CSE460: VLSI Design

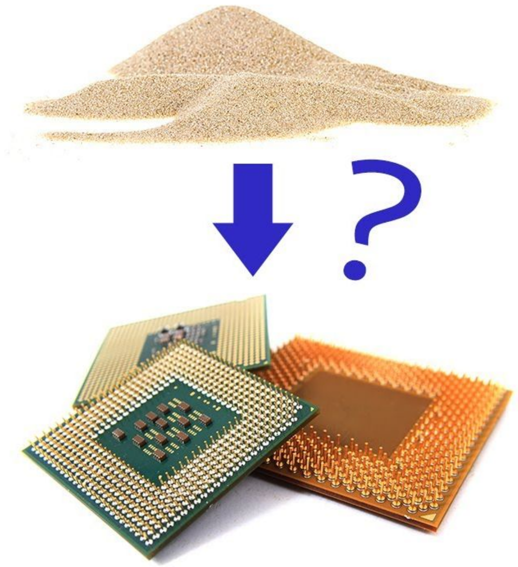
Lecture 1

Very **L**arge **S**cale **I**ntegration or **VLSI**

Contents

What will you learn in this course?

- You may have heard people say that electronics are made from sand, but do you know how?



What will you learn in this course?

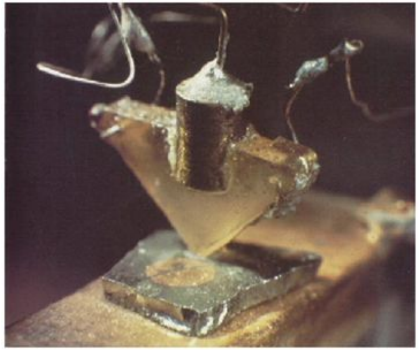
- A solid introduction to VLSI
- Different kinds of chips/ICs
- How to build one
- Theoretical background to making a good chip
- Quality measures of a chip
- The complete lifecycle of a chip

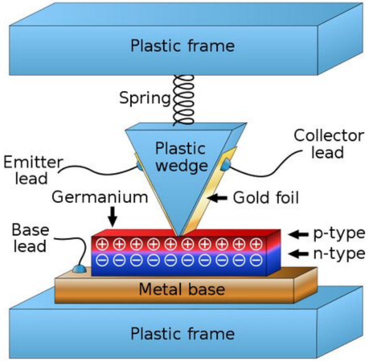
The Transistor

- Transistor concept
  - Transistors can be viewed as **electrically controlled switches** with a control terminal and two other terminals that are connected or disconnected depending on the *voltage* or *current* applied to the control terminal

Transistor Invention

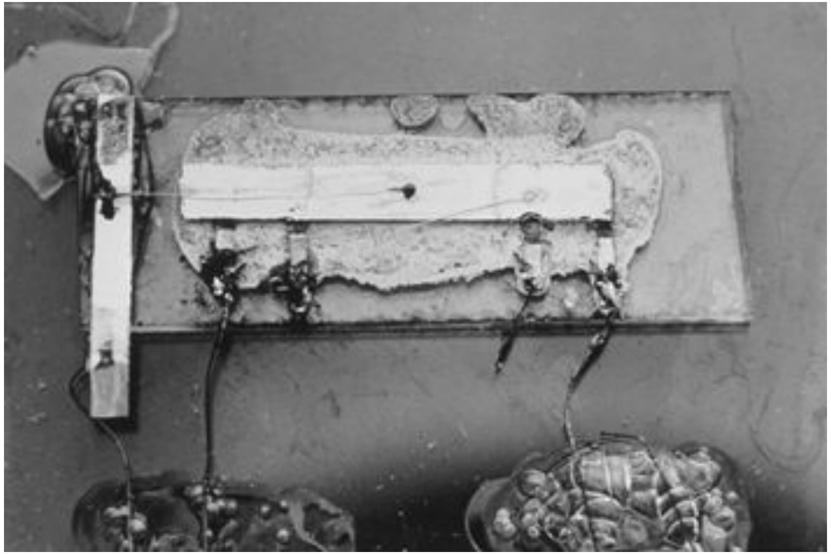
- 1947: First transistor was built
  - John Bardeen and Walter Brattain built the first functioning point contact transistor at Bell Labs
  - Nearly classified as military secret
  - Later publicly introduced by Bell Labs
  - **Nobel Prize in Physics in 1956 for Bardeen, Brattain, and their supervisor William Shockley**
  - *We have called it the Transistor, T-R-A-N-S-I-S-T-O-R, because it is a resistor or semiconductor device which can amplify electrical signals as they are transferred through it from input to output terminals. It is, if you will, the electrical equivalent of a vacuum tube amplifier. But there the similarity ceases. It has no vacuum, no filament, no glass tube. It is composed entirely of cold, solid substances.*





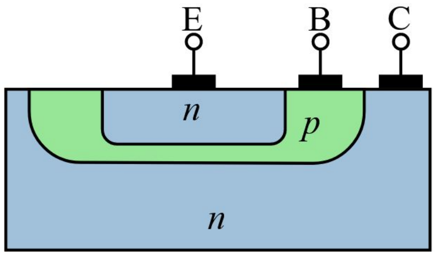
First IC

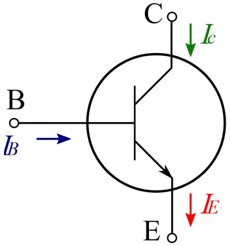
- 1959: U.S. Patent 3,138,743 for "Miniaturized Electronic Circuits"
  - Several years later after the invention of transistors, Jack Kilby at Texas Instruments realized the potential for miniaturization if multiple transistors could be built on one piece of silicon
  - **Kilby received the Nobel Prize in Physics in 2000 for the invention of the integrated circuit**

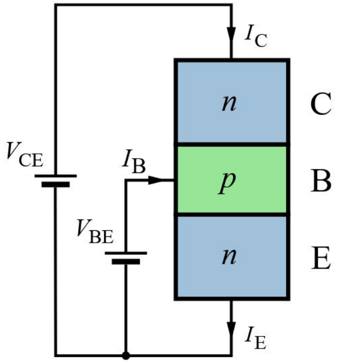


Bipolar Junction Transistor

- Bipolar Junction Transistor (BJT)
  - Developed by Bell Labs
- More reliable, less noisy, and more power-efficient than the point contact transistor
- BJTs require a small current into the control (*base*) terminal to switch much larger currents between the other two (*emitter* and *collector*) terminals
- **Power being dissipated by these base currents even when idle**

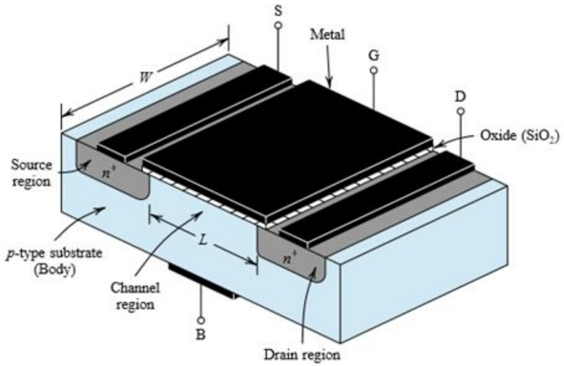


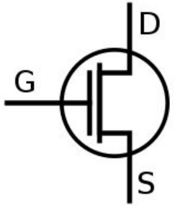


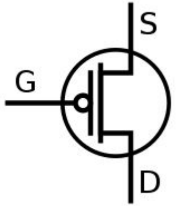


Metal Oxide Semiconductor Field Effect Transistor

- 1960s: (MOSFETs) began to enter production
- Metal Oxide Semiconductor Field Effect Transistors or MOSFETs offer the compelling advantage that they draw almost zero control current while idle.
- Two flavors: nMOS and pMOS
- Three terminals: *Gate* (control), *Drain* and *Source*







First MOSFET Gates

- 1963: First logic gate using MOSFETs
  - Frank Wanlass at Fairchild described the first logic gates using MOSFETs
- Fairchild's gates used both nMOS and pMOS transistors, earning the name Complementary Metal Oxide Semiconductor, or CMOS
- The circuits used discrete transistors but consumed six orders of magnitude less power than their bipolar counterparts
- With the development of the silicon planar process, MOS integrated circuits became attractive for their low cost because each transistor occupied less area and the fabrication process was simpler

Integration Levels

SSI: 1-12 gates

MSI: 13-99 gates

LSI: 100-9999 gates

VLSI: 10-99.9 k gates

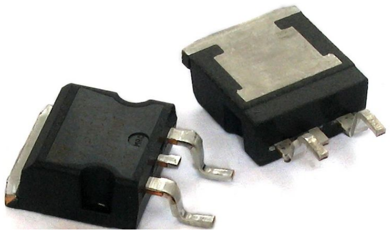
ULSI: >100k gates

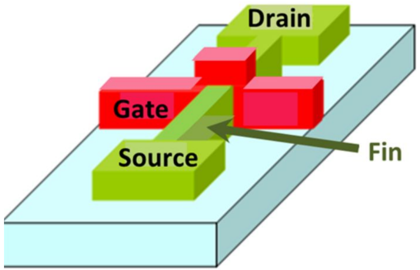
Trend in MOSFET IC Design

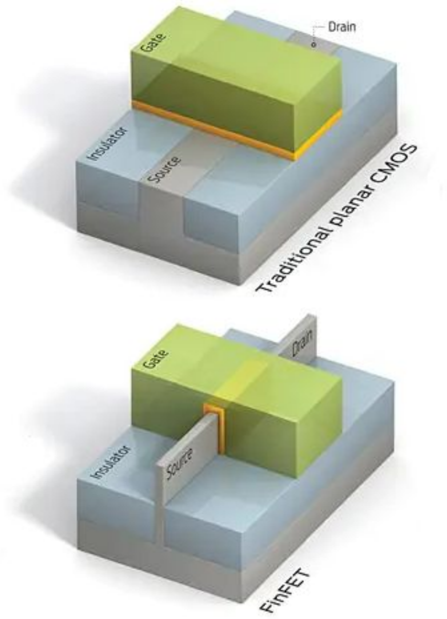
- Early commercial processes used only pMOS transistors and suffered from poor performance, yield, and reliability
- Processes using nMOS transistors became common in the 1970s
- While nMOS process was less expensive than CMOS, nMOS logic gates still consumed power while idle
- Power consumption became a major issue in the 1980s as hundreds of thousands of transistors were integrated onto a single die
- CMOS processes were widely adopted and replaced all the other technologies (pMOS, nMOS)

Types of MOSFET

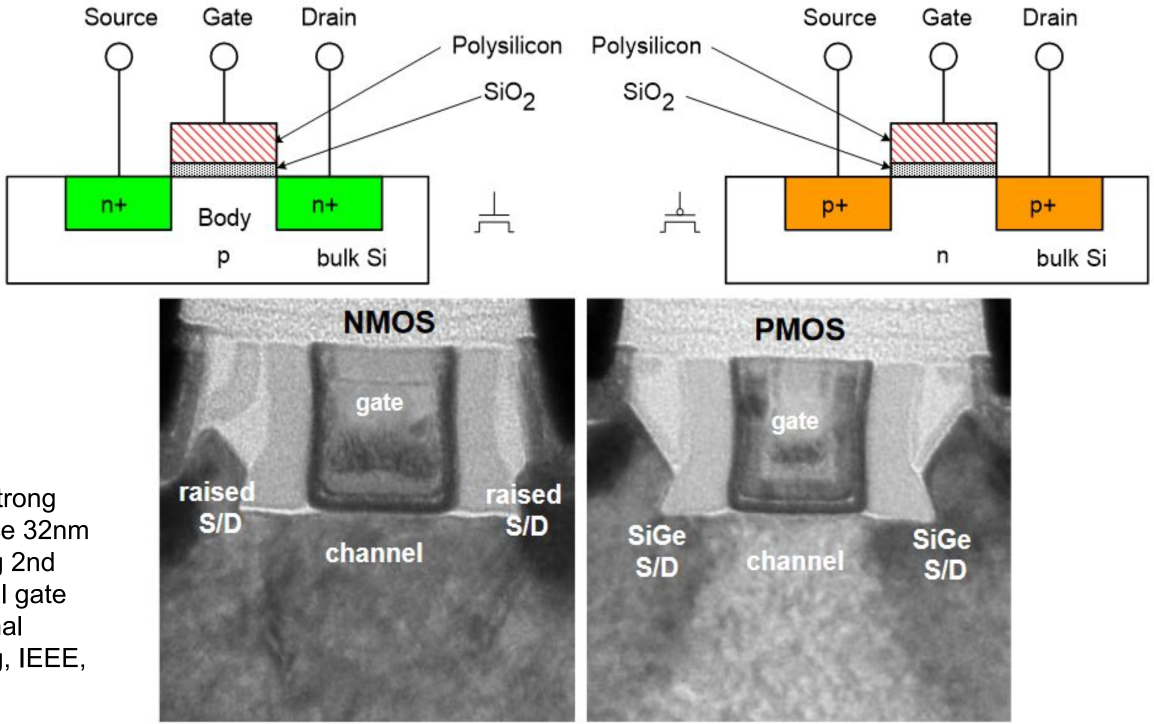
- pMOS, nMOS, CMOS
- Metal–insulator–semiconductor field-effect transistor (MISFET)
- Floating-gate MOSFET (FGMOS)
- Power MOSFET
- Multi-gate field-effect transistor (MuGFET)
- Quantum field-effect transistor (QFET)







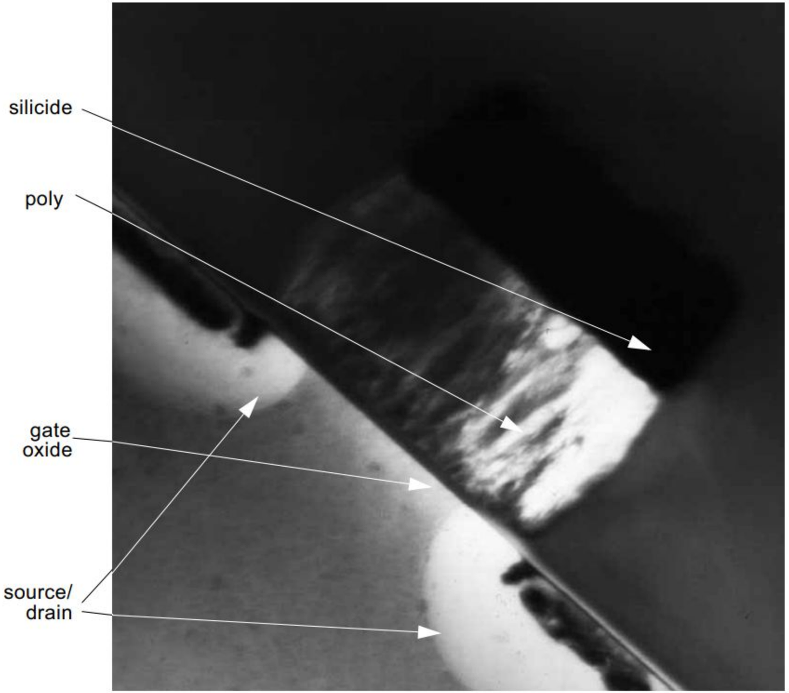
A Closer Look

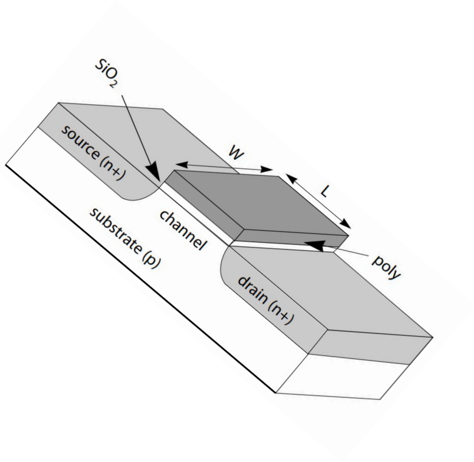


Cross sectional view of intel’s 32nm CMOS devices

Packan P, Akbar S, Armstrong M, et al. High performance 32nm logic technology featuring 2nd generation High-k + metal gate transistors. In: International Electron Devices Meeting, IEEE, 2009. 659–662

A Closer Look

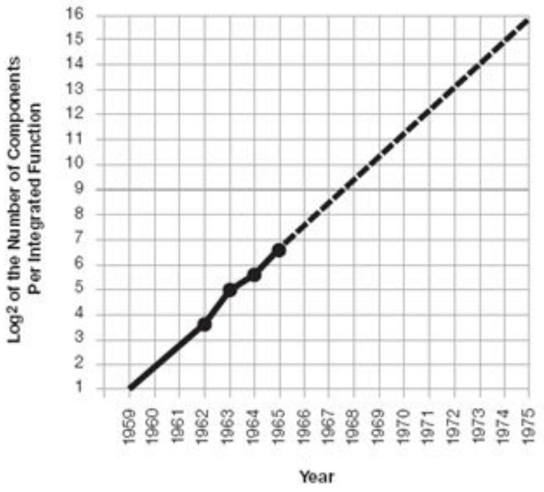


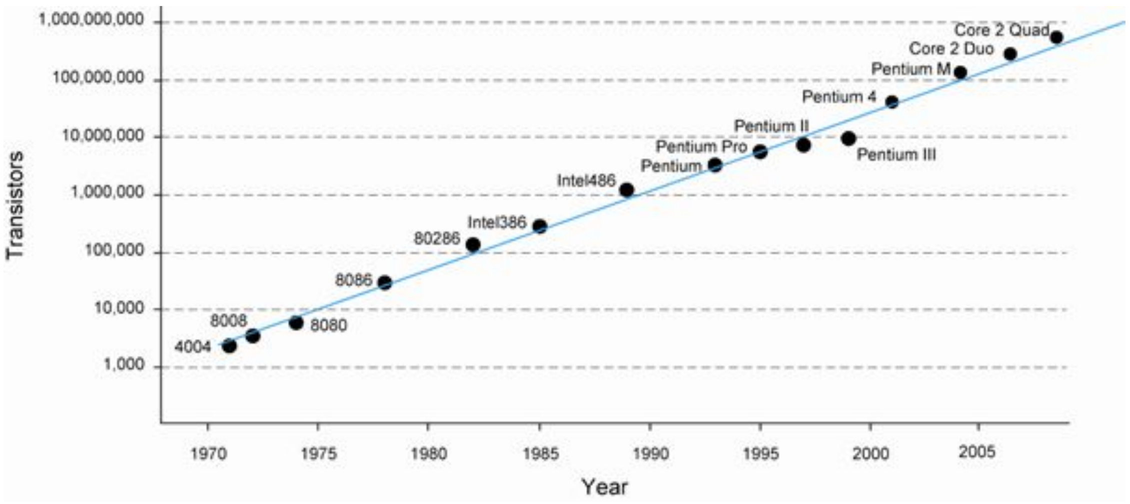


Photomicrograph of a submicron MOS transistor (courtesy Agere)

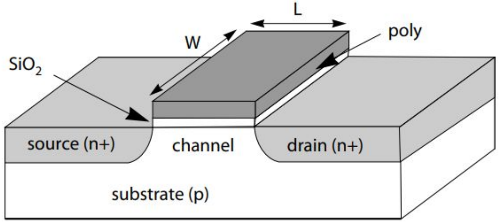
Moore’s Law

- 1965:Gordon Moore plotted # transistors on each chip vs year
  - Fit straight line on semi-log scale
  - Transistor counts have doubled about every 2 years

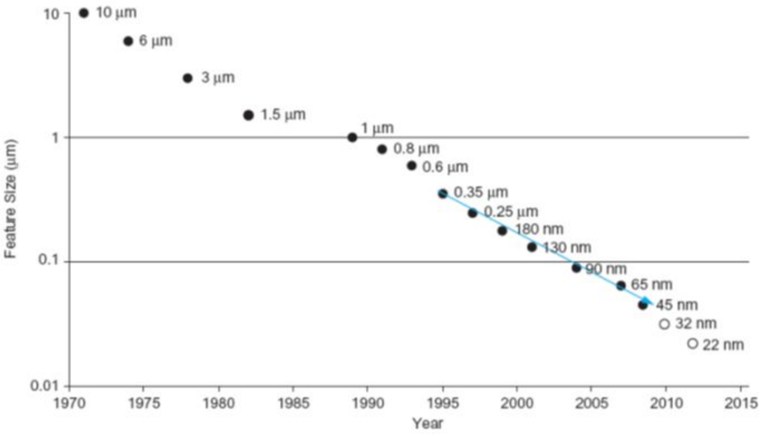




Moore’s Law

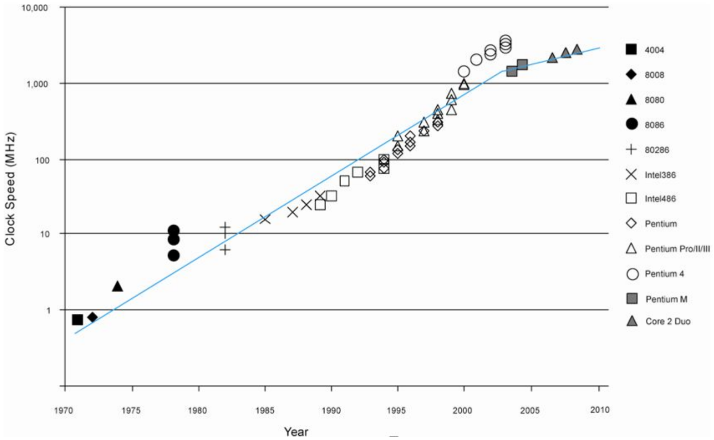


- Process generations
  - A manufacturing technology at a particular *channel length (feature size)* is called a **technology node**/**process node** (micron, submicron, nanometer technologies)



MOSFET scaling
(**process nodes**)

10 µm – 1971
6 µm – 1974
3 µm – 1977
1.5 µm – 1981
1 µm – 1984
800 nm – 1987
600 nm – 1990
350 nm – 1993
250 nm – 1996
180 nm – 1999
130 nm – 2001
90 nm – 2003
65 nm – 2005
45 nm – 2007
32 nm – 2009
22 nm – 2012
14 nm – 2014
10 nm – 2016
7 nm – 2018
5 nm – 2020



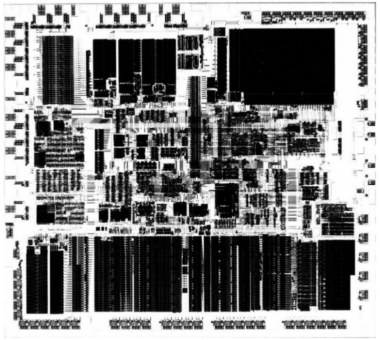
Moore’s Law

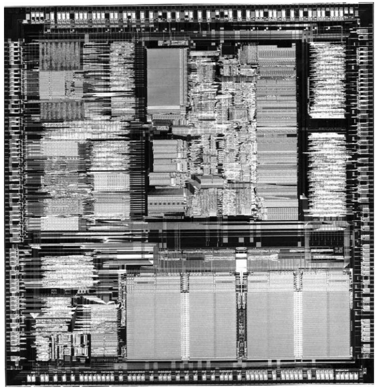
- Moore’s law and intel microprocessors

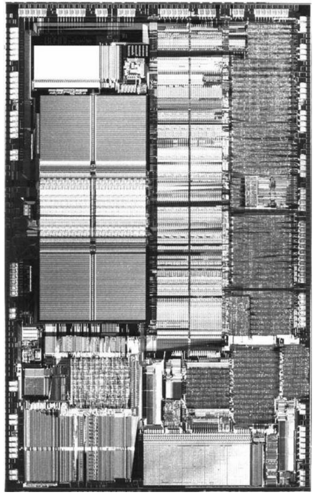
microprocessor	date of introduction	# transistors
80286	2/82	134,000
80386	10/85	275,000
80486	4/89	1,200,000
Intel Pentium™	3/93	3,100,000
Intel Pentium Pro™	11/95	5,500,000
Intel Pentium II™	1997	7,500,000
Intel Pentium III™	1999	9,500,000
Intel Pentium 4™	2000	42,000,000
Intel Itanium™	2001	25,000,000
Intel Itanium 2™	2003	220,000,000
Intel Itanium 2™ (9 MB cache)	2004	592,000,000

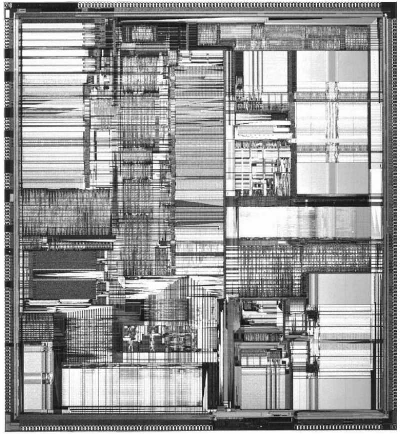
Intel Processors over the years

- 80286, 80386, 80486, Pentium



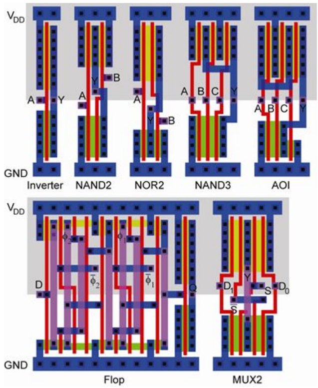


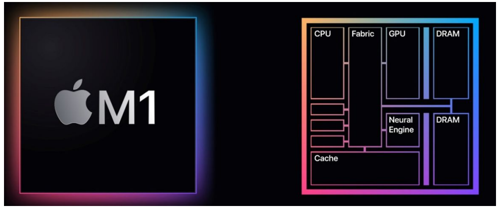




Types of chips

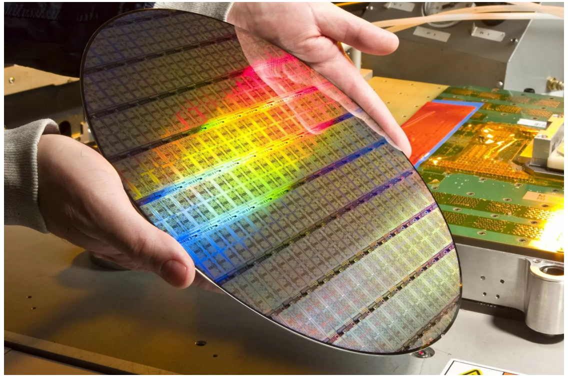
- Cell-based design
  - In the 1960s, standard parts were logic gates; in the 1970s they were LSI components. Today, standard parts include fairly specialized components: communication network interfaces, graphics accelerators
- Full custom
  - Designed manually piece by piece, fully custom layouts
- Application-specific integrated circuits (ASICs)
  - Rather than build a system out of standard parts, designers can now create a single chip for their particular application
- Systems-on-chips (SoCs)
  - a single-chip computer can include a CPU, bus, I/O devices, and memory

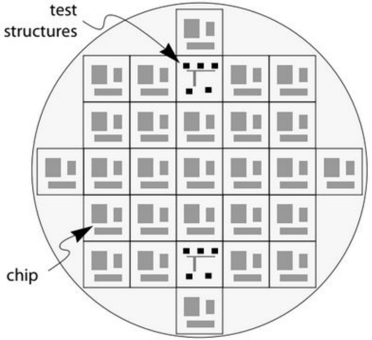


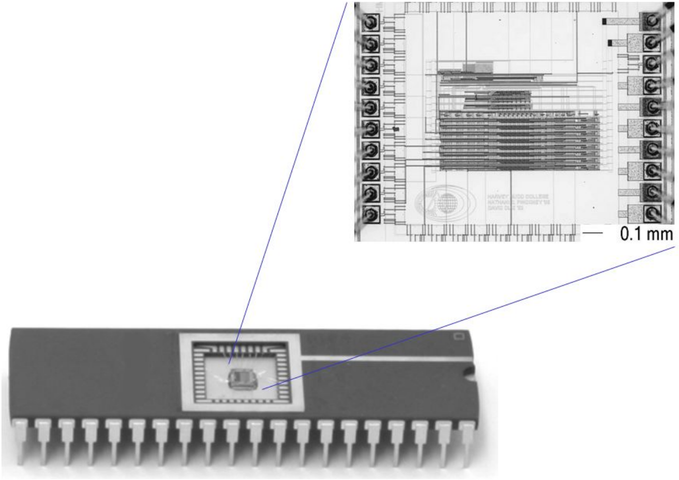


Chip Lifecycle

- A wafer > fabrication > chips > packaging

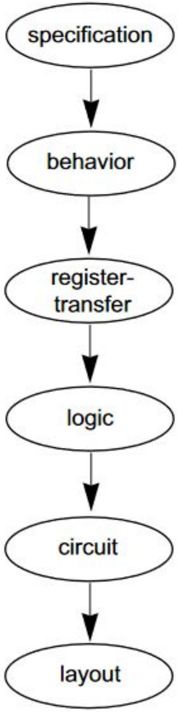






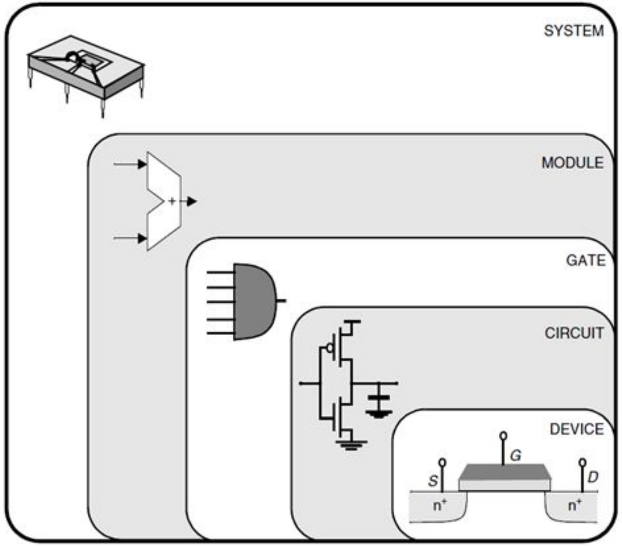
Abstraction levels

- Specification
  - A set of requirements, not a design
- Behavior
  - generally modeled as some sort of executable program
- Register-transfer
  - The system is specified as Boolean functions stored in abstract memory elements
- Logic
  - The system is designed in terms of Boolean logic gates,latches, and flip-flops
- Circuit
  - The system is implemented as transistors
- Layout
  - The final design for fabrication



Design methodologies

- Top-down approach
  - Start from the specification and reach device specification
- Bottom-up approach
  - Start from the device optimization and go up to meet specification



Text

#	Title	Author(s)	Edition
1	CMOS VLSI Design	N.H.E. Weste, D. Harris & A. Banerjee	4th ed.
2	Fundamentals of Digital Logic with Verilog Design	Stephen Brown & Zvonko Vranesic	2nd/3rd ed.

Transistors = Switches

Slide References

1. https://en.wikipedia.org/wiki/MOSFET
2. https://www.techspot.com/article/1840-how-cpus-are-designed-and-built-part-3/
3. https://ieeexplore.ieee.org/document/5424253
4. Wayne Wolf - Modern VLSI Design IP based design
5. Jan M. Rabaey - Digital Integrated Circuits
6. Weste and Harris - CMOS VLSI Design

Thank you!