussion feature isn't great and not accessible after you graduated
  - I hope some of you can start up a company to provide a one-fit-all solution…


UC San Diego
NC STATE UNIVERSITY
UC RIVERSIDE
2012 Summer
2016 Fall
2022 Winter
2014 Summer
2017 Sp
2022 Fall
2021 Fall
2017 Fal
2019 Fall
You
2023 Summer
2016 Spring
Questions & Comments?
2021 Spring
2018 Spring
2016 Summer
2018 Fall
UC ZOO
2020 Summ
2019 Spring
2019 Summer I
2019 Summer II
2020 Spring

Q & A

Announcements

- Login piazza, Canvas
- Check our website
  - Check the lab website if you got sometime as well!
- Reading quiz due **tomorrow before the lecture**

Computer
Science &
Engineering

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