COSC175 (Systems I): Computer Organization & Design

Professor Lillian Pentecost
Fall 2024

Warm-Up October 10

- Where we were
  - Memory Arrays; different ways of storing data, why it matters
- Where we are going
  - A Quick Historical Detour, a discussion of midterm exam
- Logistics, Reminders
  - TA help 7-9PM on Sundays, Tuesdays, Thursdays in C107
    - **SPECIAL midterm TA session with FOOD and EXTRA PROBLEMS, Sunday, Oct. 20 6-9PM**
  - LP Office hours M 9-10:30AM, Th 2:30-4PM
  - Weekly Exercises Due Friday 5PM (CYOA)
  - NO Weekly Exercises for next week; extra practice problems for midterm will be posted instead
  - Lab 4 Report due October 17 10PM
  - NO lab on Wednesday, October 16 (it is a Monday)
  - Weekly Exercise solutions will *not* be posted, but you are encouraged to ask (and respond to!) about specific questions or confusions using the Moodle Questions forum
  - ***Have a wonderful break!***
  - <u>***Midterm Exam, Oct. 22, 2 hour exam, 6-9:30PM, Pruyne Lecture Hall (show up no later than 7:30!!)***</u>

Midterm Logistics

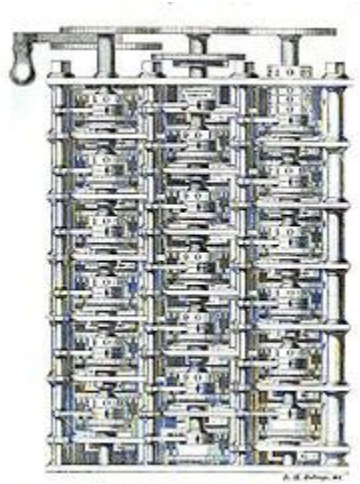
- Basics
  - You can type or handwrite; you will hand in a hard-copy, and optionally upload to Moodle
  - Tuesday, October 22, 2 hour exam + 5 minutes to submit via Moodle
  - ***You can use any of your own notes, and any materials on our Moodle page, no external resources***
  - I will grade ***anonymously*** (you will be assigned a pseudonym and given instructions when you arrive; you will make sure your pseudonym is on EVERY PAGE you submit)
- What types of questions? 1 short answer section + 3 "analysis+design" sections
  - Short-answer (2-3 sentences), from assigned readings and all in-class material (through today)
  - Be able to translate a plain-text description of a system's behavior into a circuit diagram
  - Be able to analyze a provided SystemVerilog implementation of a combinational or sequential logic design (you will not be asked to write any SystemVerilog from scratch)
  - Demonstrate comfort with binary representation, boolean expressions, and boolean algebra
  - Demonstrate understanding of important digital building blocks (e.g., ALU, Memory Arrays), and be able to analyze variations and extensions of these building blocks.
- How to study?
  - Review readings, weekly exercises, notes, and **lab reflection questions**
  - Make sure you understand terms and check-in questions from throughout the semester
  - **Ask additional questions via Moodle Questions forum by Wednesday, Oct. 16 at 5PM, and we will address with in-class review on Thursday, Oct. 17**

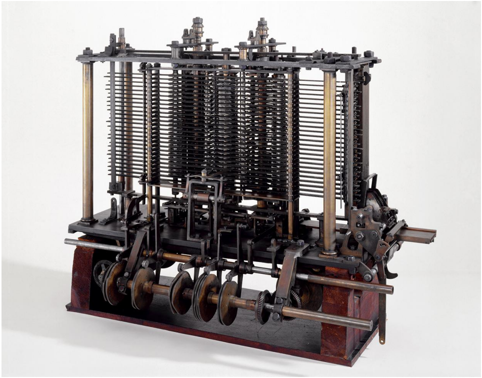
Our Brief Computer History Tour: Some Caveats

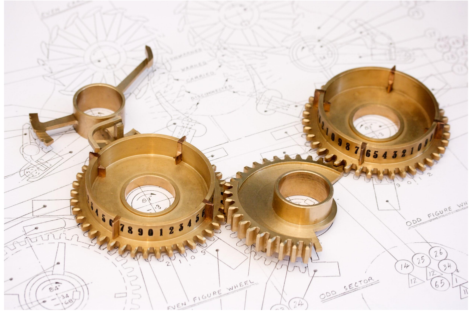
- This will be a USA-centric view, at least to start
- We will move quickly, and will focus on how the resources and the abilities of computers have evolved over the last century or so
- There are countless social, economic, and political questions to keep in mind
  - Why are these machines being built?
  - Where are these machines being developed, and who has access to them?
  - Who is doing the work of computing at each of these points in time?
- https://www.computerhistory.org/ has some great articles and is the main source of the dates and details I'll include today
- All images are gathered either via CHM or CC
- IBM archives are also an interesting resource

Way, way back: Mechanical Computers

- Lovelace and Babbage, 1830-1850
- Difference Engine(s)
  - Physical gear wheels in relative positions to represent input/output decimal values
  - Can perform specific calculations on fixed-size/type inputs by setting instructions for how to rotate many gears, then executing
  - Thousands of interlocking pieces for 16b operations
- Analytical Engine
  - Programmable via punched card
  - Separately takes instructions and data
  - Important concepts that carry though, but limited capabilities





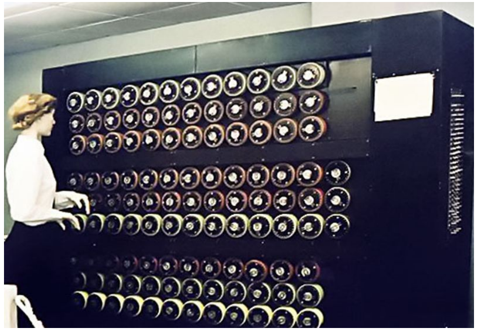


Special-Purpose Electrical Systems: 1930s-40s

- Model 1 Complex Calculator, 1939
- Model 2 in 1943, to compute weapons trajectories for the US army
- Electronic relays for telephone operators, message passing
- *Special purpose, simple circuits; data inputs via operator, punch card*

2-bit adder modeled after 1930's relay calculator

Calculator Operator, early 1940s

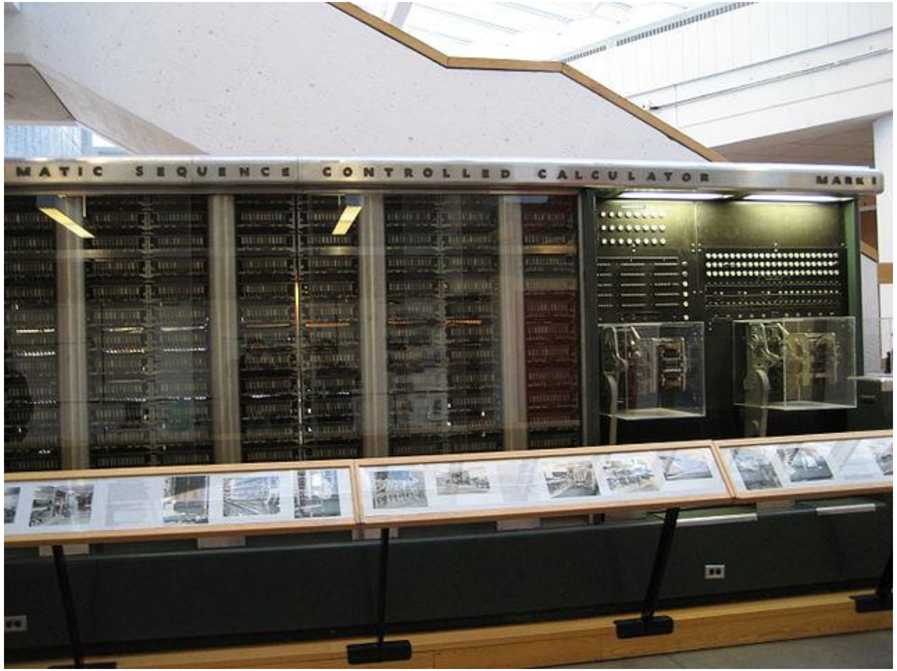


Alan Turing's ENIGMA work in WWII was an electro-mechanical machine

Teleprinters for messages during WWII

Mainframes: 1940s-1950s

- Harvard Mark I and several generations of relay-based, much larger calculators
- Programmed via punchcards, dots on paper tape, setting physical knobs for different datatypes, computations
- Ways of expressing problems, inputting data are key constraints



Harvard Mark I, completed in 1944, on display where I walked by to get to classes during my PhD

Stored-Program Mainframes: 1940s-1950s

- Electronic storage of data and instructions enables faster, more powerful interface, more flexible computations, the first ***software development***
- ENIAC could complete equivalent computations 1,000X faster than contemporaneous machines
- Primarily used for military applications, with early pioneering work in algorithmic and programming language development by the ENIAC programmers
- *10s-100s of words of data storage – less than 1 KB total*

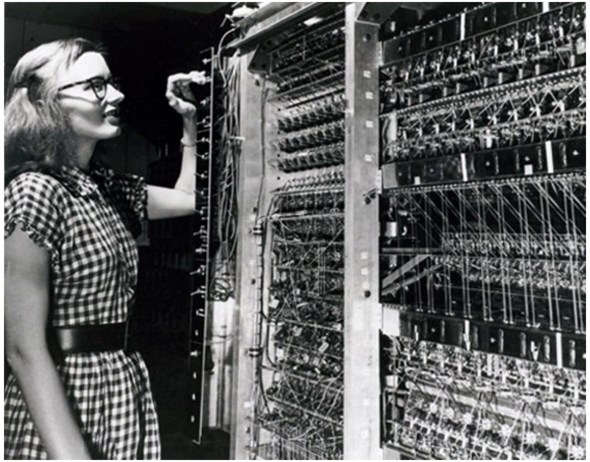
ENIAC was unveiled in 1943, takes up 1,000 square feet, and operates for 10 years

More Pictures of Mainframes: 1940s-1950s

- *10s-100s of words of storage – less than 1 KB total – programmability in terms of varied computations, just beginning to use computers for text manipulation, games, graphics*

IBM SSEC, used by NASA Apollo for moon-positioning-tables

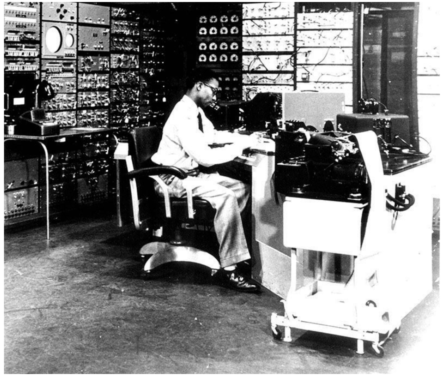
Grace Hopper with a UNIVAC I, a commercial computer



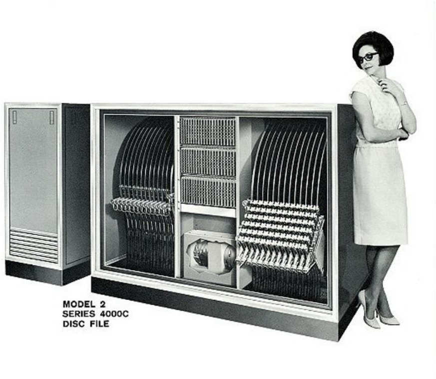
Mainframe at Los Alamos, for use in atomics weapons program

Advances in Manufacturing: 1950s-1960s

- Storage innovations: magnetic drums, keyboard input, other external devices
- About 10 KB of total storage, improved usability, exposure in (some) universities



MIT Whirlwind, piloting direct keyboard input, 1951

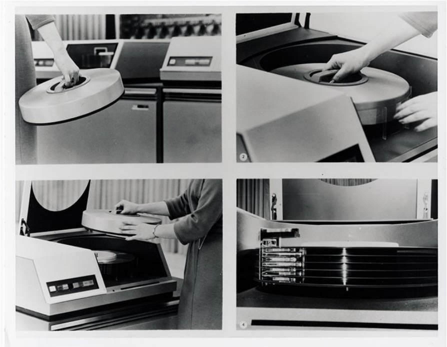


Advertisement for commercially available 10KB storage drum, mid-1950s

IBM 650, a mass-produced machine with magnetic drum storage

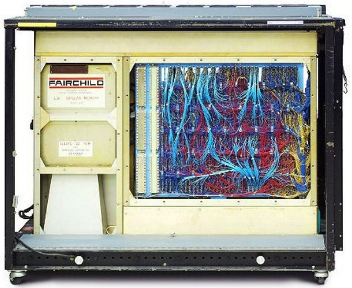
Advances in Manufacturing: 1950s-1960s

- ***The big one:*** Technological advance for storage and computation: ***transistors***
- Complemented by starting to get up to MB of storage via disk storage solutions



IBM magnetic disk storage, removable disks, early 1960s

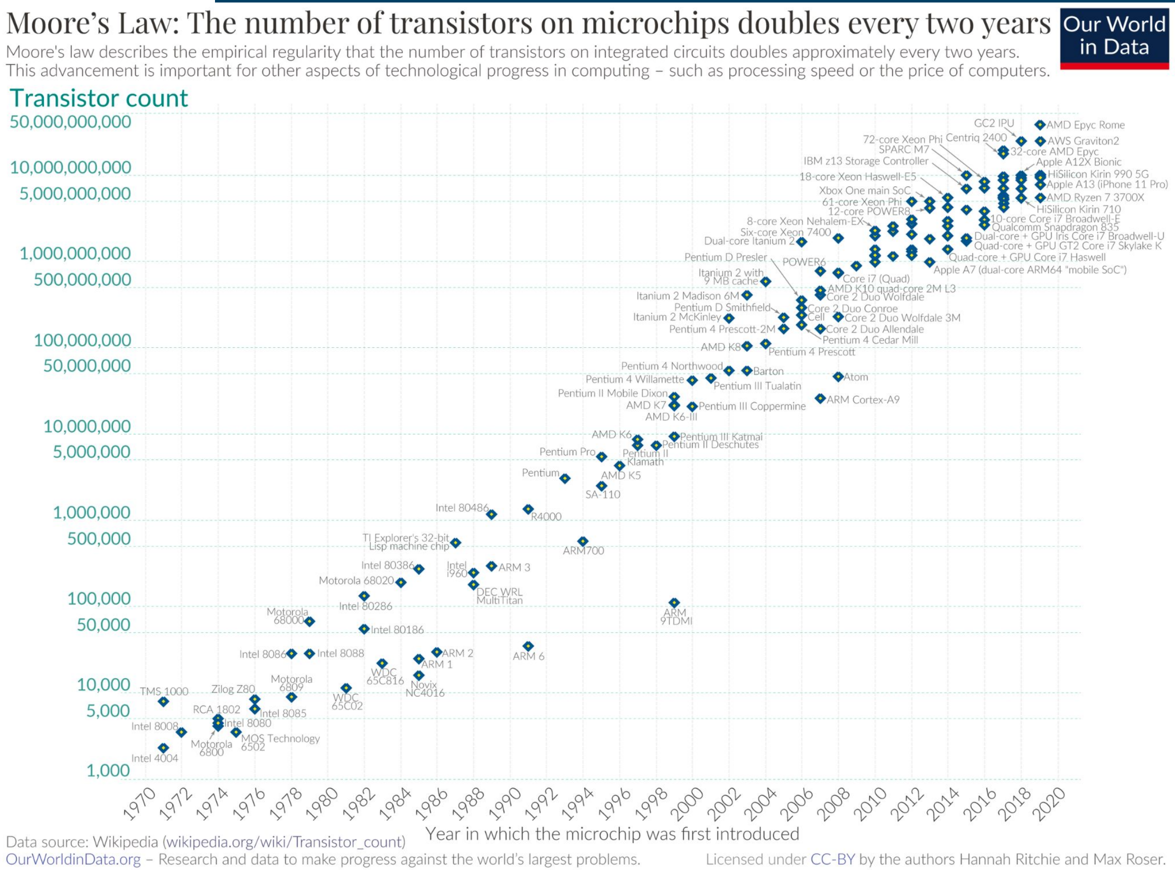
Fully transistor-based general purpose calculator in 1965, 100b capacity, but unreliable manufacturing



Fairchild Semiconductor SRAM; 16KB-1MB units used with commercial computers; consistently over 2X denser

Moore’s Law (a compulsory aside)

How is it that computers now fit in our bags and in our hands?



First Personal Computers: 1970s

A case study: Apple I in 1976

- Sold for $666.66 (just the board)
- ***<u>1 MHz CPU</u>*** → 1,000,000 instructions per second
- ***<u>4KB RAM</u>***
- Cassette Tape interface for loading/storing software and data
    - Otherwise, you re-type everything, including the programs you want to run, each time you turn on the machine
- Quickly out-paced by the Apple II

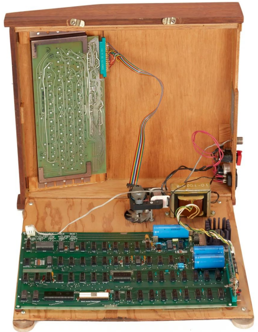


Photo credits: CNBC, NPR; specs from macrumors and NPR

First Personal Computers: 1970s

A case study: Apple II in 1977

- Sold for about $1,300, has a floppy drive controller, keyboard, and can plug into a TV or monitor, including color graphics (WOW!!!!)
- Up to 64KB RAM, similar CPU
- Primary improvements and reason for price is the usability and the interface

Photo credits: CNBC, NPR; specs from macrumors and NPR

First Personal Computers: 1970s

- Primary improvements and reason for price is the usability and the interface – ***software development*** takes off
  - Spreadsheets, word processing, graphics
- Interfaces and consistent systems become incredibly important – how to port software between machines, how do use different types of displays and programming languages?

Photo credits: CNBC, NPR; specs from macrumors and NPR

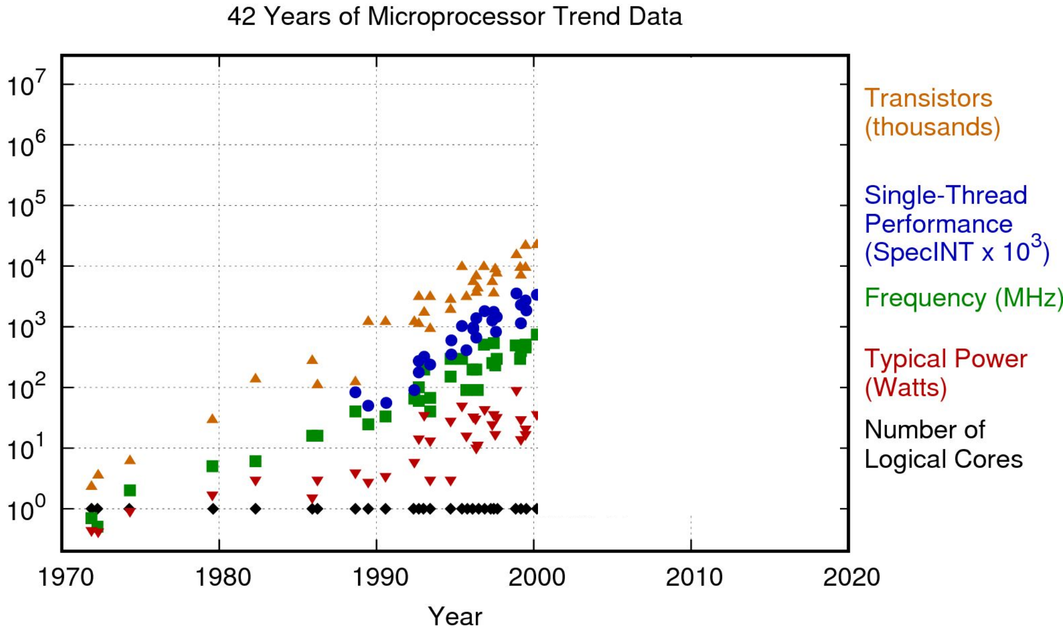
Apple Macintosh (128K) Specs

In 1984: A Personal Computer that finally "boxed up" all the key components a user would want into a pretty package, with a graphical interface, keyboard, and mouse. Apple was still relatively niche at the time, but made a big splash with this machine.

- 6 MHz processor
- 128 KB built-in RAM (a hard-to-open box made it hard to expand/tinker yourself, but the 512K model came out soon after…)
- Built-in Floppy Disk drive
- System Software 1.0 Operating System – brand new features like a menu bar + graphical file navigation
- Boot procedure + system software contained in a separate, 64KB ROM
- Bundled with applications for "creatives" – MacWrite and MacPaint
- Marketed for $2,495 (about $7-8k adjusted for 2023)

Banking in on Moore's Law: 1980s-1990s

- Machines get faster, memory gets denser, capabilities increase!
- Let the good times roll!
- Individual transistor dimensions scale from 40 microns to (most recently) ***<u>3-7 nanometers</u>***



Original data up to the year 2010 collected and plotted by M. Horowitz, F. Labonte, O. Shacham, K. Olukotun, L. Hammond, and C. Batten
New plot and data collected for 2010-2017 by K. Rupp

Banking in on Moore’s Law: 1980s-1990s

- 16 MHz+ CPU
- 4MB+ RAM
- A Hard Drive! Maybe 160MB
- Packaging a display, pre-loading some software

A new key issue emerges: how to quickly and easily share data, software across machines?

ARPAnet

Ordering your AOL installation CD in the mail to help you get connected online – early messaging and email

Listen to Steve Case of AOL on `How I Built This`, NPR

Emergence of the Memory Wall

Hitting the Memory Wall: Implications of the Obvious

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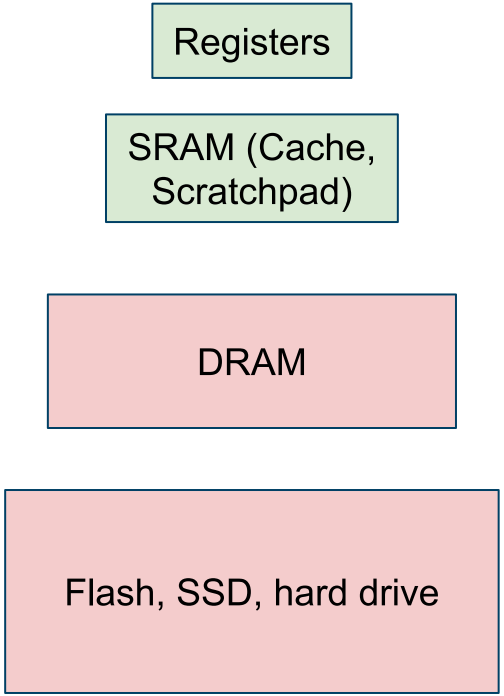
December 1994

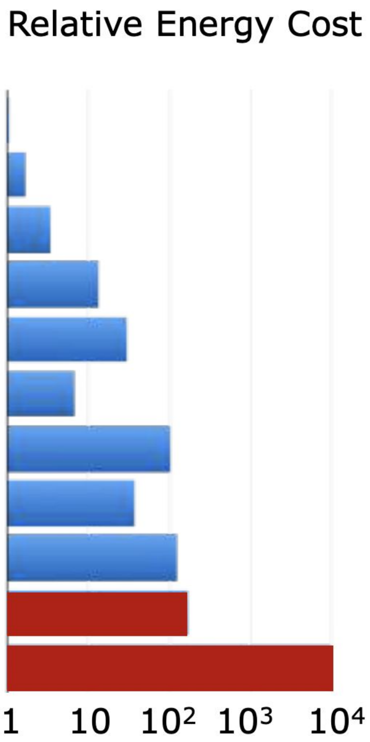
This brief note points out something obvious — something the authors "knew" without really understanding. With apologies to those who did understand, we offer it to those others who, like us, missed the point.

As noted above, the right solution to the problem of the memory wall is probably something that we haven't thought of — but we would like to see the discussion engaged. It would appear that we do not have a great deal of time.

Accessing memory remains strictly more costly; what does this mean for our applications?



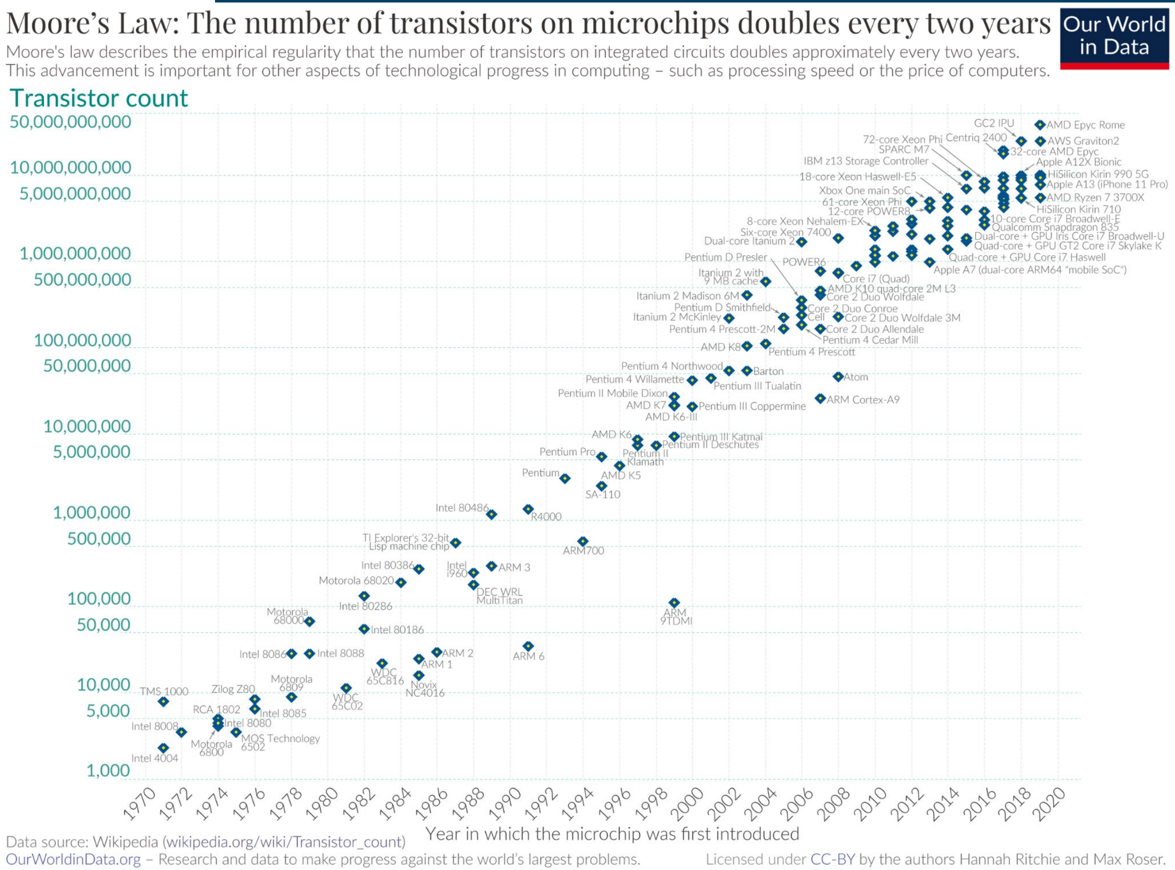
Operation:	Energy (pJ)
8b Add	0.03
16b Add	0.05
32b Add	0.1
16b FP Add	0.4
32b FP Add	0.9
8b Multiply	0.2
32b Multiply	3.1
16b FP Multiply	1.1
32b FP Multiply	3.7
32b SRAM Read (8KB)	5
32b DRAM Read	640



[**Horowitz**, *ISSCC* 2014]

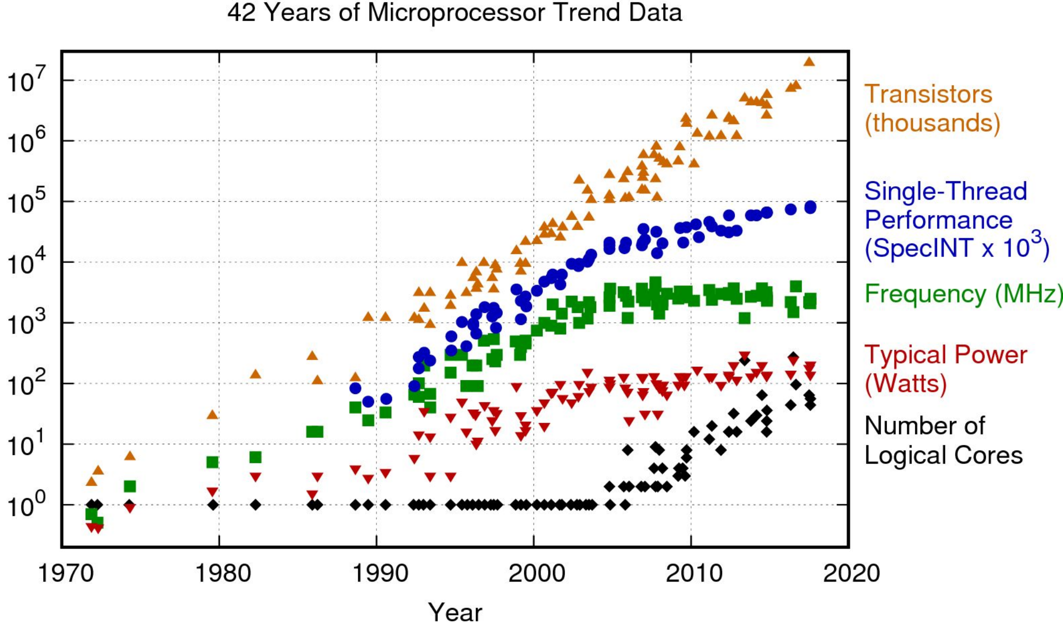
Moore's Law Check-In

(1)Read just the first section of original Moore's Law paper (until "Past and future", or as far as you get, see link on Moodle),
(2) talk to a neighbor,
(3) write down a question



Multi-Core; Delaying the Inevitable: 2000s

- Increase number of logical cores – do more in parallel to maintain same amount of productivity
- Power density and ***dark silicon***
- Complexity and management of devices increases, ***programmability and usability are paramount***



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Wrap-Up October 10

SCAN ME

- Coming up next!
  - Bringing us into the 21st century; midterm review; midterm feedback
- Logistics, Reminders
  - TA help 7-9PM on Sundays, Tuesdays, Thursdays in C107
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  - You can expect Lab2, Lab3, and Weekly Exercise feedback to be posted by Friday, October 18
  - ***Have a wonderful break!***
  - ***<u>Midterm Exam, Oct. 22, 2 hour exam, 6-9:30PM, Pruyne Lecture Hall (show up by 7:30!!)</u>***
- FEEDBACK
  - https://forms.gle/5Aafcm3iJthX78jx6