What does the Future Hold?

CS 3410: Computer System Organization & Programming

Spring 2025

[K. Bala, A. Bracy, E. Sirer, Z. Susag, and H. Weatherspoon]

Cornell Bowers CIS
Computer Science

Logistics

Final Exam is on Sat. May 17 at 2pm in Statler Auditorium (STL185)
- Review Sessions TBA

A13: Raycasting due tonight (5/6) at 11:59pm!

Course evaluations are out now! Please complete them!!
- Due Friday, May 9 at 11:59pm
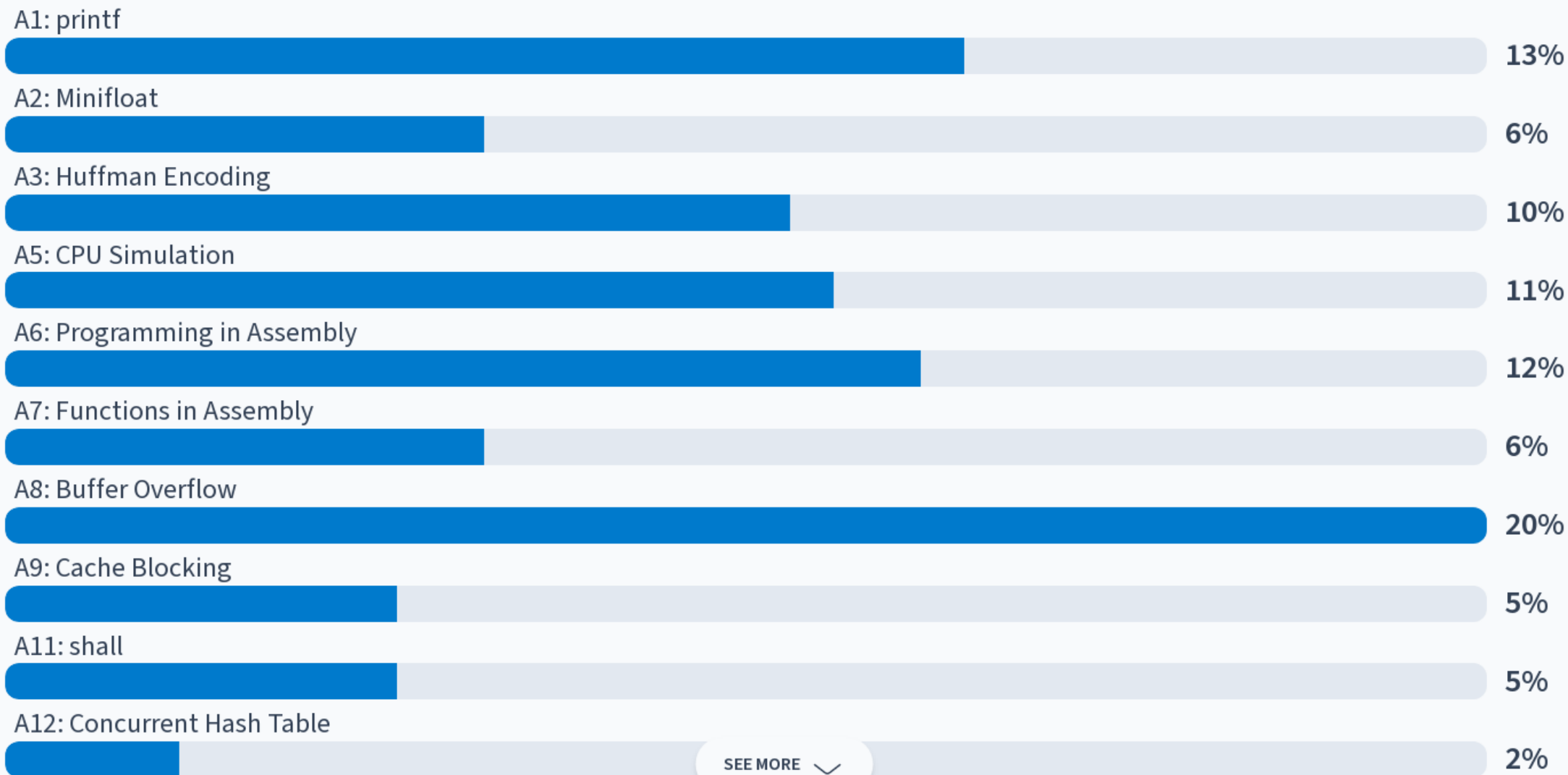- Part of the *Survey* portion of your final grade

Jeopardy!

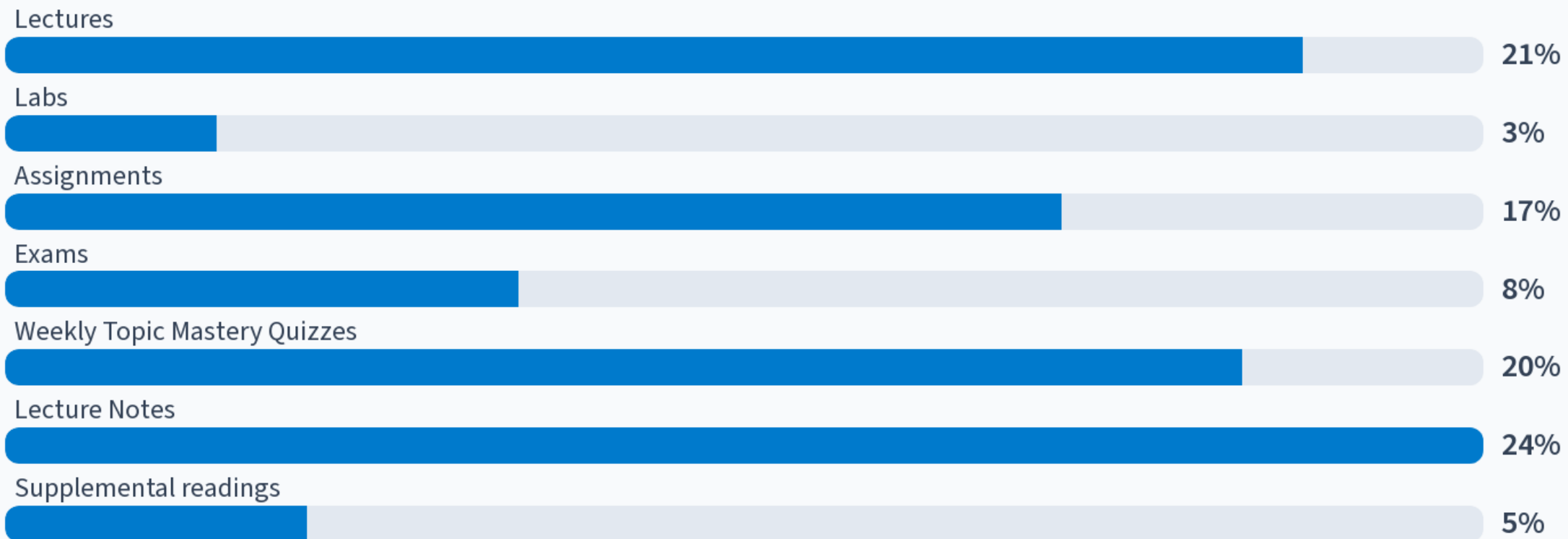# End-of-Course Feedback

0 surveys completed

0 surveys underway

Which assignment was your favorite?

A1: printf
13%

A2: Minifloat
6%

A3: Huffman Encoding
10%

A5: CPU Simulation
11%

A6: Programming in Assembly
12%

A7: Functions in Assembly
6%

A8: Buffer Overflow
20%

A9: Cache Blocking
5%

A11: shall
5%

A12: Concurrent Hash Table
2%

SEE MORE

What aspect of the course helped you understand the course material the most?

Lectures

21%

Labs

3%

Assignments

17%

Exams

8%

Weekly Topic Mastery Quizzes

20%

Lecture Notes

24%

Supplemental readings

5%

Big Pic

TECH

Satya Nadella says as much as 30% of Microsoft code is written by AI

Jordan Novet
@JORDANNOVET

Jonathan Vanian
@IN/JONATHAN-VANIAN-B704432/

SHARE

KEY POINTS

- Microsoft CEO Satya Nadella on Tuesday said that as much as 30% of the company's code is now written by artificial intelligence.

- Nadella made the comments during a conversation before a live audience with Meta CEO Mark Zuckerberg at the social media company's LlamaCon AI developer event.

- Zuckerberg said Meta is focused on developing an AI model that can in turn build as much as half of other AI models within the next year.

● **WATCH LIVESTREAM**

Prefer to Listen?

NOW	**Power Lunch**
UP NEXT	**Closing Bell**

TRENDING NOW

Where Trump is likely getting his $1.98 gas price figure

Trump to ask Hollywood studios if they're happy with 100% foreign film tariff idea

I'm a psychologist who studies couples—the No. 1 toxic phrase that's 'more damaging than you think'

CLUB Here's why we're not buyers in Monday's session, even as stocks move lower

S&P 500 slides for first time in 10 sessions as traders await details on trade deals

Facebook's CEO Mark Zuckerberg (L) speaks with Microsoft's CEO Satya Nadella after posing for a family picture with guests who attend the "Tech for Good" Summit at the Elysee Palace in Paris, on May 23, 2018.
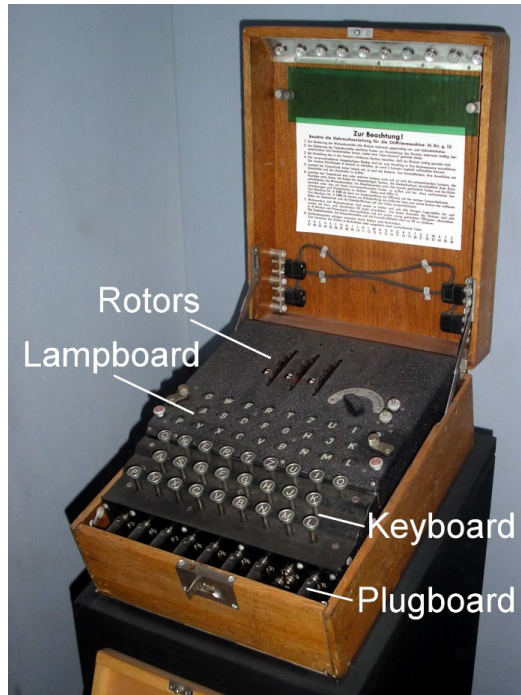*Charles Platiau | AFP | Getty Images*

"Sometimes it is the people that no one imagines anything of who do the things that no one can imagine"
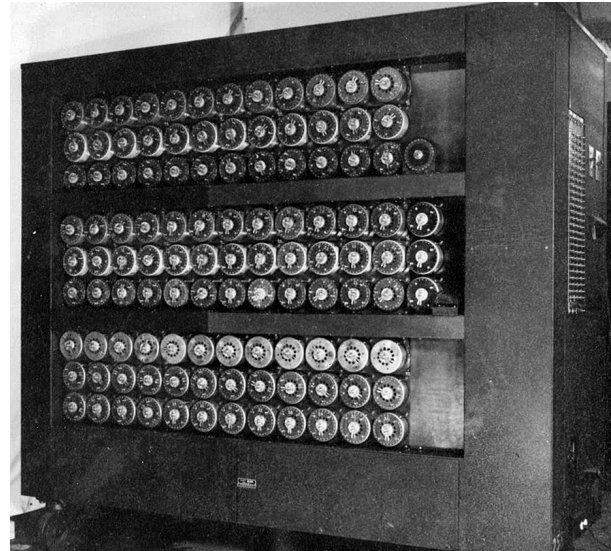
-- The Imitation Game

The Enigma Machine & The Bombe

Enigma Machine
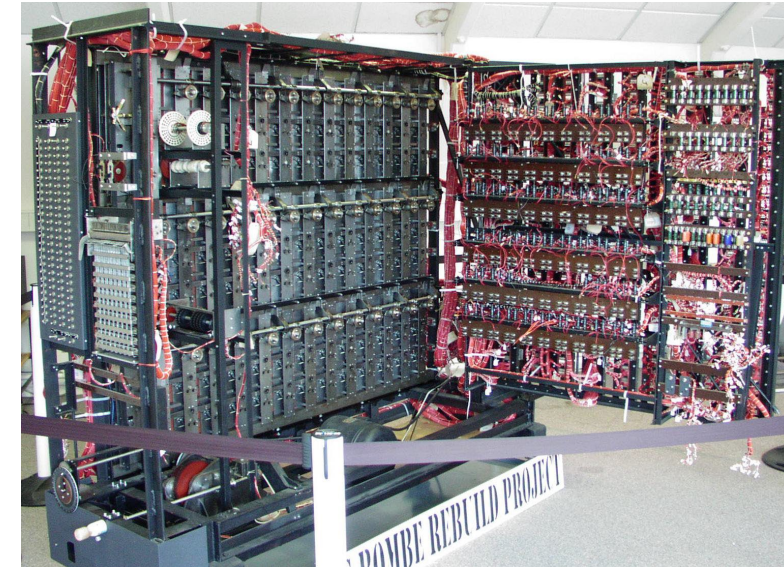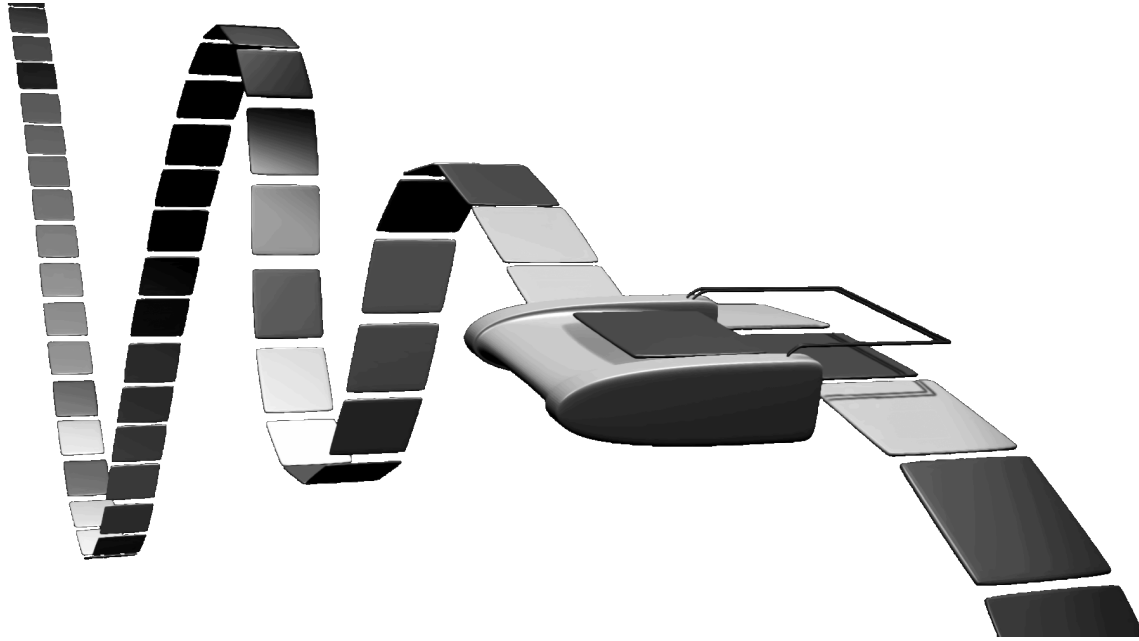

Rotors
Lampboard
Keyboard
Plugboard

Used by the Germans during World War II to encrypt and exchange secret messages

The Bombe

Used by the Allies to break the German Enigma machine during World War II

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Turing Machine
1936

Alan Turing

= abstract model for CPU that can simulate any algorithm

The Big Picture

What is this?

```
#include <stdio.h>

int main() {
    printf("Hello world!\n");
    return 0;
}
```
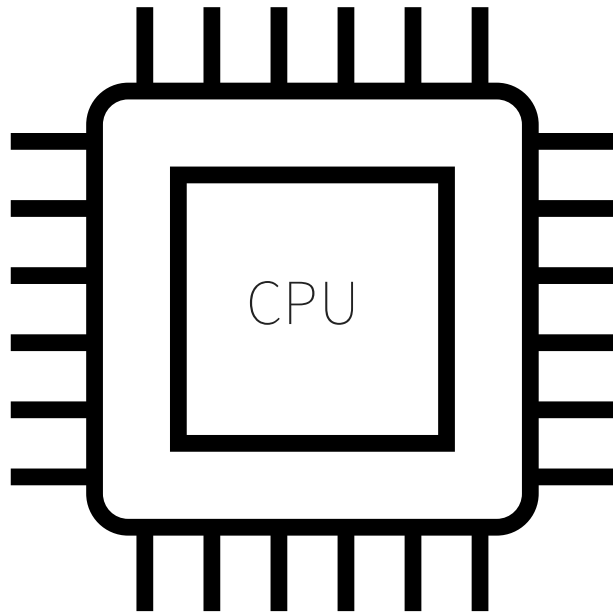
How does it work?
I'm glad you asked…
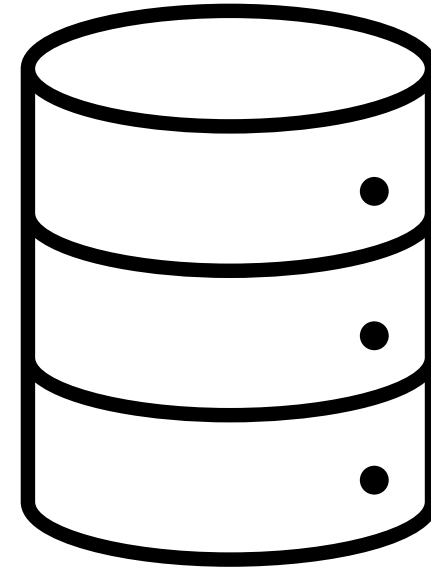 15 weeks later and you'll know!
"I know Kung Fu."

You had me at
hello world.

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Big Picture

Processor

CPU

☑ Runs code; does computations

☒ Doesn't remember anything

Memory

☒ Can't compute anything

☑ Stores data

Big Picture

Processor

64

Reg 0
Reg 1
....
Reg 30
Reg 31

register file

D_W Q_A Q_B

W R_W R_A R_B

ALU

64   64   64   64

✅ Runs code; does computations

❌ Doesn't remember anything

Memory

Instruction memory   32

Data memory

D_{in} D_{out} 64

64   addr   64

PC   new pc calculation

64   2 00   2 00
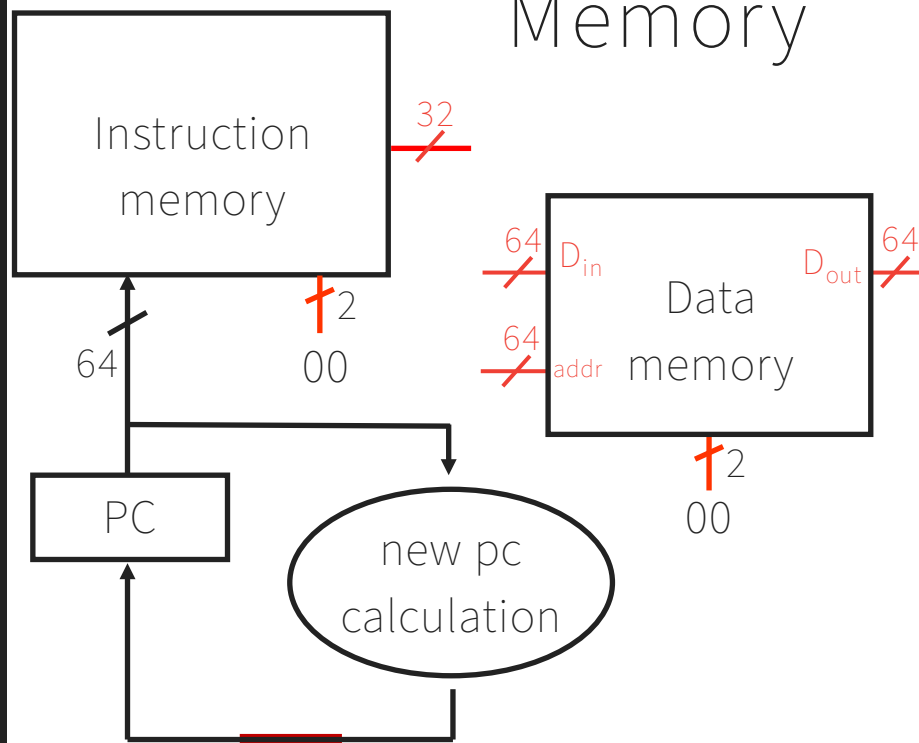
❌ Can't compute anything

✅ Stores data

CS 3410 in 1 slide

C
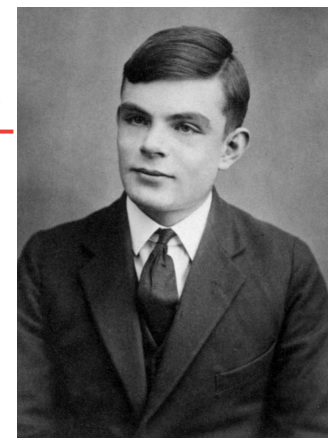
compiler

RISC-V assembly
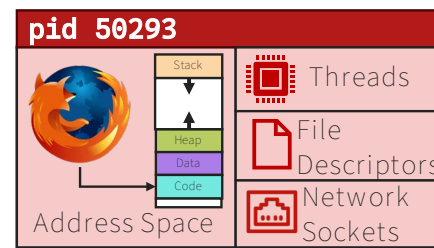
assembler

machine code

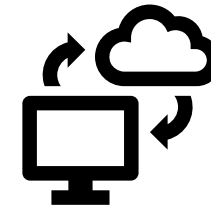loader

```
int x = 10;
x = 2* x + 15;

addi x5, x0, 10
muli x5, x5, 2
addi x5, x5, 15
```

RISC-V

```
00000000101000000000000001010010011
00000000001000101000001010000000
00000000111100101000001010010011
```
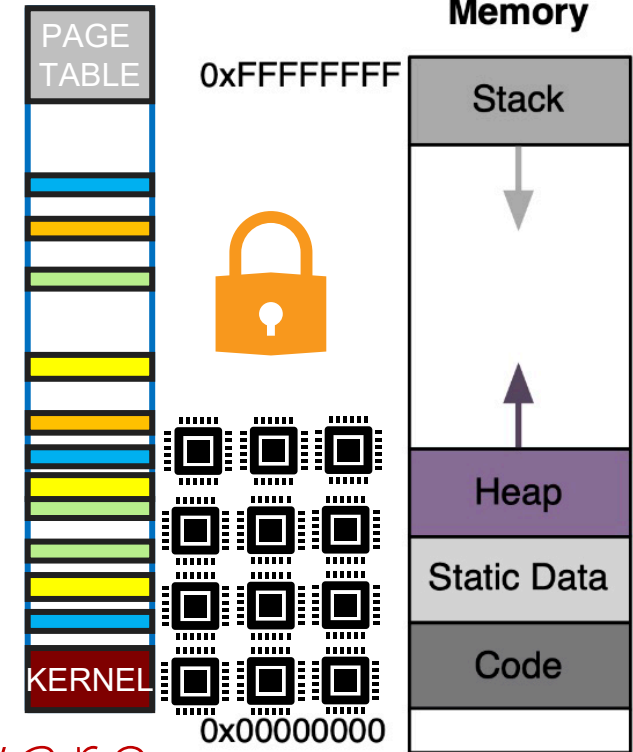
Calling Conventions

pid 50293

Stack
Heap
Data
Code

Address Space

Threads

File Descriptors

Network Sockets

System calls
Exceptions
Interrupts
I/O

PAGE TABLE

0xFFFFFFFF

KERNEL

0x00000000

Memory

Stack

Heap

Static Data

Code

Software

Hardware

CPU

Circuits

Gates

Transistors

Silicon

D

clk

C

S

C

S

D
Q

A
L
U

A
B

Architecture -- ISA
Microarchitecture
- **Pipelining**
- **Caches**

Registers

L1 Cache

L2 Cache

L3 Cache

Main Memory

Disk (SSD)

Instruct Mem

Register File

A
L
U

Data Mem

+4

>PC

control

5

5 5

FETCH   DECODE   EXECUTE   MEMORY   WRITEBACK

17
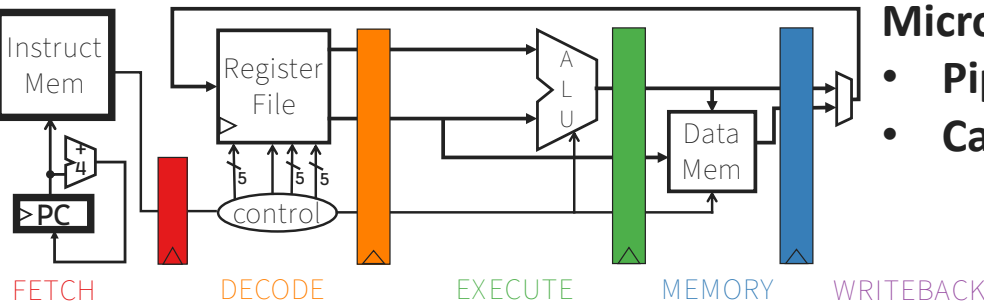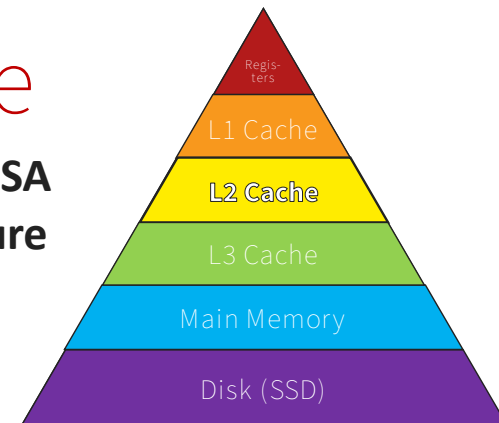
More Than Moore

More computation, more storage, more data, more electricity, more parallelism, more concurrency, more heat, more networks, more domains, more architectures, more attack surfaces, more code, more bugs, more integration, more bits, more of more…

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Moore's Law

- 1965
  - # of transistors integrated on a die doubles every 18-24 months (*i.e.,* grows exponentially with time)

- Amazingly visionary
  - 2300 transistors, 1 MHz clock (Intel 4004) - 1971
  - 16 Million transistors (Ultra Sparc III)
  - 42 Million transistors, 2 GHz clock (Intel Xeon) – 2001
  - 55 Million transistors, 3 GHz, 130nm technology, 250mm^2 die (Intel Pentium 4) – 2004
  - 290+ Million transistors, 3 GHz (Intel Core 2 Duo) – 2007
  - 721 Million transistors, 2 GHz (Nehalem) - 2009
  - 1.4 Billion transistors, 3.4 GHz Intel Haswell (Quad core) – 2013
  - 7.2 Billion transistors, 3-3.9 GHz Intel Broadwell (22-core) – 2016
  - 20 Billion transistors, 3.49 GHz Apple M2 (8 core) — 2022
  - 28 Billion transistors, 4.4 GHz Apple M4 (16x core) — 2024

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Moore's Law: The number of transistors on microchips doubles every two years

Moore's law describes the empirical regularity that the number of transistors on integrated circuits doubles approximately every two years. This advancement is important for other aspects of technological progress in computing – such as processing speed or the price of computers.

Data source: Wikipedia (wikipedia.org/wiki/Transistor_count)
OurWorldinData.org – Research and data to make progress against the world's largest problems.   Licensed under CC-BY by the authors Hannah Ritchie and Max Roser.

https://en.wikipedia.org/wiki/Moore%27s_law

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Why Multicore?

- Moore's law
    - A law about transistors
    - Smaller means more transistors per die
    - And smaller means faster too

- But: Power consumption growing too…
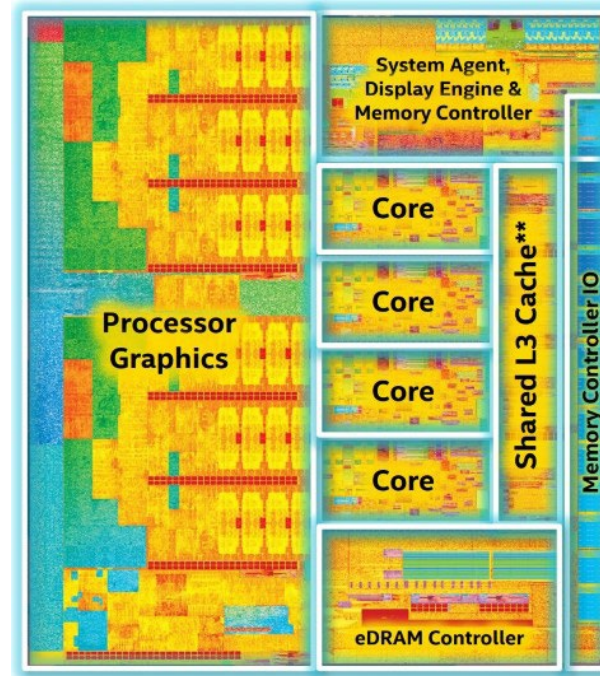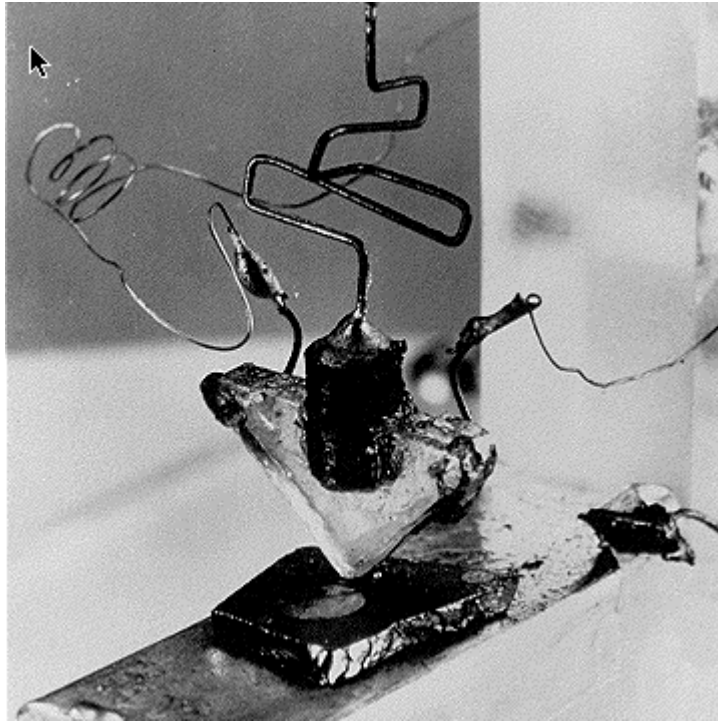
Multi-core
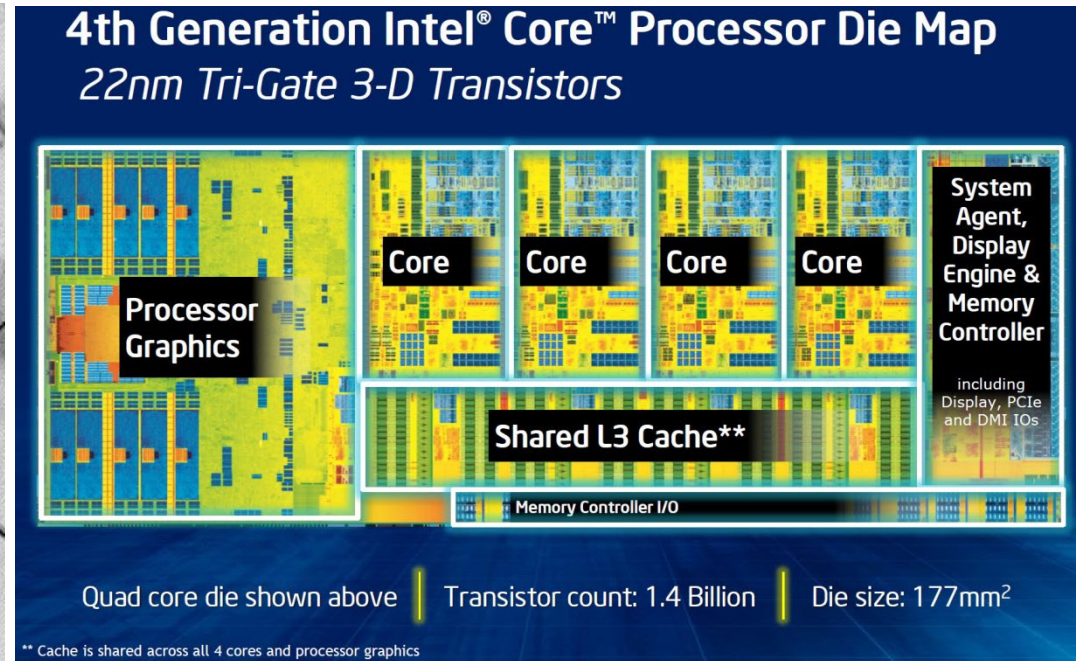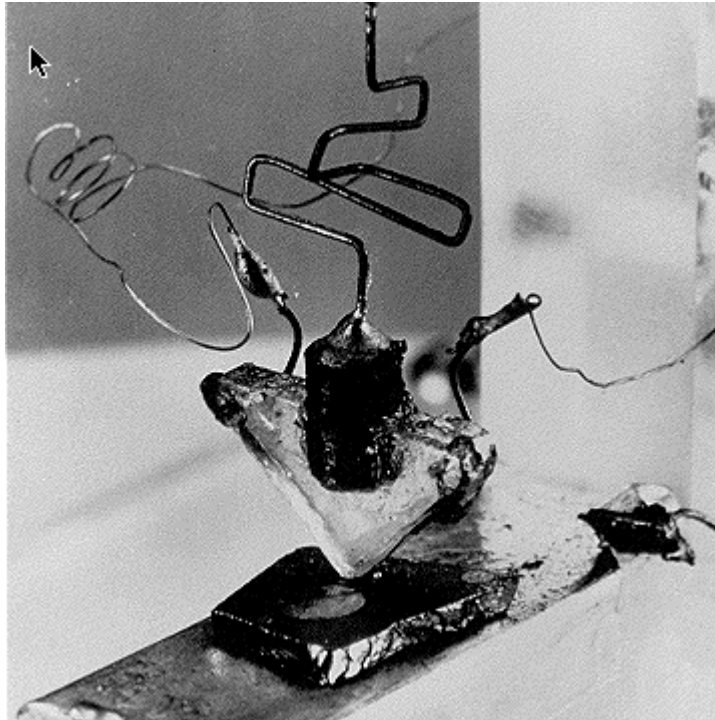
4th Generation Intel® Core™ Processor Die Map
22nm Tri-Gate 3-D Transistors

http://techguru3d.com/4th-gen-intel-haswell-processors-architecture-and-lineup/

- ## The first transistor
  - One workbench at AT&T Bell Labs
  - 1947
  - Bardeen, Brattain, and Shockley

- ## Intel Haswell
  - 1.4 billion transistors, 22nm
  - 177 square millimeters
  - Four processing cores

https://en.wikipedia.org/wiki/Transistor_count

Multi-core

https://www.computershopper.com/computex-2015/performance-preview-desktop-broadwell-at-computex-2015

- ## The first transistor
  - One workbench at AT&T Bell Labs
  - 1947
  - Bardeen, Brattain, and Shockley

- ## Intel Broadwell
  - 7.2 billion transistors, 14nm
  - 456 square millimeters
  - Up to 22 processing cores

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https://en.wikipedia.org/wiki/Transistor_count

Multi-core
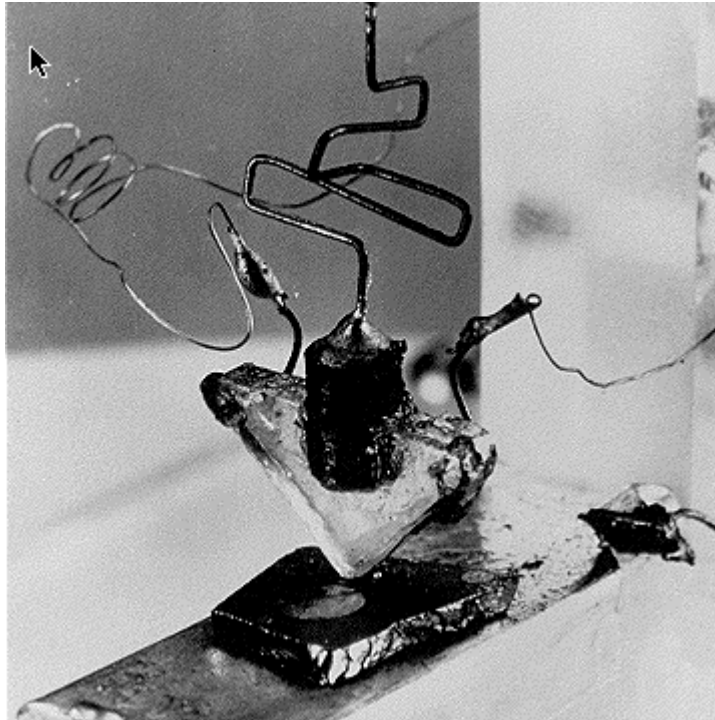
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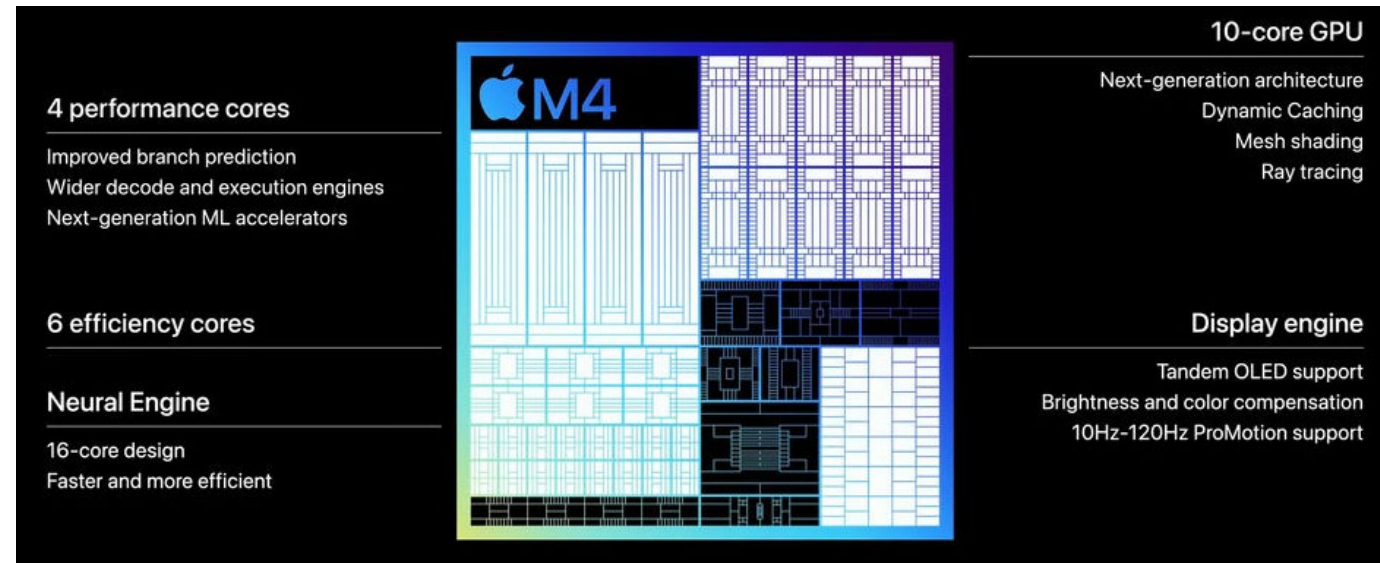
- ## Apple M4
  - 28 billion transistors, 3nm
  - 177 square millimeters
  - 4x-10x performance, 4x-6x efficiency, 8x-40x GPU, 16x Neural processing cores

Cloud Computing

Cloud Computing

- The Cloud
  - A computer utility, warehouse computers; a commodity
  - Catalyst for technology economy
  - Revolutionizing artificial intelligence, machine learning, health care, financial systems, scientific research, and society

Cloud Computing

- The Cloud
  - *ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction.*
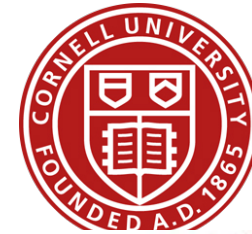
NIST Cloud Definition

Cloud Computing

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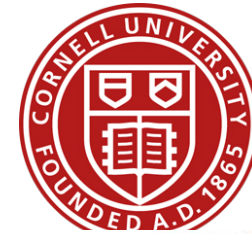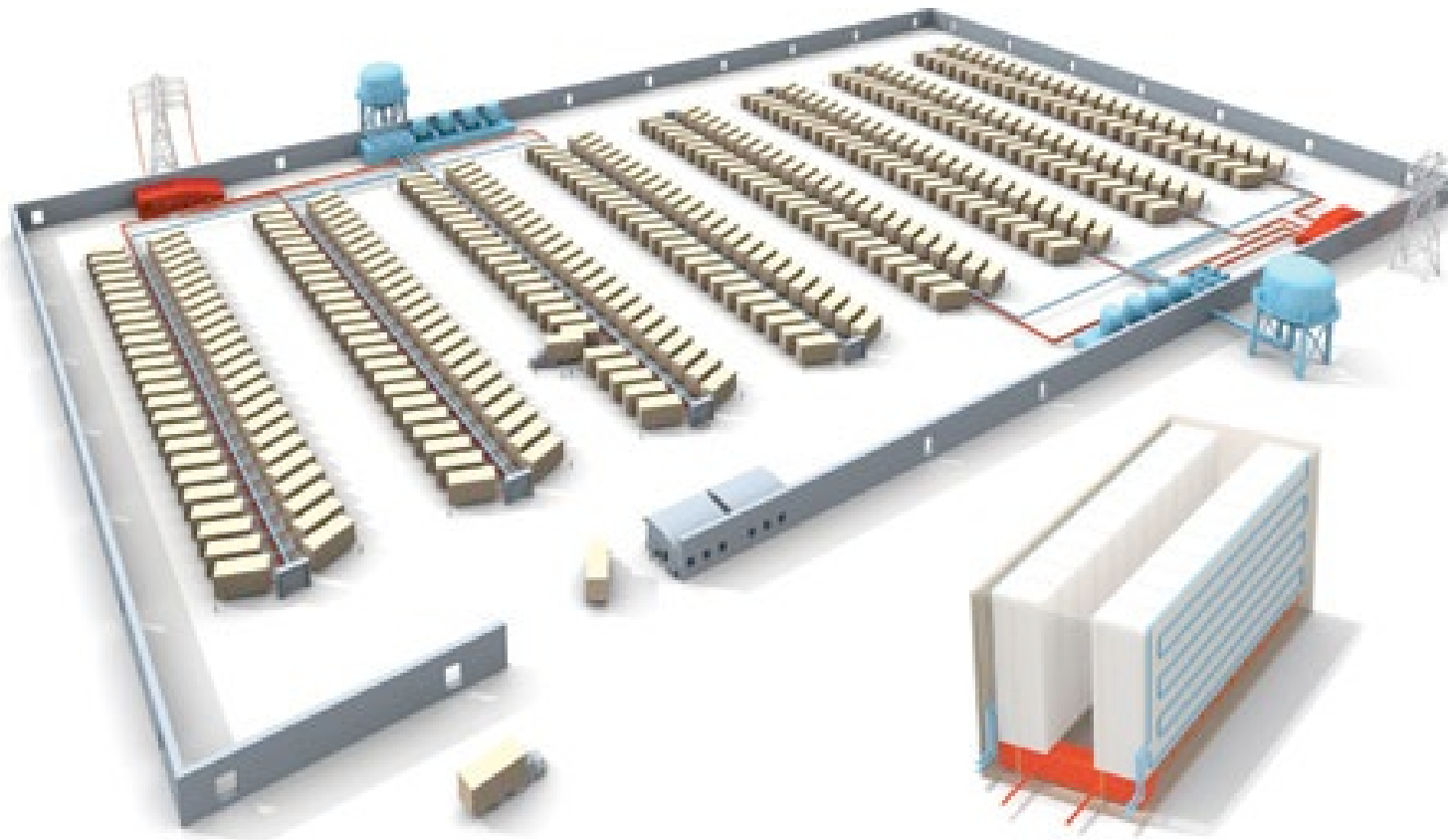
NIST Cloud Definition

Cloud Computing

- How big is Big Data in the Cloud?
  - Exabytes: Delivery of petabytes of storage daily

Titan tech boom, randy katz, 2008

Cloud Computing

- How big is Big Data in the Cloud?
    - Most of the worlds data (and computation) hosted by few companies

cooling towers

warehouse-scale computer

power substation

Cloud Computing

- How big is Big Data in the Cloud?
  - Most of the worlds data (and computation) hosted by few companies

- Currently 4.72 billion internet users
  - 900,000 new users each day [Hootsuite]

- Growing to 175 zettabytes in 2025

- 65% of this data will stored and processed in datacenters [IDC]

cooling towers

warehouse-scale computer

power substation

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Cloud Computing

- How big is Big Data in the Cloud?
  - Most of the worlds data (and computation) hosted by few companies

Power Demands Rapidly Increasing

NATIONAL

Three Mile Island nuclear plant will reopen to power Microsoft data centers

SEPTEMBER 20, 2024 · 1:40 PM ET

By C Mandler

The Three Mile Island nuclear plant is seen in March 2011 in Middletown, Pa.
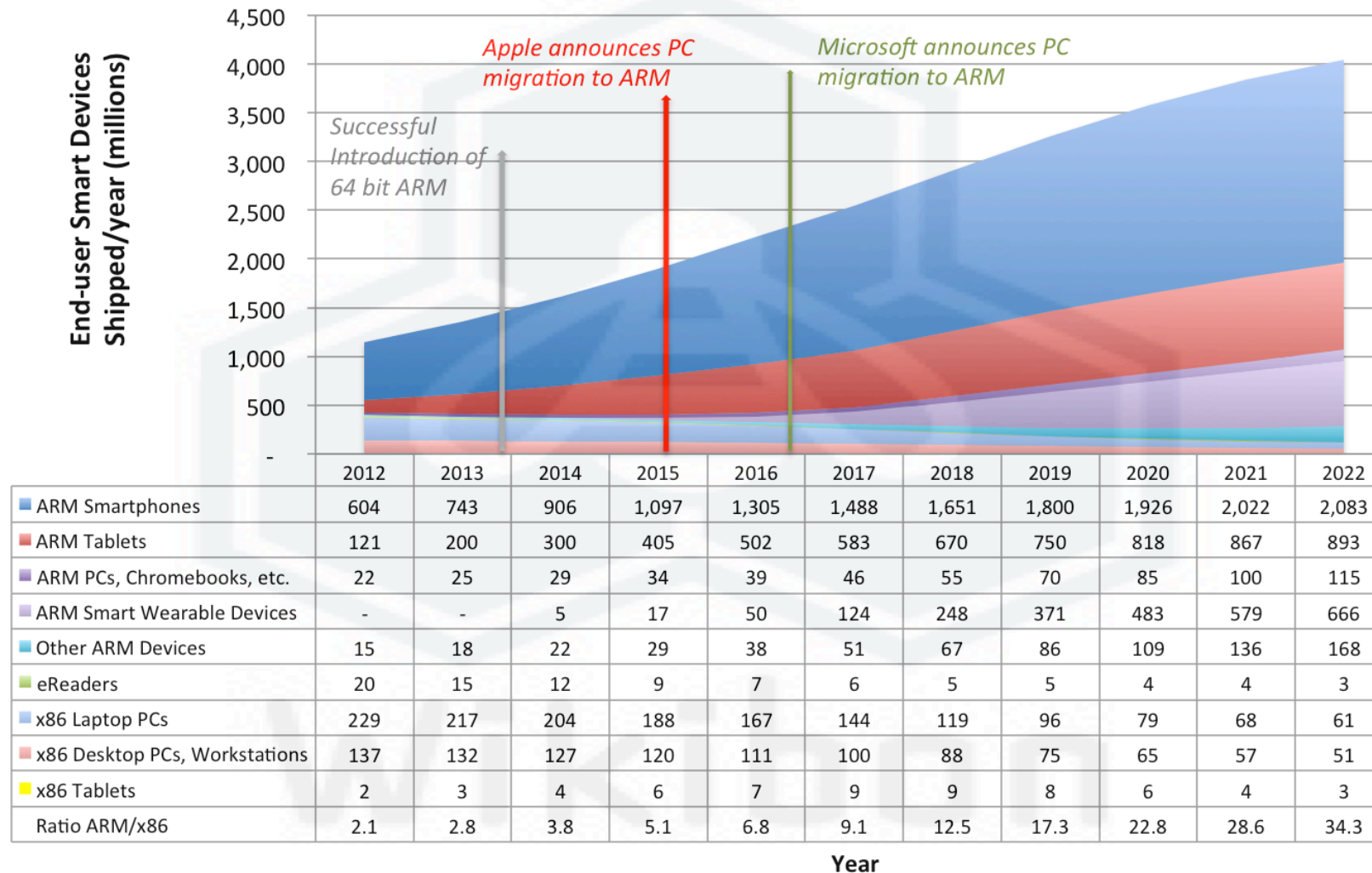*Jeff Fusco/Getty Images*

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Embedded Processors

Where is the Market?

End-user device shipments per year

Apple announces PC migration to ARM

Microsoft announces PC migration to ARM

Successful Introduction of 64 bit ARM

End-user Smart Devices Shipped/year (millions)

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
ARM Smartphones	604	743	906	1,097	1,305	1,488	1,651	1,800	1,926	2,022	2,083
ARM Tablets	121	200	300	405	502	583	670	750	818	867	893
ARM PCs, Chromebooks, etc.	22	25	29	34	39	46	55	70	85	100	115
ARM Smart Wearable Devices	-	-	5	17	50	124	248	371	483	579	666
Other ARM Devices	15	18	22	29	38	51	67	86	109	136	168
eReaders	20	15	12	9	7	6	5	5	4	4	3
x86 Laptop PCs	229	217	204	188	167	144	119	96	79	68	61
x86 Desktop PCs, Workstations	137	132	127	120	111	100	88	75	65	57	51
x86 Tablets	2	3	4	6	7	9	9	8	6	4	3
Ratio ARM/x86	2.1	2.8	3.8	5.1	6.8	9.1	12.5	17.3	22.8	28.6	34.3

Year

Source: © Wikibon 2013, IDC & Gartner 2013 shipments & forecast, & Wikibon 2014-2022 projections. Assumption: Apple & Microsoft migrate to 64-bit ARM

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http://wikibon.org/wiki/v/64-bit_ARM_Ushers_in_the_Mobile-Cloud_Application_Model
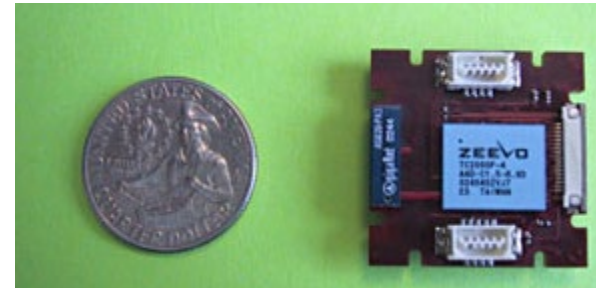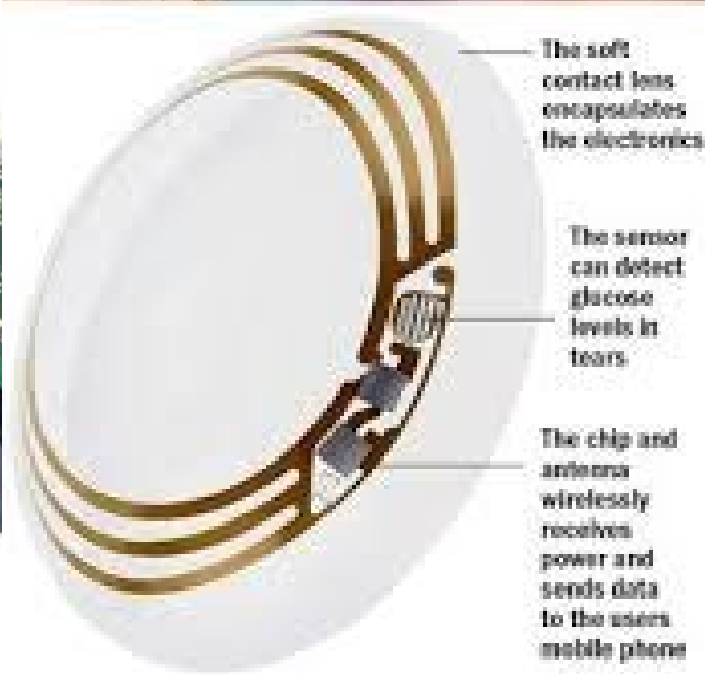
Internet of Things (IoT)

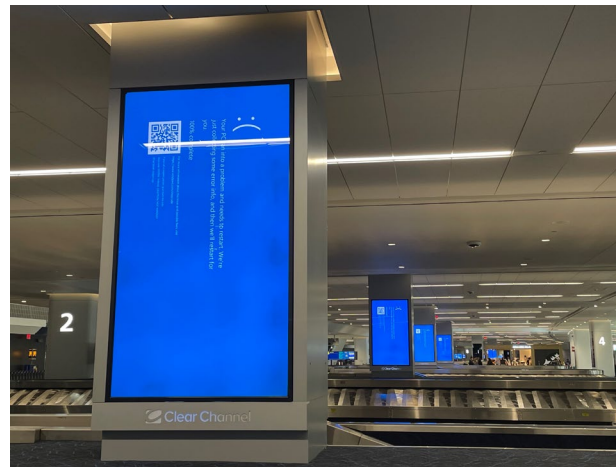- E.g. Cornell Institute for Digital Agriculture (CIDA)

Where to?

- Smart Dust

Security

Before

buffer[1024]
ret address of CalcAverage()
...
rest of the stack
...

After

"Success ;)"
nothing meaningful here
address of printf
return address of main()
address of buffer[0]
... rest of the stack ...

BACK TO THE BUILDING BLOCKS:

A Path Toward Secure and Measurable Software

FEBRUARY 2024

THE WHITE HOUSE
WASHINGTON

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Moore's Law

- 1965
  - # of transistors integrated on a die doubles every 18-24 months (*i.e., grows exponentially with time)

- Amazingly visionary
  - 2300 transistors, 1 MHz clock (Intel 4004) - 1971
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  - 20 Billion transistors, 3.49 GHz Apple M2 (8 core) — 2022
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Moore's Law
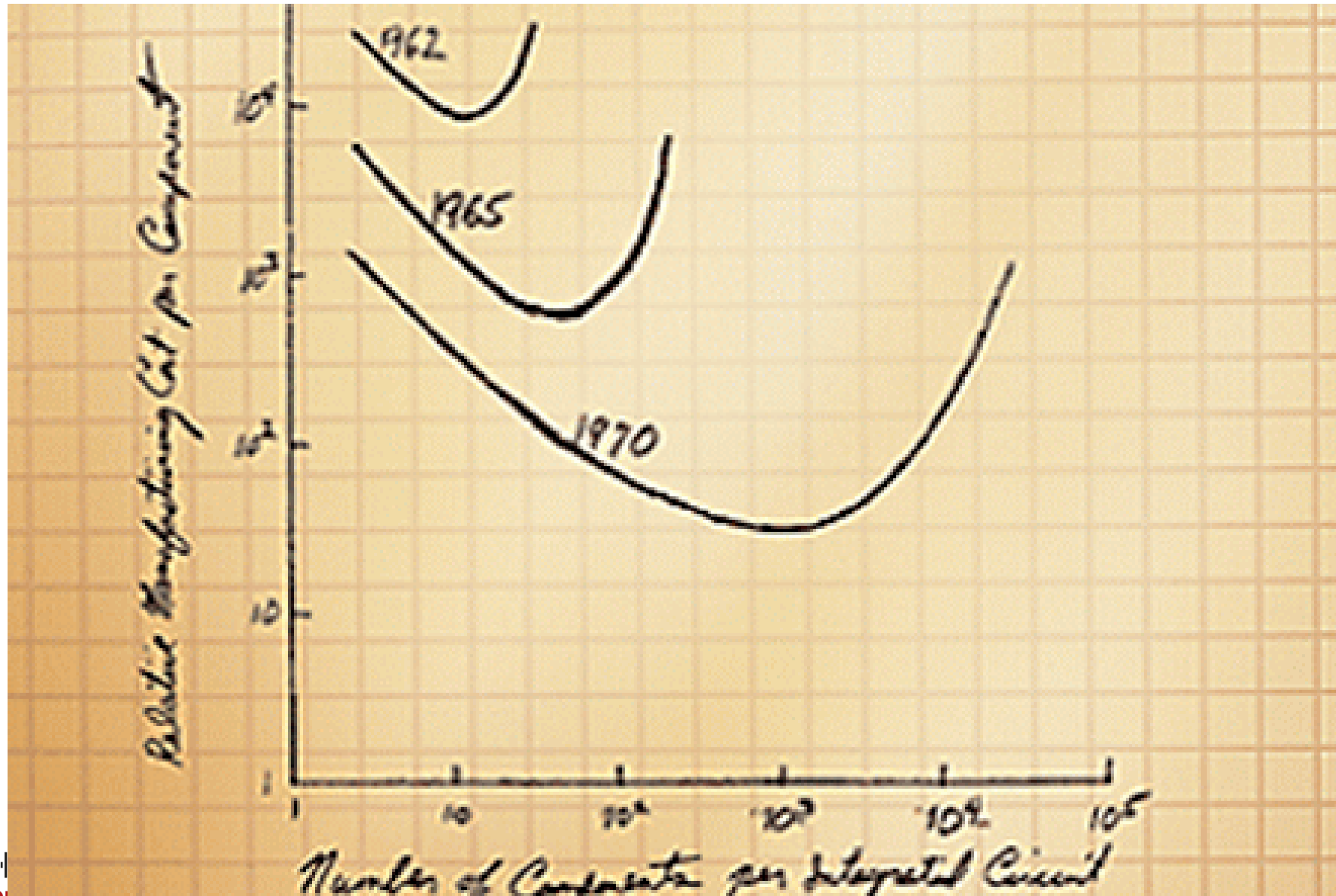
Parallelism

- Dennard scaling: power

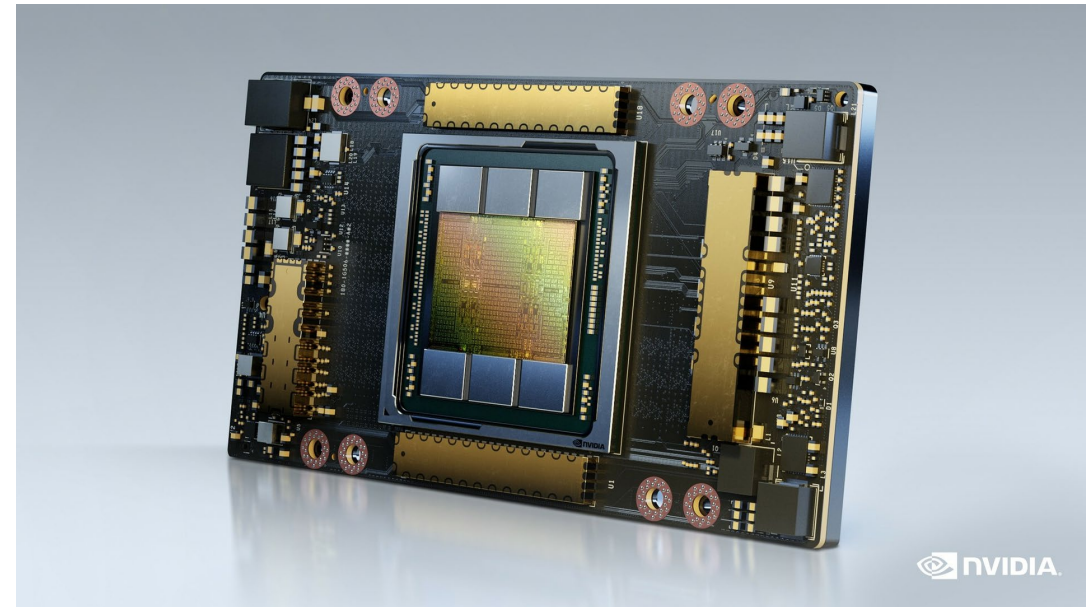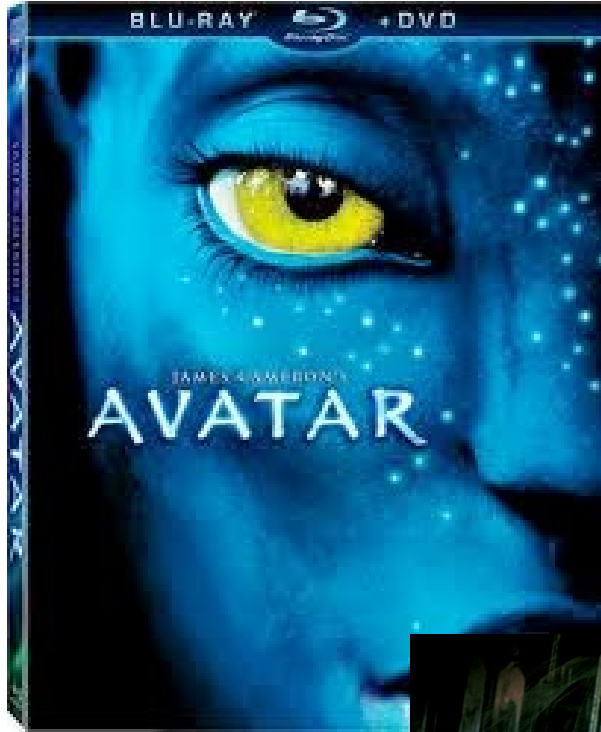- Must exploit parallelism for performance

- AI
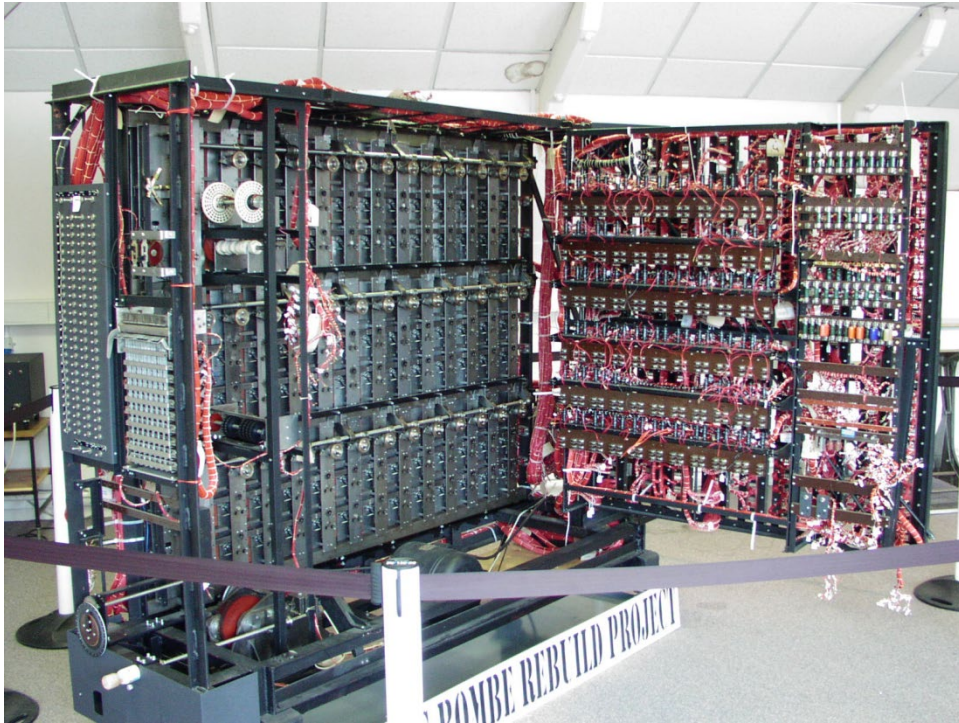- AI
- AI!

Systems for AI and Deep Learning
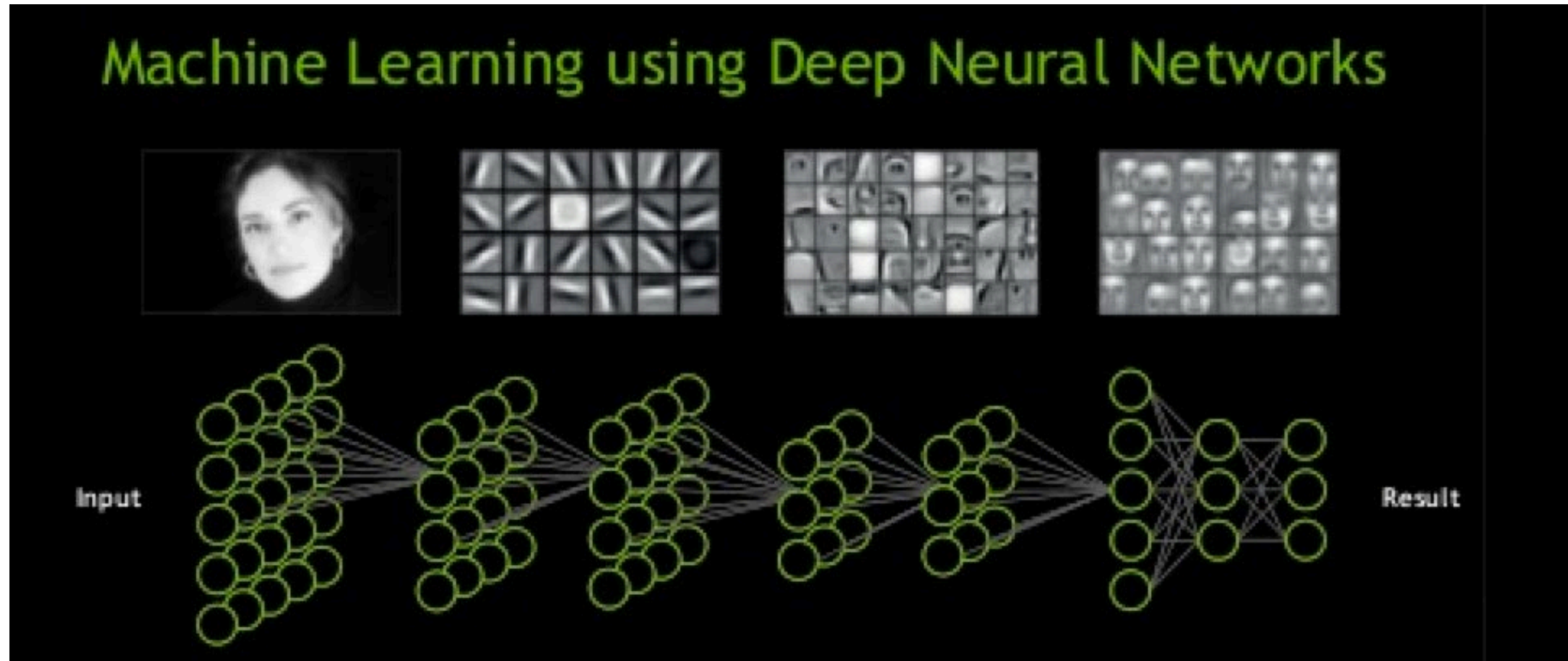
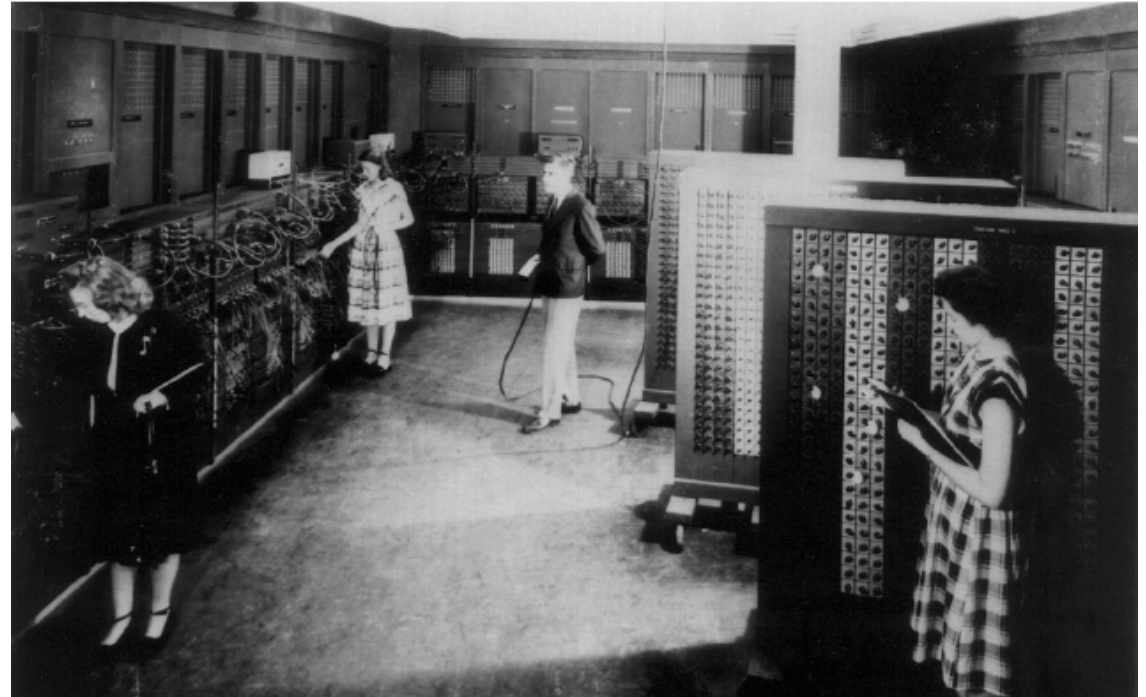# GPUs for Graphics, of course

NVIDIA A100

You Could Save The World One Day!

ENIAC - 1946
First general purpose
electronic computer. Designed
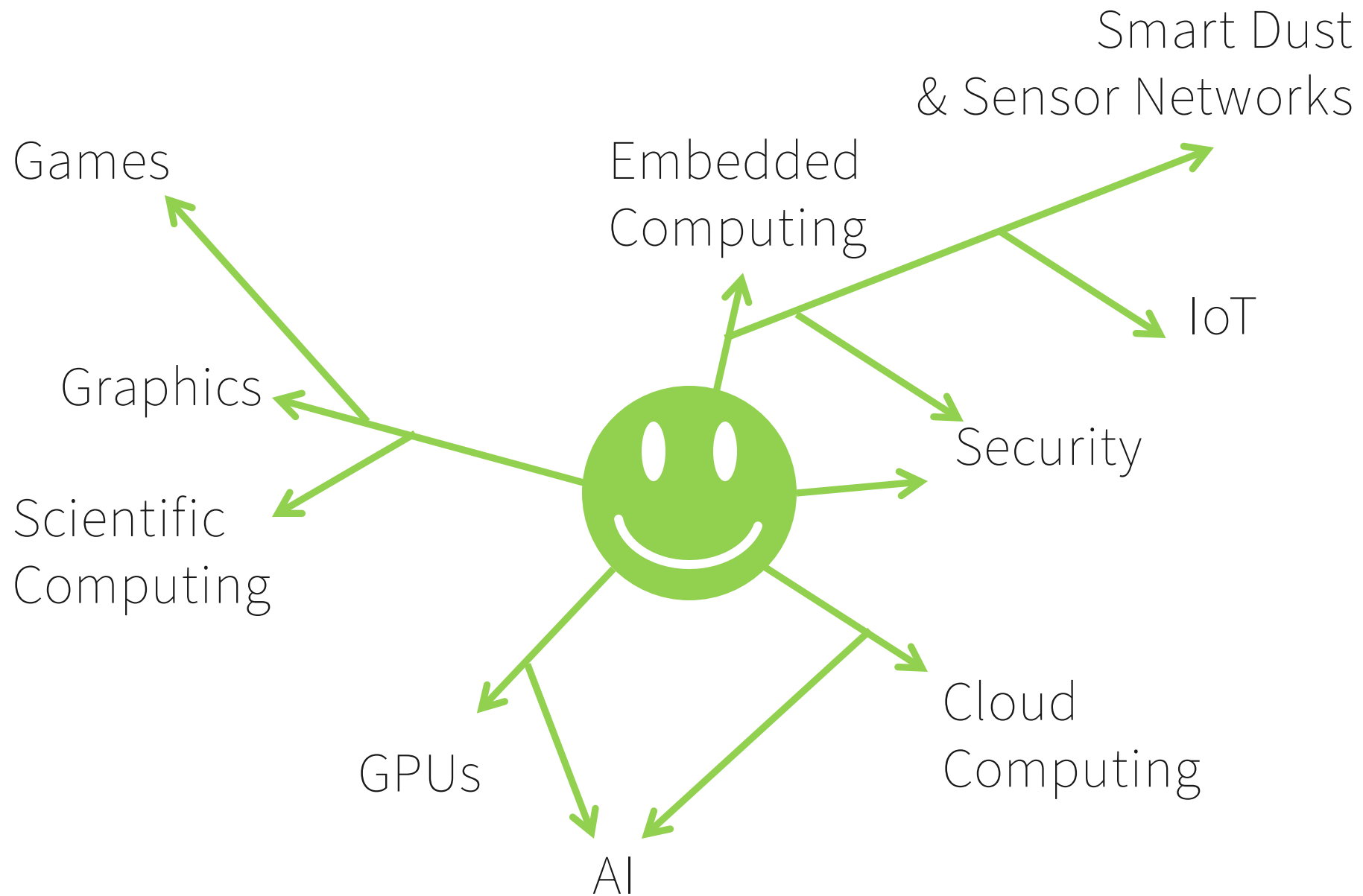to calculate ballistic
trajectories

Human Computers programming the IBM 7090

Mary Jackson


Hidden Figures

Courses Offered in Fall 2025

- CS 4410: Operating Systems (not offered in the Fall 2025, but offered Spring 2026)

- CS 4411: Practicum in Operating Systems

- CS 4414: Systems Programming

- **CS 4420 (ECE 4750): Computer Architecture

- CS 5414 - Distributed Computing Principles

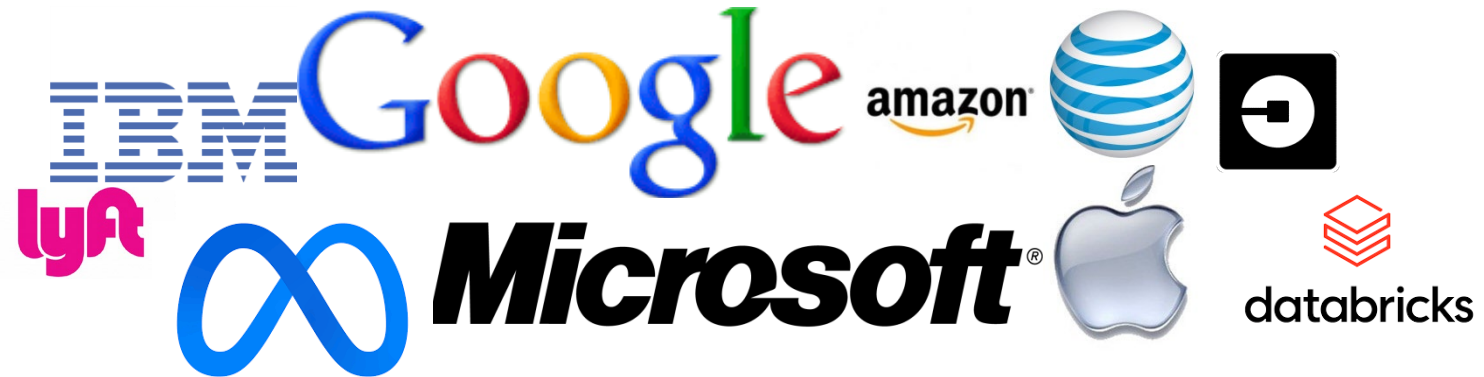- CS 5416 - Cloud Computing and ML Hosting

Where to?

- Your job as a computer scientist will require knowledge the computer
- Research/University
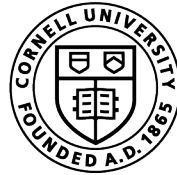
- Industry

- Government

Where are you going to be this summer?

"If you want to make an apple pie from scratch, you must first create the universe."

– Carl Sagan