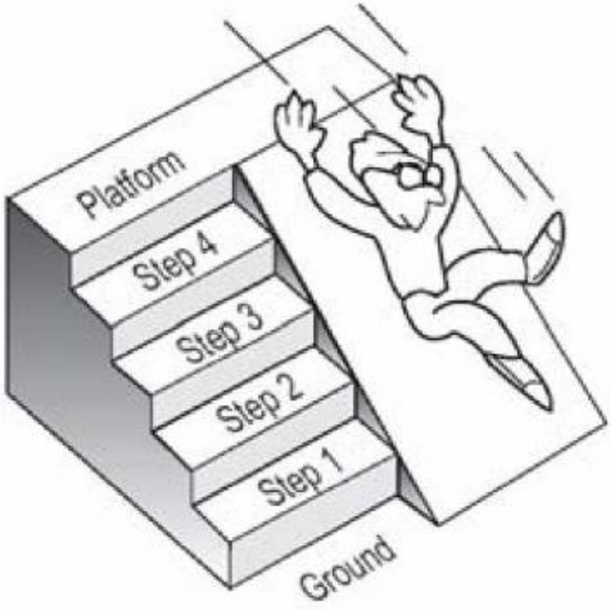
Digital Circuits and Logic Design

Lecture1 : Digital System

Digital and Analog

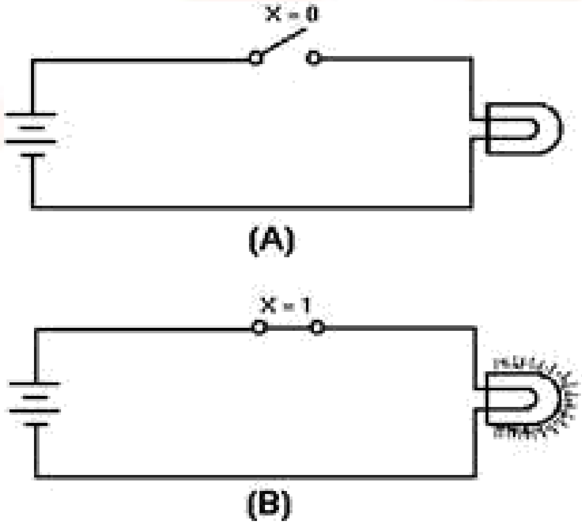
A **digital signal** is a signal that at any time can have one of a finite set of possible values , and is also know as *a discrete signal* .

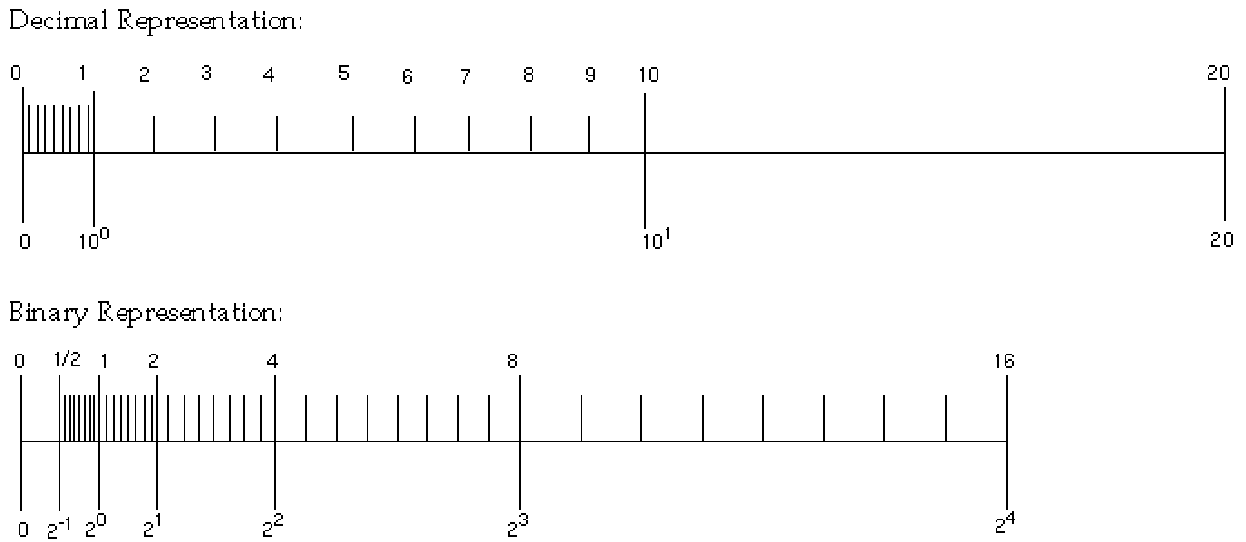
An **analog signal** can have one of an infinite number of possible values , and is also know as *a continuous signal*



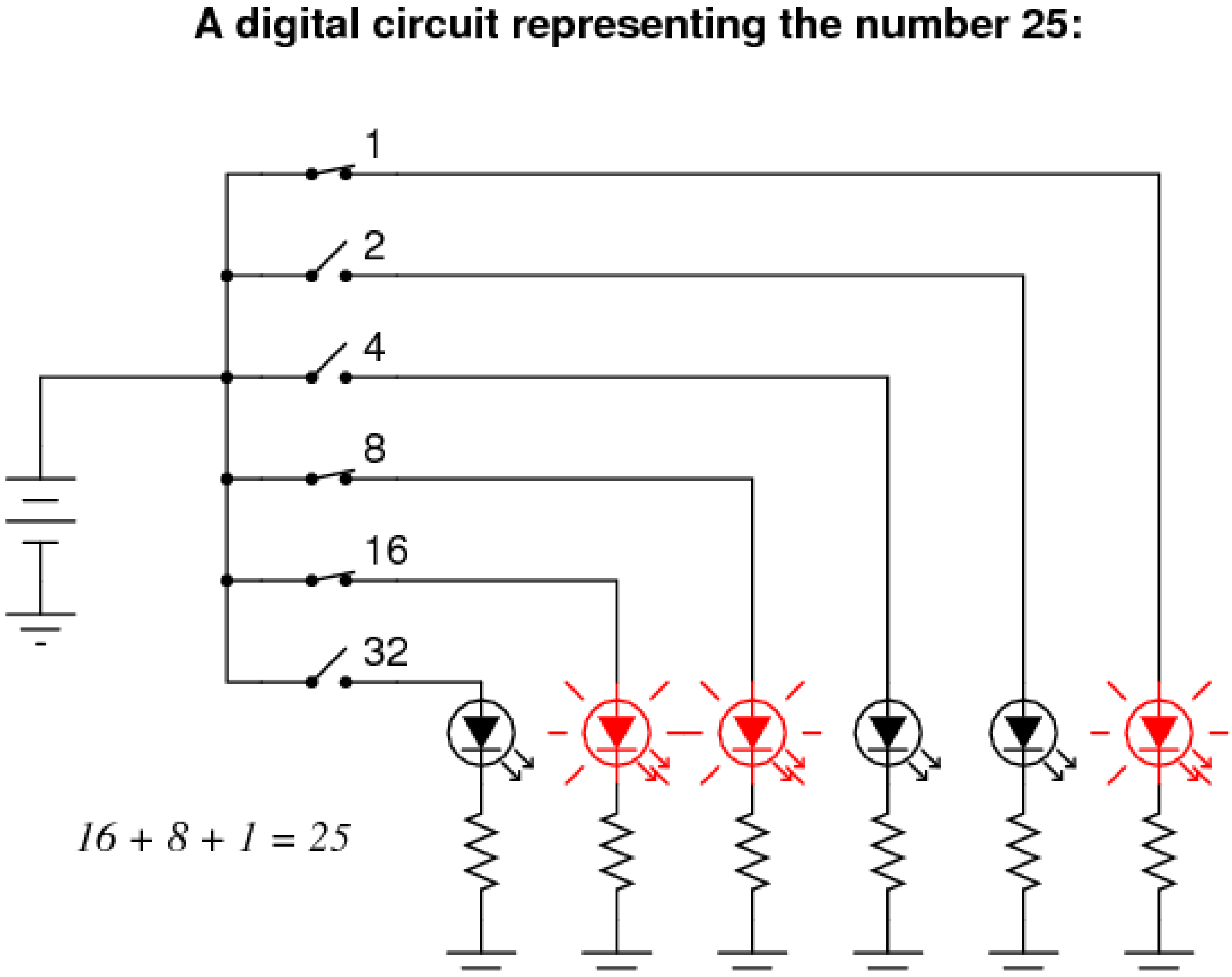
Switch and Binary Representation

The most commom digital signal are those that can have one of only two possible values , like on or off (0 and 1) => switch => a binary representation

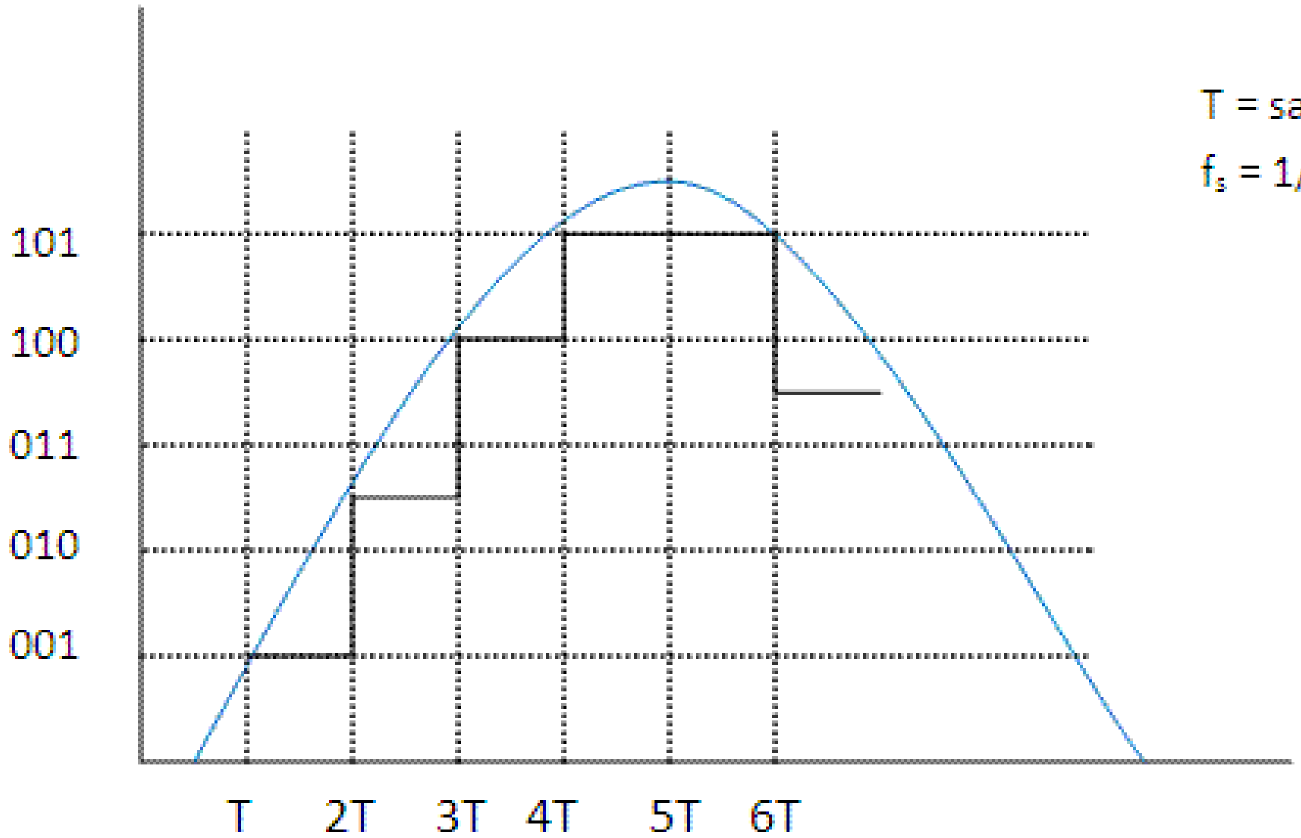




Switch and Binary Representation



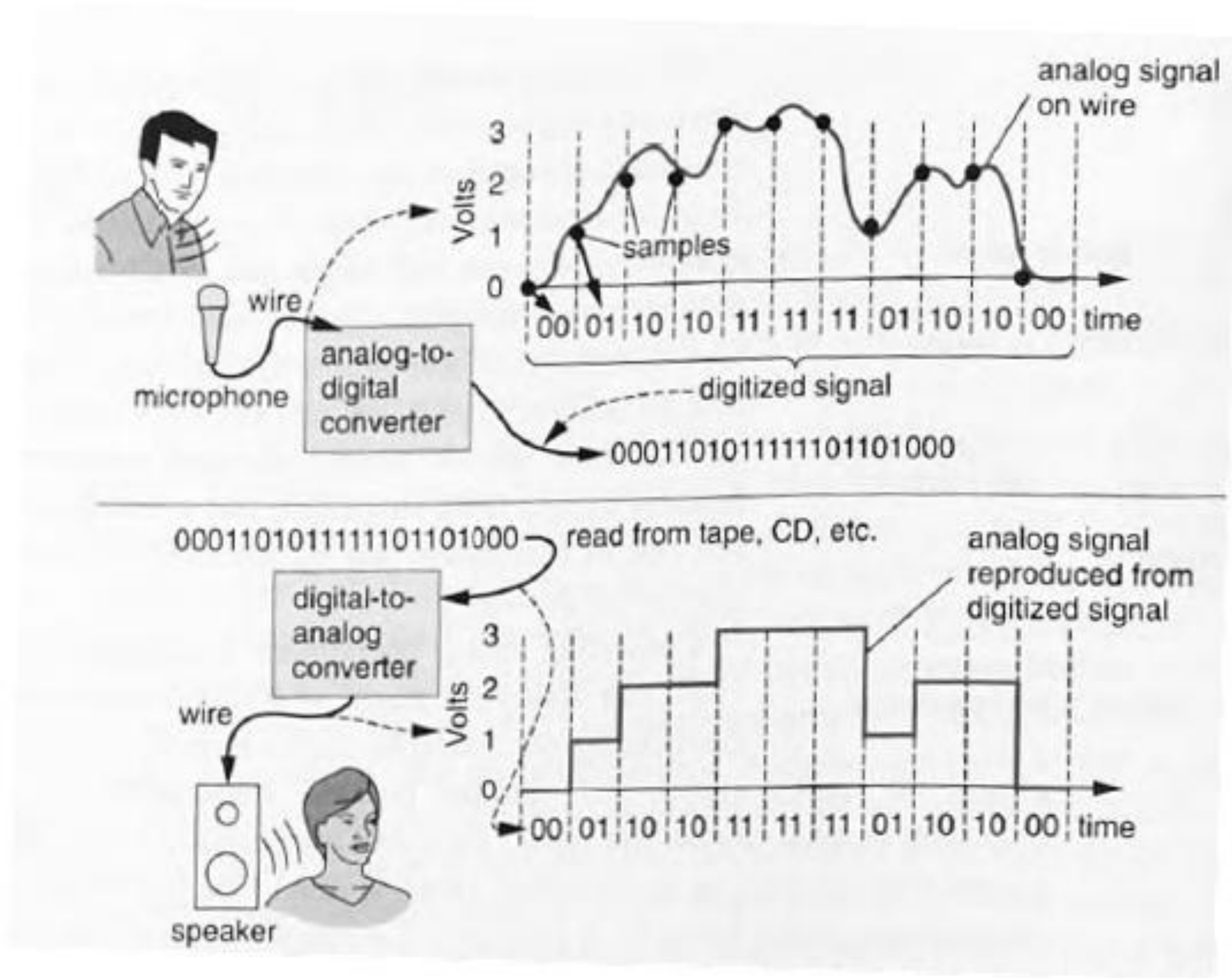
Digital and Analog



T = sampling period

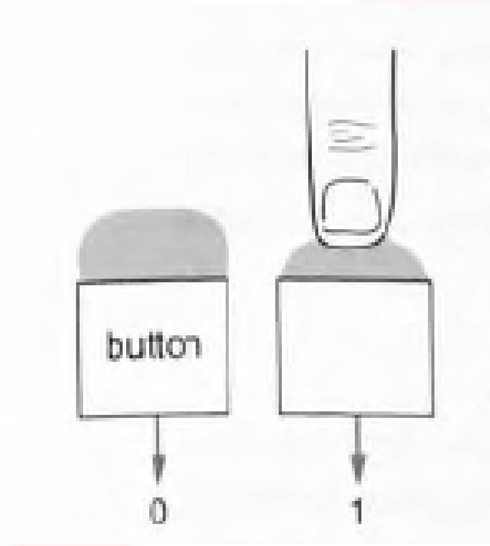
f_s = 1/T = sampling frequenc

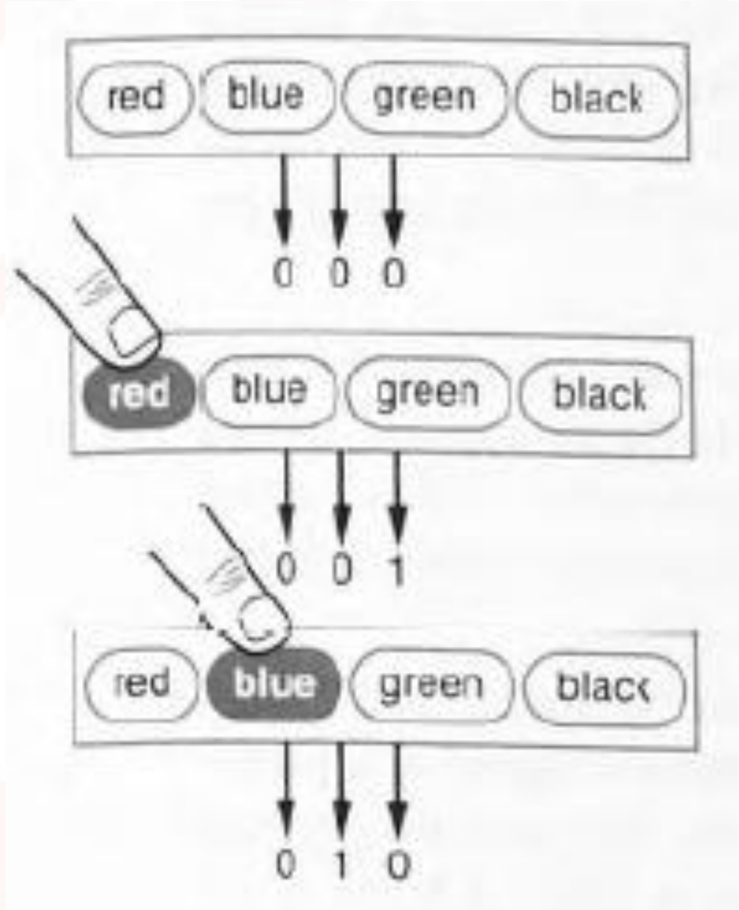
Digital and Analog



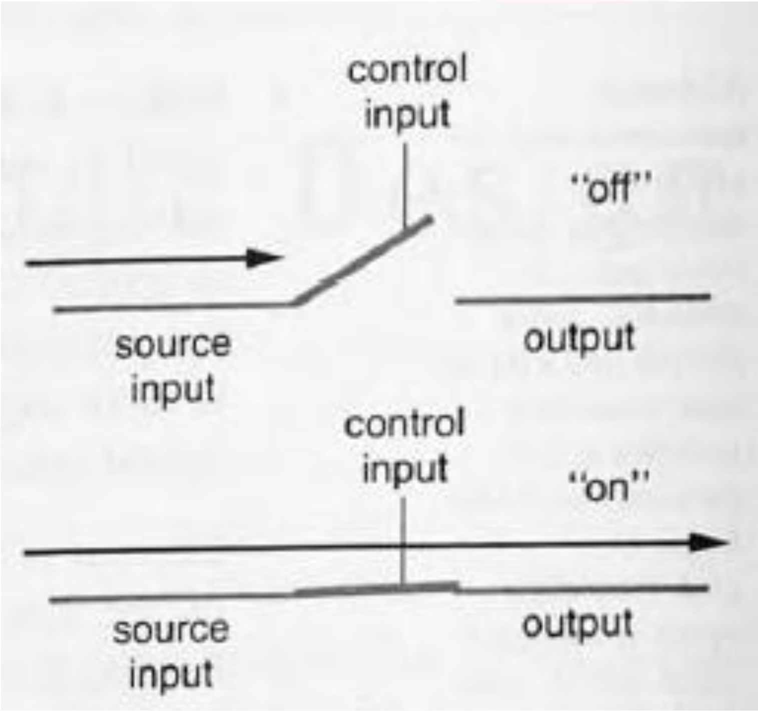
More and more analog products are becoming digital.

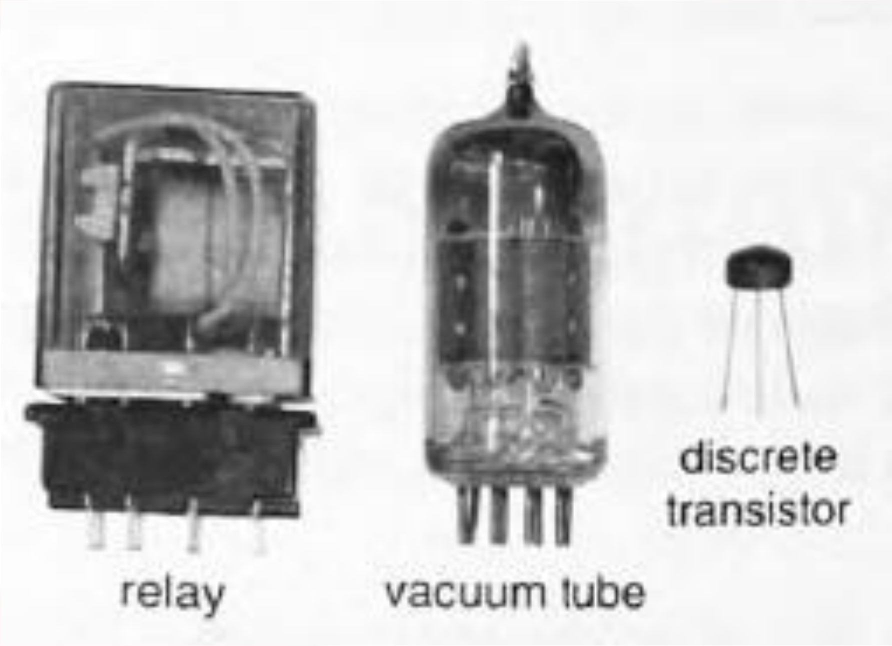
Ex. Keypad Encoding





Ideal Switch to Real Switch





Digital Hardware

1930’s Relays

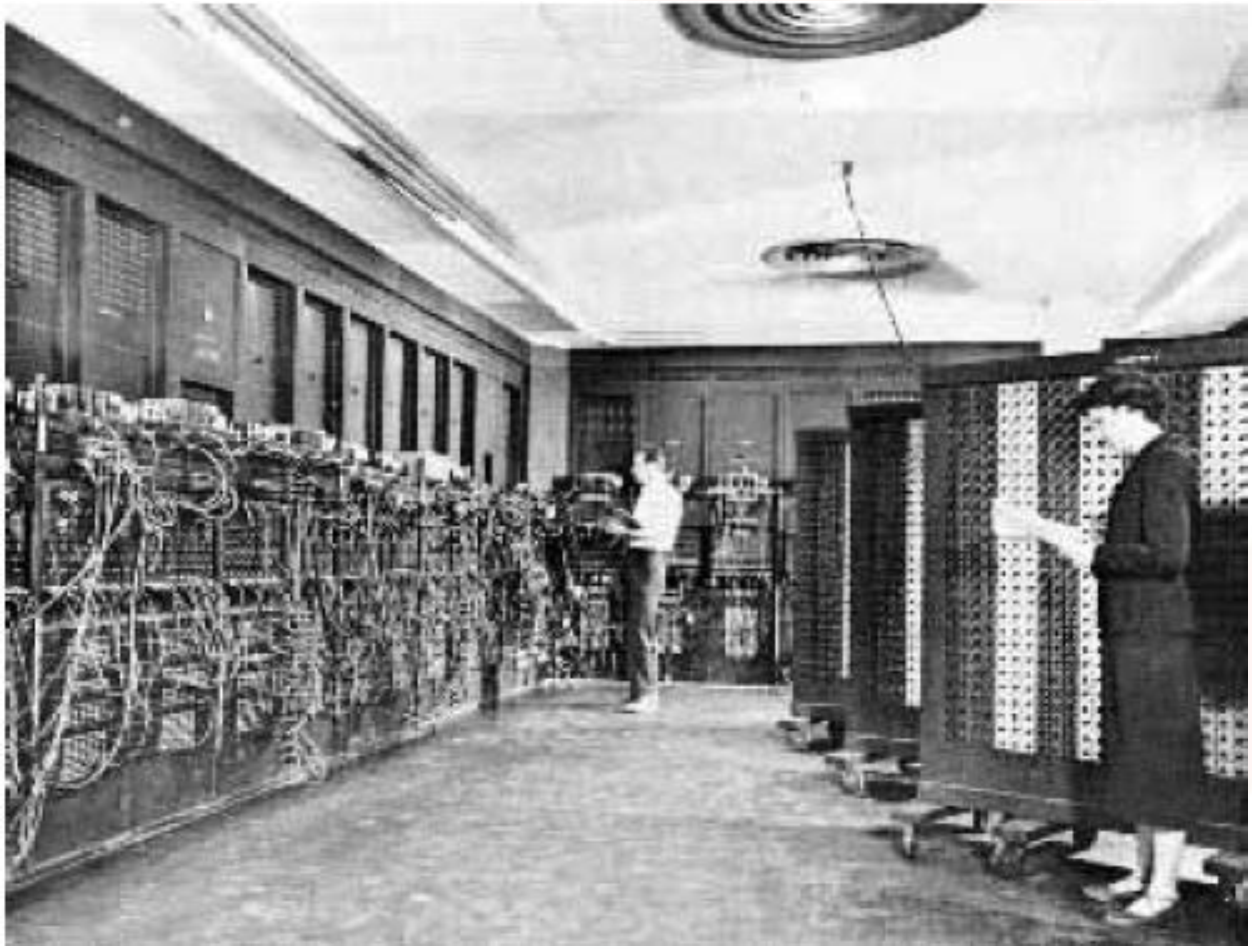
1940’s VacuumTube – No moving part ,
Faster than Relays

Digital Hardware

- Logic circuits are used to build computer hardware as well as other products
- Late 1960's and early 1970's saw a revolution in digital capability
  - Smaller transistors
  - Larger chip size
- More transistors/chip gives greater functionality, but requires more complexity in the design process

ENIAC - The First Electronic Computer

ENIAC (Electrical Numerical Integrator And Calculator) 1946



5000 addition per second OR 400 multiplications per second (200,000 times speed up compared with hand calculation)

ENIAC - The First Electronic Computer

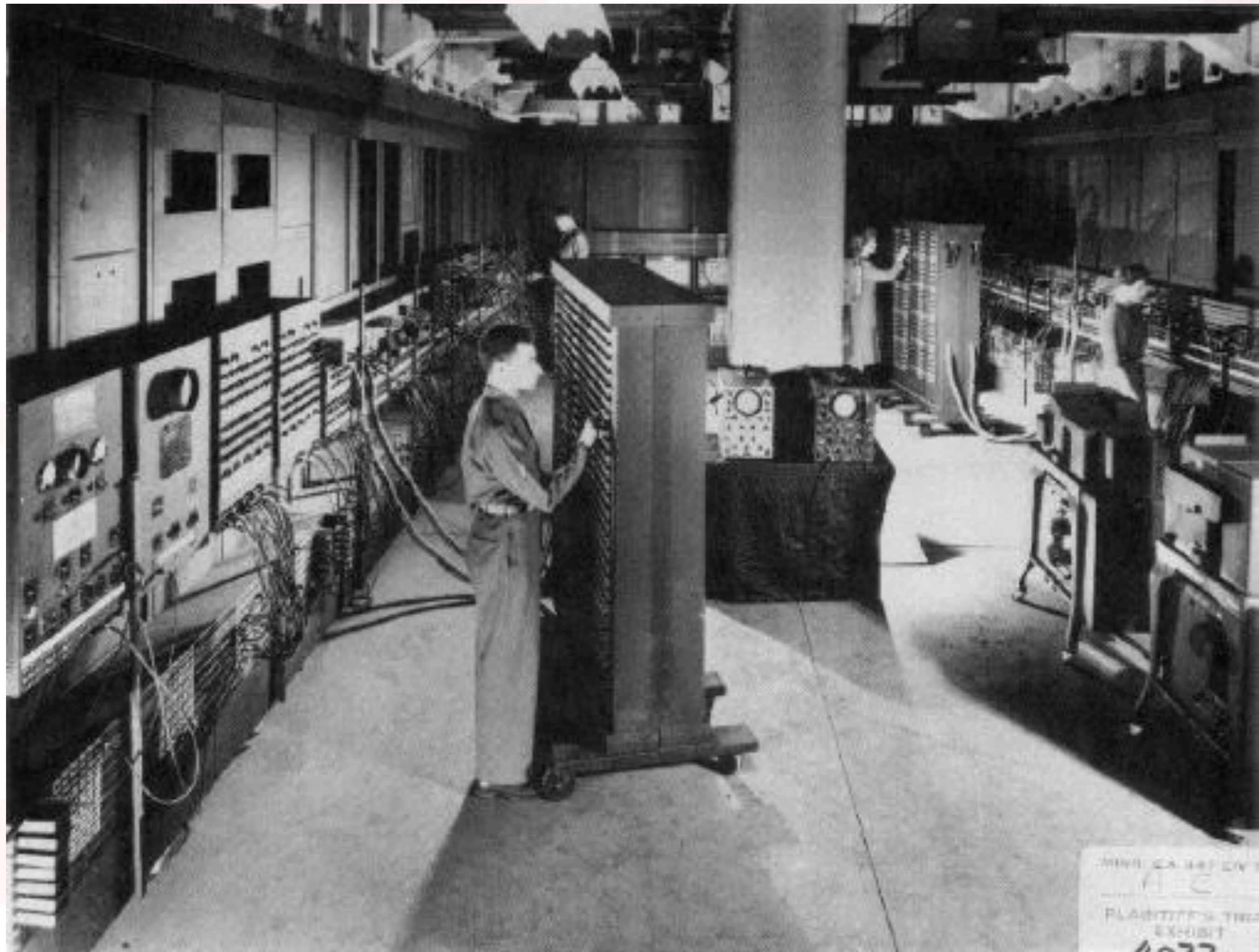
17,468 vacuum tubes
70,000 resistors
10,000 capacitors
1,500 relays
6,000 manual switches
160 kilowatts
167 square meters
30 tons

Size:

-80 feet long

-30 feet wide

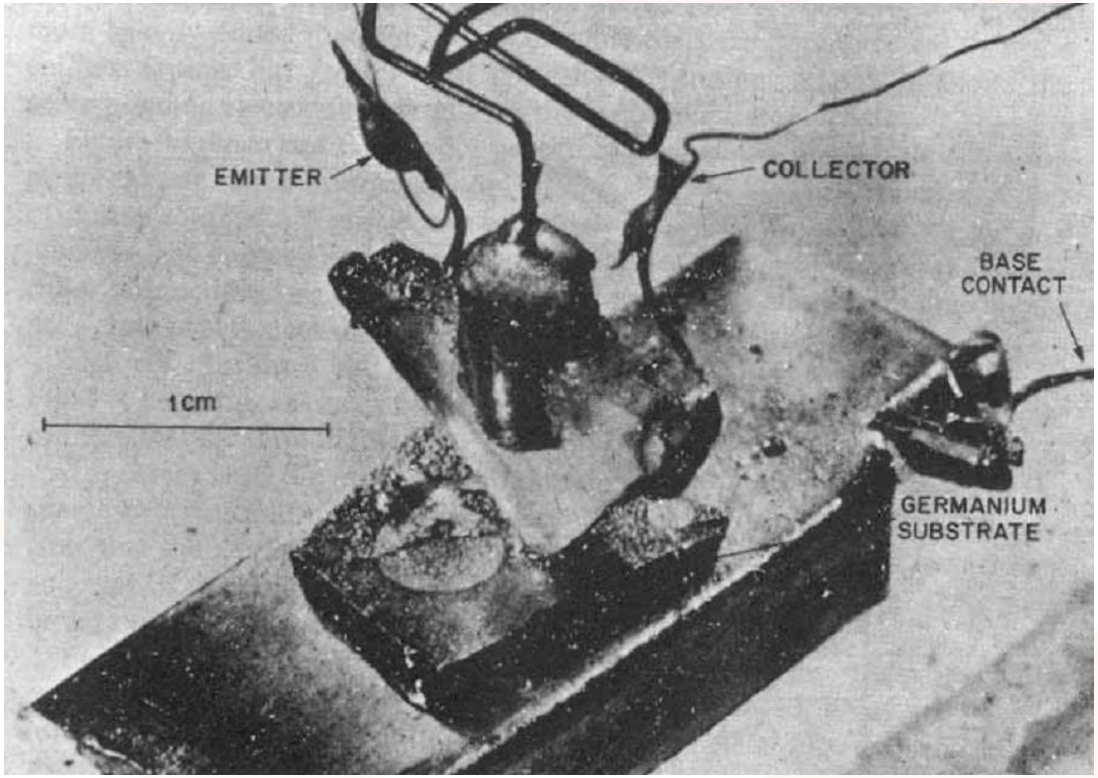
-8.5 feet high



The First 'BUG'

In 1947, Grace Murray Hopper was working on the Harvard University Mark II Aiken Relay Calculator (a primitive computer). On the 9th of September, 1947, when the machine was experiencing problems, an investigation showed that there was a moth trapped between the points of Relay #70, in Panel F.

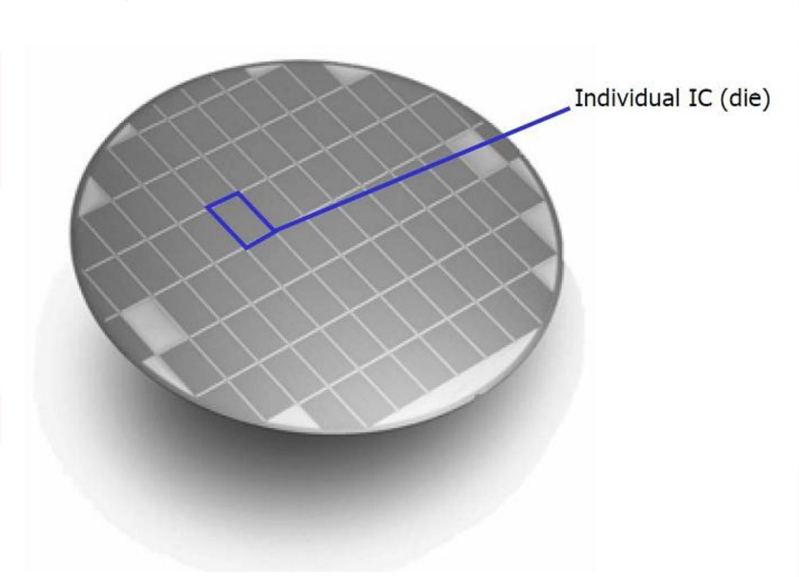
The First Transistor (1947)

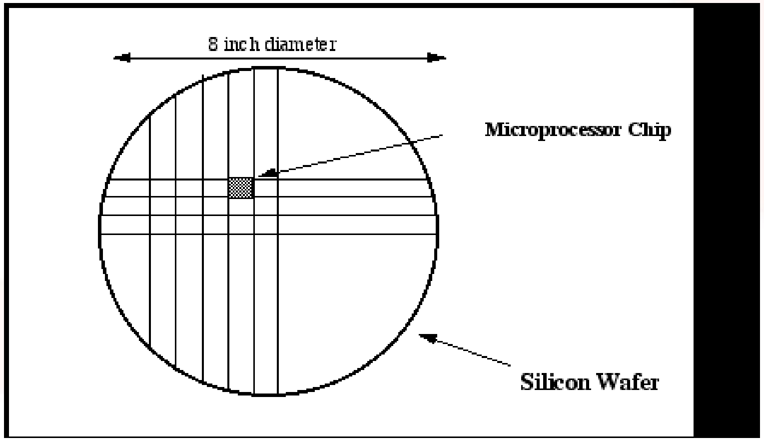


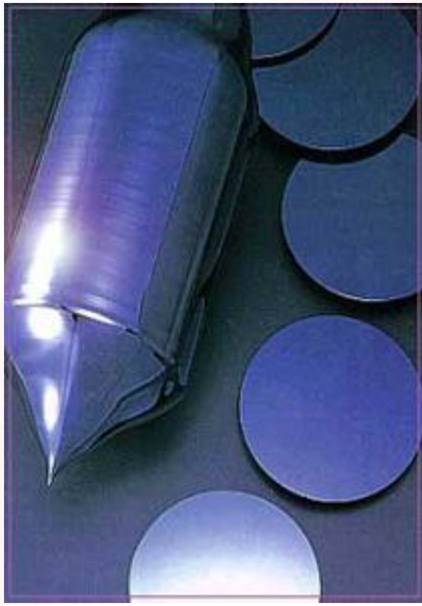
John Bardeen, William Shockley and Walter Brattain

Silicon Wafer

Silicon wafer is a high-purity doped silicon

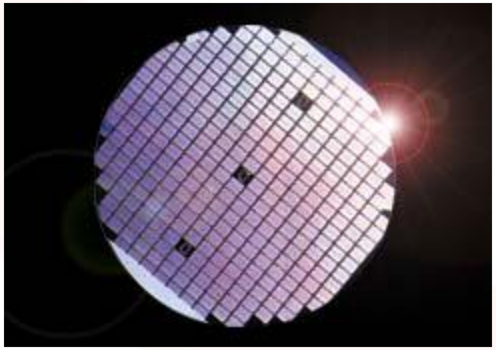


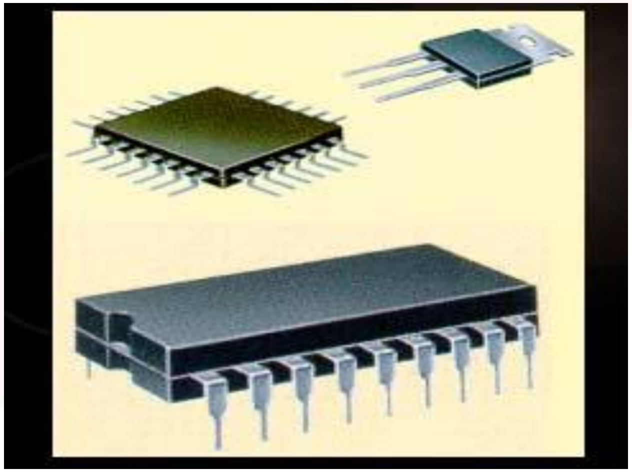




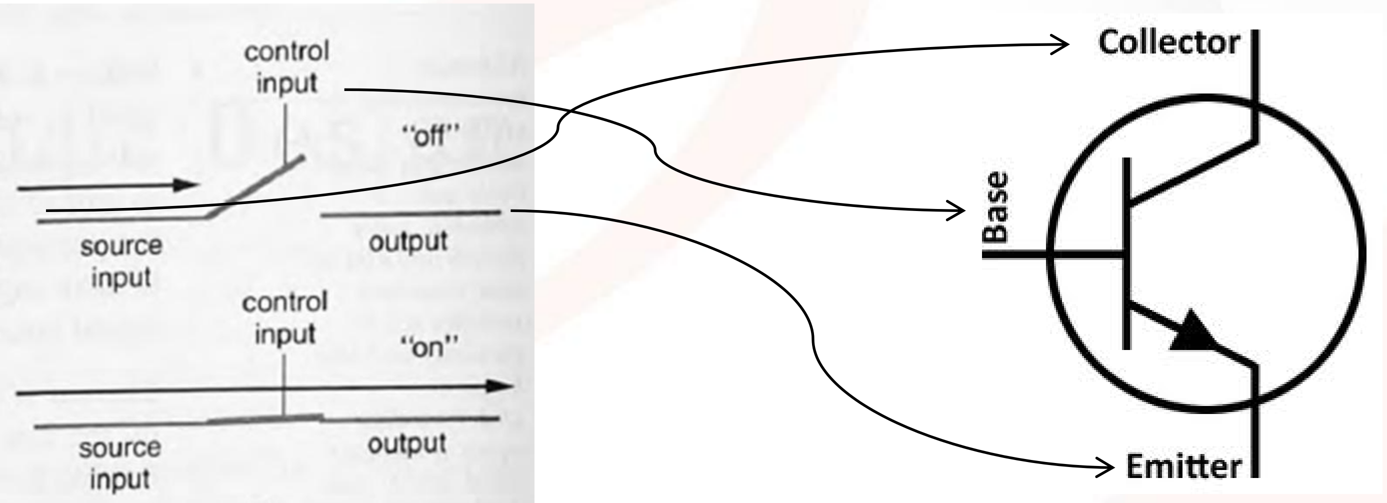
Silicon Wafer

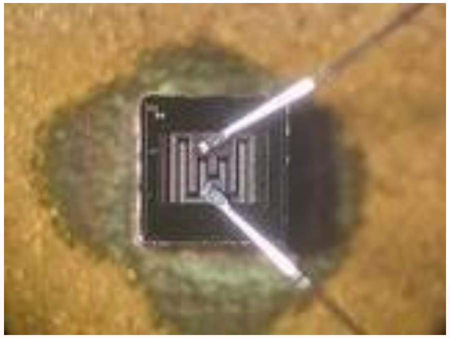
Silicon wafer is mainly used for making integrated circuit (IC) chip such as microprocessors, memory devices, diodes, transistors specific IC application. A small portion for sensor or detector manufacturing.



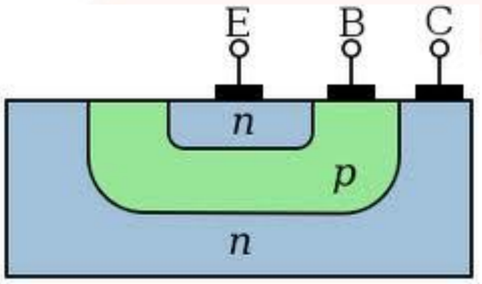


Bipolar Junction Transistor





Die of a KSY34 high-frequency NPN Transistor

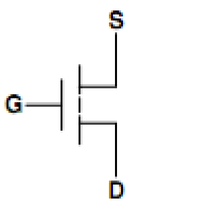


Simplified cross section of a planar *NPN* bipolar junction transistor

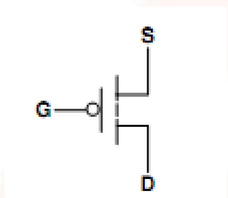
CMOS

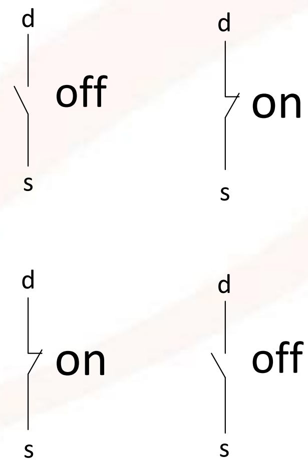
g=0 g=1

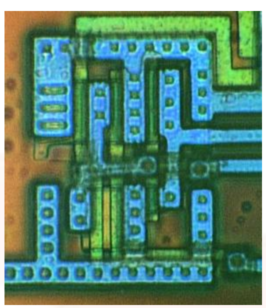
nMOS



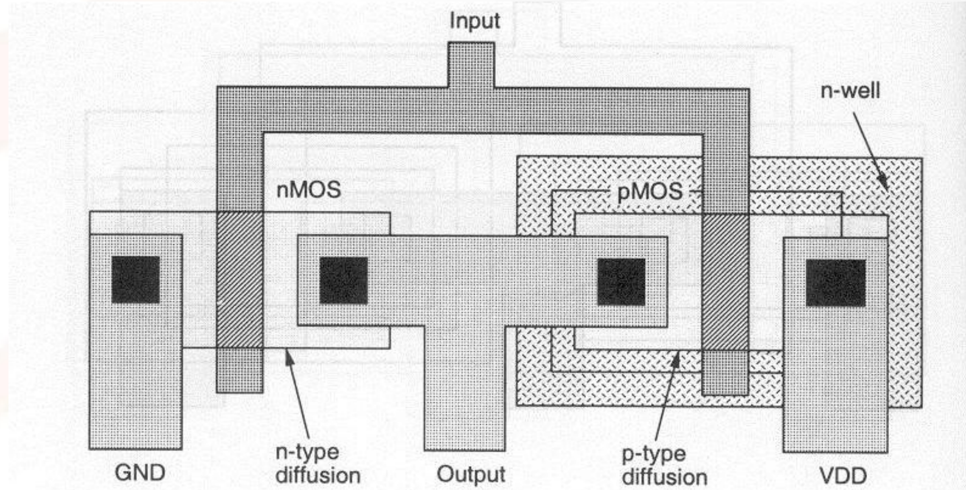
pMOS

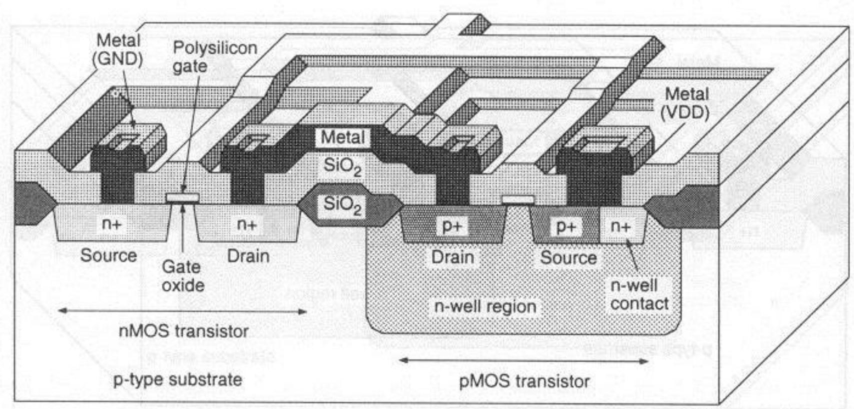






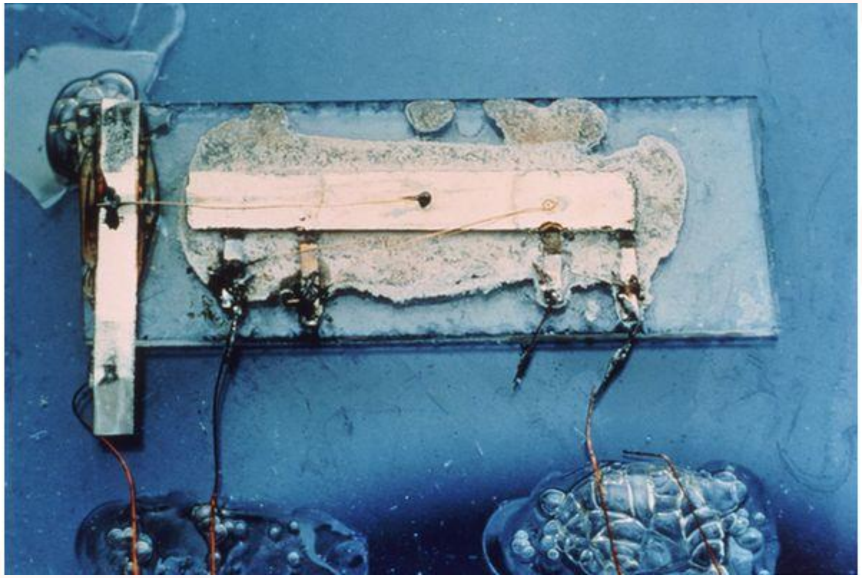
Ex. CMOS AND gate





Complementary metal–oxide–semiconductor (CMOS)

The First Integrated Circuit (IC)



The first working integrated circuit was created by Jack Kilby in 1958. It contains a single transistor and supporting components on a slice of germanium and measures 1/16 by 7/16 inches (1.6 x 11.1 mm).

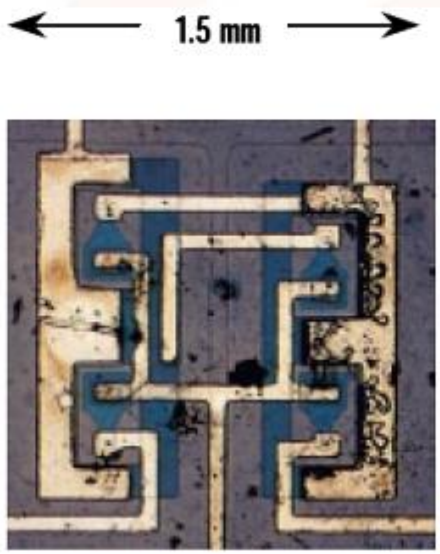
- Jack Kirby, invented Integrated Circuits in 1958 at Texas Instruments.
- He argued that by putting all electronic components into a single die, performance would increase and cost would decrease.

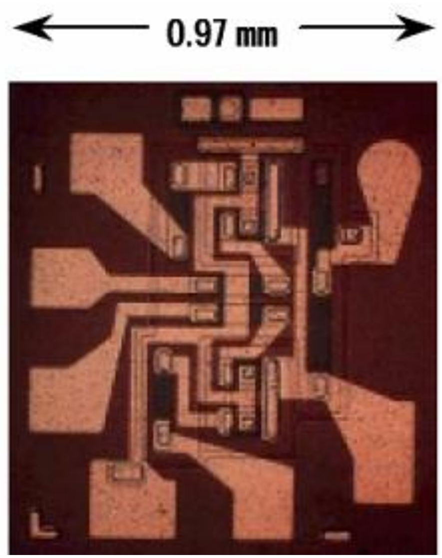
The First Logic IC

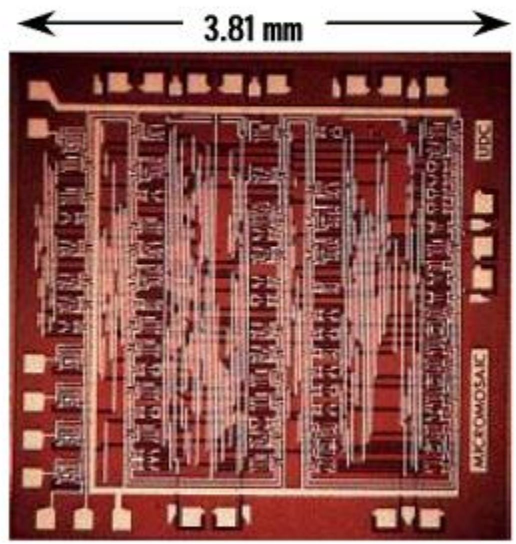
1961: TI and Fairchild introduced the first logic IC's (cost ~$50 in quantity!). This is a dual flip-flop with 4 transistors.

1963: Densities and yields are improving. This circuit has four flip flops.

1967: Fairchild markets the semi-custom chip shown below. Transistors could be easily rewired using a two-layer interconnect to create different circuits. This circuit contains ~150 logic gates.







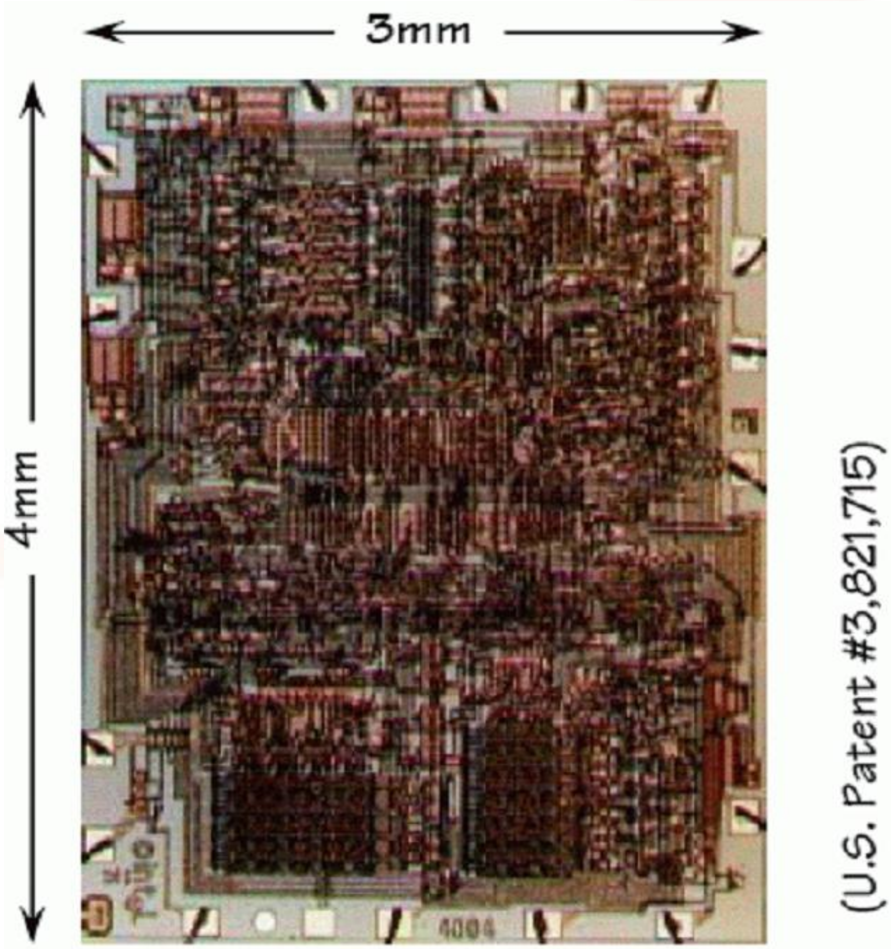
INTegrated ELectronics=Intel (1968)


[2] Gordon Moore [right] relaxes with fellow pioneers of the electronic age: Robert Noyce [center] and Andrew Grove [left]. Moore and Noyce contributed to the development of the planar IC. Grove is now president and chief executive officer of Intel Corp.

Noyce and Moore leave Fairchild and found Intel. No business plan, just a promise to specialize memory chips.

Pioneers of the Electronic Age

Intel 4004 Micro-Processor (1971)



First microprocessor (1971)

- For Busicom calculator

Characteristics

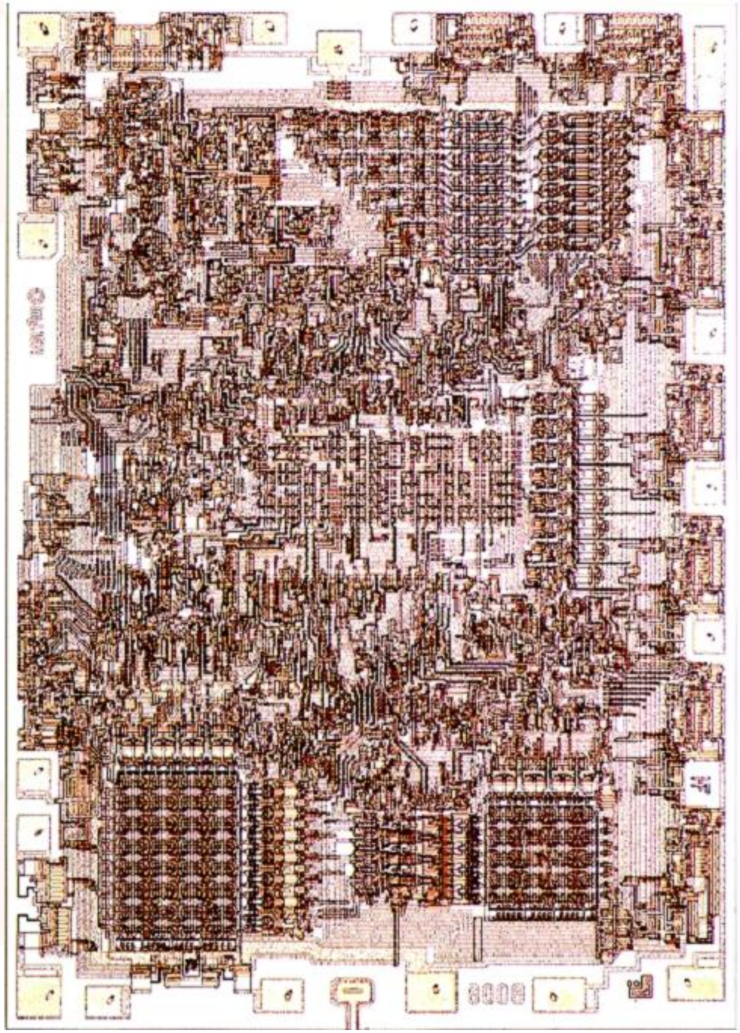
- 10 μm process
- 2300 transistors
- 400 – 800 kHz
- 4-bit word size
- 16-pin DIP package

8008

8-bit follow-on (1972)
- Dumb terminals

Characteristics
- 10 μm process
- 3500 transistors
- 500 – 800 kHz
- 8-bit word size
- 18-pin DIP package

Note 8-bit datapaths
- Individual transistors visible



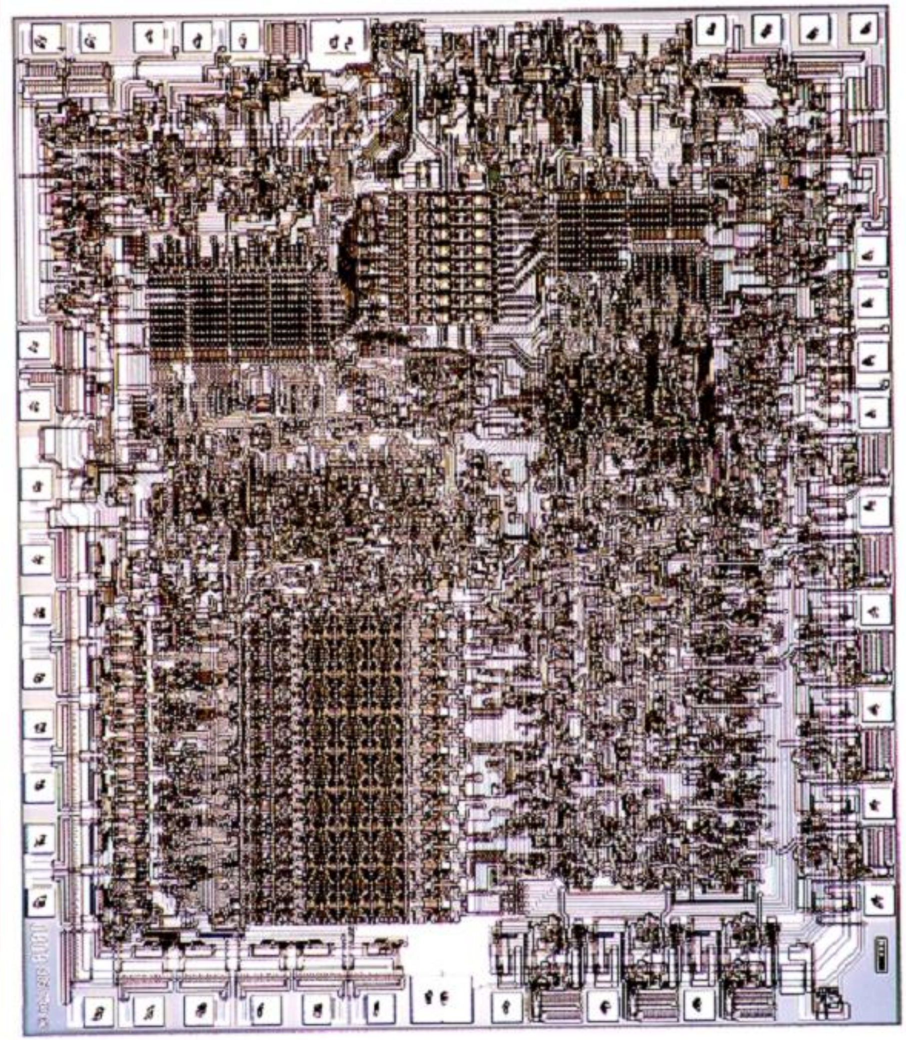
8080

16-bit address bus (1974)

- Used in Altair computer
  - (early hobbyist PC)

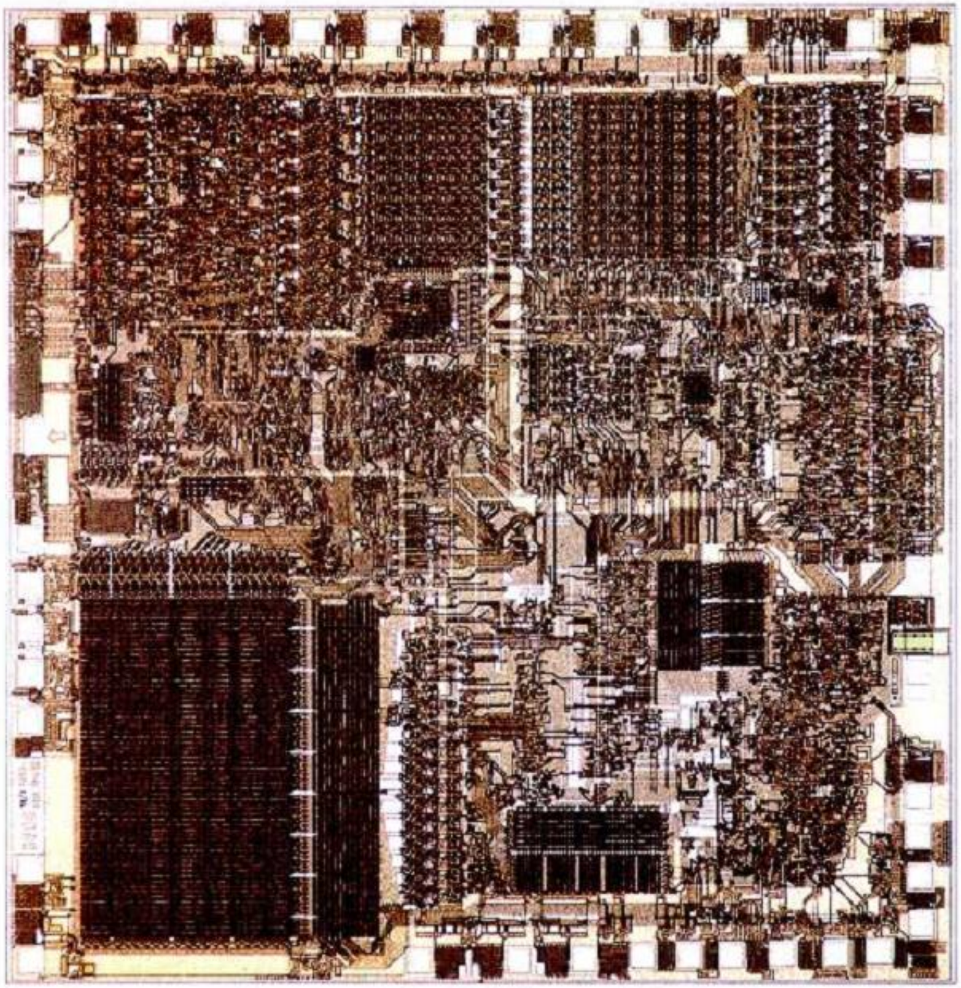
Characteristics

- 6 μm process
- 4500 transistors
- 2 MHz
- 8-bit word size
- 40-pin DIP package



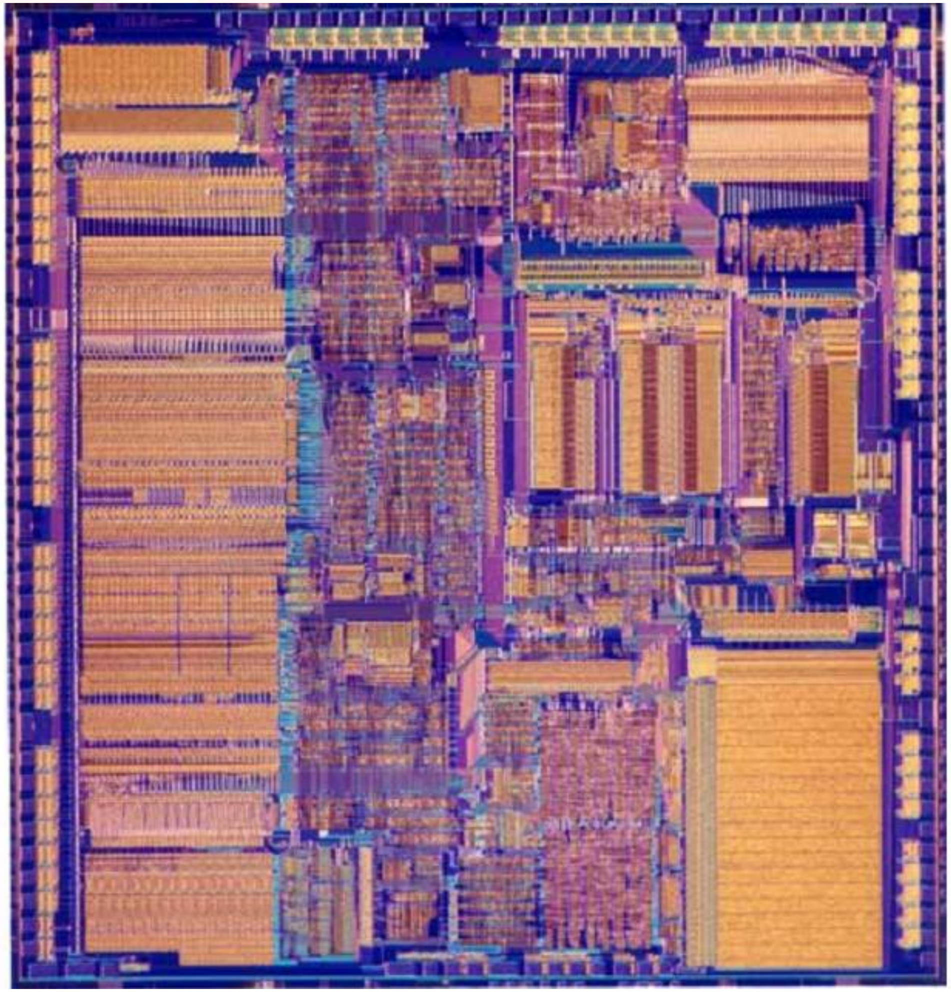
8086/8088

- 16-bit processor (1978-9)
  - IBM PC and PC XT
  - Revolutionary products
  - Introduced x86 ISA
- Characteristics
  - 3 μm process
  - 29k transistors
  - 5-10 MHz
  - 16-bit word size
  - 40-pin DIP package
- Microcode ROM



80386

- 32-bit processor (1985)
  - Modern x86 ISA
- Characteristics
  - 1.5-1 μm process
  - 275k transistors
  - 16-33 MHz
  - 32-bit word size
  - 100-pin PGA
- 32-bit datapath, microcode ROM, synthesized control



Pentium 4

Deep pipeline (2001)

- Very fast clock
- 256-1024 KB L2$

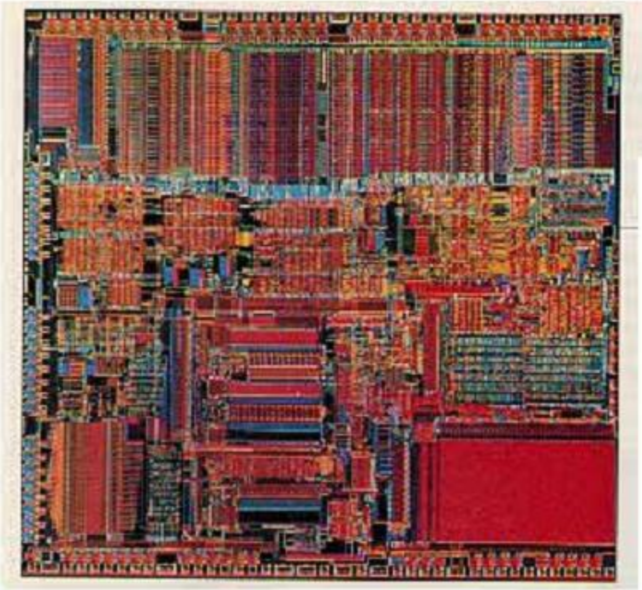
Characteristics

- 180 – 90 nm process
- 42-125M transistors
- 1.4-3.4 GHz
- 32-bit word size
- 478-pin PGA

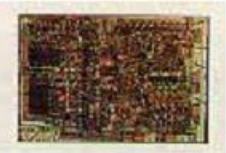
Units start to become invisible on this scale

The Die of Intel CPU

Pentium Pro



386



4004

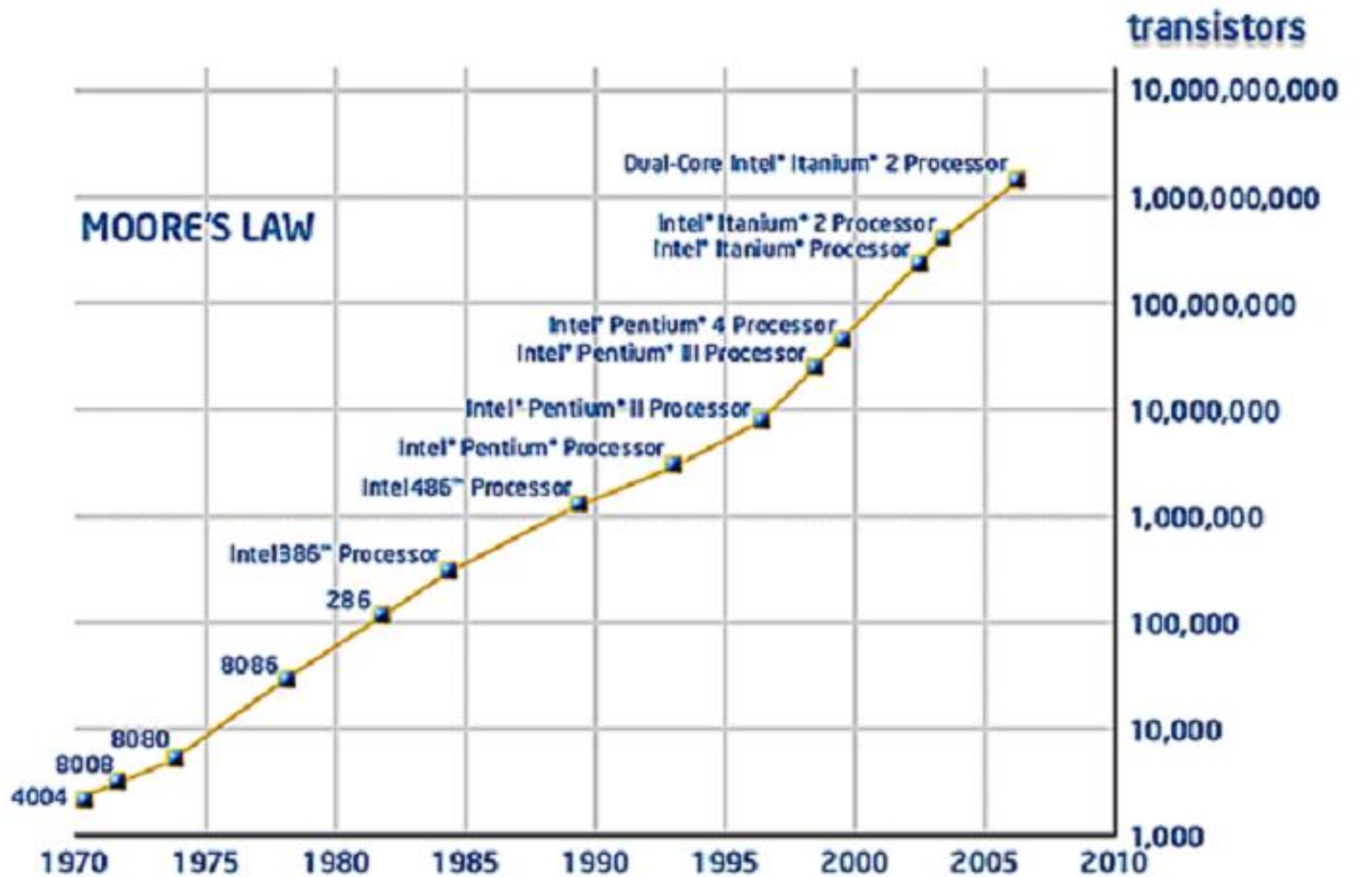
Intel summary

Processor	Year	Feature Size (µm)	Transistors	Frequency (MHz)	Word size	Package
4004	1971	10	2.3k	0.75	4	16-pin DIP
8008	1972	10	3.5k	0.5–0.8	8	18-pin DIP
8080	1974	6	6k	2	8	40-pin DIP
8086	1978	3	29k	5–10	16	40-pin DIP
80286	1982	1.5	134k	6–12	16	68-pin PGA
Intel386	1985	1.5–1.0	275k	16–25	32	100-pin PGA
Intel486	1989	1–0.6	1.2M	25–100	32	168-pin PGA
Pentium	1993	0.8–0.35	3.2–4.5M	60–300	32	296-pin PGA
Pentium Pro	1995	0.6–0.35	5.5M	166–200	32	387-pin MCM PGA
Pentium II	1997	0.35–0.25	7.5M	233–450	32	242-pin SECC
Pentium III	1999	0.25–0.18	9.5–28M	450–1000	32	330-pin SECC2
Pentium 4	2001	0.18–0.13	42–55M	1400–3200	32	478-pin PGA

Moore's Law

- Gordon Moore: co-founder of Intel.
  - Predicted that number of transistors per chip would grow exponentially (double every 18 months).
  - Exponential improvement in technology is a natural trend: steam engines, dynamos, automobiles.
- Today, the price of a transistor is less than a grain of rice

Moore's Law



transistors
MOORE'S LAW
10,000,000,000
1,000,000,000
100,000,000
10,000,000
1,000,000
100,000
10,000
1,000
Dual-Core Intel® Itanium® 2 Processor
Intel® Itanium® 2 Processor
Intel® Itanium® Processor
Intel® Pentium® 4 Processor
Intel® Pentium® III Processor
Intel® Pentium® II Processor
Intel® Pentium® Processor
Intel486™ Processor
Intel386™ Processor
286
8086
8080
8008
4004
1970
1975
1980
1985
1990
1995
2000
2005
2010

Types of chips

Standard chips
– Contain a small amount of circuitry (<100 transistors)
– Performs simple functions
– Ex. 7400 series devices

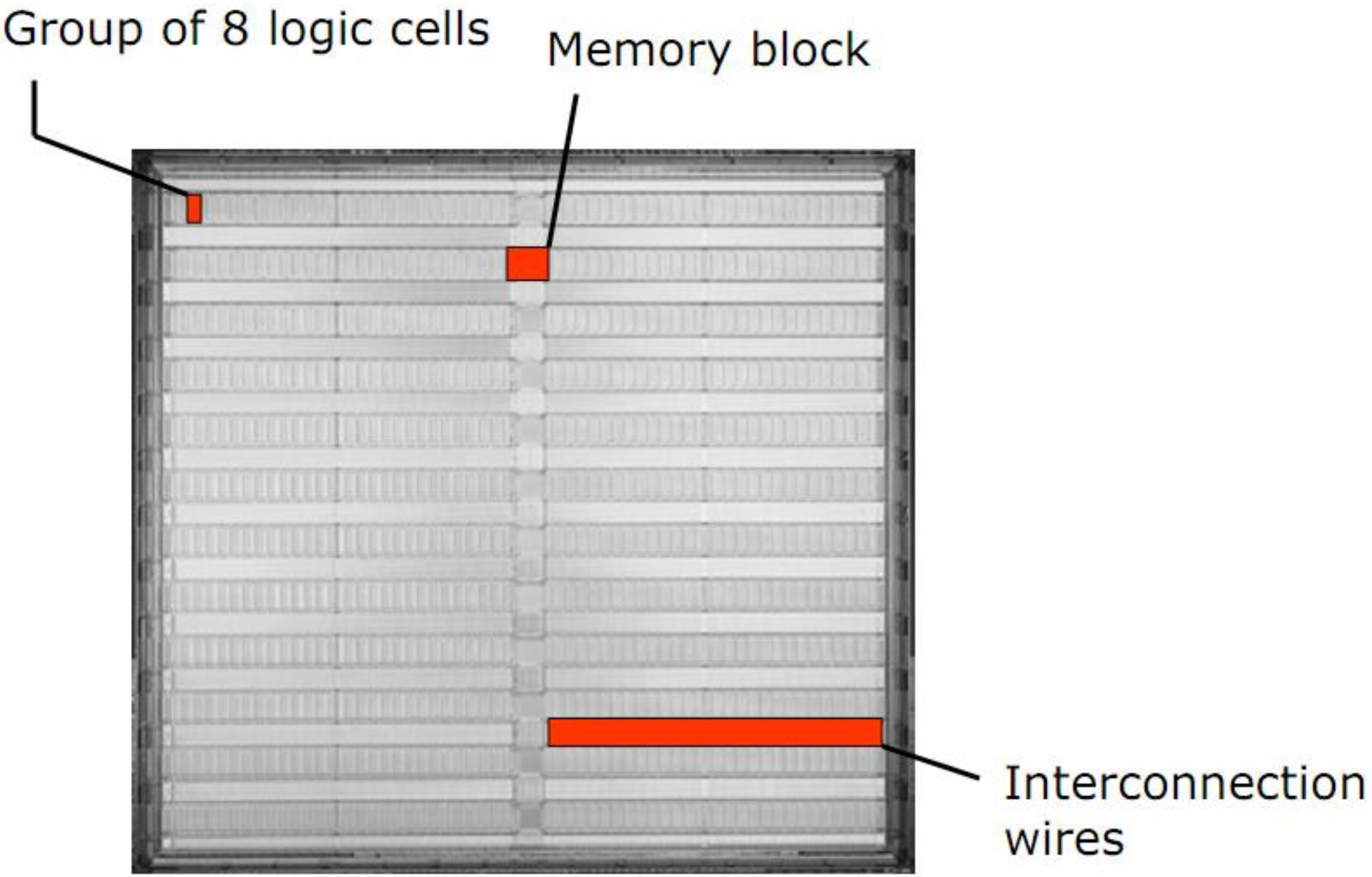
Programmable logic devices (PLD)
– Collection of gates with programmable interconnections
– Function is configurable by designer/user
– Design with PLD is via a CAD tool

Types of chips

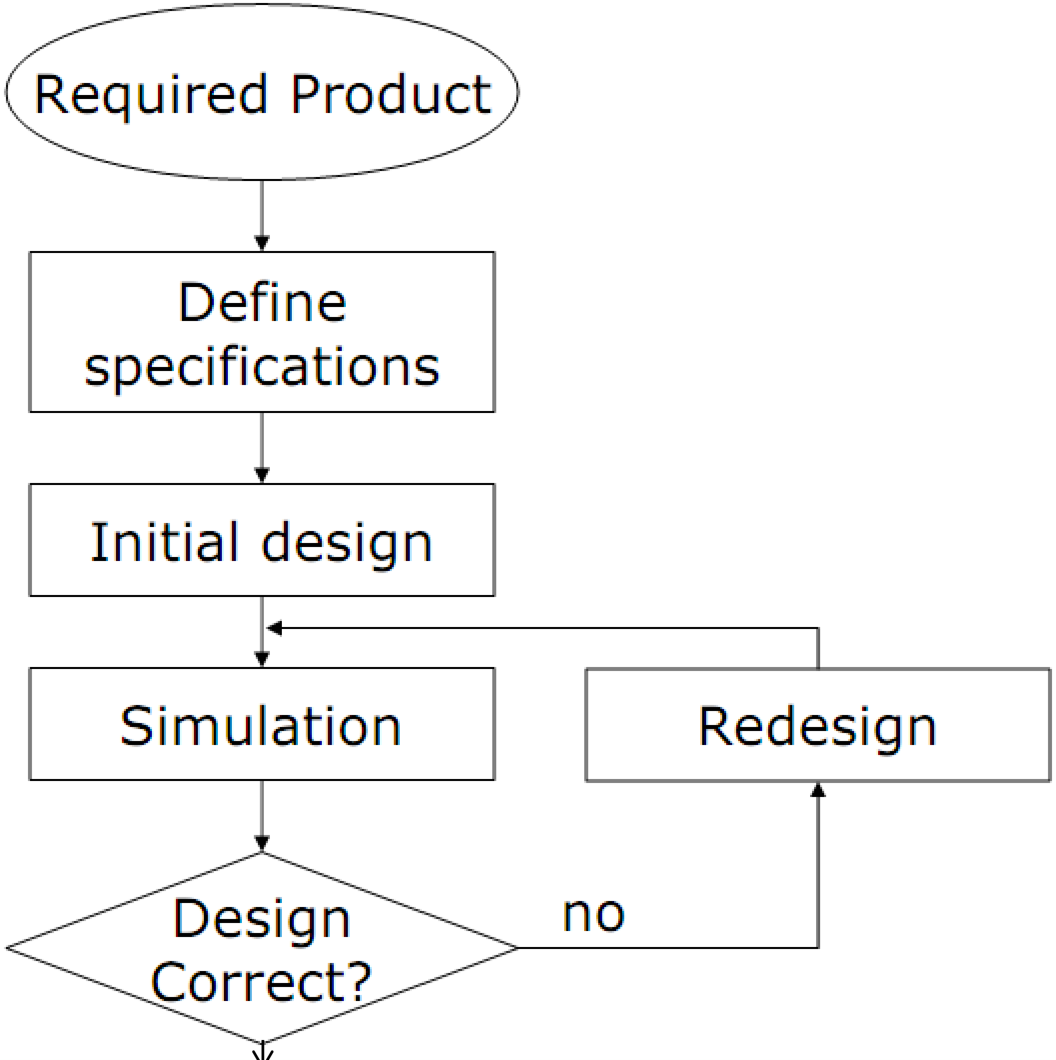
Custom-designed chips

– Optimized for a specific task – better performance
– Larger amount of logic circuitry
– Cost of production is high
– Large volume required to justify cost

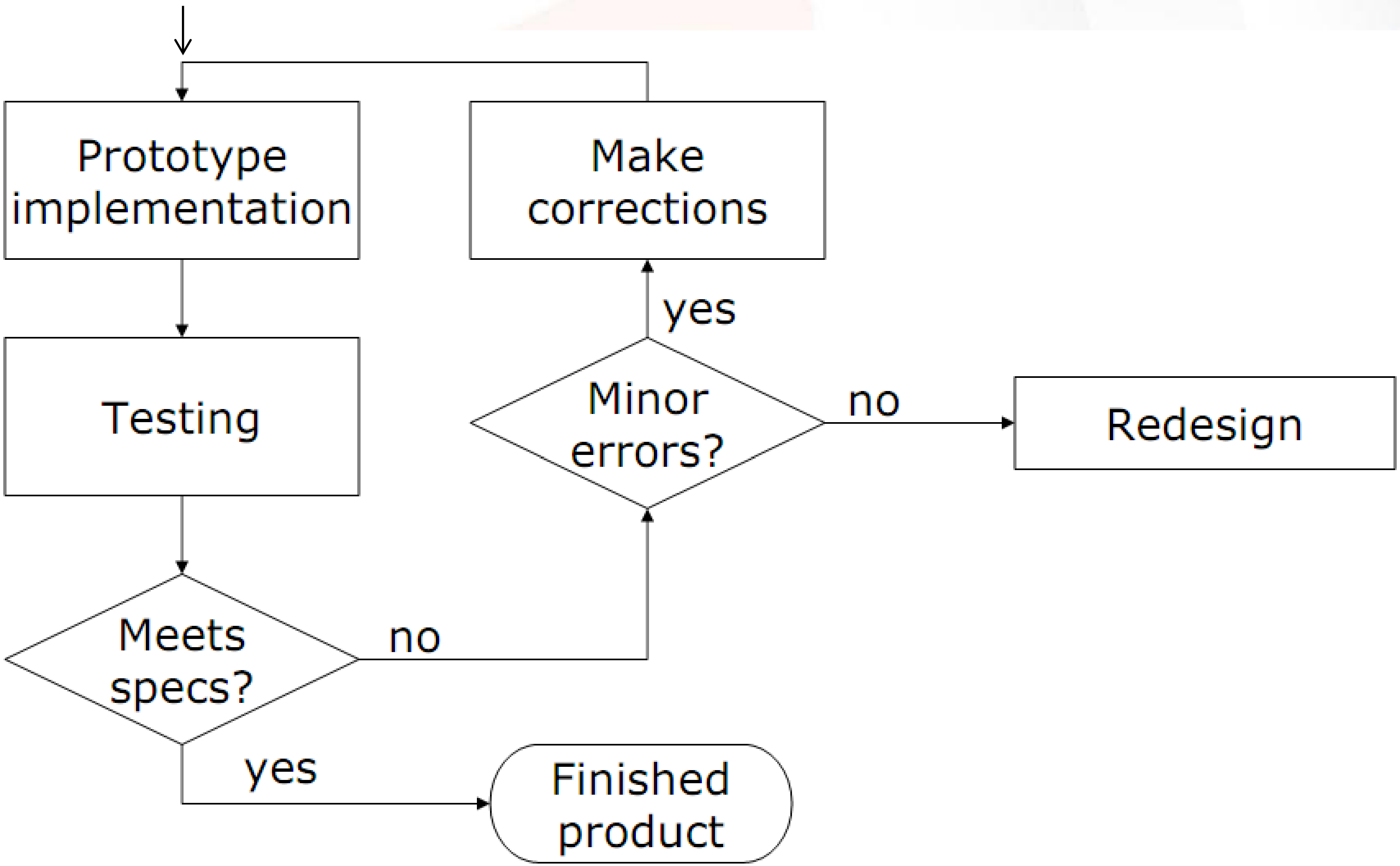
A field-programmable gate array



The Development Process (1)



The Development Process (2)



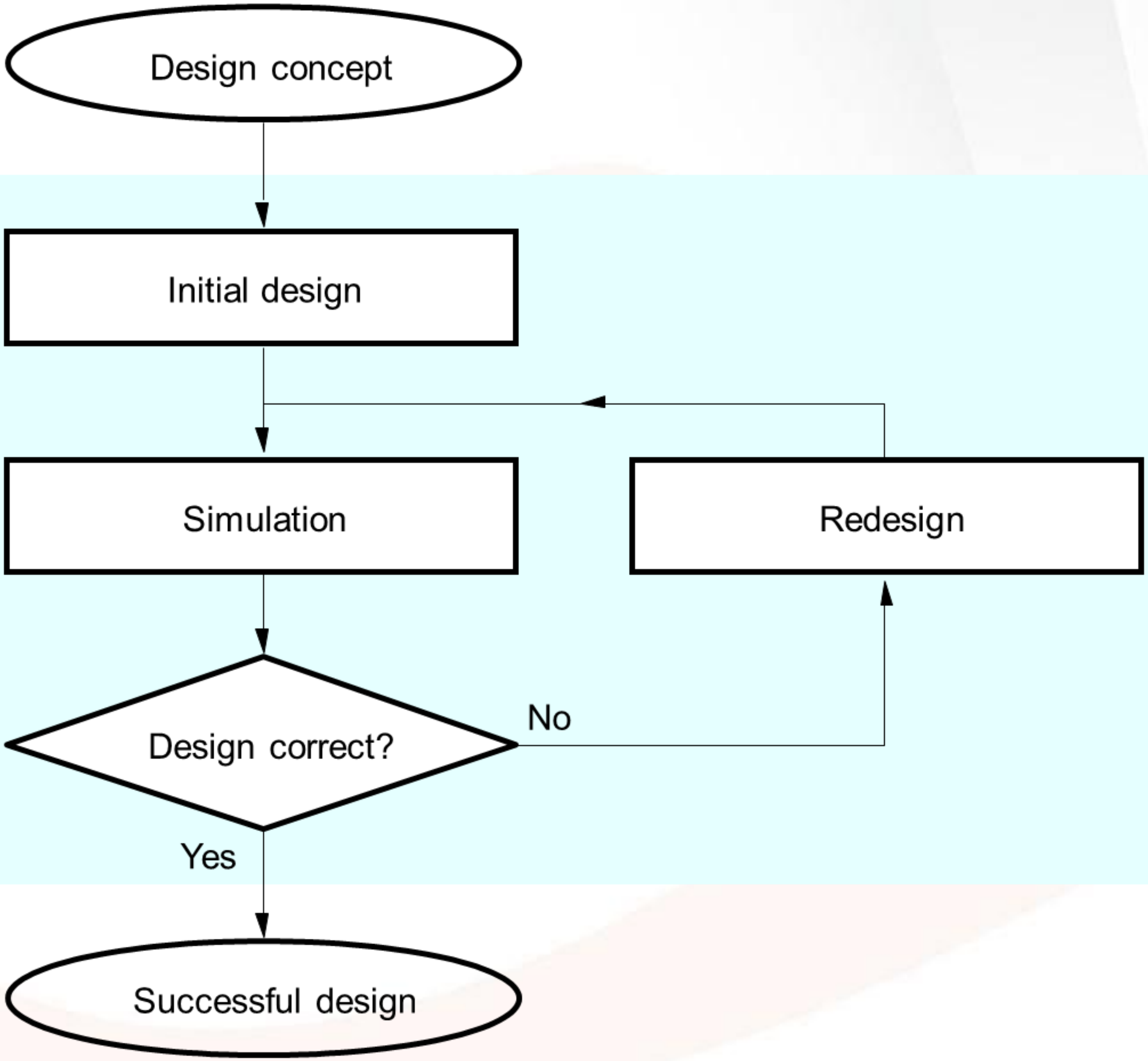


Figure 1.4. The basic design loop.

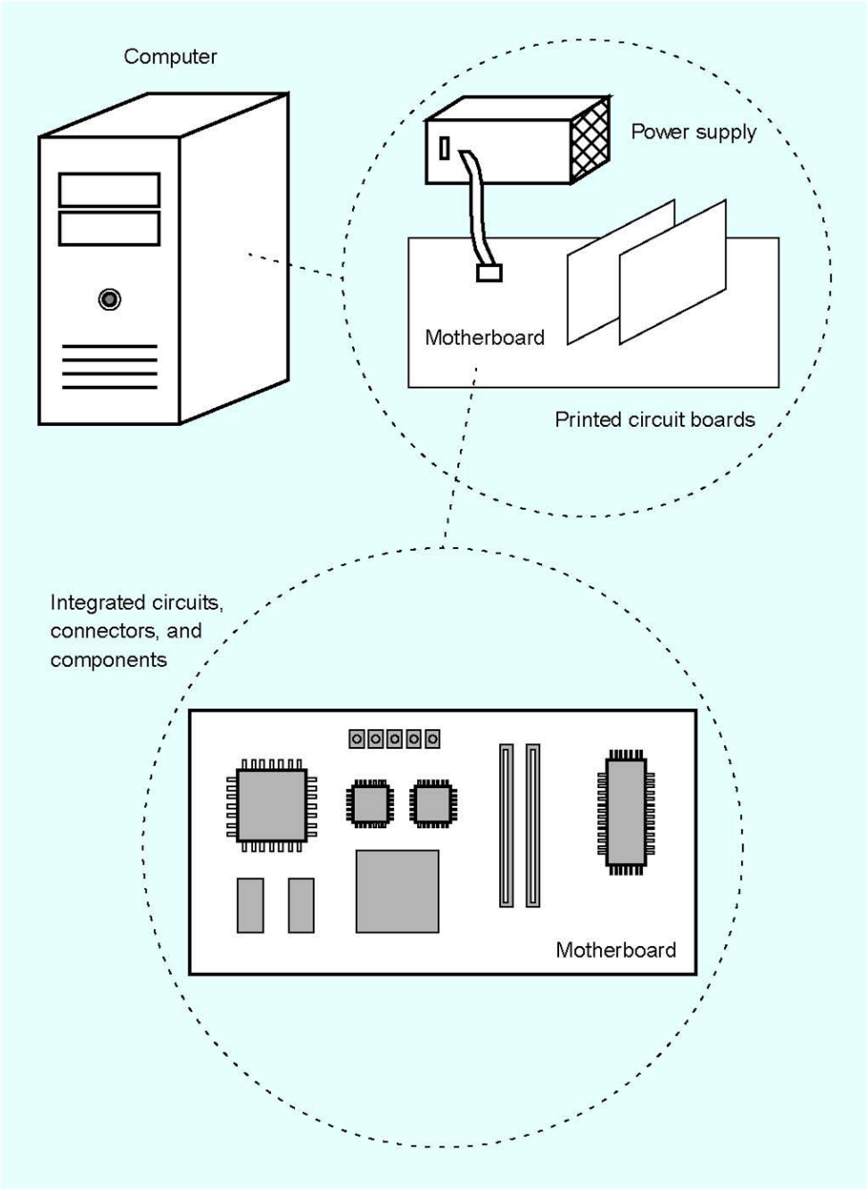


Figure 1.5. A digital hardware system (Part *a*).

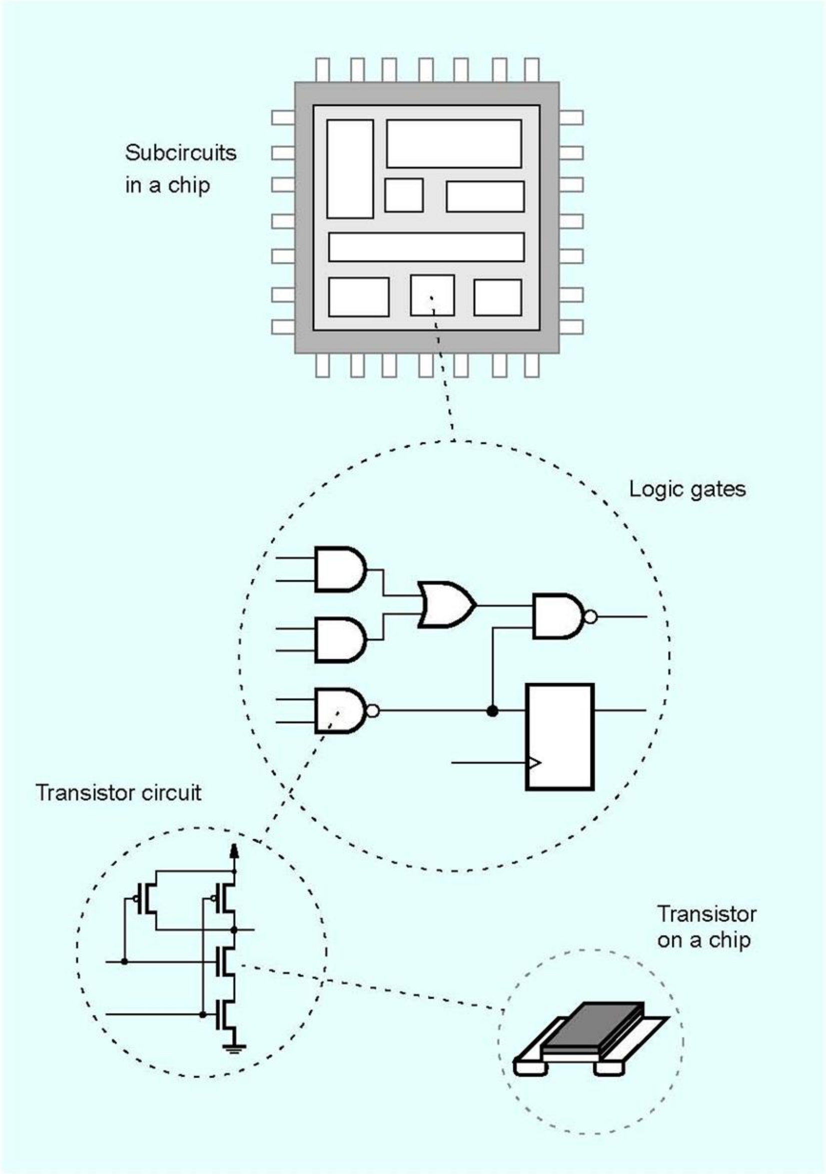


Figure 1.5. A digital hardware system (Part *b*).

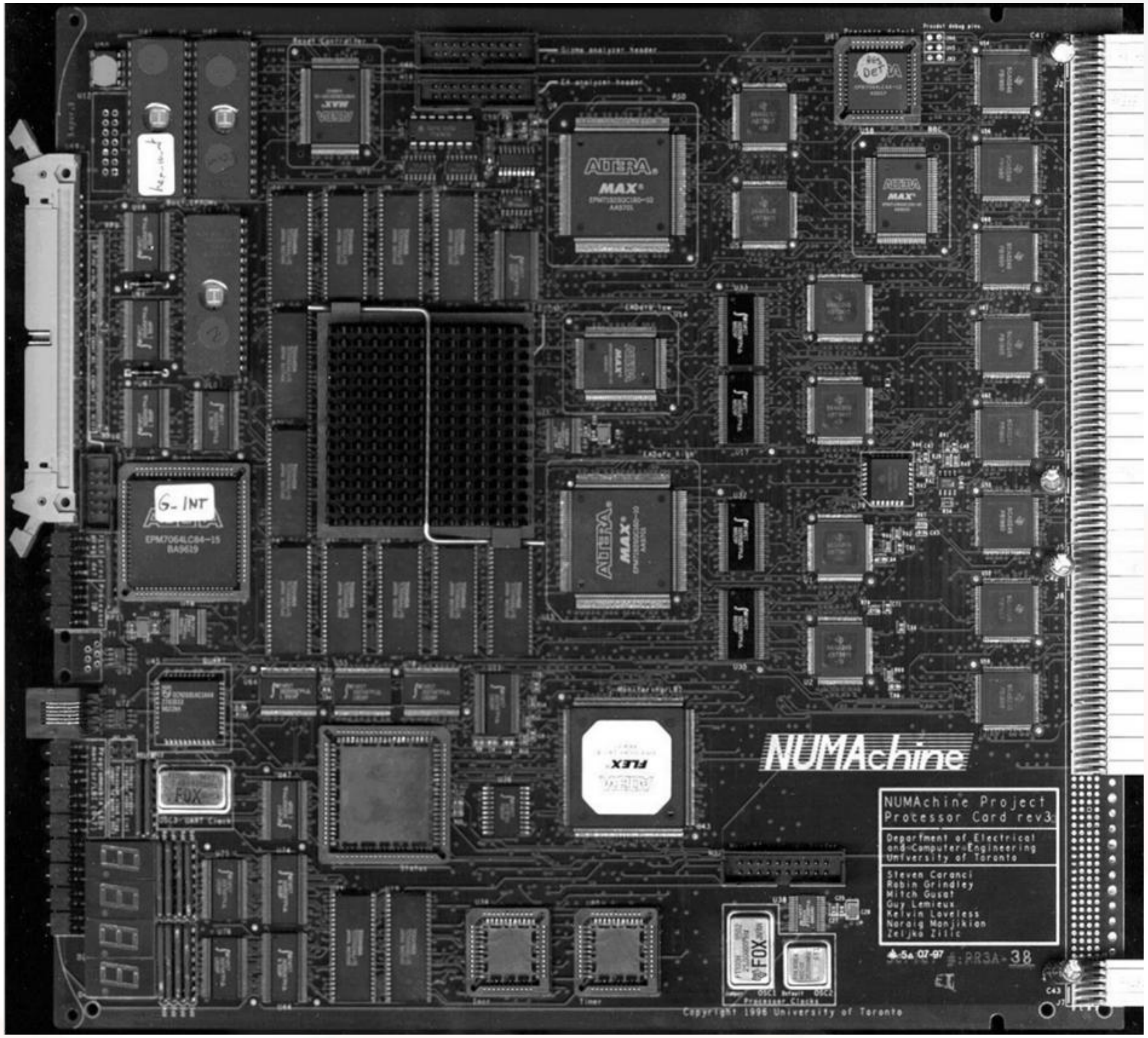


Figure 1.6. A printed circuit board.

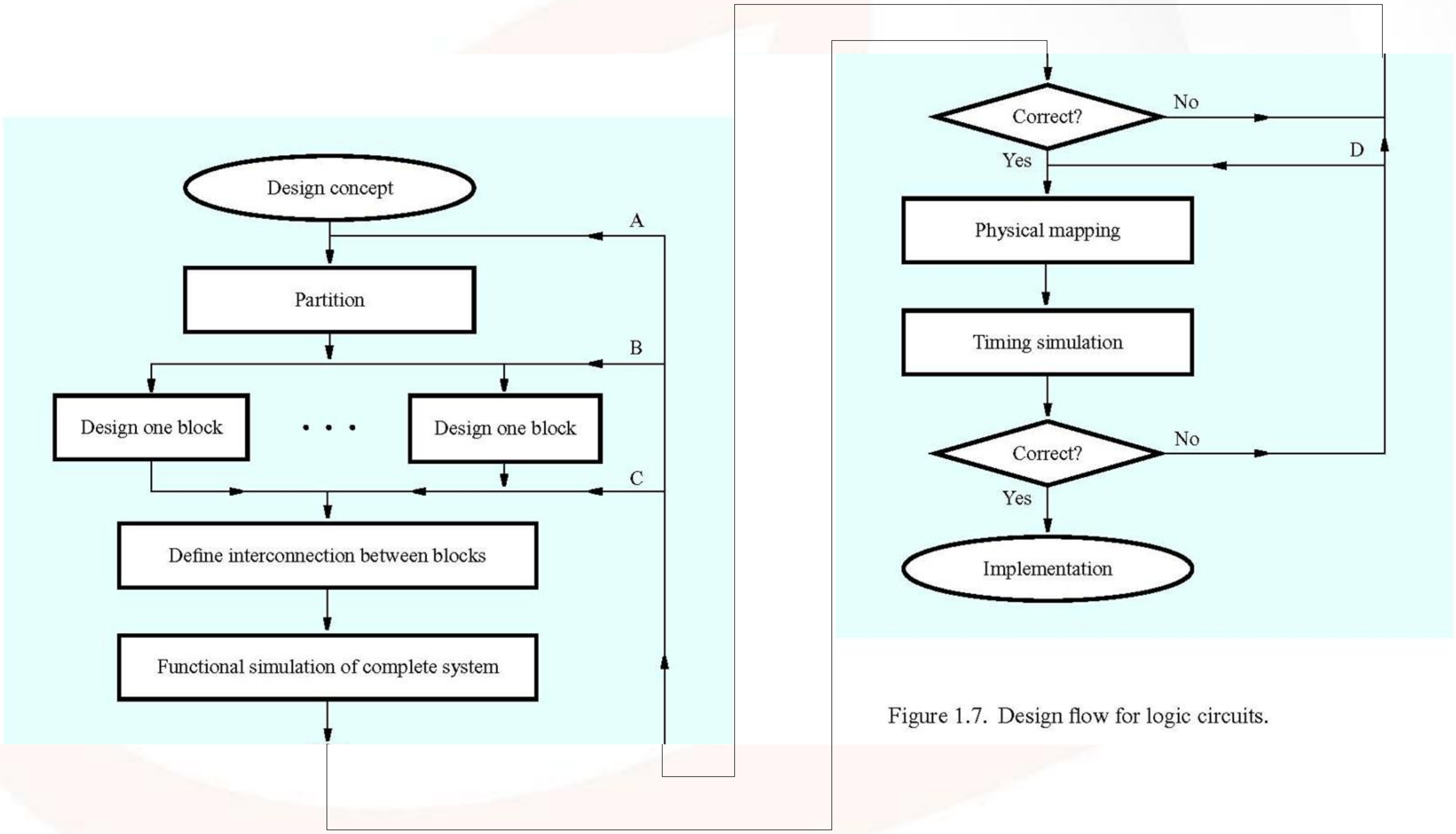


Figure 1.7. Design flow for logic circuits.

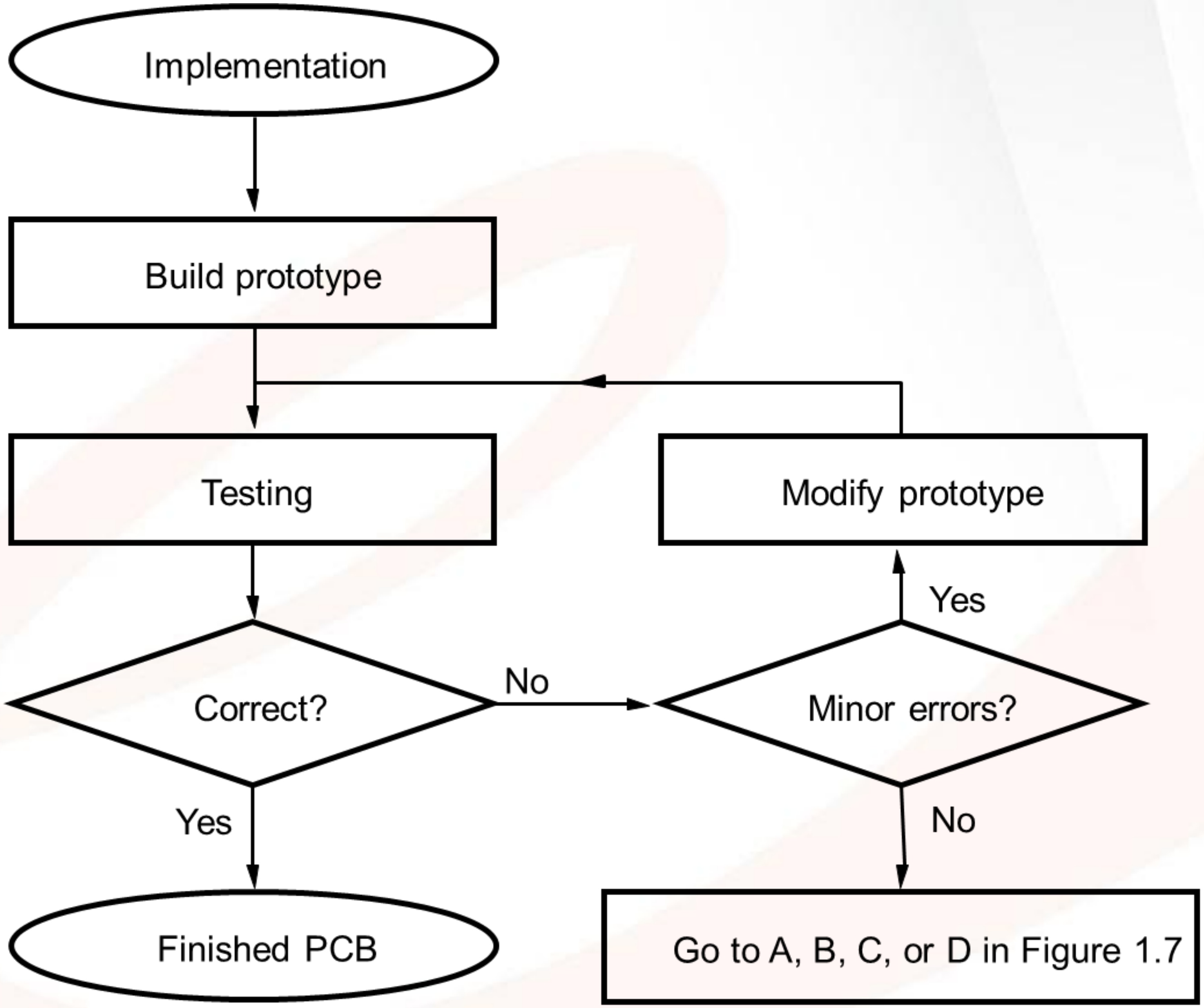


Figure 1.8. Completion of PCB development.