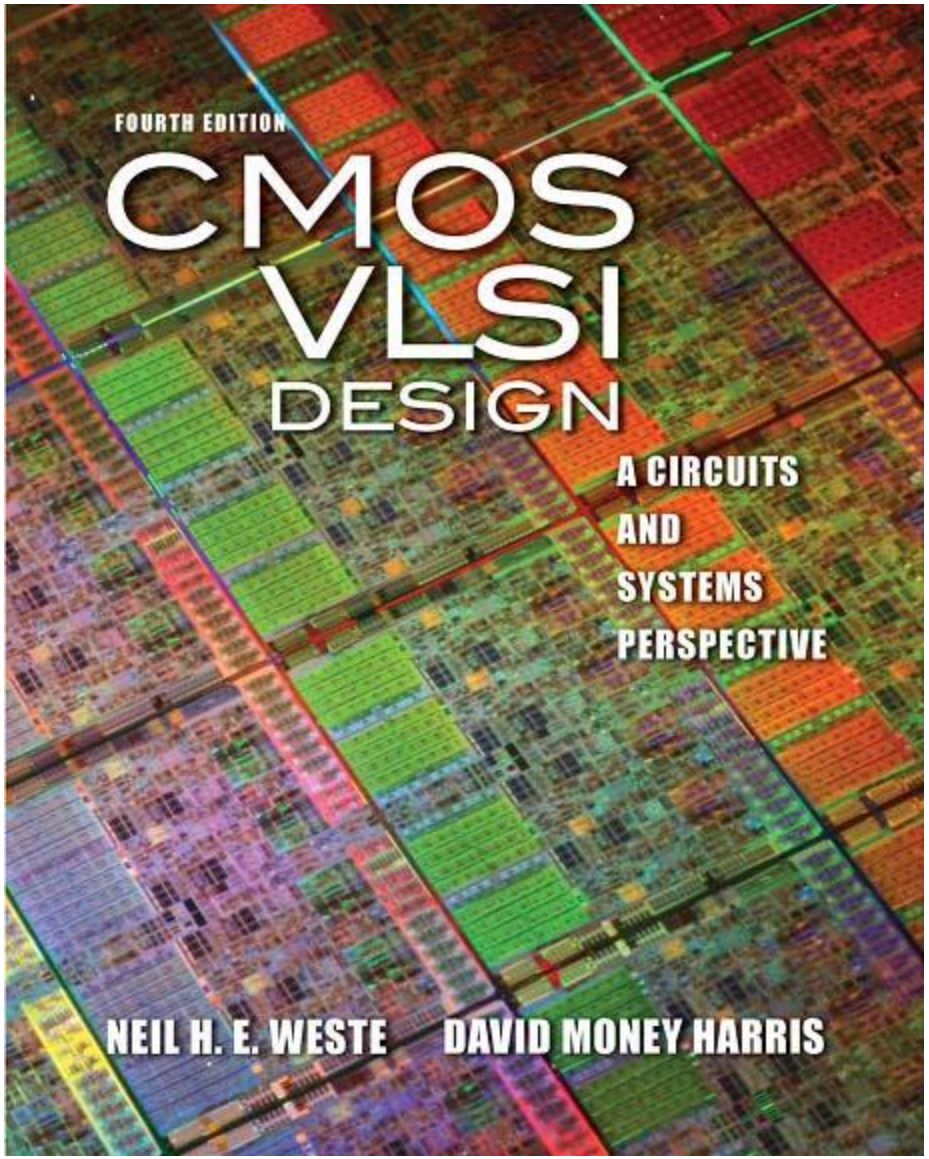


Introduction

Dr. Bassam Jamil

Adopted from slides of the textbook

Outline

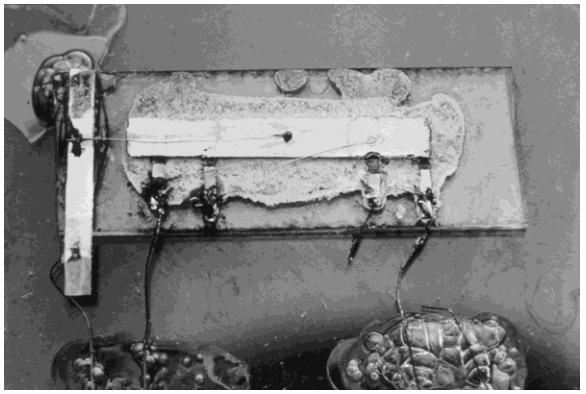
- Brief History
- MOS Transistor

Introduction

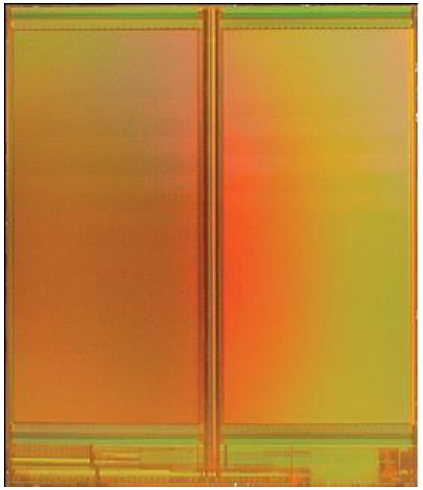
- Integrated circuits: many transistors on one chip.
- *Very Large Scale Integration* (VLSI): bucketloads!
- *Complementary Metal Oxide Semiconductor*
  - Fast, cheap, low power transistors
- Today: How to build your own simple CMOS chip
  - CMOS transistors
  - Building logic gates from transistors
  - Transistor layout and fabrication
- Rest of the course: How to build a good CMOS chip

A Brief History

- 1958: First integrated circuit
  - Flip-flop using two transistors
  - Built by Jack Kilby at Texas Instruments
- 2010
  - Intel Core i7 μprocessor
    - 2.3 billion transistors
  - 64 Gb Flash memory
    - > 16 billion transistors



Courtesy Texas Instruments



[Trinh09]

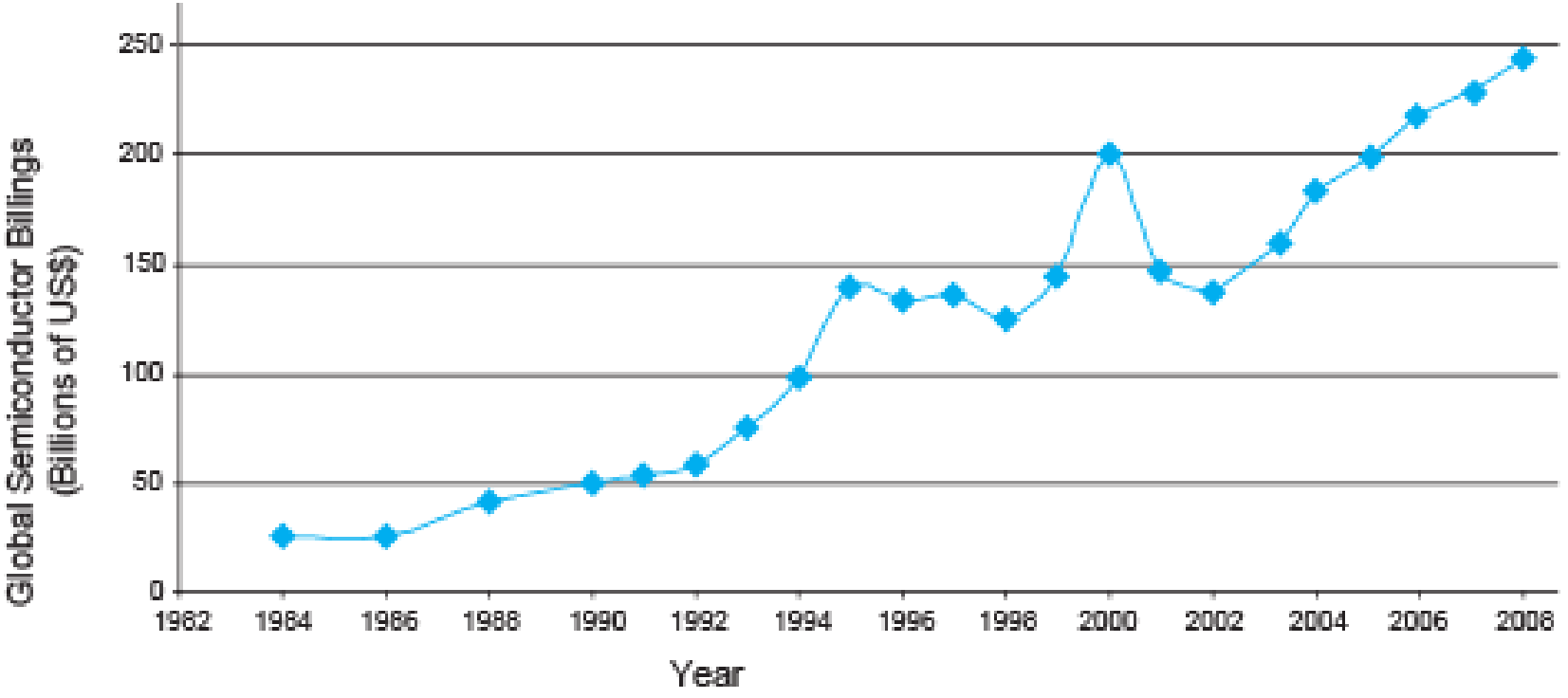
Growth Rate

- 53% compound annual growth rate over 50 years
  - No other technology has grown so fast so long
- Driven by miniaturization of transistors
  - Smaller is cheaper, faster, lower in power!
  - Revolutionary effects on society

[Moore65]
Electronics Magazine

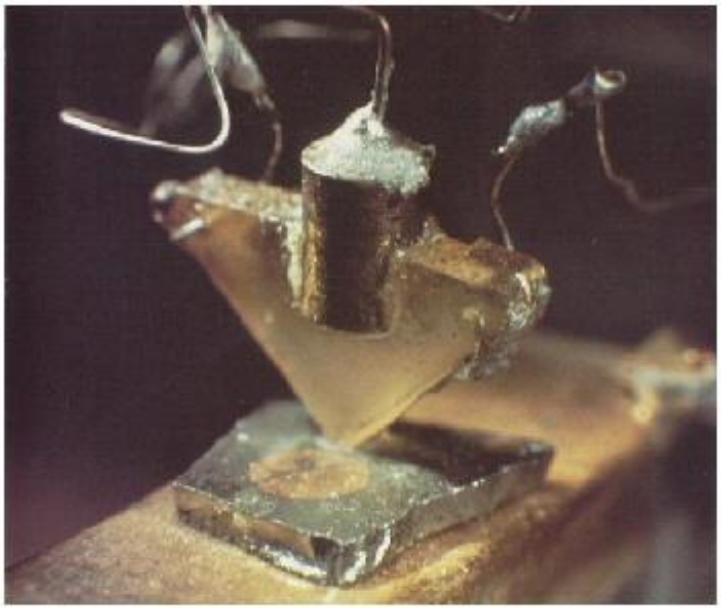
Annual Sales

- >10^{19} transistors manufactured in 2008
  - 1 billion for every human on the planet



Invention of the Transistor

- Vacuum tubes ruled in first half of 20th century
  Large, expensive, power-hungry, unreliable
- 1947: first point contact transistor
  - John Bardeen and Walter Brattain at Bell Labs
  - See *Crystal Fire*
    by Riordan, Hoddeson



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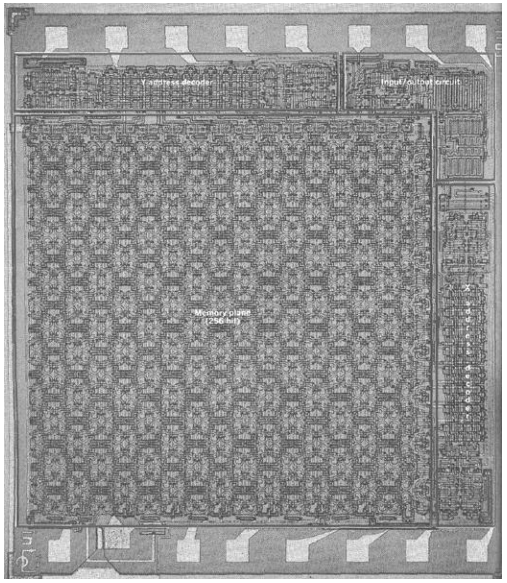
Transistor Types

- Bipolar transistors
  - npn or pnp silicon structure
  - Small current into very thin base layer controls large currents between emitter and collector
  - Base currents limit integration density
- Metal Oxide Semiconductor Field Effect Transistors
  - nMOS and pMOS MOSFETS
  - Voltage applied to insulated gate controls current between source and drain
  - Low power allows very high integration

MOS Integrated Circuits

- 1970's processes usually had only nMOS transistors
  - Inexpensive, but consume power while idle



[Vadasz69]

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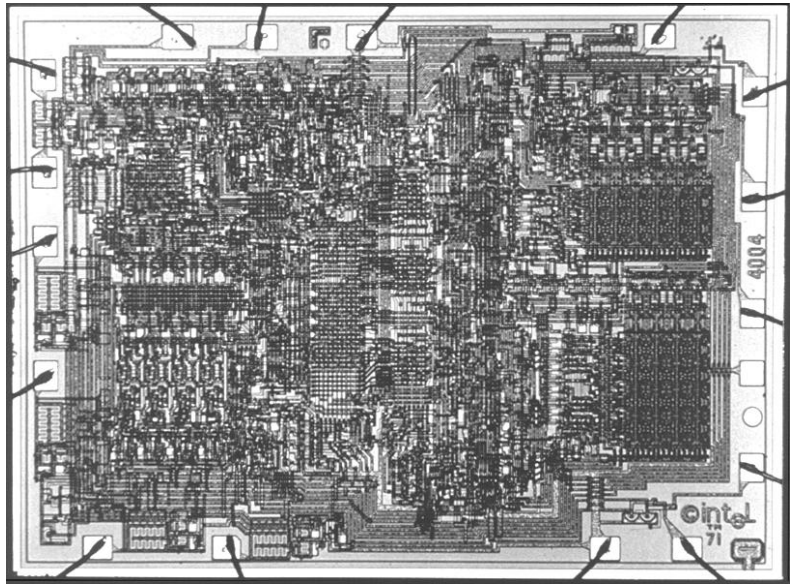
Intel 1101 256-bit SRAM



Intel Museum.

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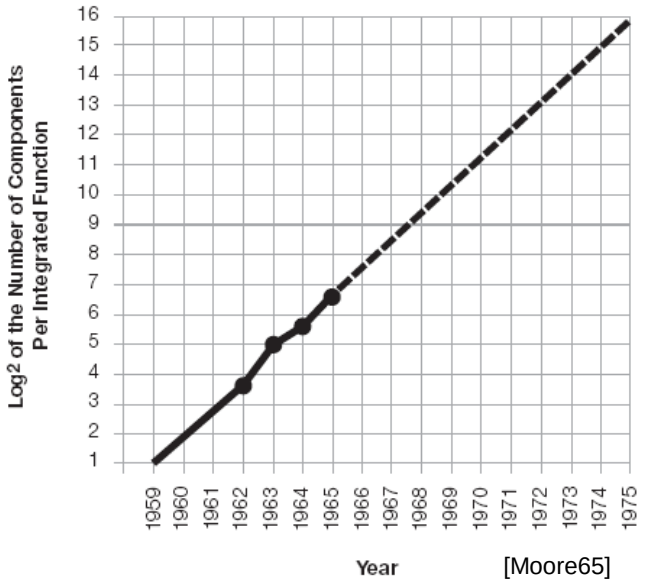
Intel 4004 4-bit μProc

- 1980s-present: CMOS processes for low idle power

Moore's Law: Then

- Gordon Moore found transistor count doubling every 18 months



[Moore65]

Electronics Magazine

Integration Levels

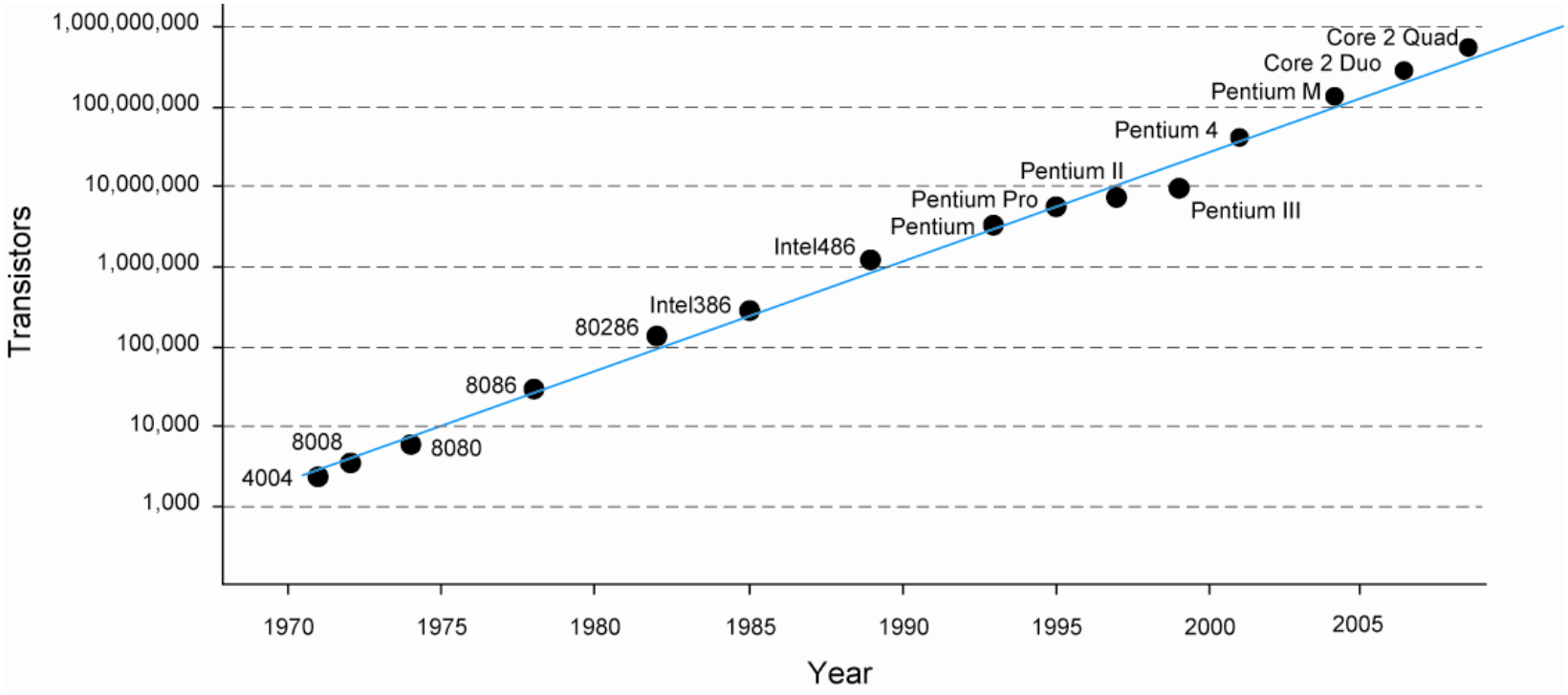
SSI: 10 gates

MSI: 1000 gates

LSI: 10,000 gates

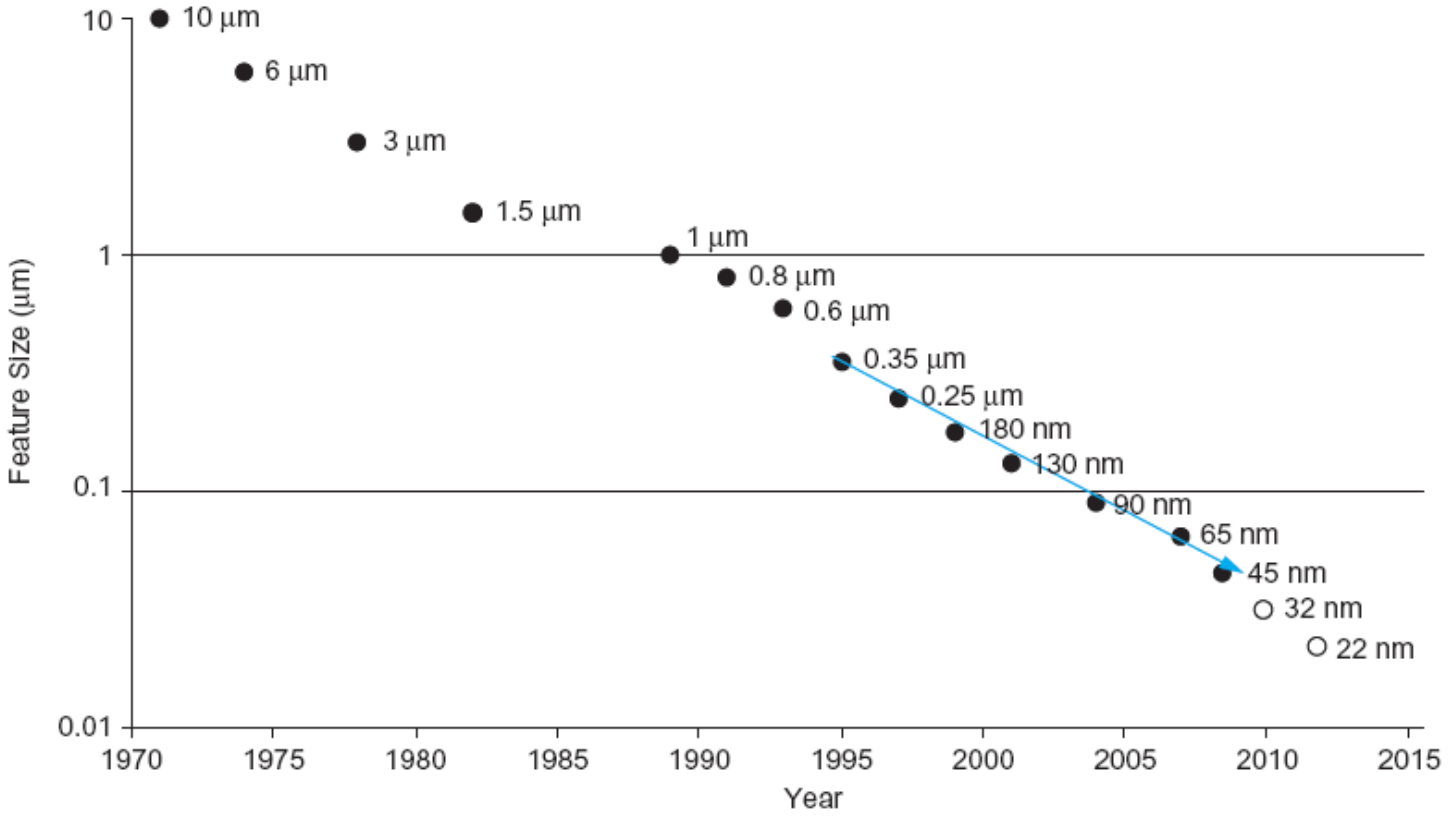
VLSI: > 10k gates

And Now…


1,000,000,000
100,000,000
10,000,000
1,000,000
100,000
10,000
1,000
Transistors
1970
1975
1980
1985
1990
1995
2000
2005
Year
4004
8008
8080
8086
80286
Intel386
Intel486
Pentium
Pentium Pro
Pentium II
Pentium III
Pentium 4
Pentium M
Core 2 Duo
Core 2 Quad

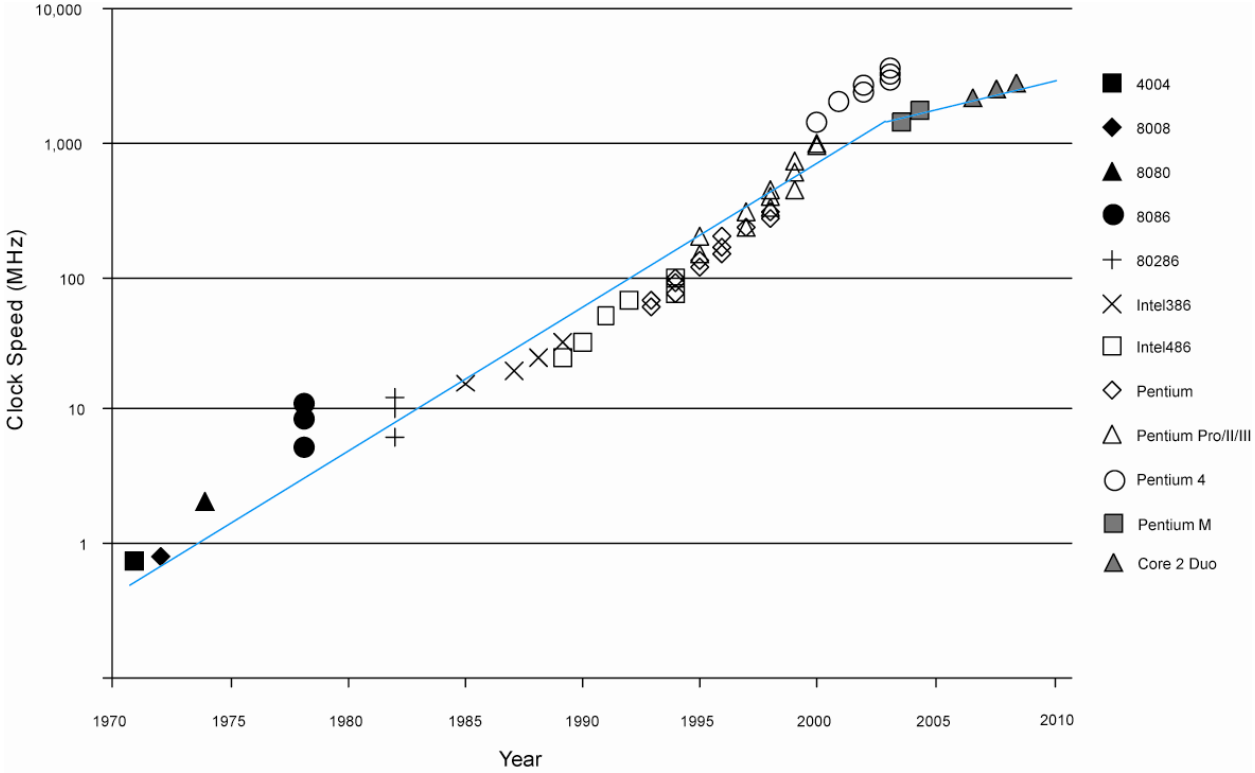
Feature Size

- Minimum feature size shrinking 30% every 2-3 years



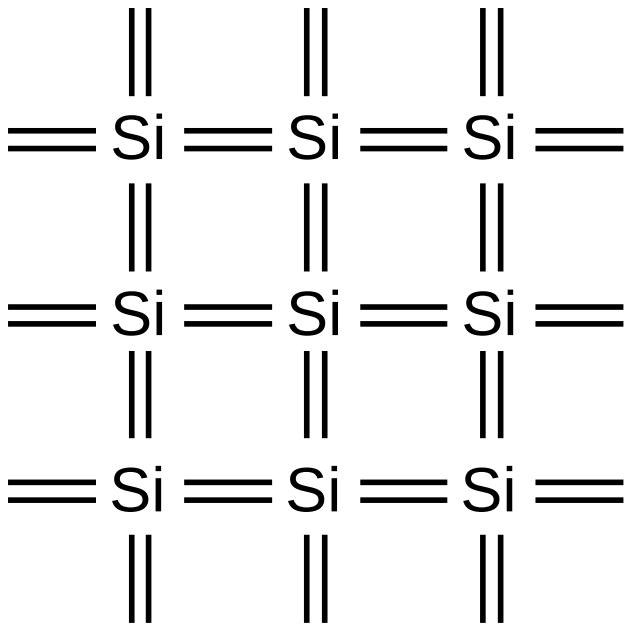
Corollaries

- Many other factors grow exponentially
  - Ex: clock frequency, processor performance



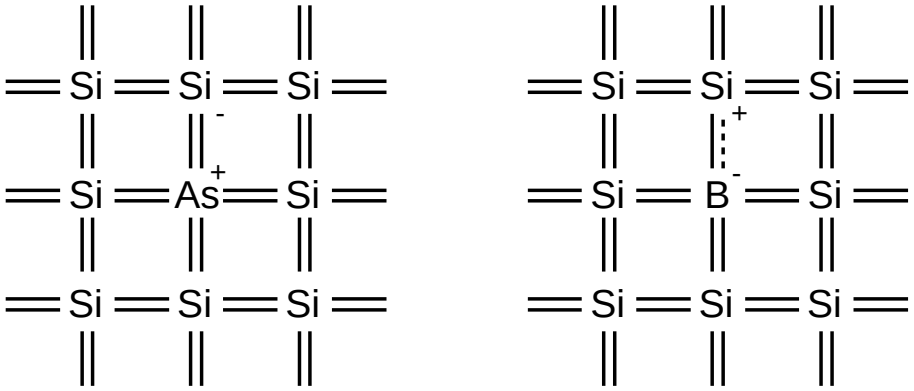
MOS Transistor: Silicon Lattice

- Transistors are built on a silicon substrate
- Silicon is a Group IV material
- Forms crystal lattice with bonds to four neighbors



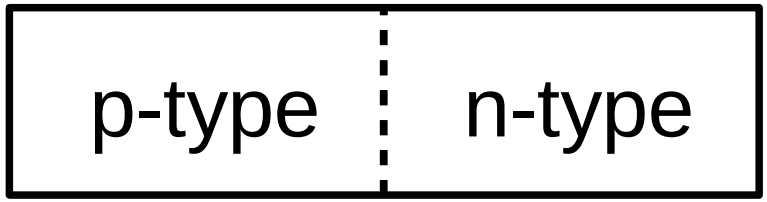
Dopants

- Silicon is a semiconductor
- Pure silicon has no free carriers and conducts poorly
- Adding dopants increases the conductivity
- Group V: extra electron (n-type)
- Group III: missing electron, called hole (p-type)

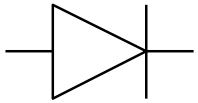


p-n Junctions

- A junction between p-type and n-type semiconductor forms a diode.
- Current flows only in one direction

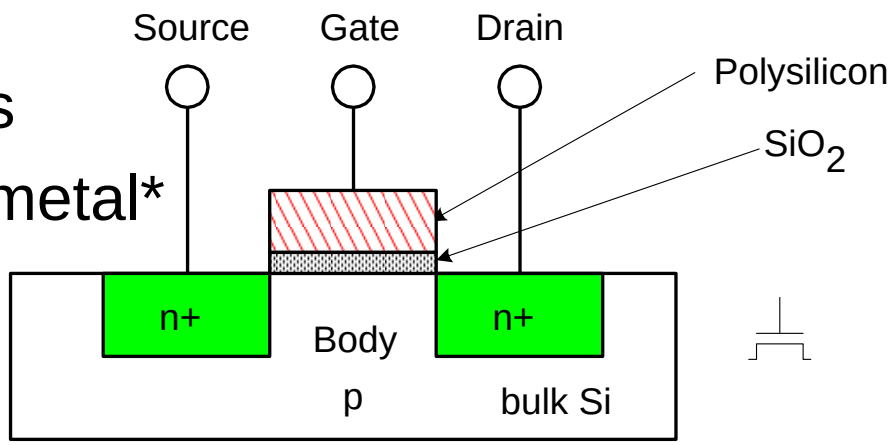


anode cathode



nMOS Transistor

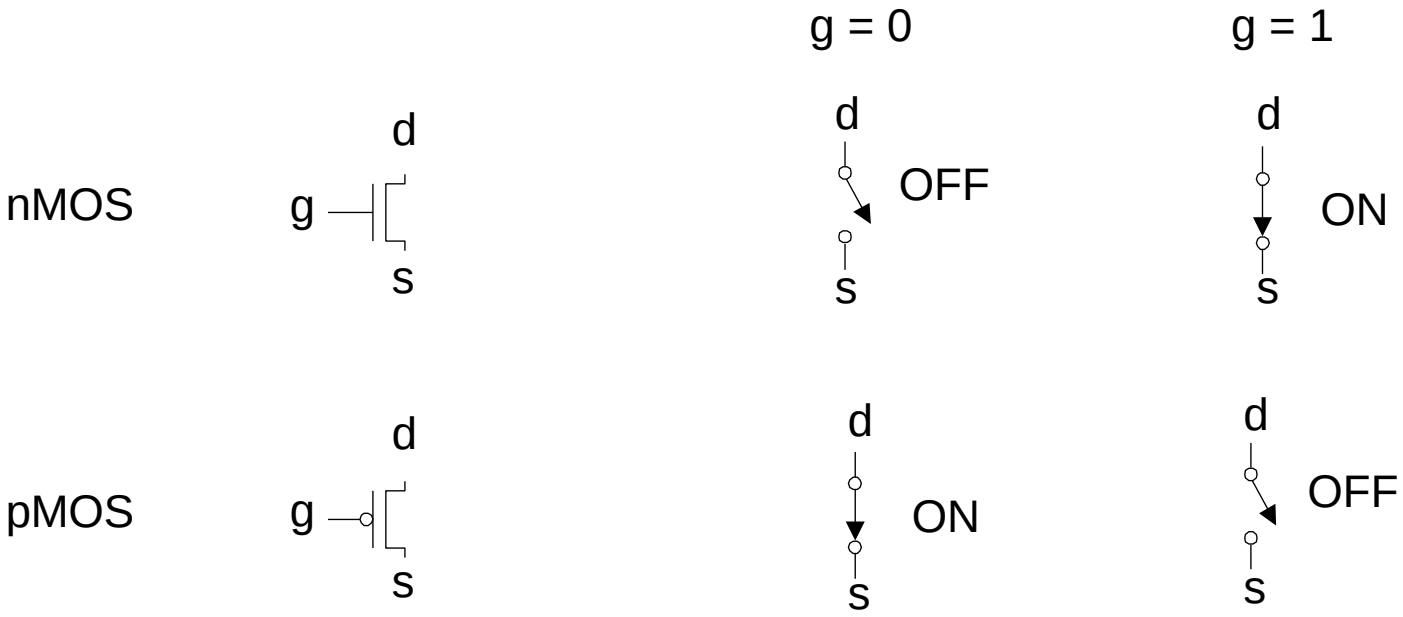
- Four terminals: gate, source, drain, body
- Gate – oxide – body stack looks like a capacitor
  - Gate and body are conductors
  - SiO_2 (oxide) is a very good insulator
  - Called metal – oxide – semiconductor (MOS) capacitor
  - Even though gate is no longer made of metal*



* Metal gates are returning today!

Transistors as Switches

- We can view MOS transistors as electrically controlled switches
- Voltage at gate controls path from source to drain



CMOS Inverter

A	Y
0	1
1	0