

VLSI Design

EEC 116

Lecture 1

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Thursday, September 28, 2023

Today

- Administrative items
 - Syllabus and course overview
 - Course objective and strategies
- My background
- Chapter 1
- Read *Chapter 1*
- Read "Cramming more components onto integrated circuits," Gordon Moore, *Electronics*, April 19, 1965.
- Homework 1 posted on web page; due next Thursday

Course Workload

- 4 unit course
- Upper division
- This course requires significant effort and time
 - Circuits
 - Layout
 - Tools
 - Magic
 - Irsim
 - (Design Compiler, Innovus)
 - Major design project

Lectures

- Ask questions at any time
 - Please raise your hand
 - Ask a question at any pause (zoom)
- Be respectful of others
 - Hold conversations outside of class
 - Silence phones
 - Sit in the back if you come in late or need to leave early

Course Communication

- In class during lecture
- Canvas announcements → Email
 - Time-critical announcements only
- Web page
 - Primary source of course information
- Office hours
 - Tue/Th after lecture
 - Wed 2pm tentative
 - Posted on the course web page
 - Let me know by the second lecture if you have a conflict
- Please see me (or TA) in person or by zoom with questions rather than email

My Teaching Philosophy

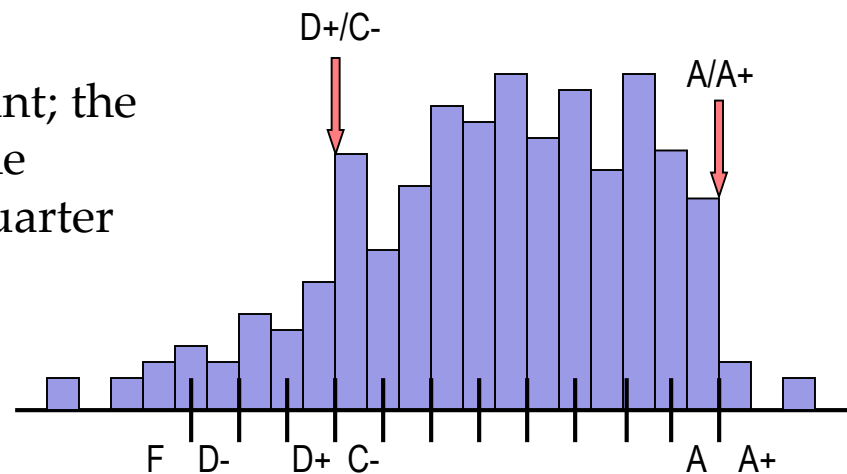
- Primary goal (mine and yours):
Learn VLSI design well
- Achieve this through:
 - Reading textbook
 - Lectures
 - Solving problems on paper
 - Solving problems in lab
 - Discussions with other students, TA, myself
 - Come to office hours

Grading Philosophy

- Grading serves two main purposes:
 - 1. Motivate you to do the work required to learn
 - 2. Give others an indication of how well you know the material
 - Requires honest work and fair grading

Letter Grade Assignments

- I assign a letter grade only for the final course grade
- You can see score statistics for each graded item on Canvas
- I look at the final exams and course record of the class and assign two key dividing points: the A/A+ and D+/C- boundaries, and assign course grades from there using equally-sized intervals
 - No required numbers of any particular letter grades
 - Absolute scores are not important; the boundaries shift according to the difficulty of the exams in any quarter
 - In fact, easy exams cause large grade drops for small errors
 - **Ignore any letter grades you might see on canvas**



Working With Others

- Collaboration
 - Asking questions and explaining principles produces better work and dramatically increases learning
 - Working with others
 - Do homework and prelabs with classmates nearby
 - Ask each other questions, help each other—regarding **principles**, and **general approaches** to solving only
 - See *Course Collaboration Policy* on web page
- Final Project: done individually
 - Groups of 2
- Dishonesty
 - Copying produces similar work, stunts learning, is not fair to honest students, and is not allowed in this course
 - Students engaged in dishonest work will be referred to Student Judicial Affairs
 - I will try to keep in-class exams honest
 - Steps will be taken to keep out of class work honest

Penalties for Violating the *Policy on Student Conduct and Discipline*

- Penalties
 - Minimum penalty: meetings with SJA officer, zero grade on work, record with SJA
 - Permanent F grade on your transcript, no credit for the class
 - One to three quarter suspension from the university
 - Permanent dismissal from all ten campuses of the University of California. Permanent notation on your transcript.

Penalties for Violating the *Policy on Student Conduct and Discipline*

- Several perspectives
 - Personal obvious reasons
 - ECE and UCD (especially for those inclined to share work with someone doing poorly in class)
Cheating harms our major and university's reputation among employers who interview our graduates.
- In summary: The purpose of the penalties and this discussion is so that no one will get the penalty!!!
Don't do anything that violates the Policy on Student Conduct!

Penalties for Violating the *Policy on Student Conduct and Discipline*

- Typical scenario:
 - Someone shares code/design with another
 - They get caught
 - The “Copier” feels terrible guilt for causing a friend to get a zero
 - The “Sharer” deeply regrets sharing resulting in a zero when he/she should have had a full score

Exam and Quiz Regrades

- Some number of exams and quizzes will be scanned before being returned
- Key take-away messages:
 - Do not change anything on your work if you request a regrade
 - Students have in the past and got in big BIG trouble!!!

Cheating Websites

chegg, coursehero, etc.

- The university has recently taken a very strong stand against paying for work (2-quarter suspension for first offense in the last case)
- Key take-away messages:
 - Do not post assignments
 - Of course do not use any unpermitted outside material in work you submit
 - Of course do not post solutions
 - Two students did last year and got caught!!!

Submitting Work

- Homework drop box on the second floor of Kemper
- ~~• Unless announced otherwise, materials due must be submitted through canvas as instructed~~
- ~~• Only pdf format~~
 - ~~— It greatly simplifies grading~~

Course Web Page

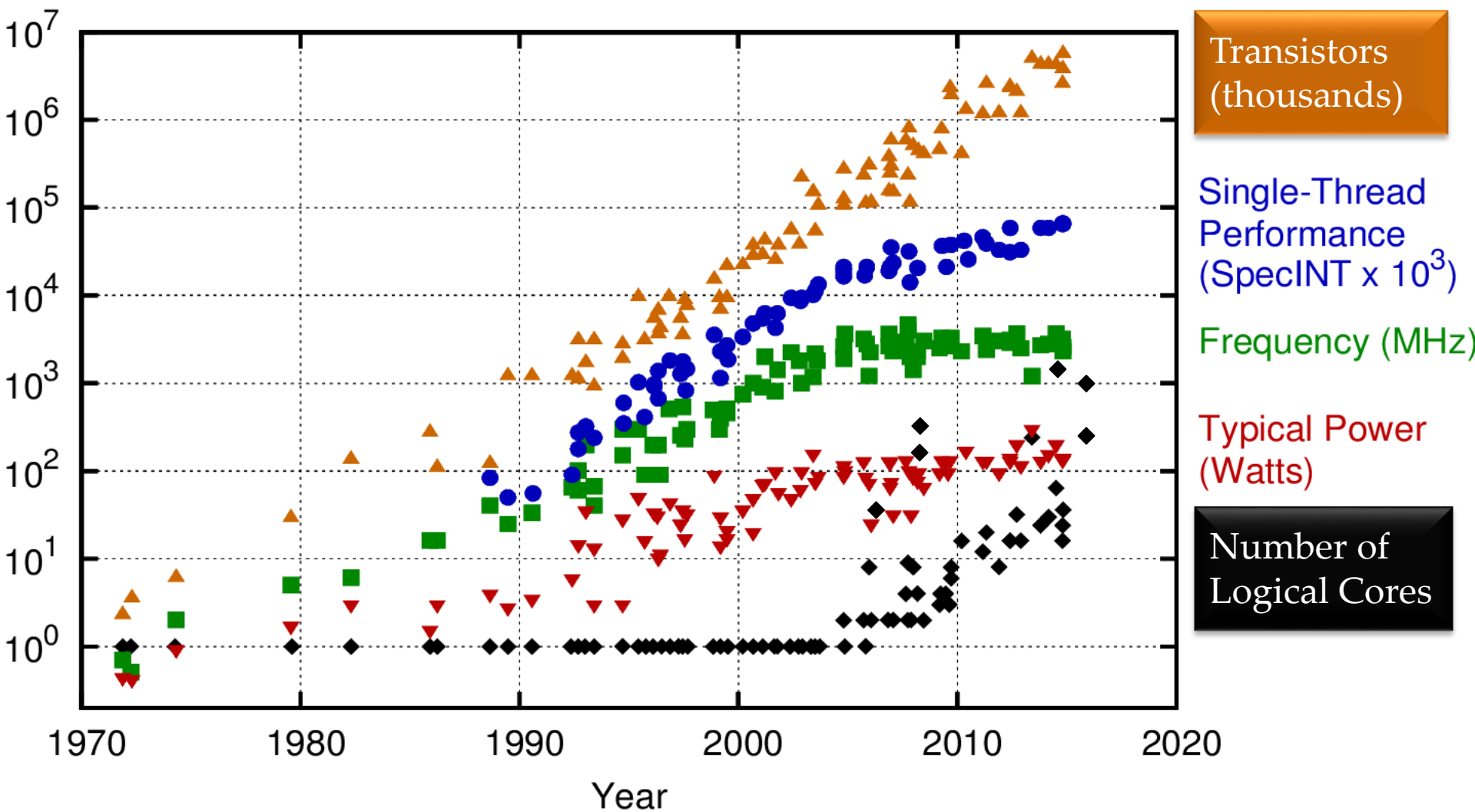
`http://www.ece.ucdavis.edu/~bbaas/116/`

- This link is posted on the canvas home page

Colored pencils

- Buy colored pencils or pens whose colors match magic layout tool layer colors
 - green
 - brown (orange next closest?)
 - red
 - blue
 - purple
- Used for “stick diagrams”
- Slightly transparent pencils or pens work best

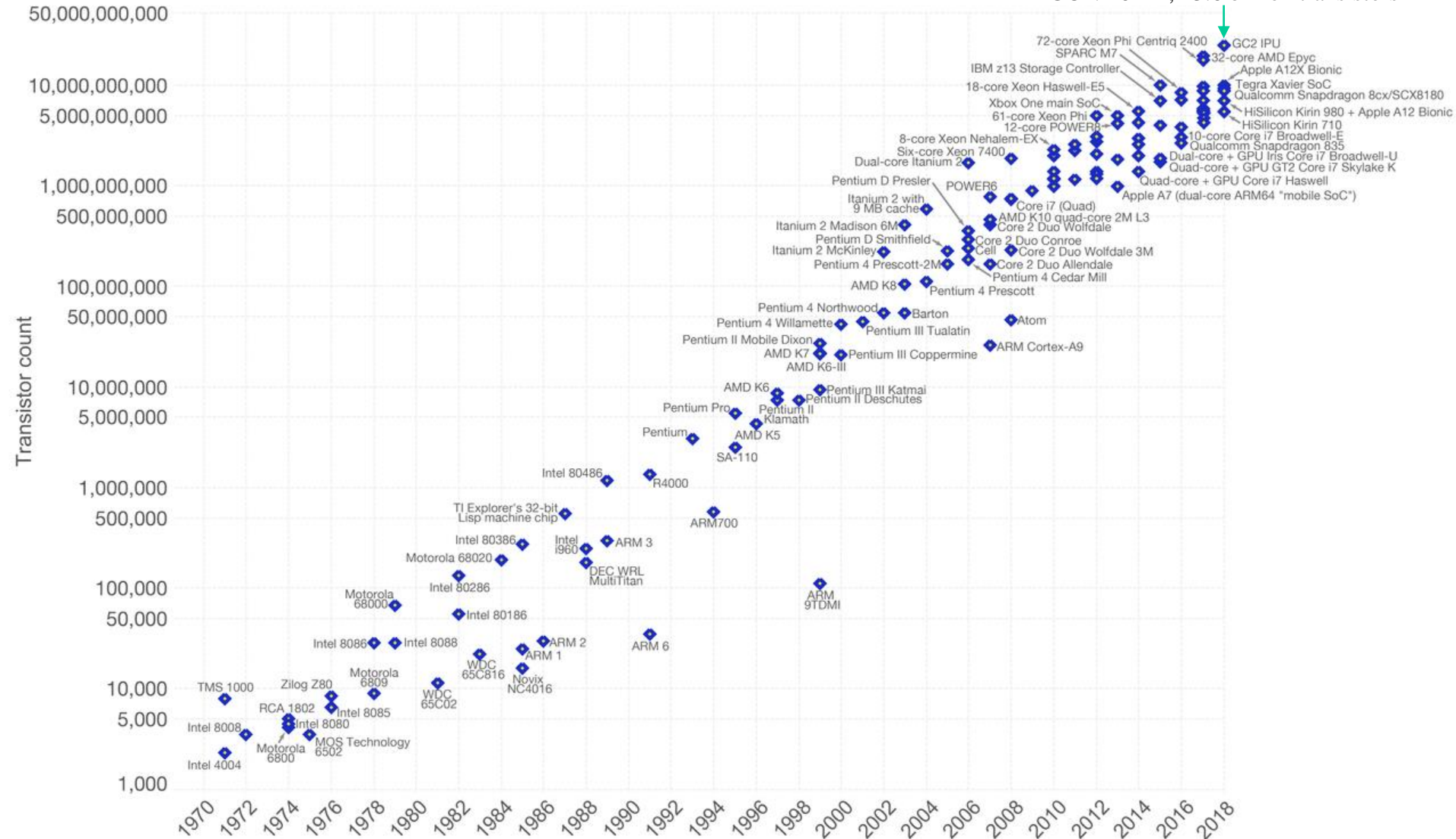




Original data up to the year 2010 collected and plotted by M. Horowitz, F. Labonte, O. Shacham, K. Olukotun, L. Hammond, and C. Batten
 New plot and data collected for 2010-2015 by K. Rupp
 New data added by B. Baas

Moore's Law – The number of transistors on integrated circuit chips (1971-2018)

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

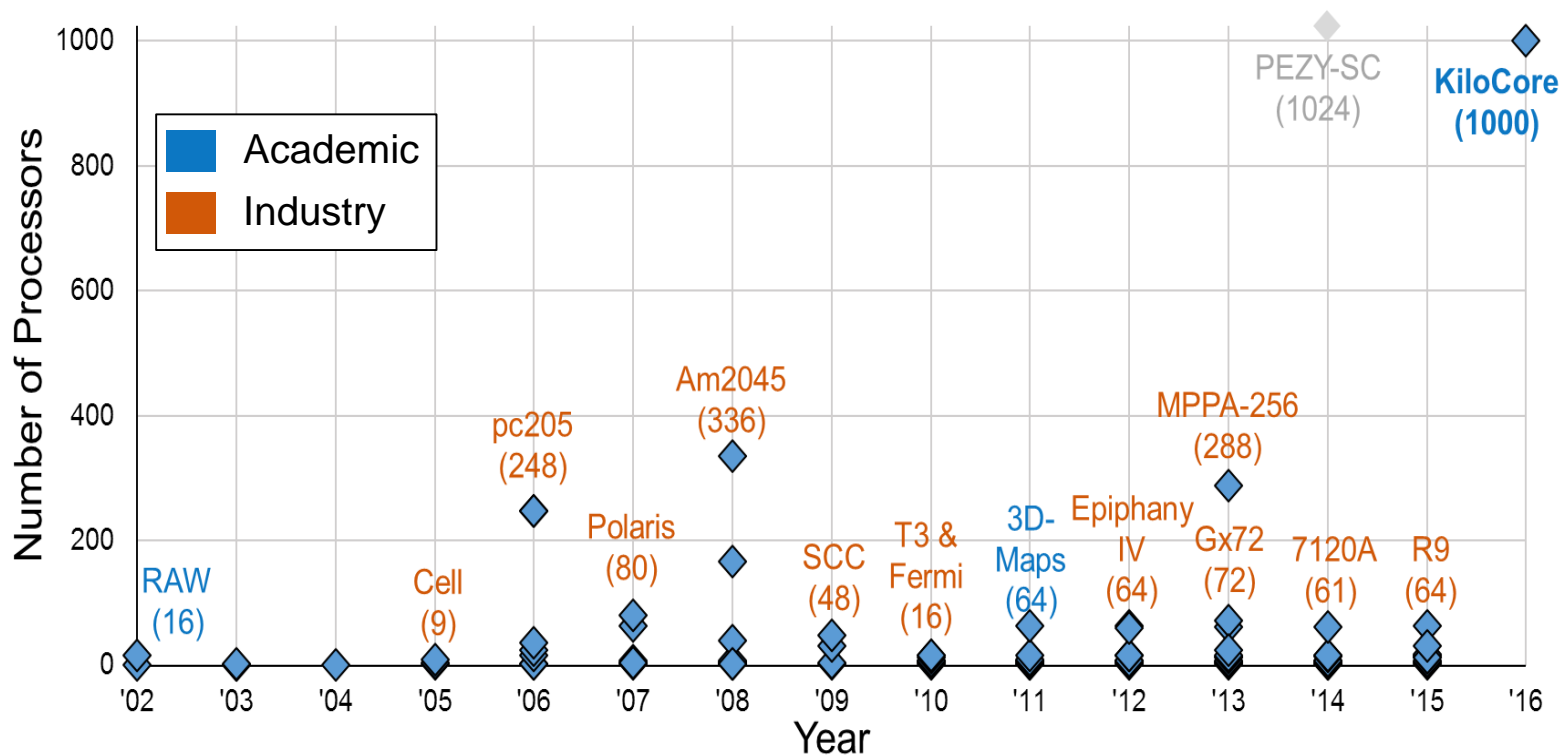


Data source: Wikipedia (https://en.wikipedia.org/wiki/Transistor_count)

The data visualization is available at [OurWorldinData.org](https://www.ourworldindata.org). There you find more visualizations and research on this topic.

Licensed under CC-BY-SA by the author Max Roser.

Processors Over Time



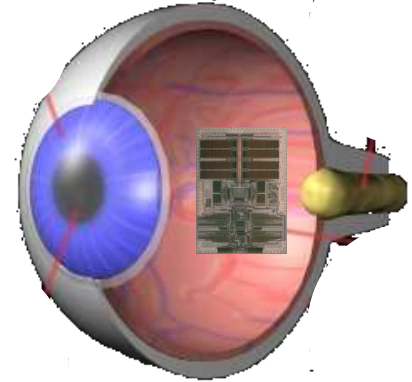
- Number of processors on a single die vs. year
- Each processor capable of independent program execution

Undergraduate Research

- Talk to me after the midterm if you are interested
- Unfortunately I can not take all interested students
- I will say that there is a very strong correlation with GPA and success in research

Future Applications

- Very limited power budgets
- Require significant digital signal processing



Some Points on Course Coverage

- Emphasis on low-level design (full custom layout, circuits). EEC 180 is higher-level
- Emphasis on VLSI-specific issues
 - Coverage of CMOS fabrication technology
- Focus on digital circuits rather than analog circuits
 - Due to tremendous simplifications in circuit design, layout extraction, and simulation
- Limited coverage of digital circuits such as what is covered in EEC 118

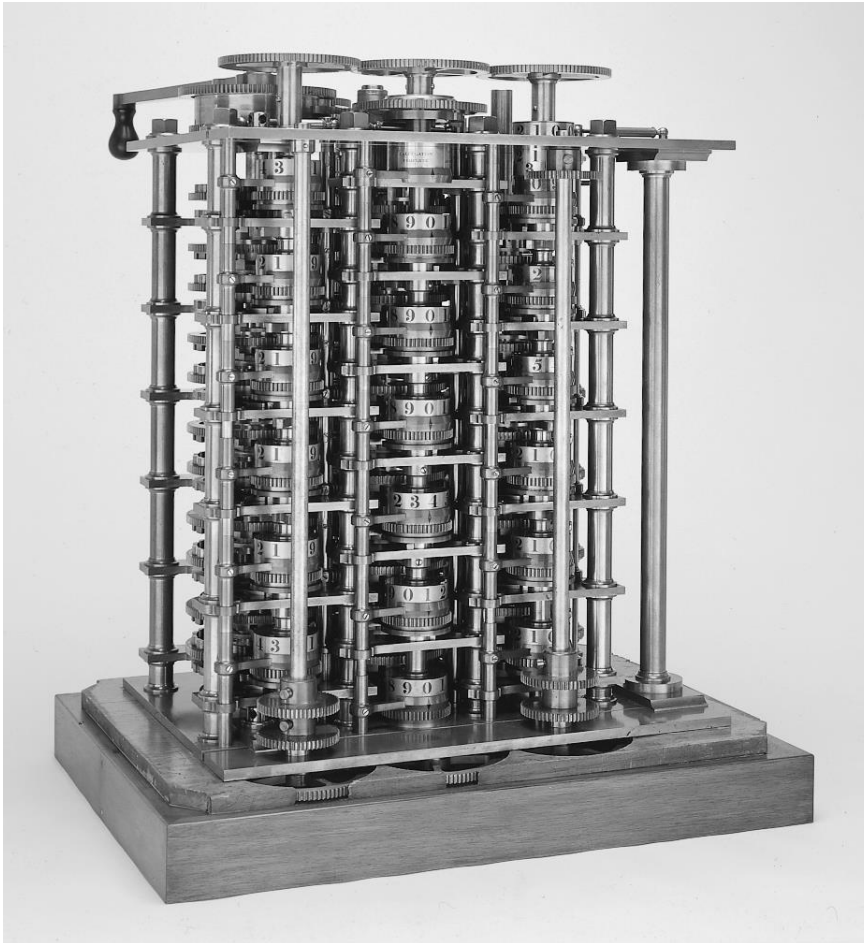
EEC 116 Outline

- Introduction
- Cost, yield
- CMOS fabrication
- CMOS VLSI layout
- Inverter characteristics
- MOS resistance, capacitance
- Sequential circuits
- Optimizing performance
- Complex combinational gates
- Logic circuit styles
- Wires
- Chip-level structures
- Chip-level issues
- Array memories
- Packaging
- Standard cell P&R overview

Chapter 1—Introduction

- History of computing
- What is inside a processor
- How they are designed

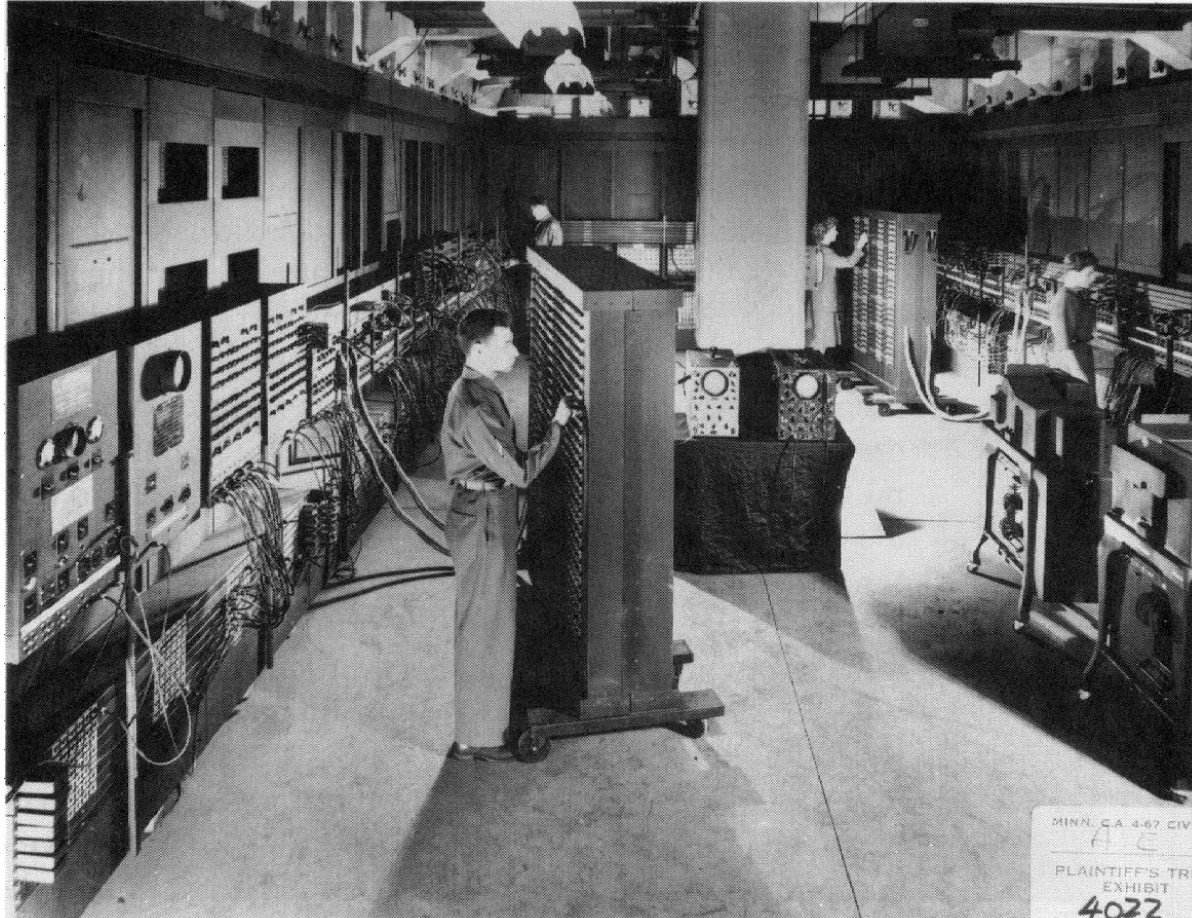
The First Computer



**The Babbage
Difference Engine
(1832)**

**25,000 parts
cost: £17,470**

ENIAC - The first electronic computer (1946)



What Is A *Processor*?

- Something that processes!



Example applications:

- Microwave oven controller
- CD or DVD player
- Hearing aid
- Personal computer
- Digital watch
- Cell phone
- Radar for an airplane
- Datacenter server processor

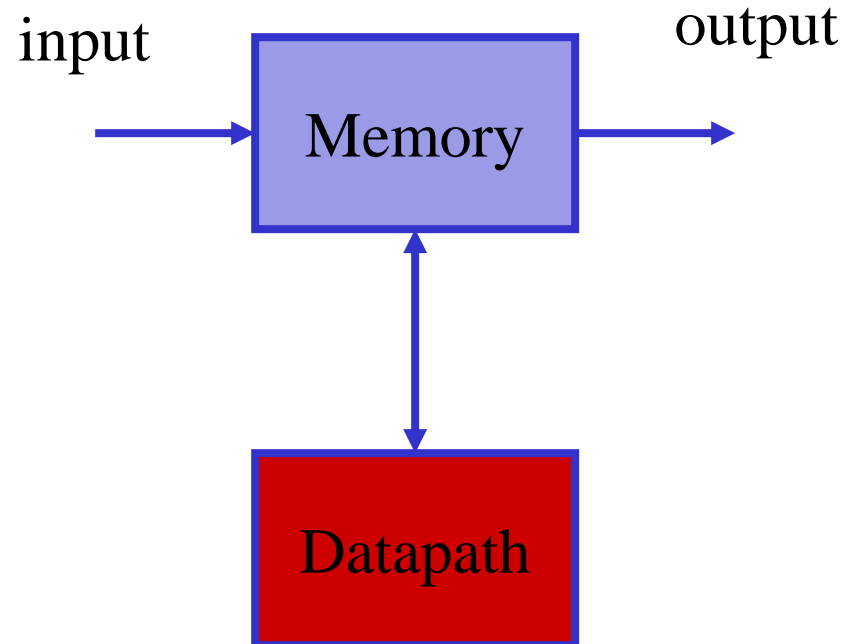
What Is Inside One?

- Three main components
 - Memory



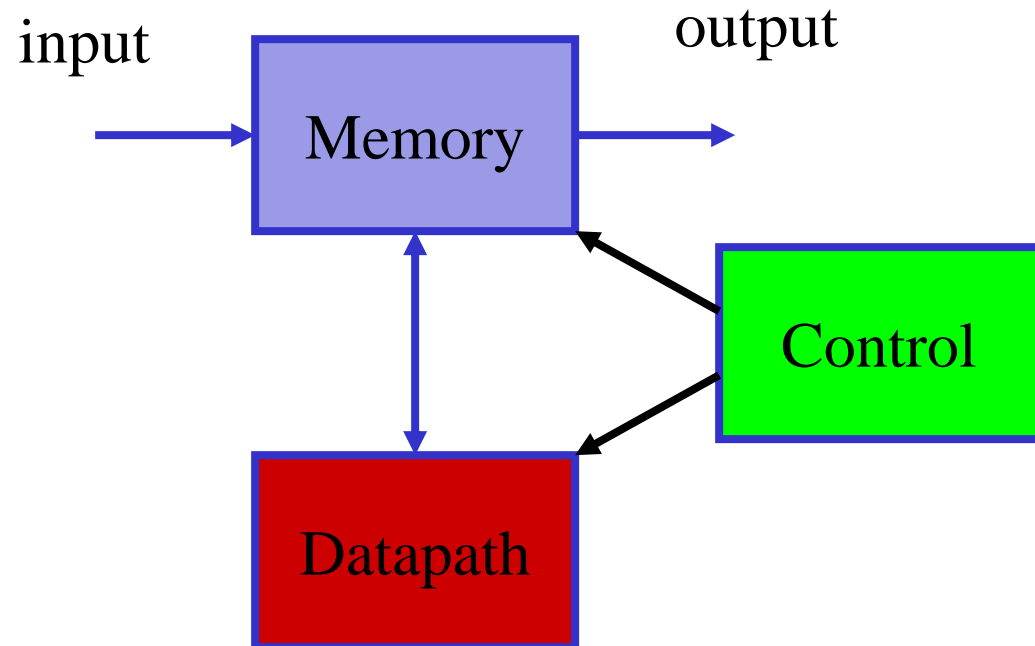
What Is Inside One?

- Three main components
 - Memory
 - Datapath



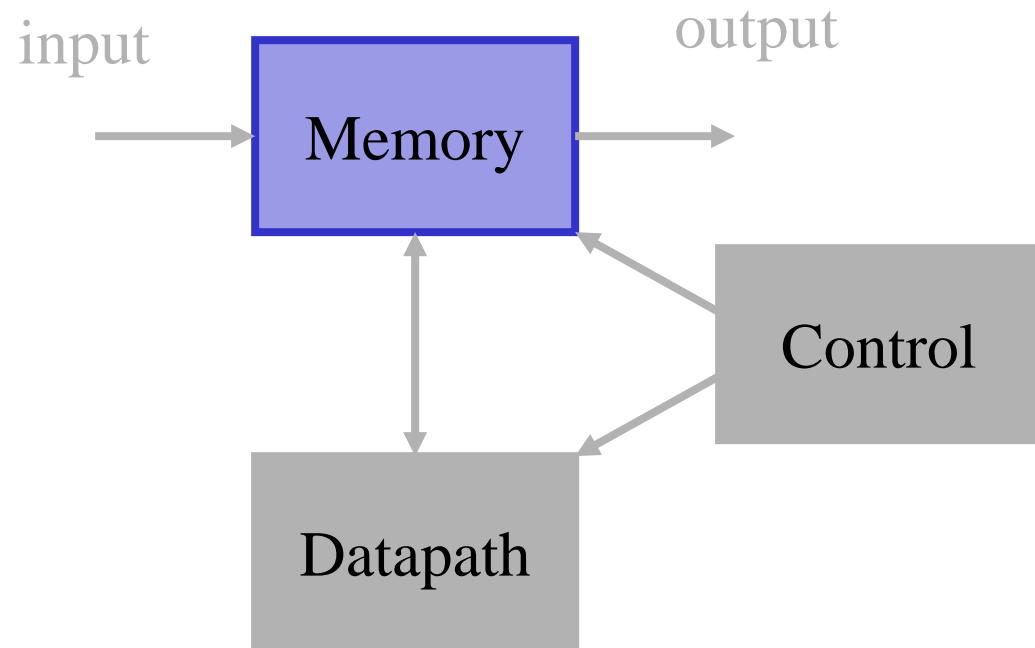
What Is Inside One?

- Three main components
 - Memory
 - Datapath
 - Control



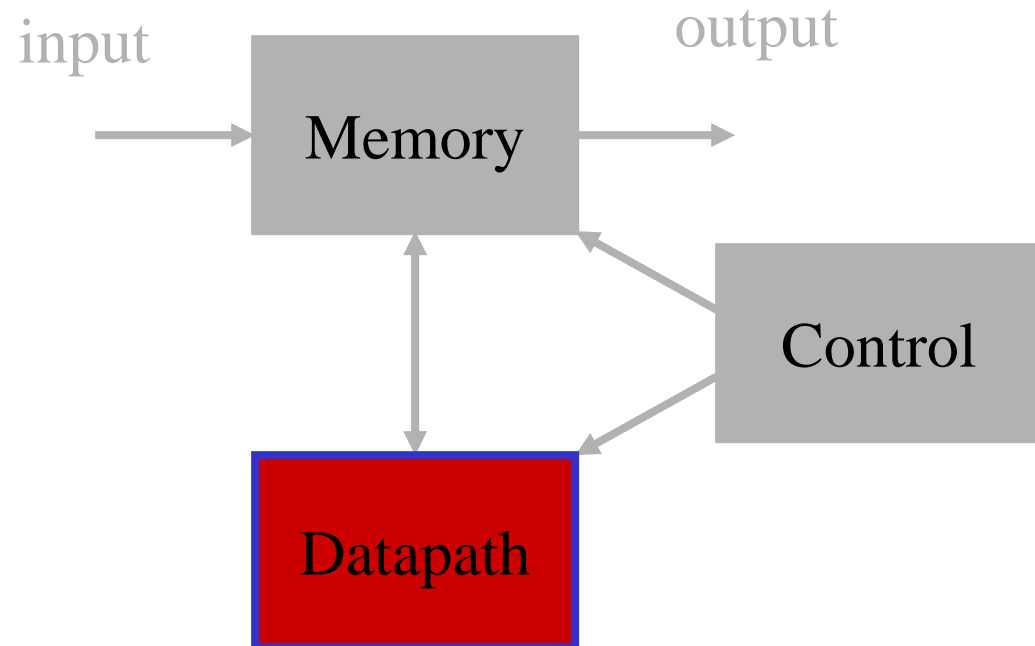
Memory

- Stores information
- Examples
 - Temporary chip memory
 - “256 MB RAM”
 - Permanent chip memory
 - “Flash non-volatile memory”
 - Hard disk
 - “80 GB disk”



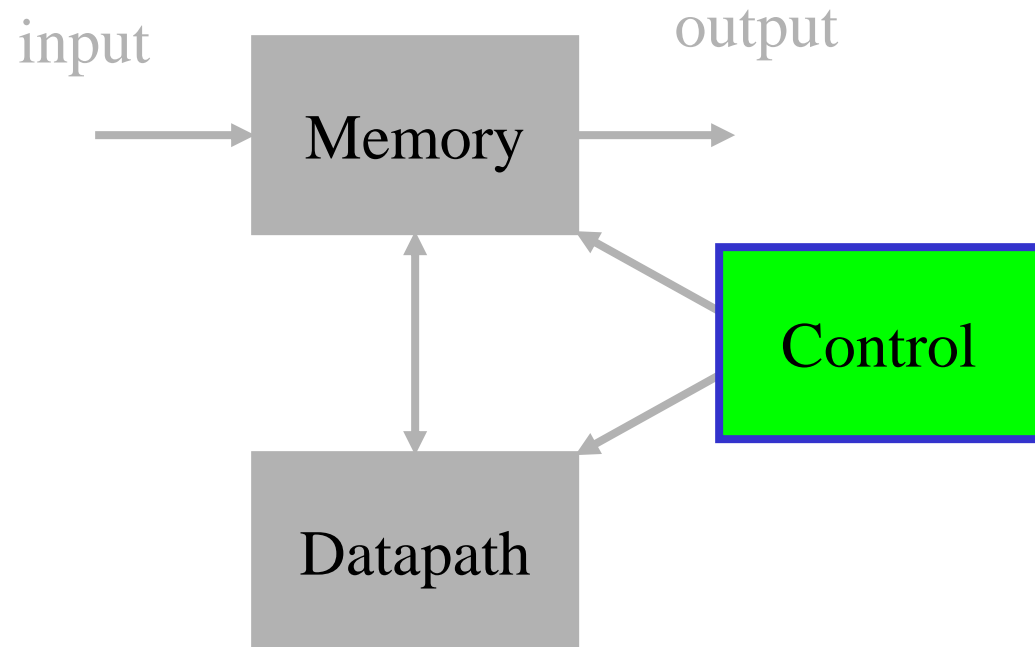
Datapath

- Processes information
- Example tasks
 - Add
 - Multiply
 - Move
 - Compare



Control

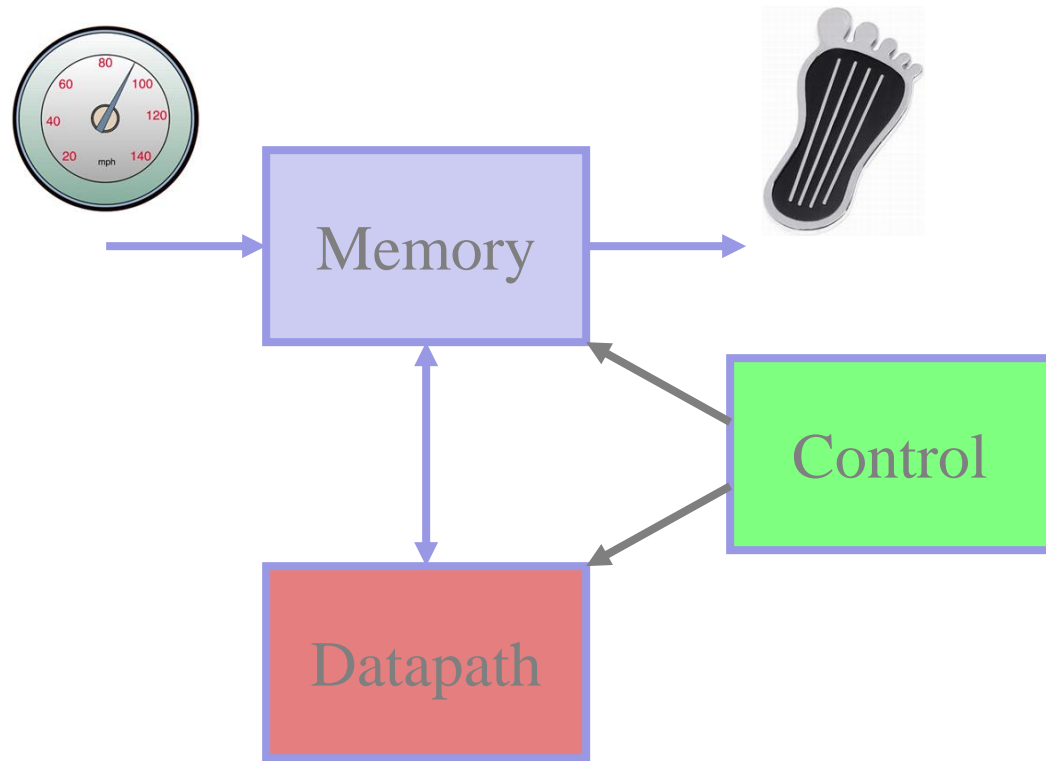
- Runs the show
- Examples
 - Software
 - Word, Excel
 - Large database
 - Hardware (best for simpler, fixed, high-speed tasks)
 - MP3 player
 - Signal processing



Simple Blocks Working Together

Example #1

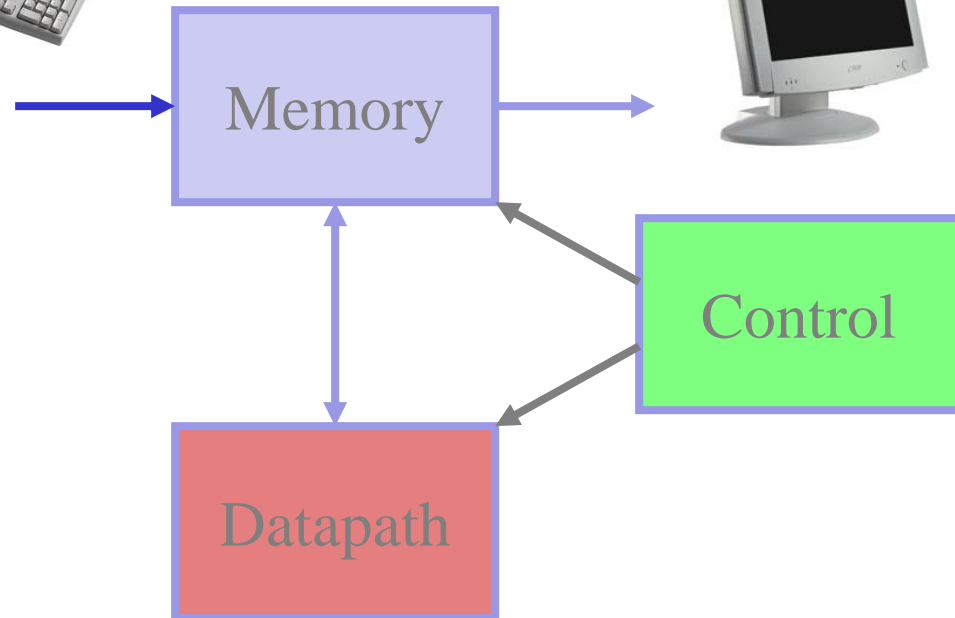
- Auto cruise control
 - Watch car's speed (*input*)
 - Compare with set speed (*datapath, compare*)
 - If adjustment is needed, add or subtract (*datapath*) from setting and send update to gas pedal (*output*)



Simple Blocks Working Together

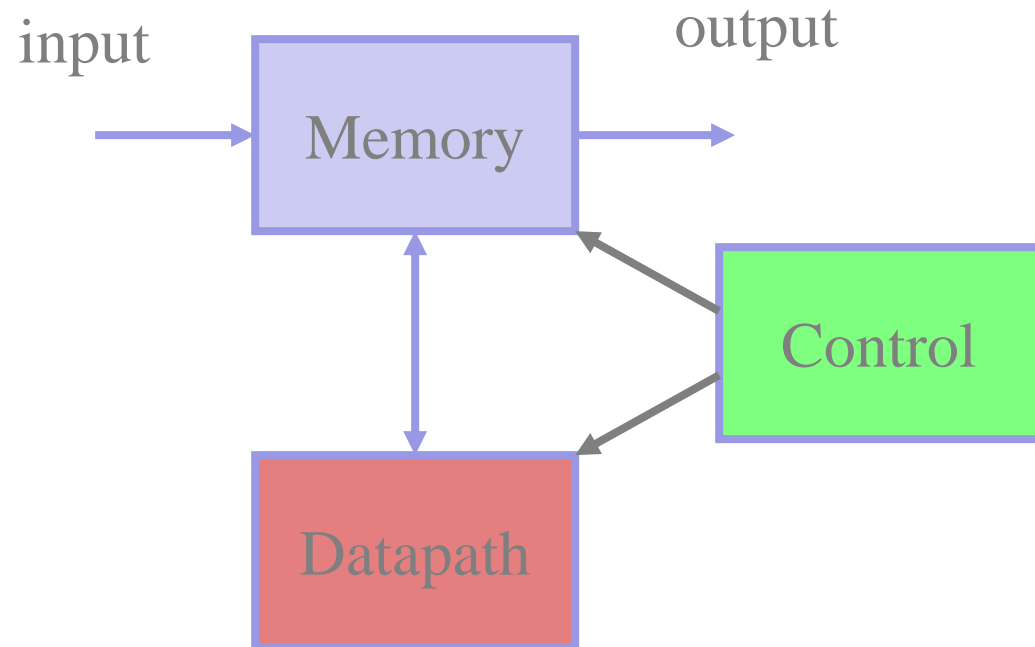
Example #2

- Google search
 - Type in search words (*input*)
 - Look through large database of web pages (*memory*) until matches are found (*datapath, compare*)
 - When list is found, send it to user (*output*)



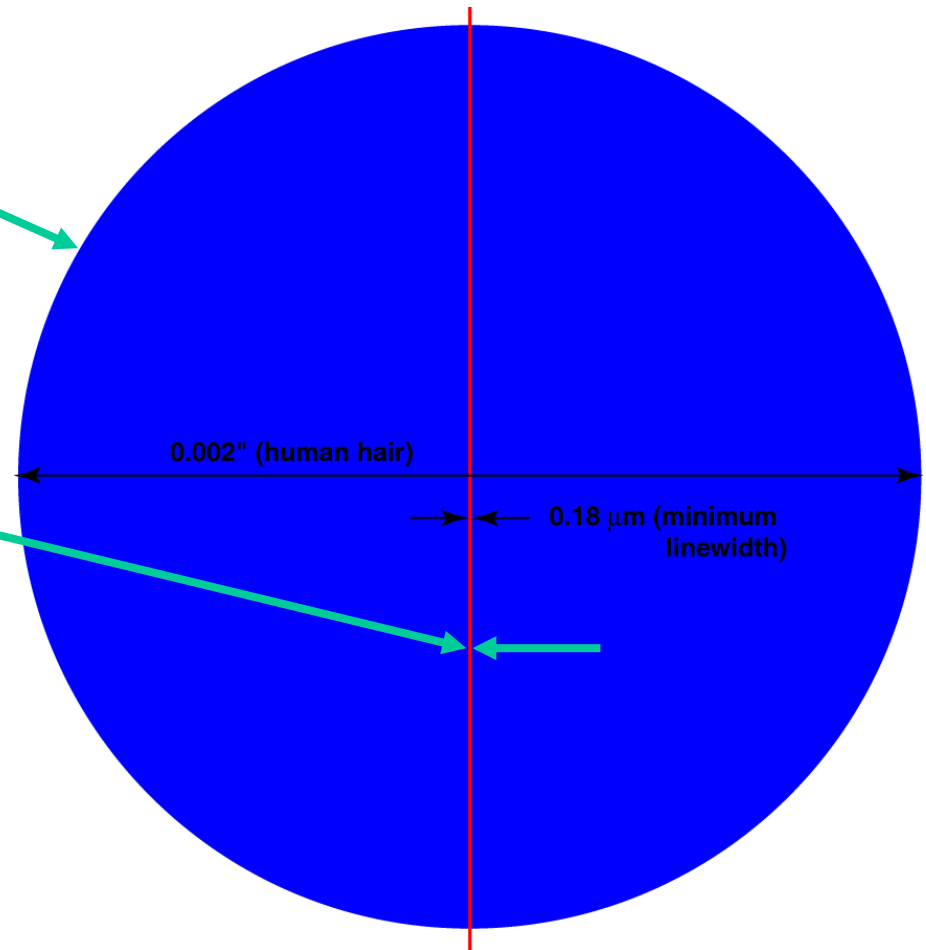
Simple Blocks Working Together

- Key point
 - Simple operations alone can not do much, but billions of simple operations per second can do a lot!



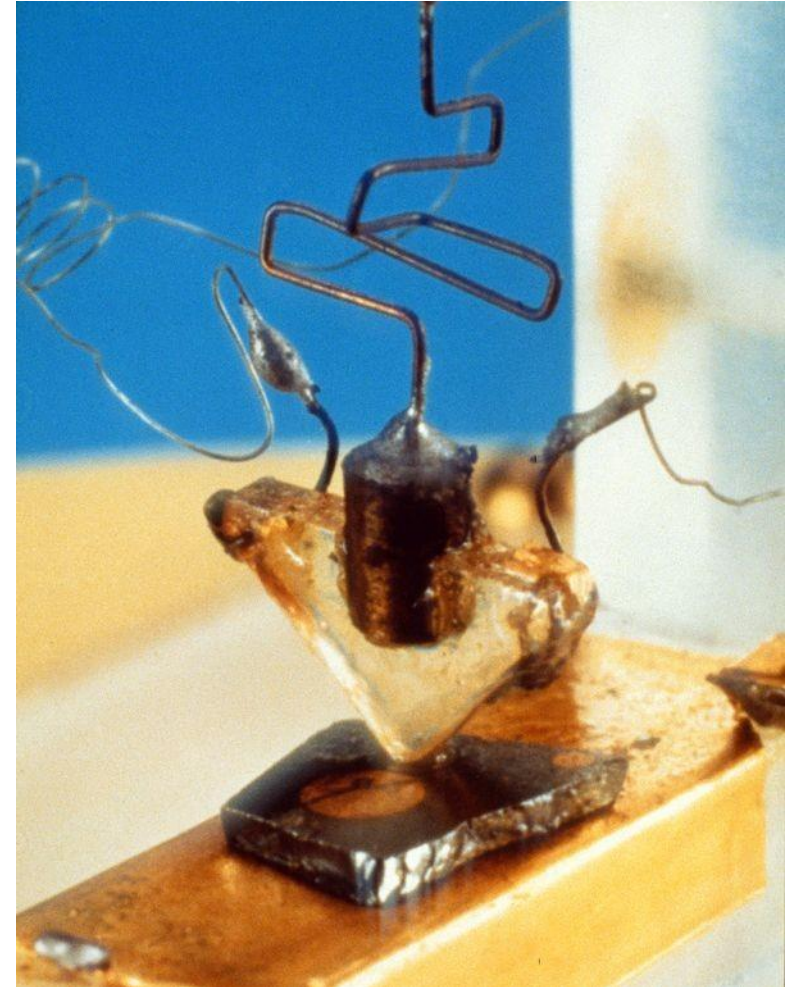
How Large Are Transistors?

- If a human hair were this large...
- A transistor that was state of the art around the year 2002 ($0.18\ \mu\text{m}$) would be this long
- Modern transistors are approximately $35\times$ smaller...



The First Transistor

- Fabricated at Bell Labs on December 16, 1947. The inventors William Shockley, John Bardeen, and Walter Brattain won the Nobel prize in physics in 1956 for the invention. It is one of the most important inventions in history.



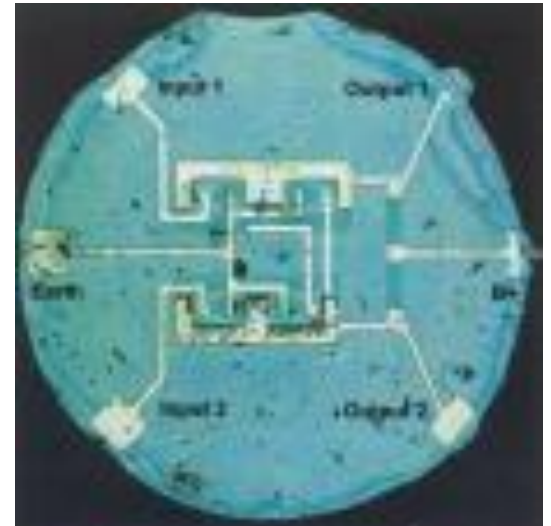
The First Integrated Circuit

- This is the first IC made by Jack Kilby of Texas Instruments. It was built in 1958.



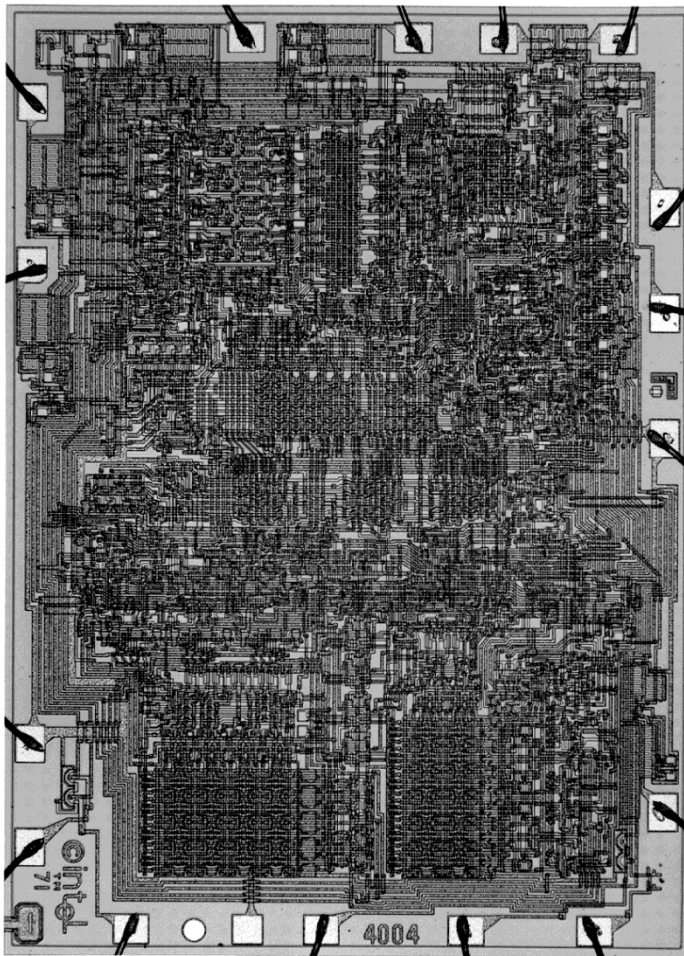
An Early "Planar" IC

- This is an early planar IC from Fairchild.

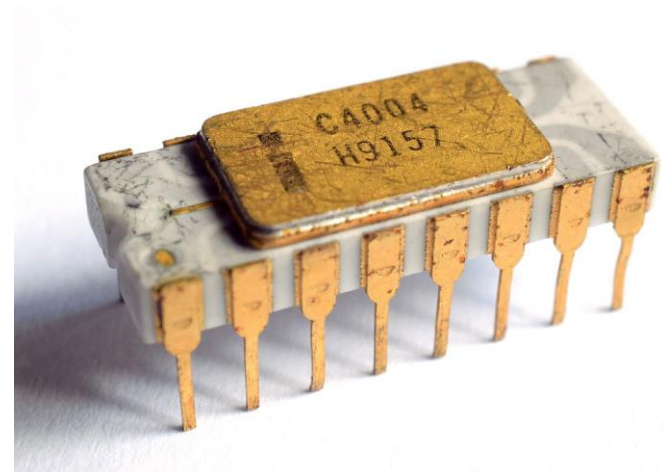


Intel 4004

The First Single-Chip Microprocessor

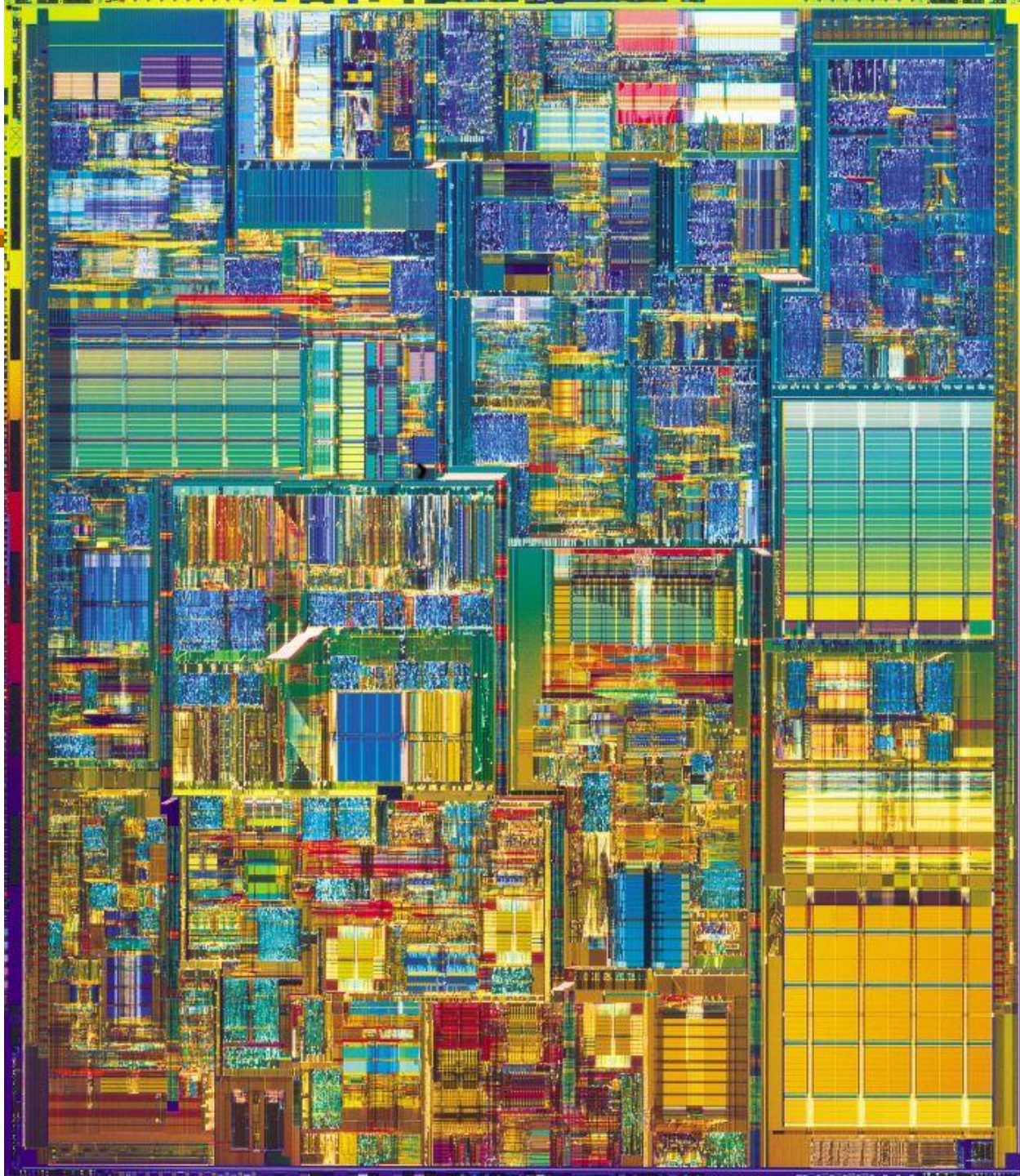


- released in 1971
- 2,250 transistors
- 10 μm minimum feature size
- 0.75 MHz max clock rate



Intel Pentium 4 Microprocessor

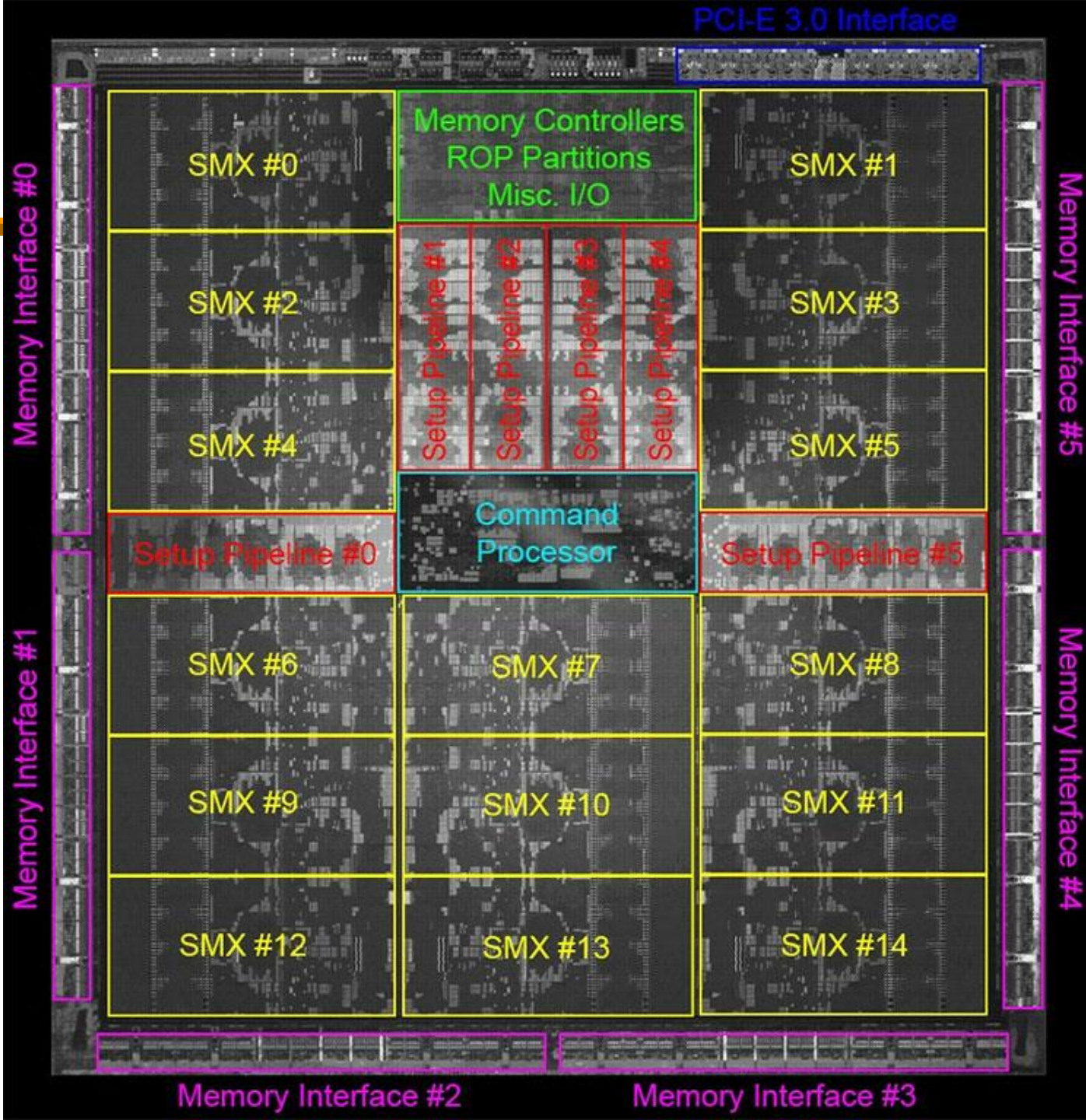
- Introduced in 2000
 - 42 million transistors
 - 0.18 μm CMOS



Source: Intel
http://www.intel.com/museum/online/hist_micro/hof/

Nvidia Kepler GK110

- 7.1 Billion transistors
- 2880 CUDA datapaths



Source: xxxxxx

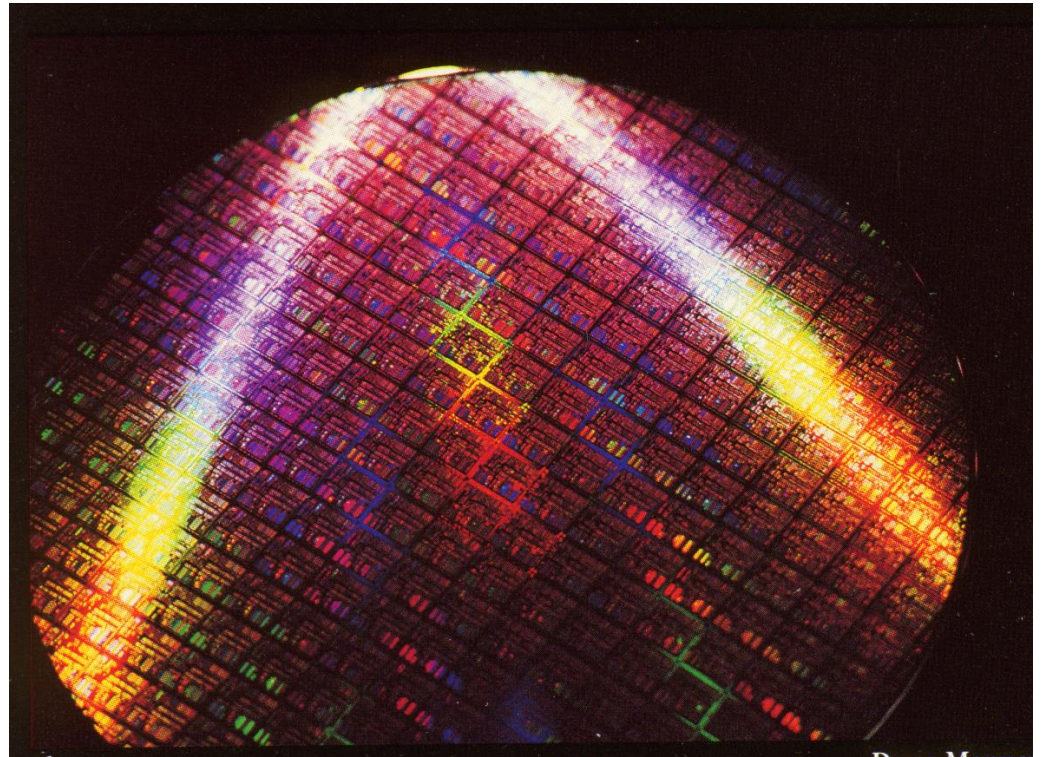
Silicon

- Silicon is the second most common element in the Earth's crust.
- Semiconductor-grade Si is 99.999999 % pure.
- Ingots like this one weigh several hundred pounds and cost \$16,000
- The ingot will be sliced into very thin wafers.



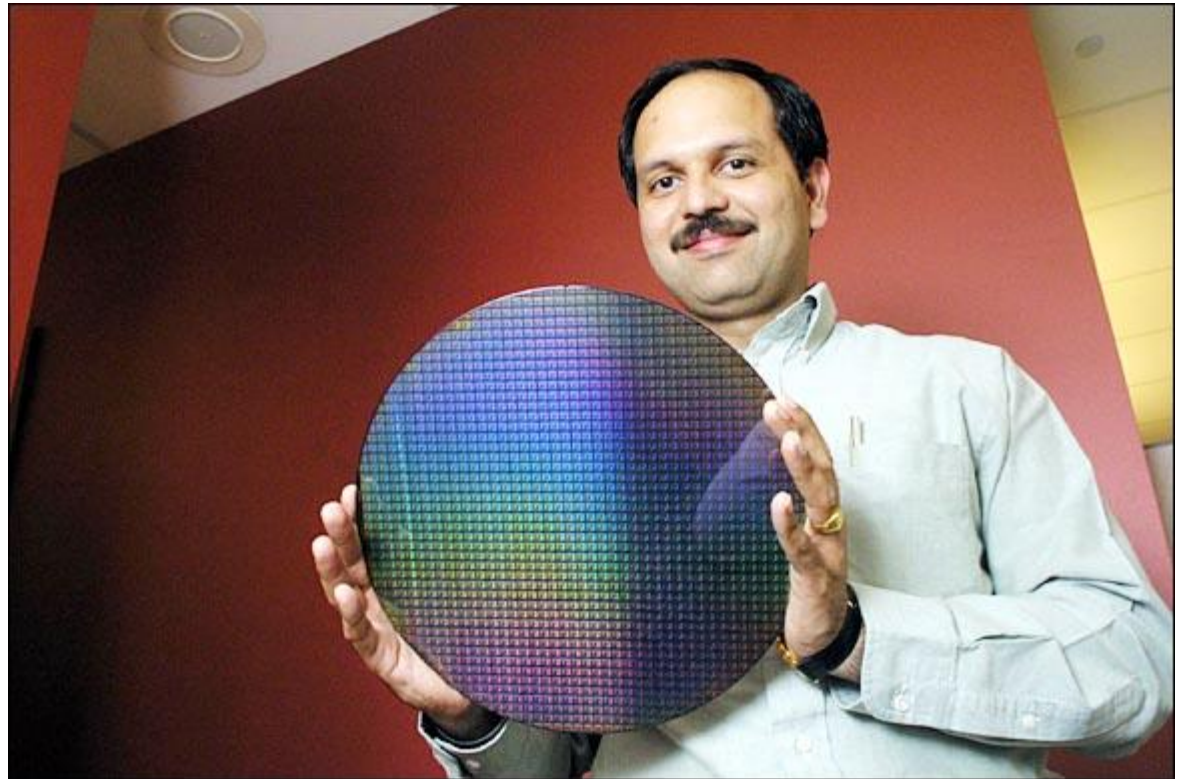
A Silicon Wafer

- This 8-inch wafer contains about 200 Pentium II chips (1997).
- Each chip contains more than 20 million transistors.
- More than 1 billion microprocessors are made each year.



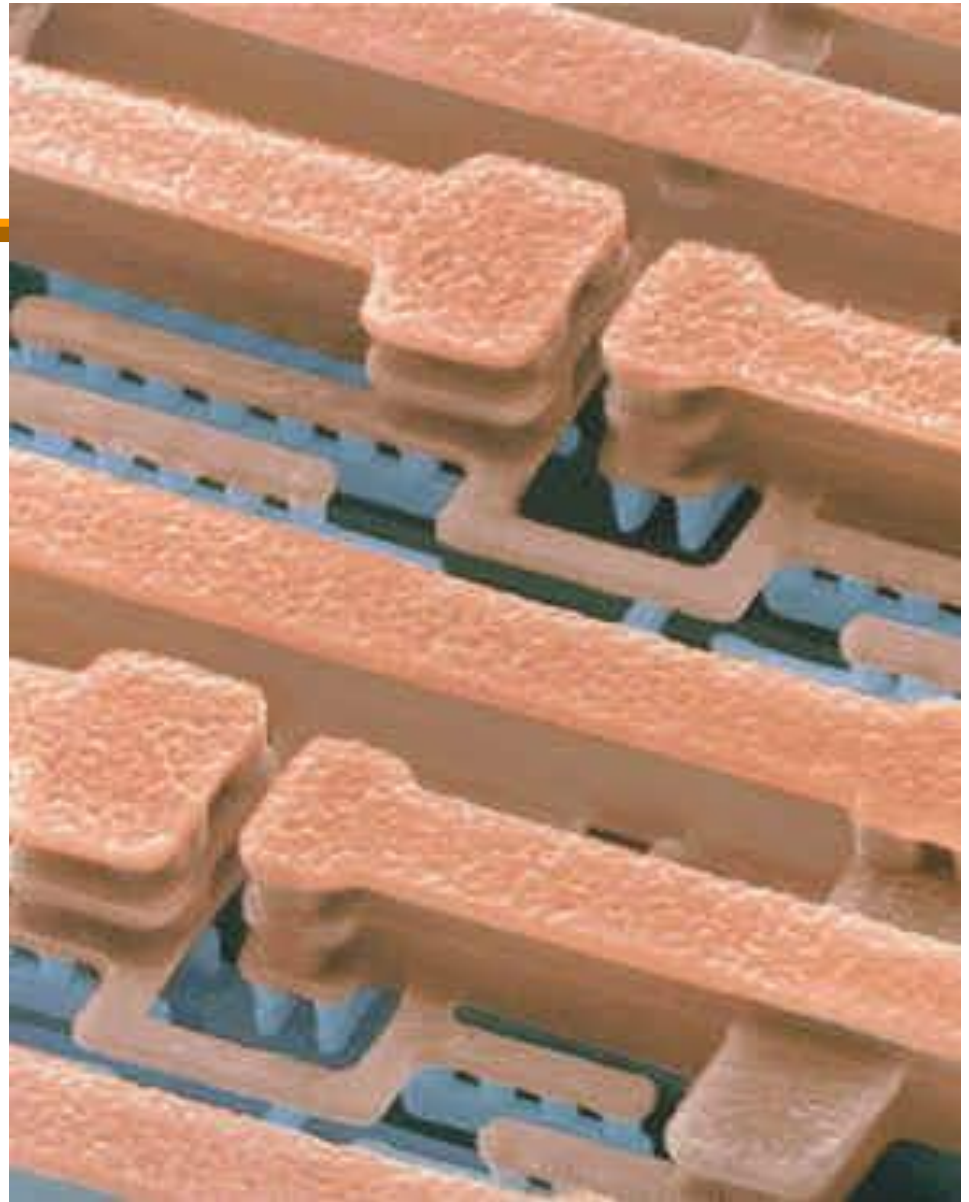
A State-of-the-art Wafer

- 300 mm diameter wafer



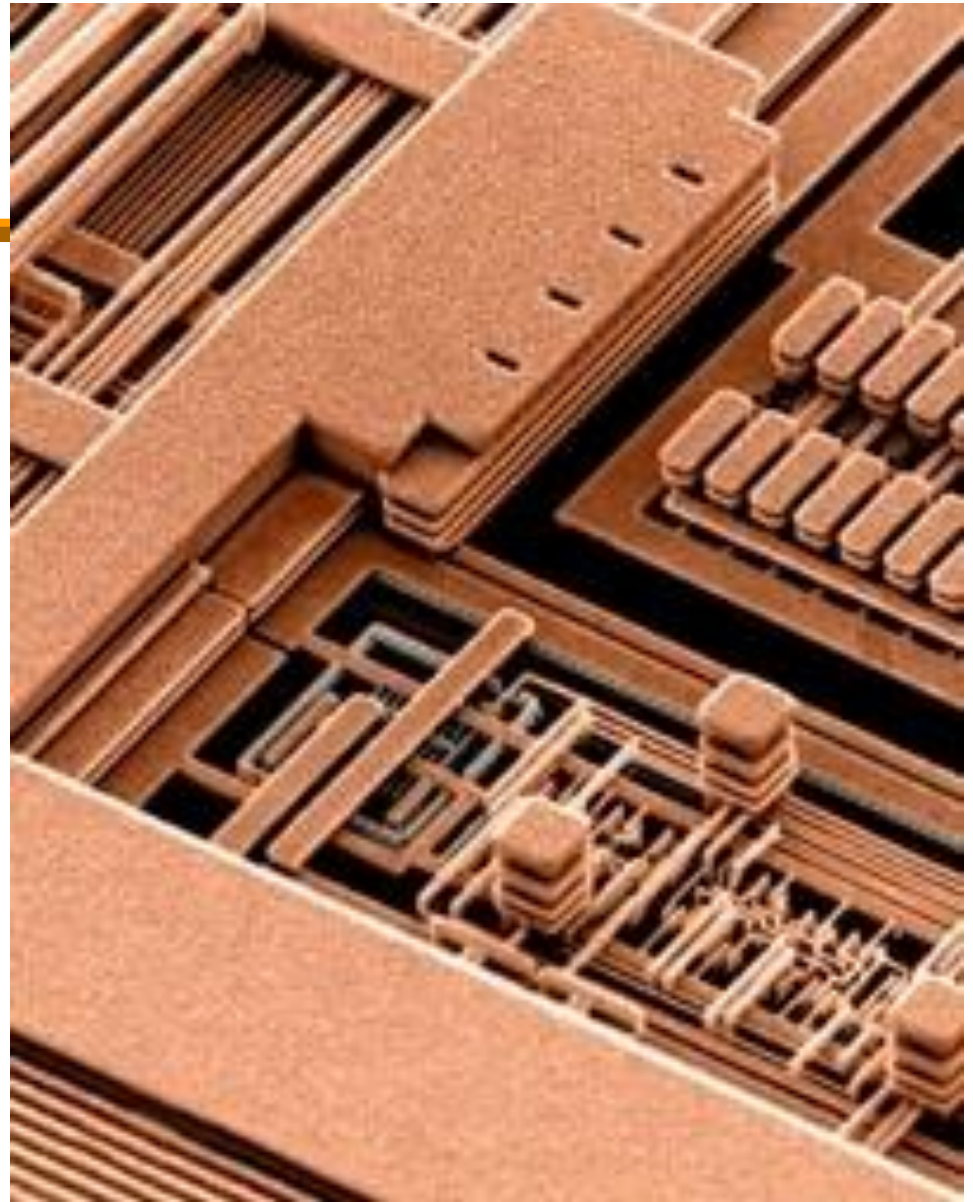
Wires

- Four levels of wires shown here
- Designers specify each layer and connections between layers

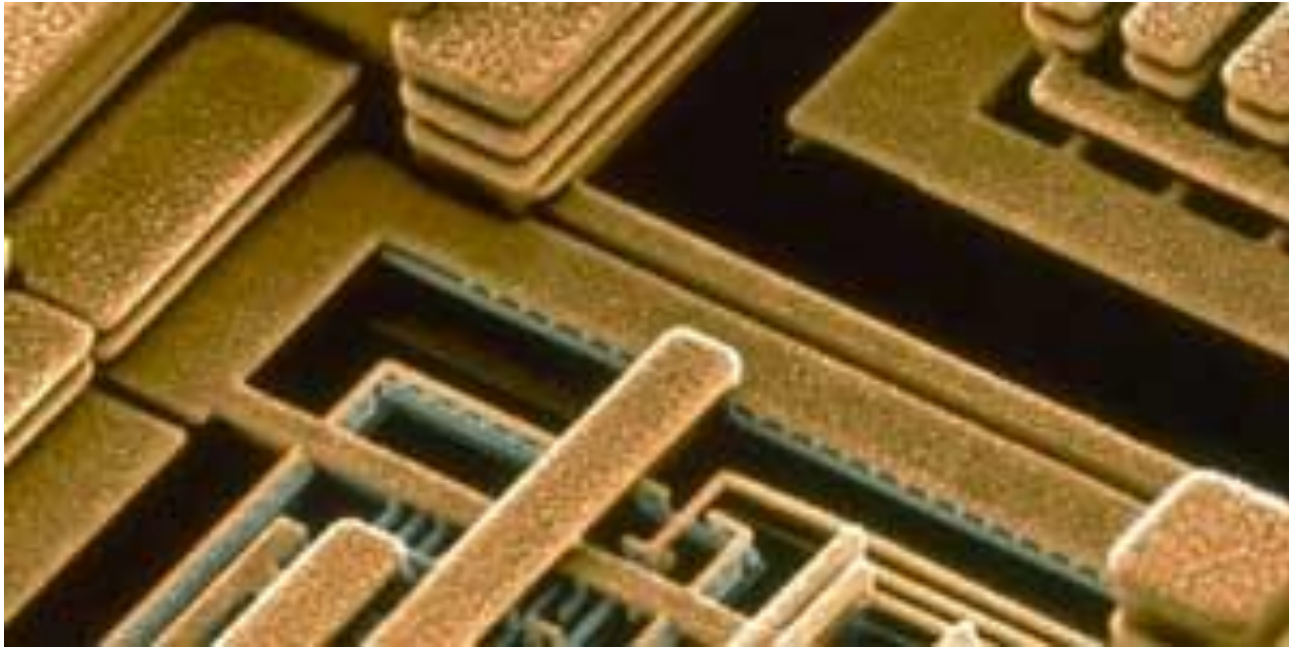


Chip Wires

- Modern chips have up to 13+ layers of wires

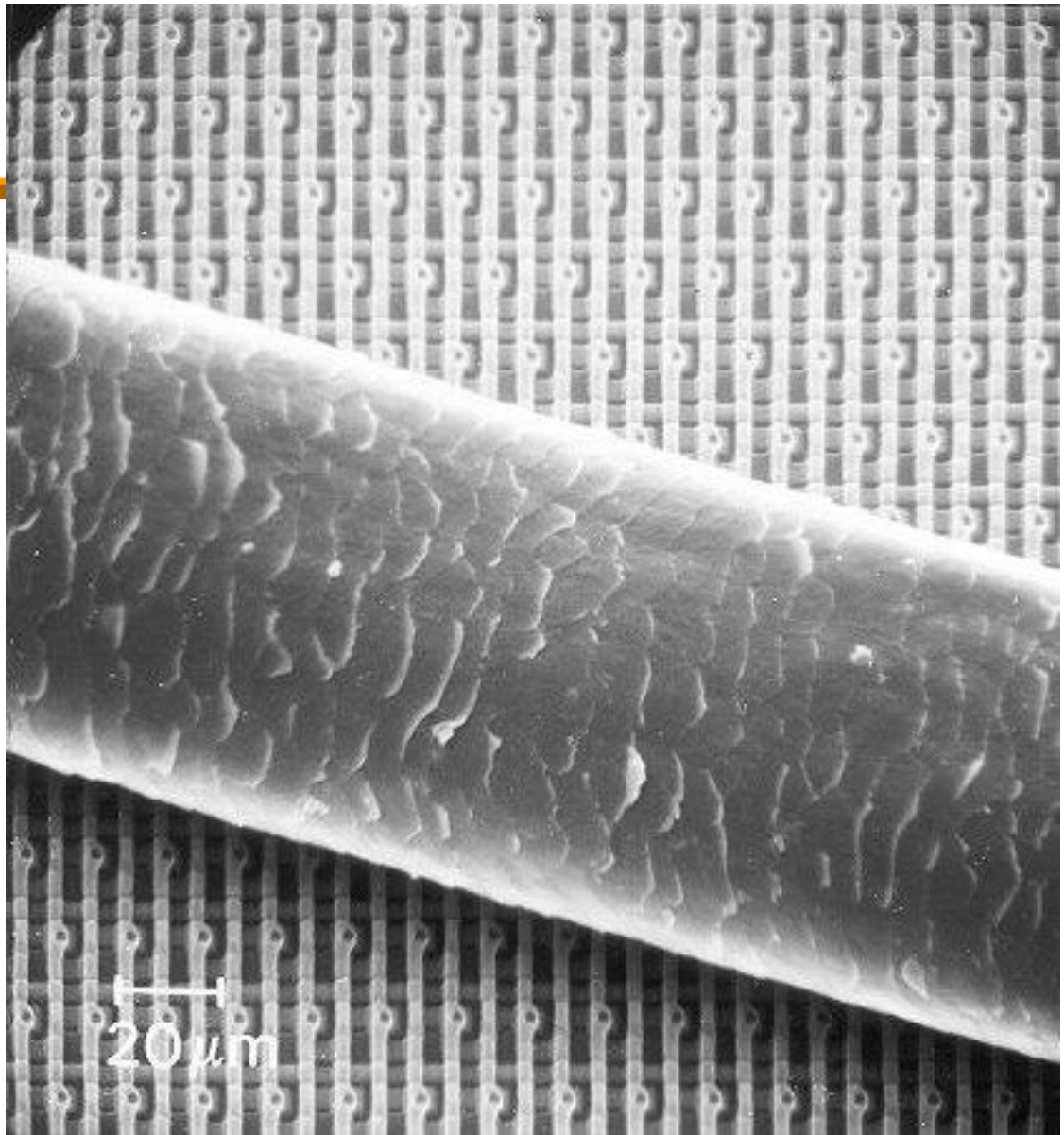


Chip Wires



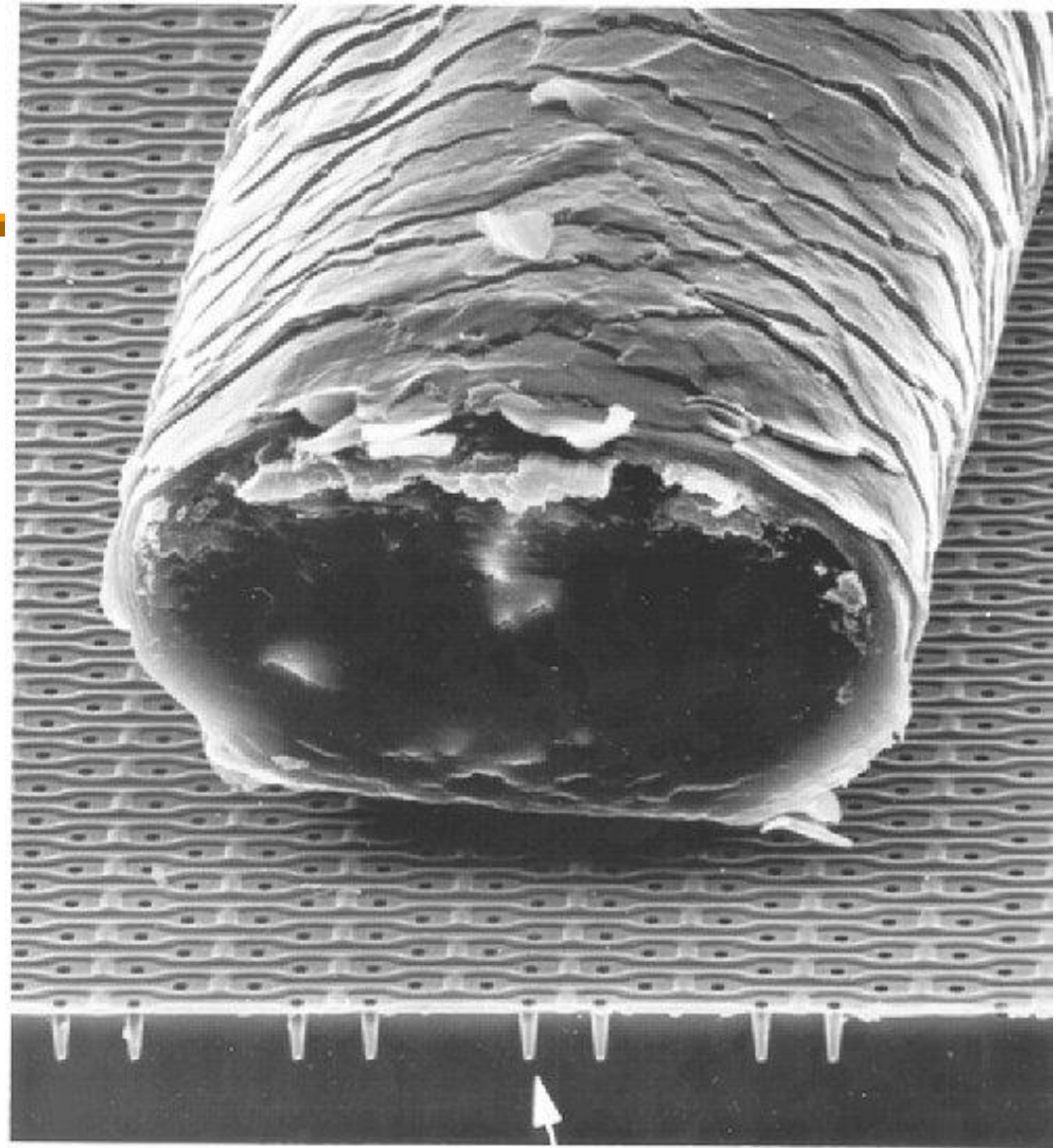
Memory Array

- Human hair on a 256 Kbit memory chip



Memory Array

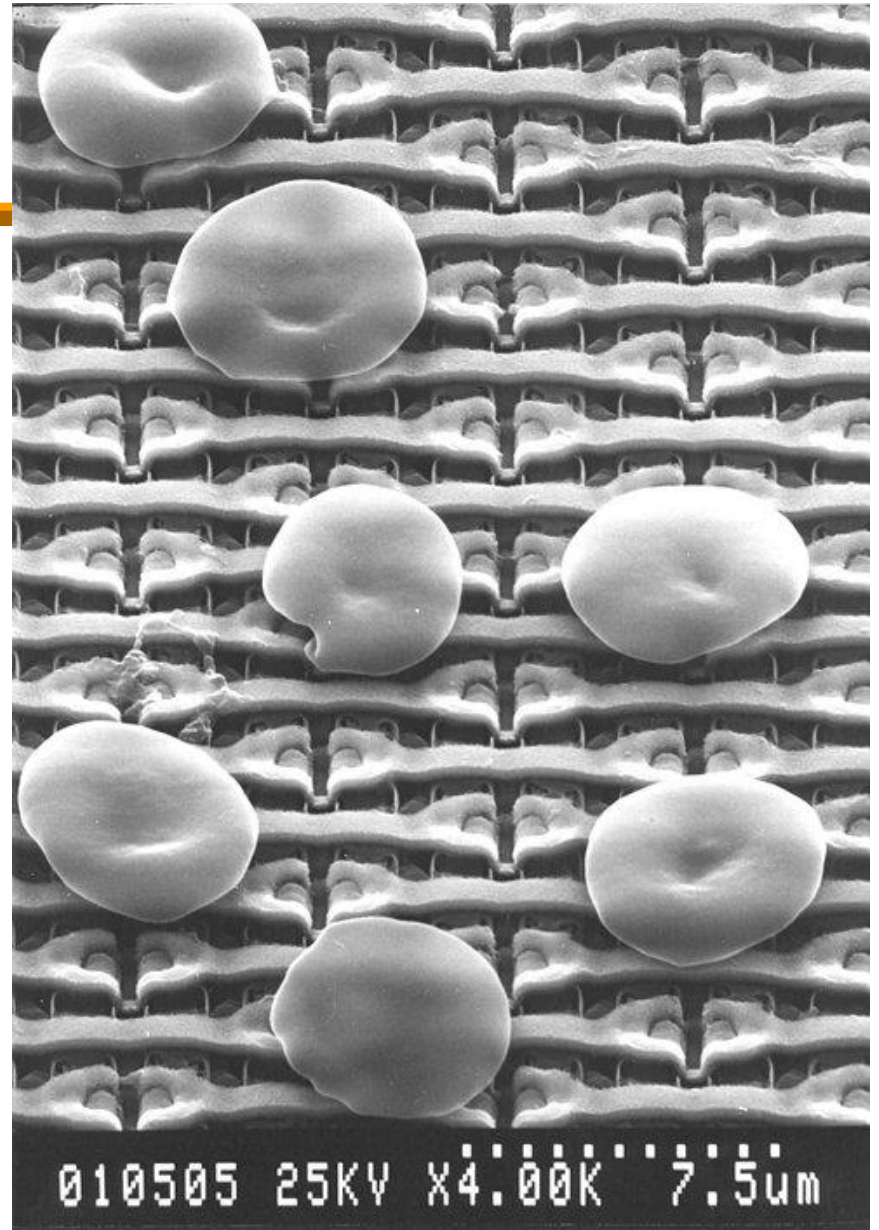
- Human hair on a 4 Mbit memory chip
- Note DRAM trench capacitors



10 μm **Trench**

Memory Array

- Red blood cells on a 1 Mbit memory chip

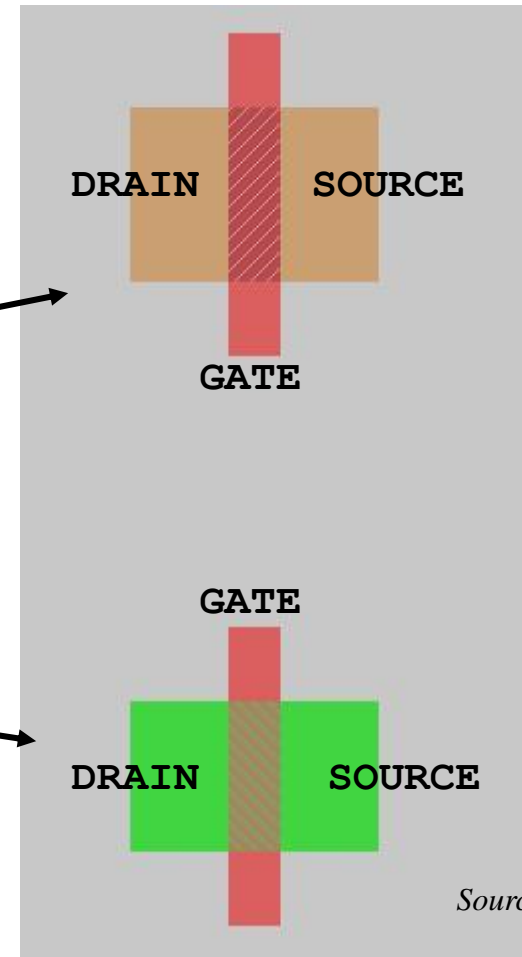


Transistor Layout

- Drawing a transistor is this easy!

PMOS transistor

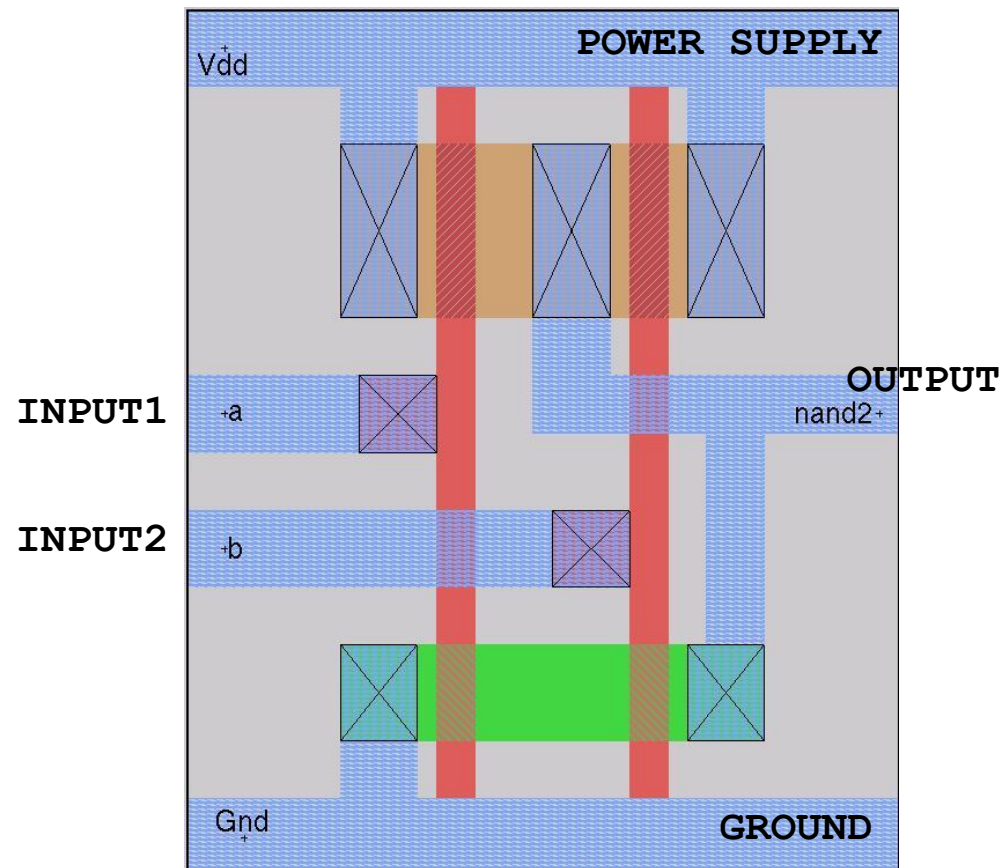
NMOS transistor



Source: Mike Lai

AND Gate Layout

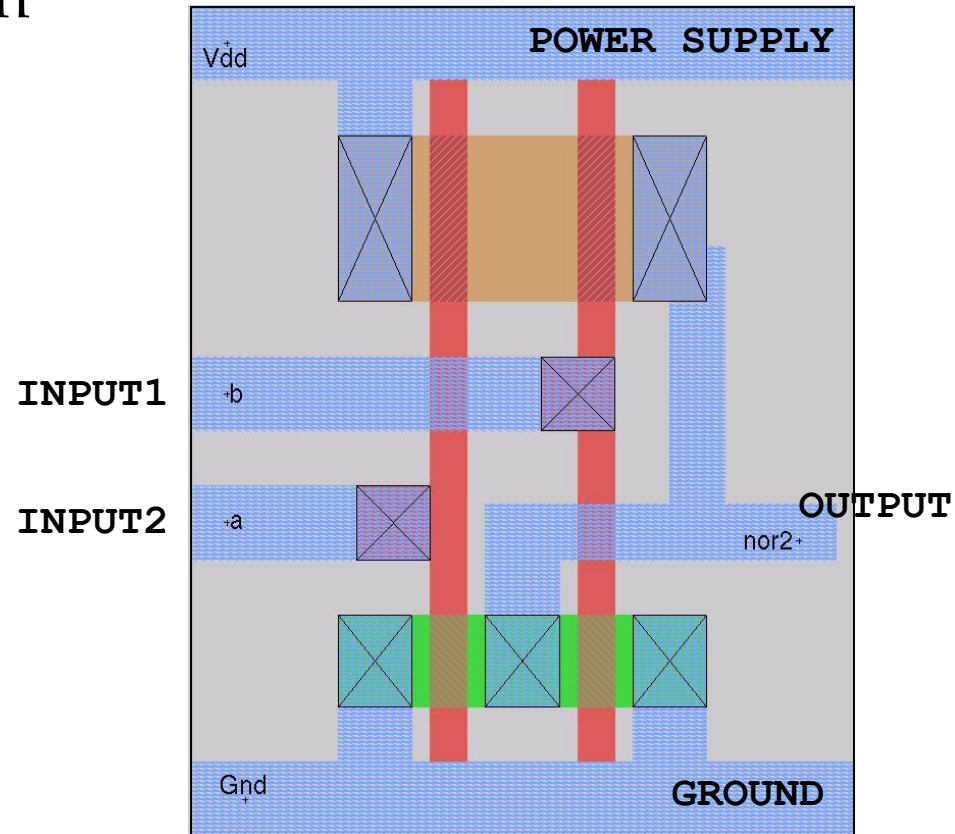
- Here is an AND gate (with an inverted output, which is called a NAND)



Source: Mike Lai

OR Gate Layout

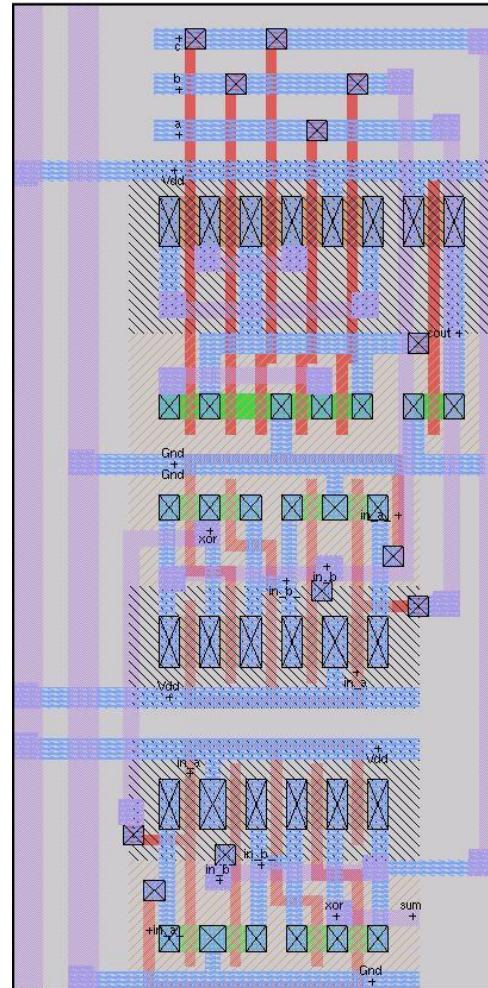
- Here is an OR gate (with an inverted output, which is called a NOR)



Source: Mike Lai

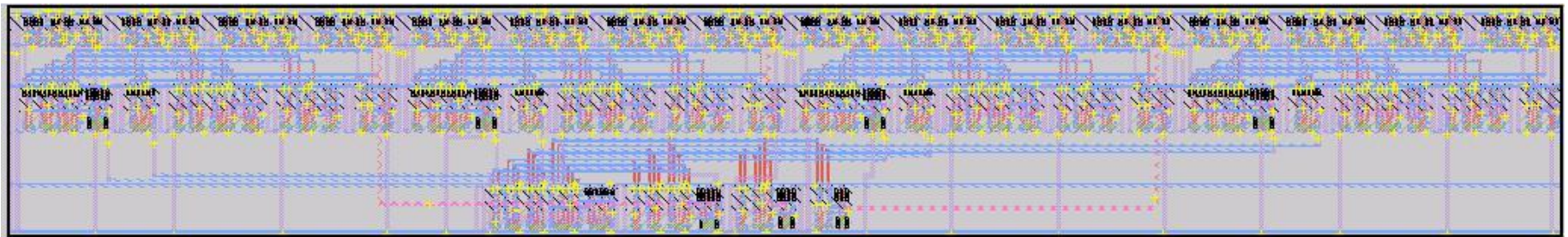
Full Adder Layout

- Here is a Full Adder



16-bit Adder Layout

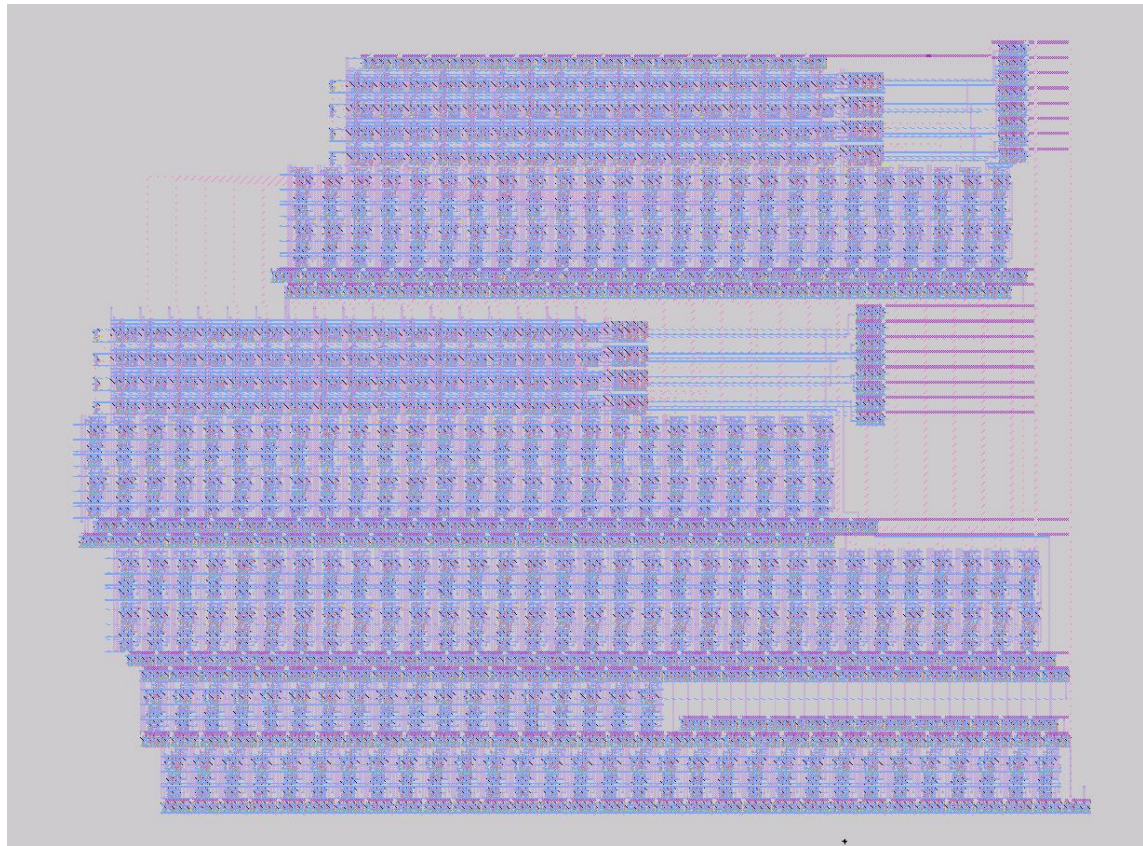
- Here is a complete 16-bit adder (it adds two numbers where each input can range from $-32,000$ to $+32,000$)
- This adder contains 16 full adders (essentially) plus additional circuits for fast addition



Source: Mike Lai

16-bit Multiplier Layout

- Here is a complete 16-bit x 16-bit multiplier (each input can range from -32,000 to +32,000)



Let's Build Some More Complex Things

- We'll use our big building blocks
 - Memory
 - Silicon memories
 - Datapath
 - Adders/subtractors
 - Multipliers
 - Shifters
 - Controllers
- And LOTS of wires to connect things