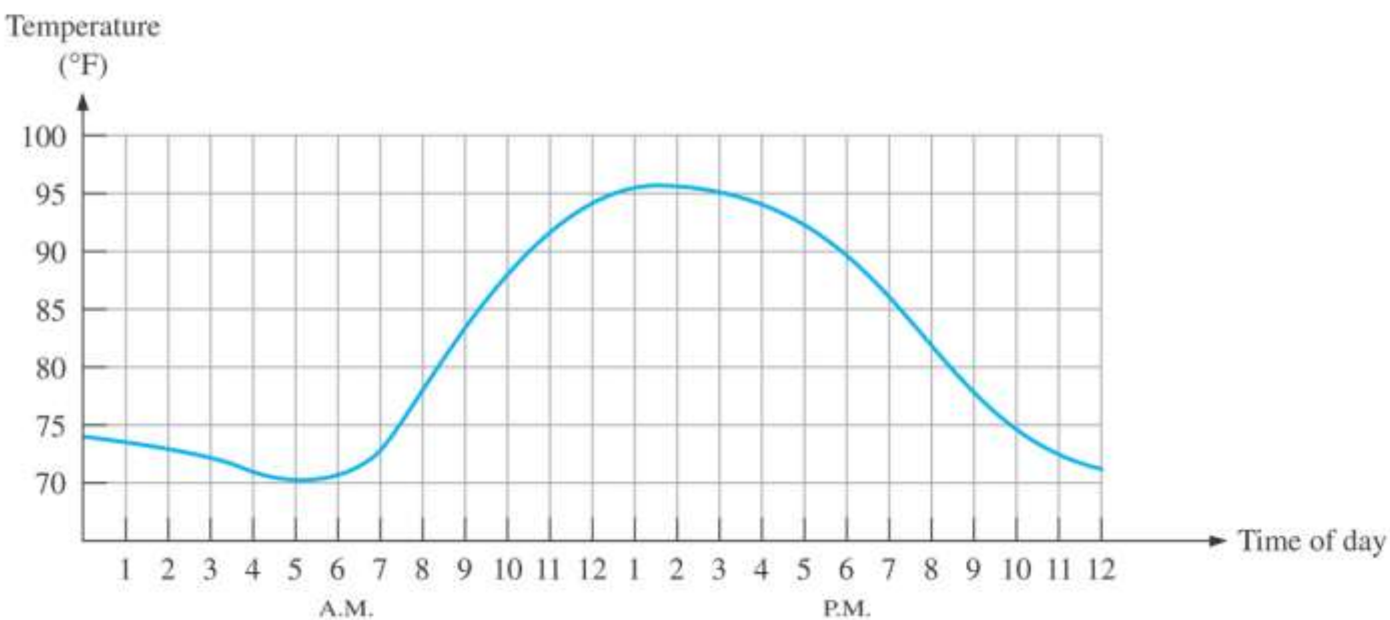
Chapter 1 Introduction to Digital System Design

Digital vs. Analog

- **Examples**
  - Thermometer
  - Photography
  - Audio System
  - Storage
  - Information Processing

Example I: Thermometer



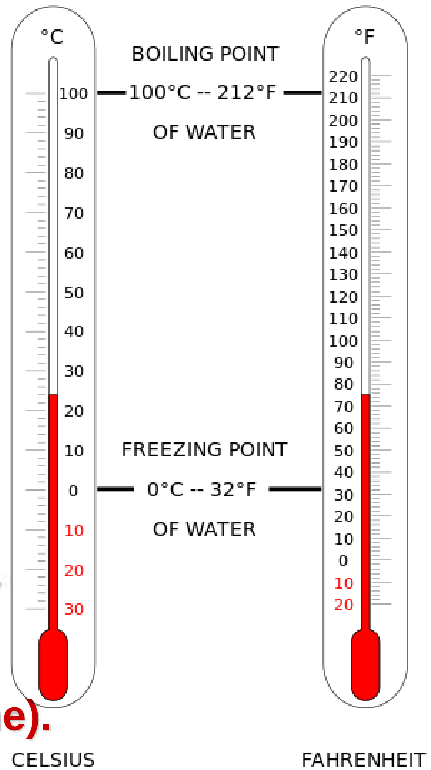


Figure 1–1 **Graph of an analog quantity (temperature versus time).**

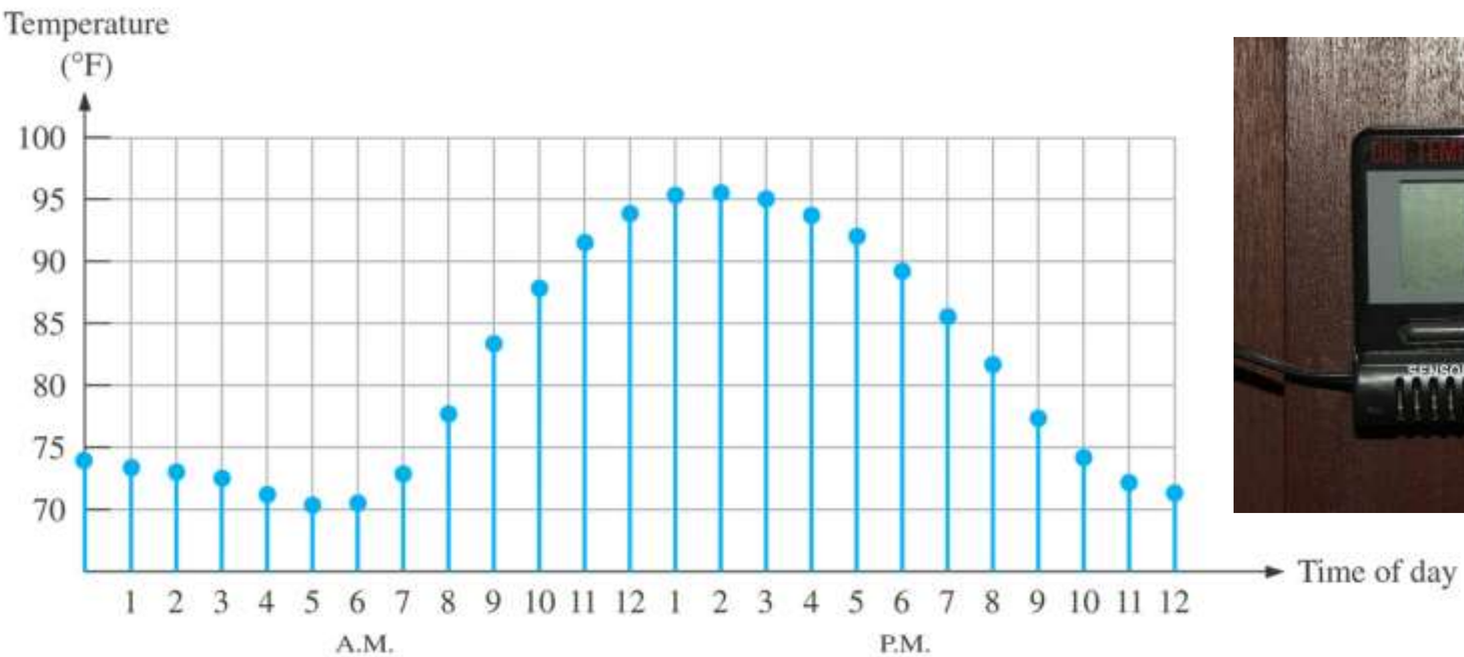
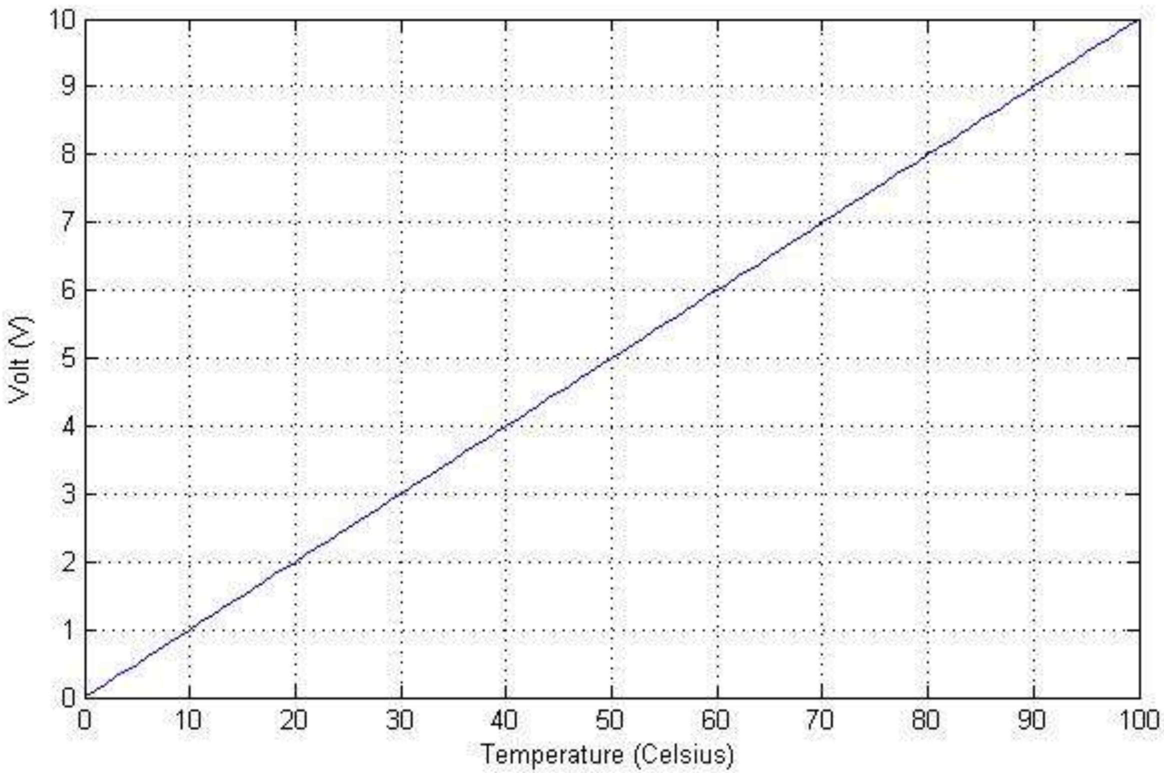


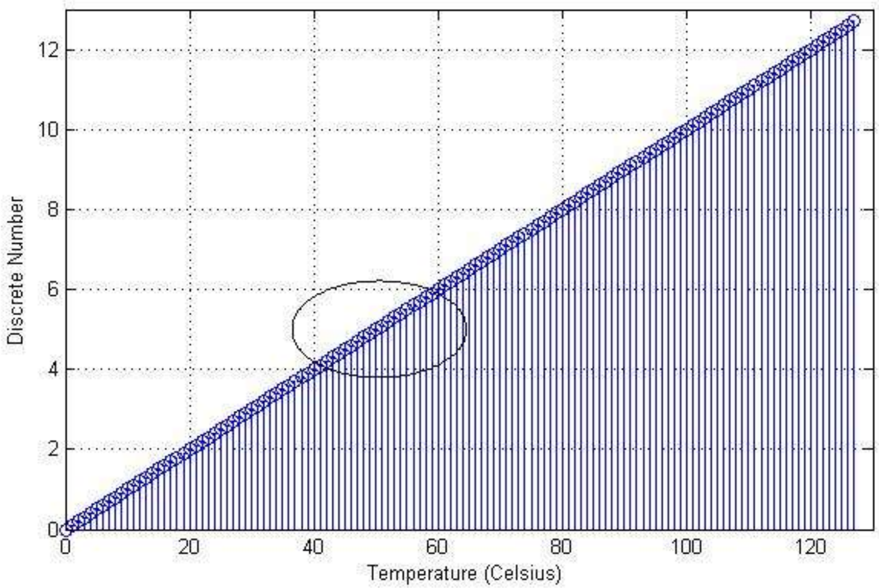
Figure 1–2 Sampled-value representation (quantization) of the analog quantity in Figure 1–1. Each value represented by a dot can be digitized by representing it as a digital code that consists of a series of 1s and 0s.

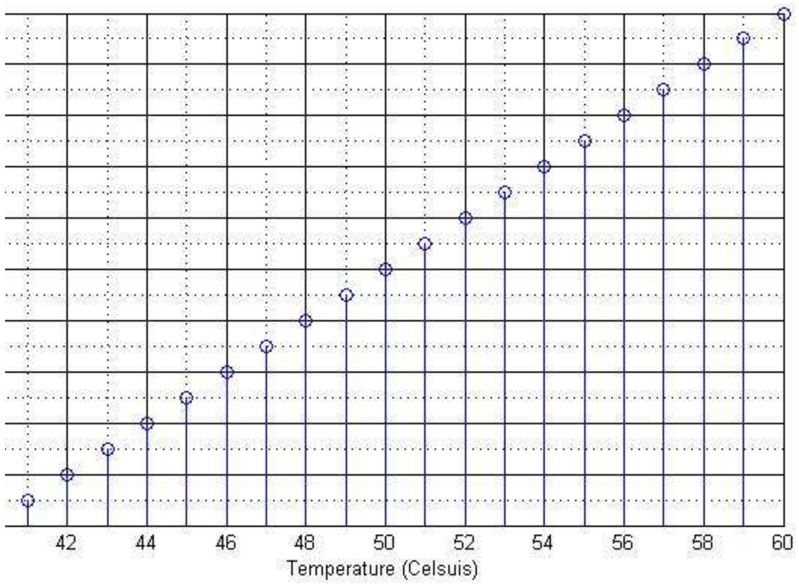
An Example

- Analog thermometer
  - 0V to 10V, could be used to represent 0°C to 100° C
  - Each 1/10 volt represents 1 degree



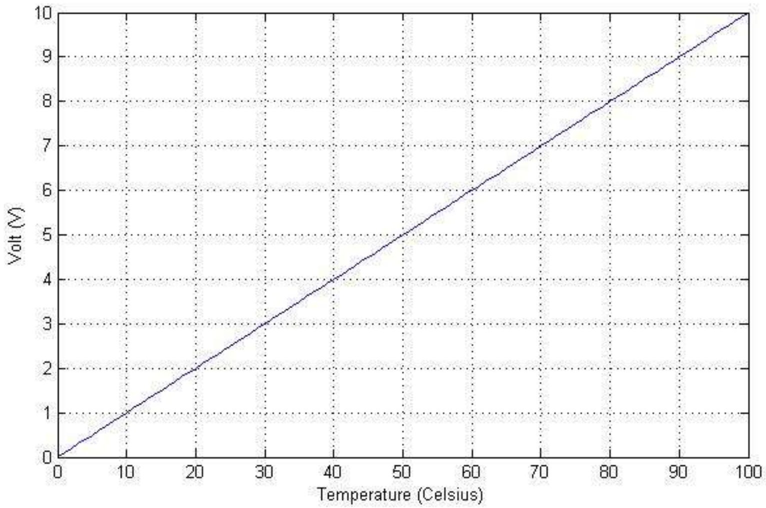
- Digital thermometer
  - 7-bit binary number could be used to represent 0°C to 127° C
  - 0000000 ----→ 0°C; 0000001 ----→ 1°C; ….
    1111111 ----→ 127 °C

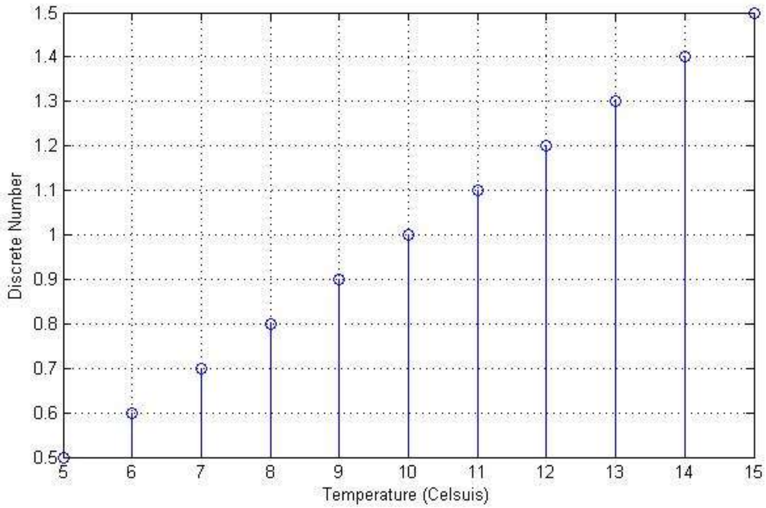




Digital Precision

- How would you represent 10.5° C?
- Analog example: 1.05V
- Digital example:
  - $0001010_2 = 10_{10}$ ----→ 10°C
  - $0001011_2 = 11_{10}$ ----→ 11°C
  - We must either add bits or decrease the range



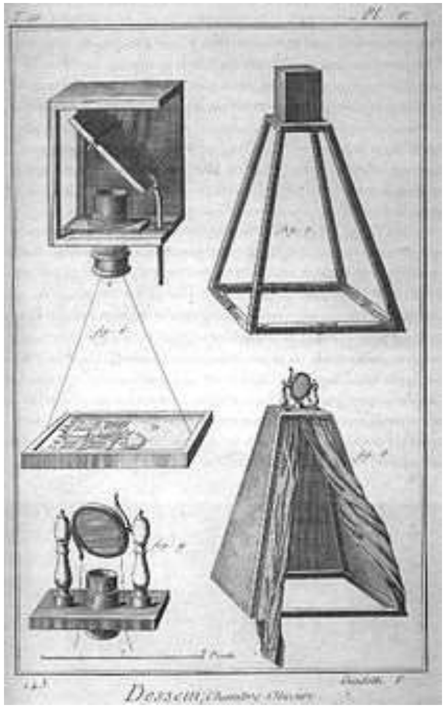


Digital Precision

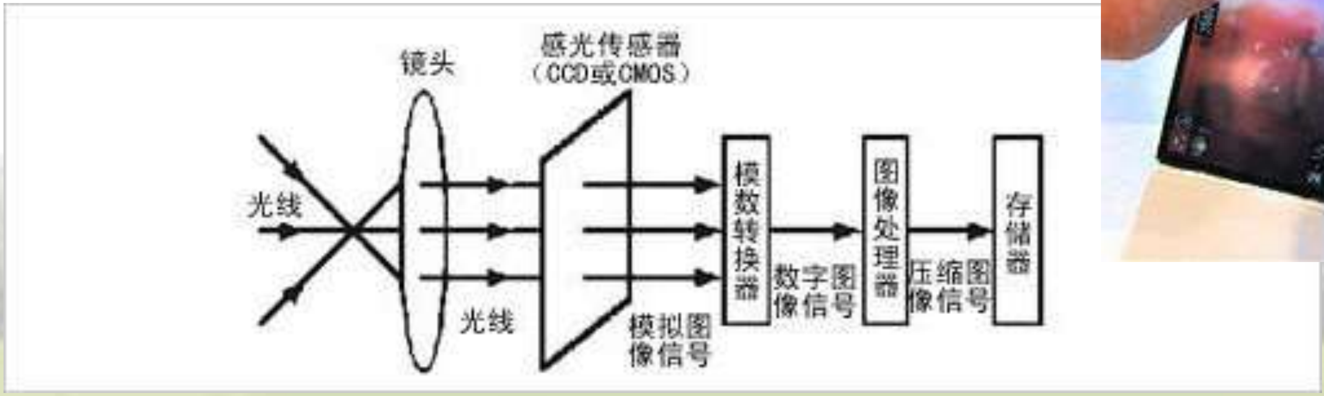
- 9-bit thermometer, 0° to 127.75° C
  - Each discrete number increase represents 0.25° C
  - 10.5° C → 10.5/0.25 = 42 = 000101010_2
- 7-bit thermometer, 0° to 12.7° C
  - Each discrete number represents 12.7°/127 = 0.1° C
  - 10.5° C → 10.5/0.1 = 105 = 1101001_2
- It is impossible to represent *all* values exactly using digital representation
  - Example: 1/3 can't be represented in binary, just like it can't be represented in decimal

Example II: Photography

- Analog photography
  - An analog camera uses a chemical reaction in the film when exposed to light
  - The amount of exposure is directly related to the amount of light that hits the film



- **Digital Photography**
  - A digital camera uses an array of light-sensitive receptors that measures the light as a binary number
  - Image quality is determined mostly by two factors:
    - The number of bits per pixel
    - The number of pixels per image



Example: Digital Photography

1284x897 pixels, 24-bit color

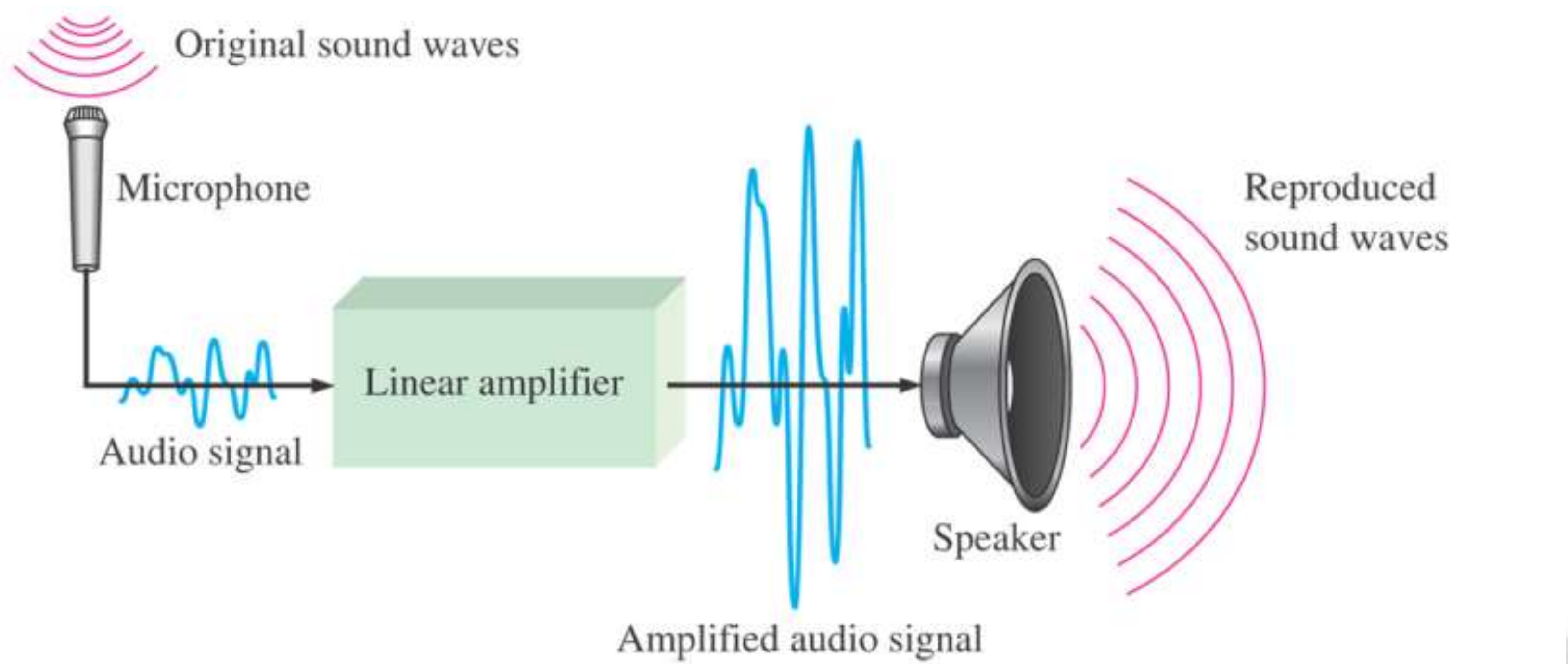
100x70 pixels, 24-bit color

1284x897 pixels, 6-bit color

100x70 pixels, 6-bit color

Example III: Audio System

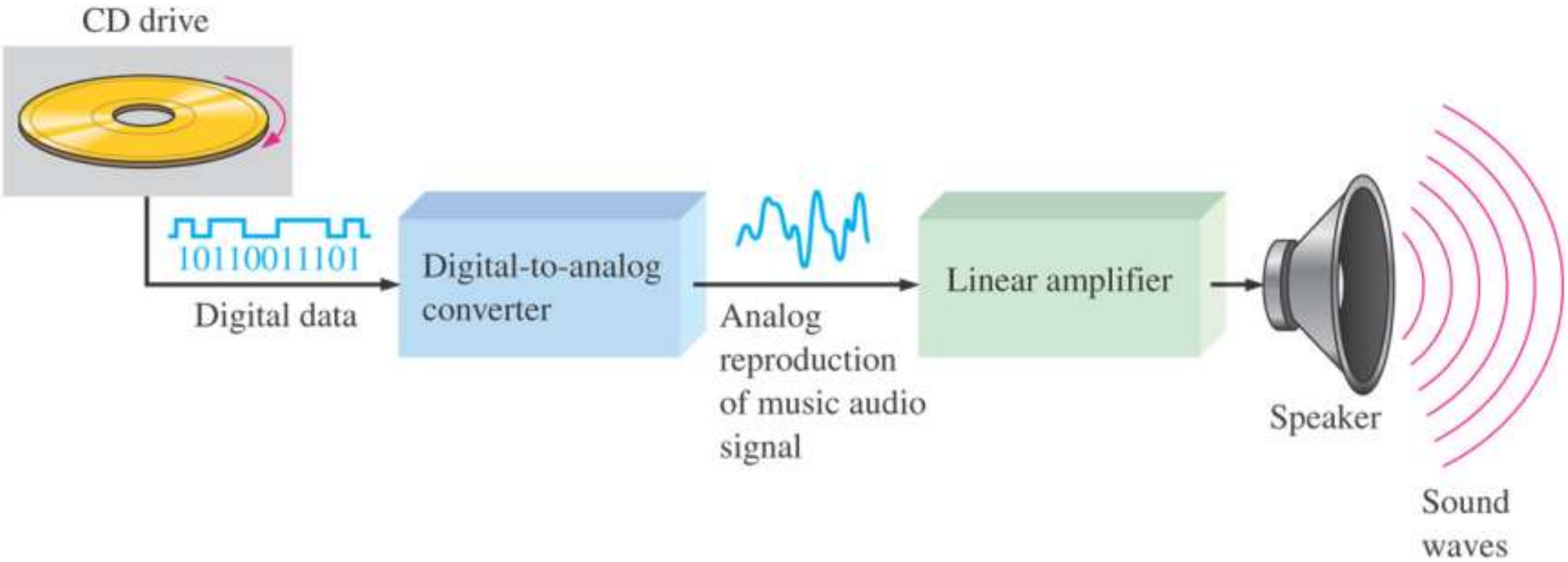
A basic audio public address system.



Example III: Audio System

Phonograph

Basic block diagram of a CD player.



Example IV: Storage

- ***Analog*** storage mediums fade over time due to gradual physical degradation
  - Photos turn yellow with time
  - Cassette audio tapes lose their clarity

Example IV: Storage

- ***Digital*** storage mediums don’t “fade” like analog
  - If a 0 or 1 fades it will still be a 0 or 1
  - A .jpg image taken 10 years ago is *exactly* the same today

Analog vs. Digital Storage

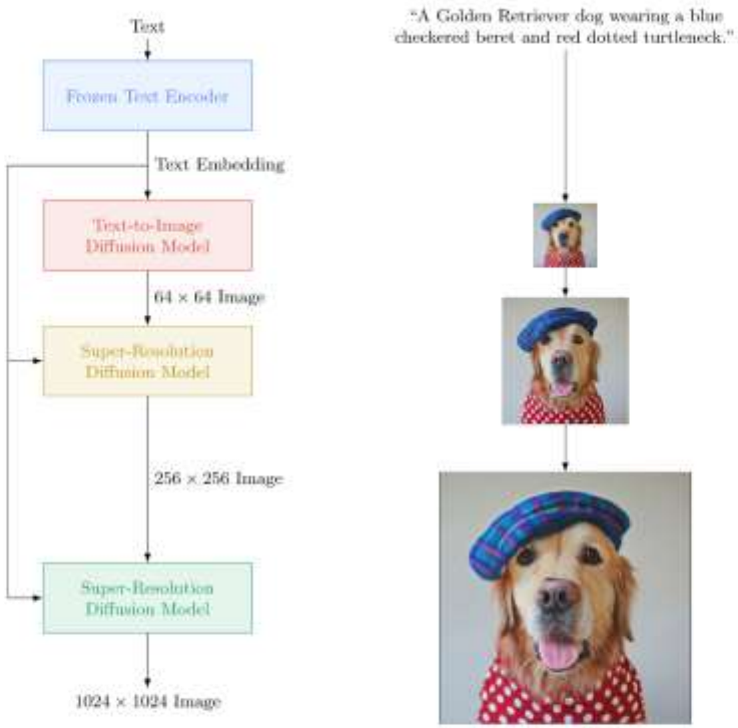
- Making an analog copy implies measuring the storage medium
  - Always introduces some errors
  - Copies of copies are even worse
- Making digital copies implies distinguishing 0’s from 1’s so copies are exact
  - Copies can be made without any error
  - Copies of copies are identical

Example V: Analog vs. Digital Processing

- Modern computers and digital circuits make it easy to do extremely complex processing
- Digital processing allows precision and error to be exactly predicted

Digital Processing: AI Generated Content

Digital Processing: AI Generated Content



Sora by OpenAI

1-1 Digital and Analog Quantities

- **Analog quantity: having continuous values**
  - Analog systems represent information using physical quantities
  - Voltage on a wire, magnetic field strength
- **Digital quantity: having a discrete set of values**
  - Digital systems represent information using binary digits, or *bits*
  - 1 or 0, high or low, on or off

How to represent digital quantity?

-- Positional Number Systems

- Two discrete values are insufficient for most applications
- We combine bits to represent more values
- We use a positional number system for binary just like we do in decimal

Positional Number Systems

- ***Decimal,*** base 10, means we have 10 digits (0-9)
  - Example:

$$1032_{10} = 1\times10^{3} + 0\times10^{2} + 3\times10^{1} + 2\times10^{0}$$

- ***Hexadecimal,*** base 16, means we have 16 digits (0-9, A-F)
  - Example:

$$2A5_{16} = 2\times16^{2} + 10\times16^{1} + 5\times16^{0} = 512 + 160 + 5 = 677$$

- ***Binary,*** base 2, follows the same pattern
  - Example:
    $1011_{2} = 1\times2^{3} + 0\times2^{2} + 1\times2^{1} + 1\times2^{0} = 8 + 0 + 2 + 1 = 11$
- Counting in any base is analogous to counting in decimal

莱布尼茨

- 1701年, 莱布尼茨提交了《数字新科学论》，但被巴黎皇家科学院以“看不出二进制有何用处”为由拒绝
- 写信给居住在北京的法国耶稣会神父白晋并介绍了论文的主要内容。白晋回信指出了莱布尼茨二进制与《易经》八卦图符号的相似之处。
- 发表《论只使用符号0和1的二进制算术，兼论其用途及它赋予伏羲所使用的古老图形的意义》

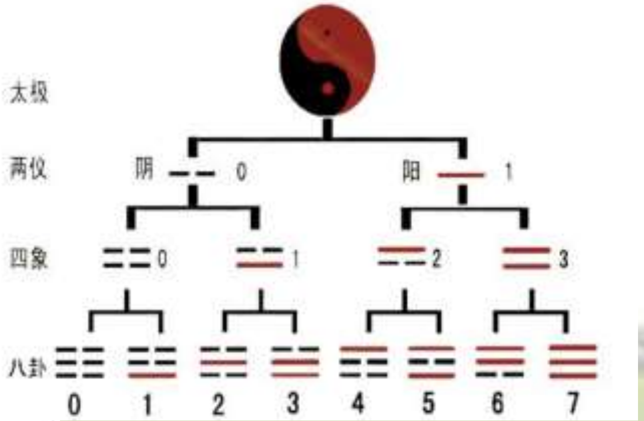
莱布尼茨：古代的中国人早已掌握二进制

DES SCIENCES. 85

EXPLICATION DE L'ARITHMETIQUE BINAIRE,

Qui se sert des seuls caractères 0 & 1; avec des Remarques sur son utilité, & sur ce qu'elle donne le sens des anciennes figures Chinoises de Fohy.

Par M. Leibnitz.

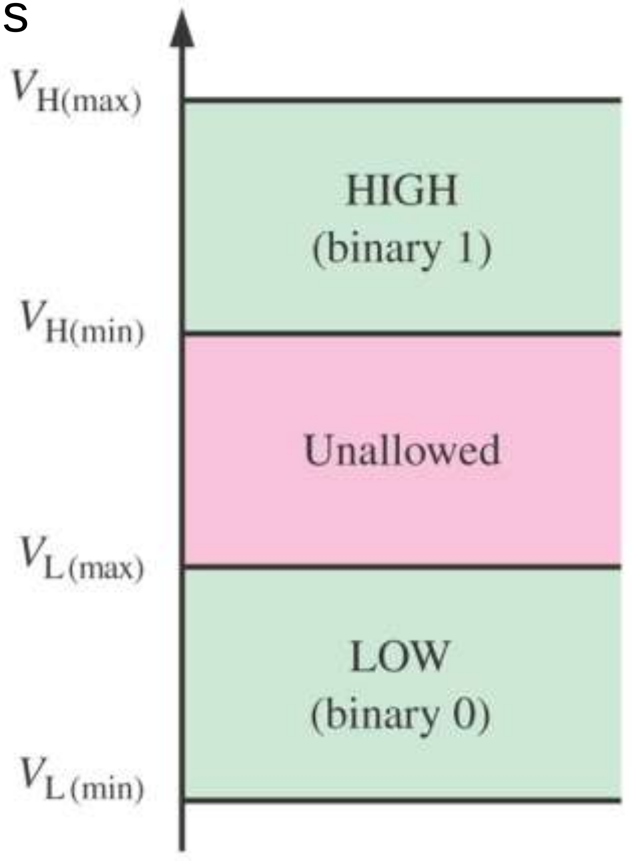


1-2 Binary Digits, Logic Levels, and Digital Waveforms

- **Binary Digits**
  - *Positive logic*
    - *'1' is represented by HIGH*
    - *'0' is represented by LOW*
  - Negative logic
  - Groups of bits: *codes*

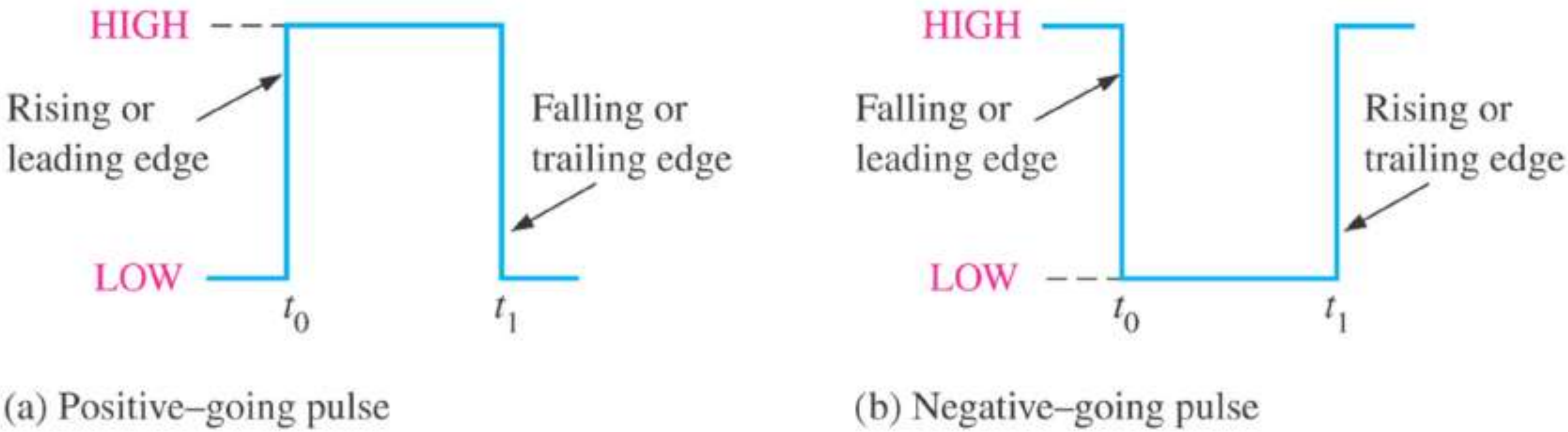
Logic Level

- Logic levels: the voltages used to represent a ‘1’ and a ‘0’
- This figure answers the question how to represent the binary logic with voltages

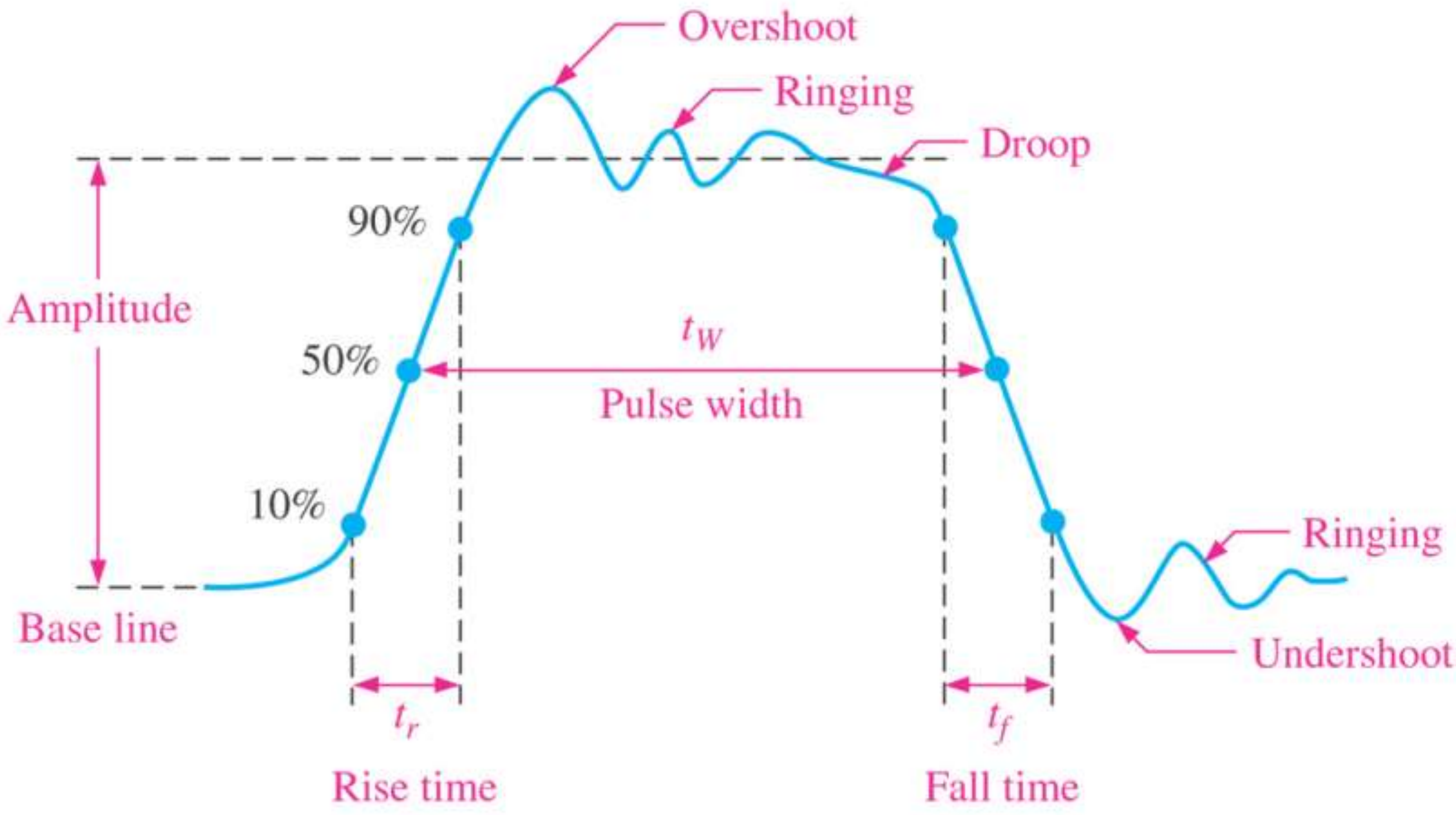


Logic level ranges of voltage for a digital circuit.

- **Digital Waveforms**

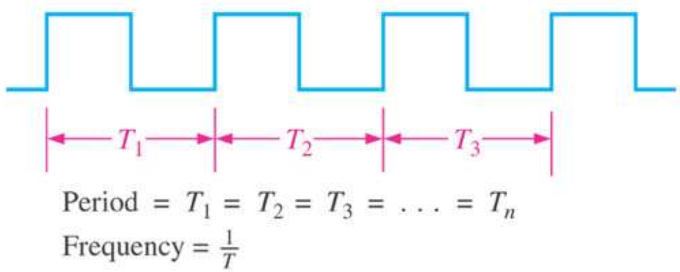


Ideal pulses



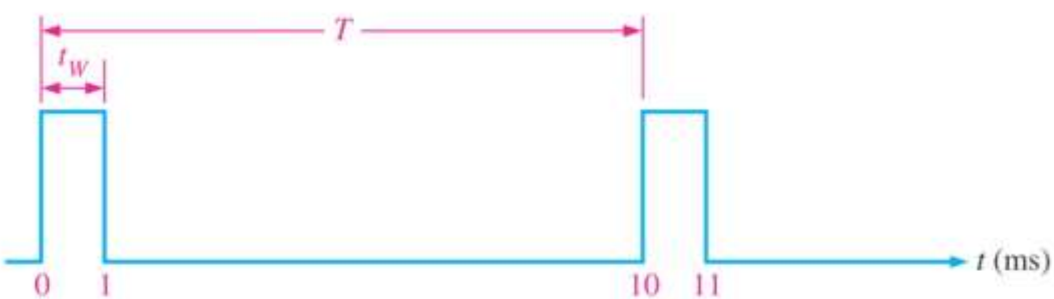
Nonideal pulse characteristics.

- **Waveform characteristics**
  - Period （周期）
  - Frequency （频率）
  - Duty cycle（占空比）



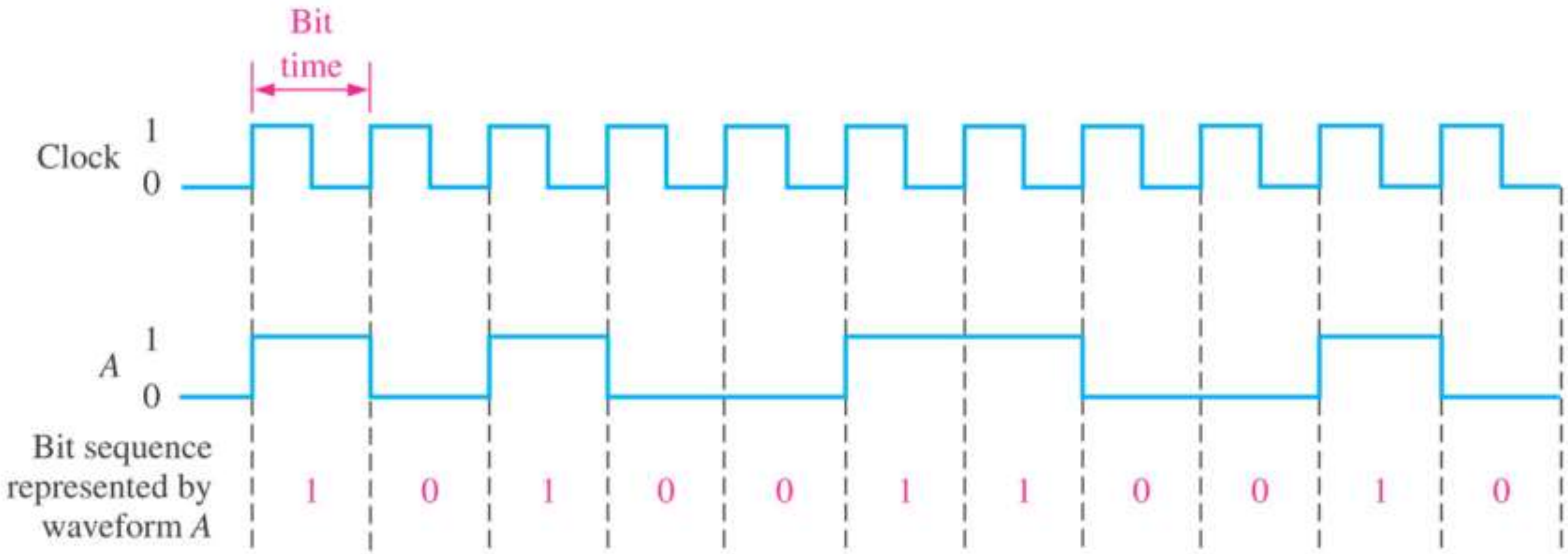
(a) Periodic (square wave)

(b) Nonperiodic

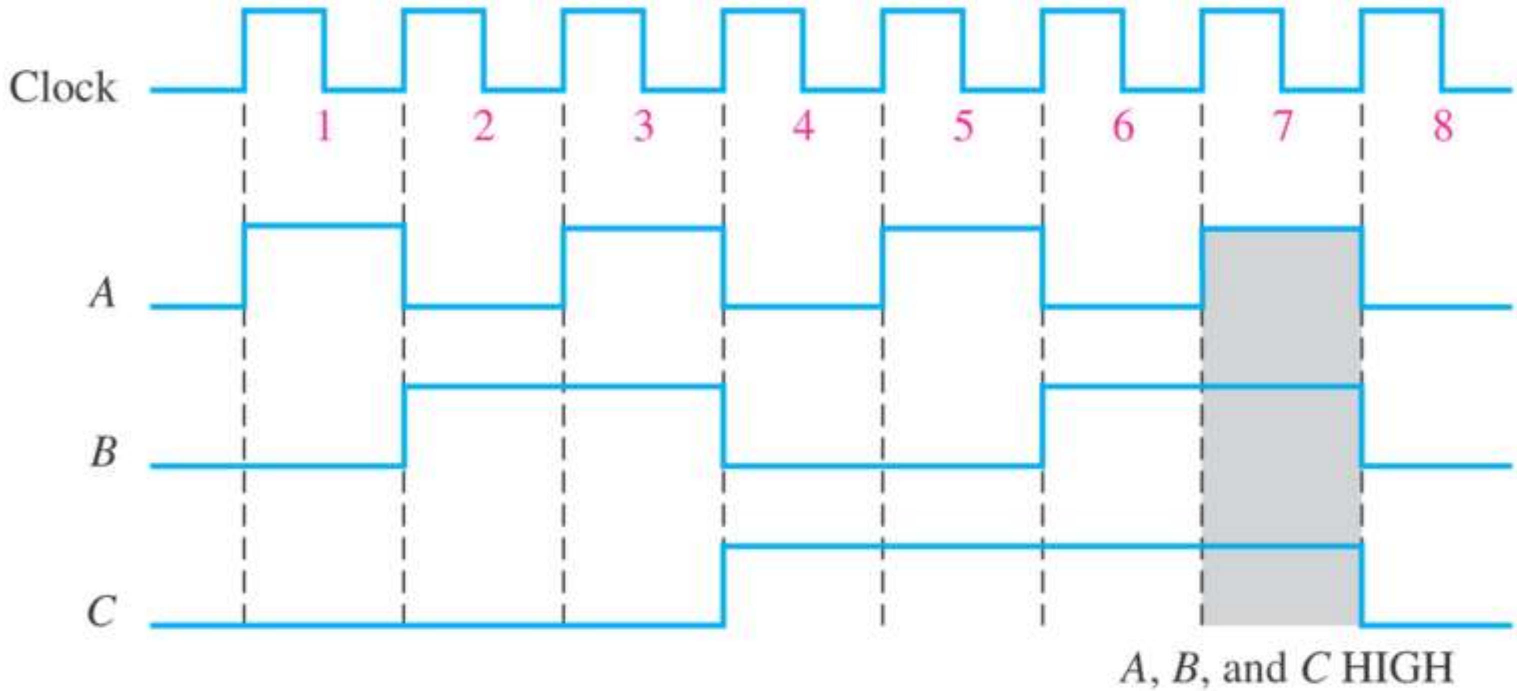


$$\text{Duty cycle} = \left(\frac{t_w}{T}\right)100\%$$

A Digital Waveform Carries Binary Information

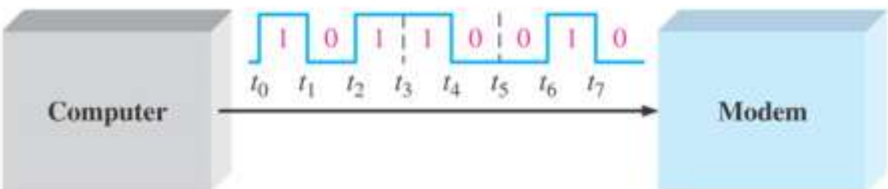


Example of a clock waveform synchronized with a waveform representation of a sequence of bits.

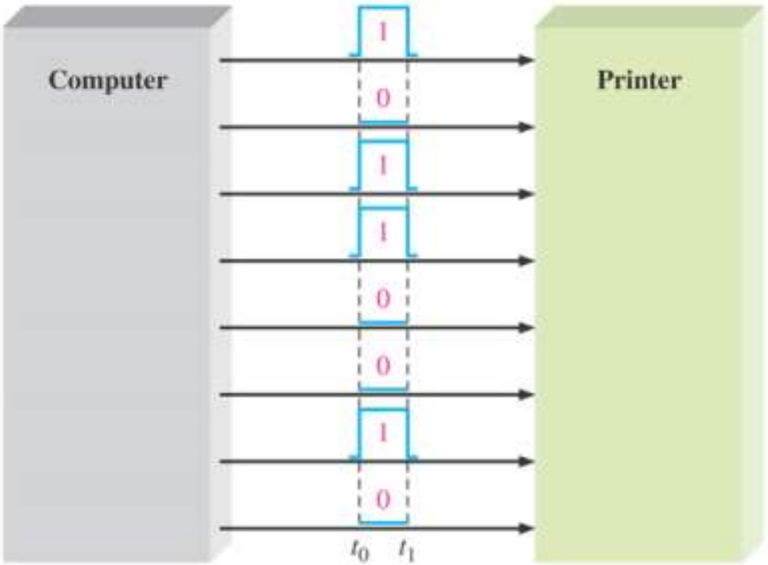


Example of a timing diagram.

- **Data Transfer**
  - Serial transfer （串行传输）
  - Parallel transfer（并行传输）



(a) Serial transfer of 8 bits of binary data from computer to modem. Interval t_0 to t_1 is first.



(b) Parallel transfer of 8 bits of binary data from computer to printer. The beginning time is t_0.

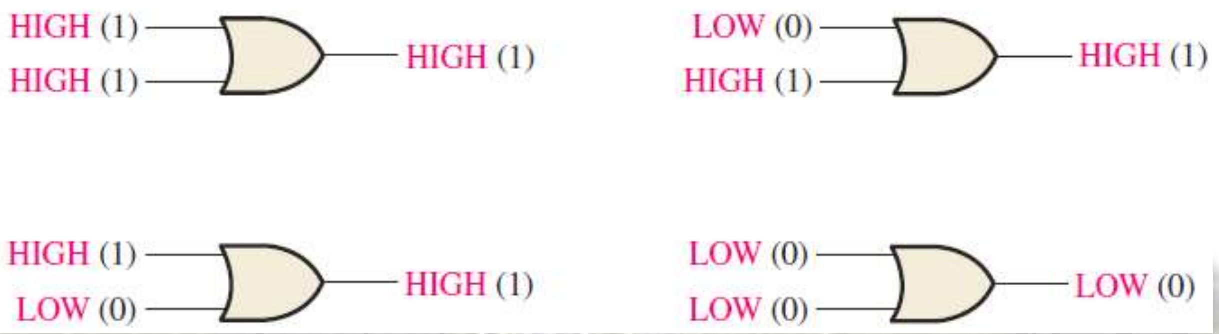
Illustration of serial and parallel transfer of binary data. Only the data lines are shown.

1-3 Basic Logic Operations

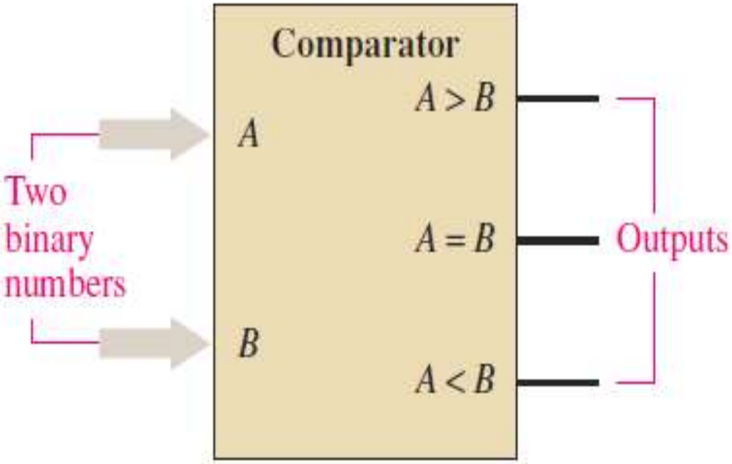
- **NOT**

- **AND**

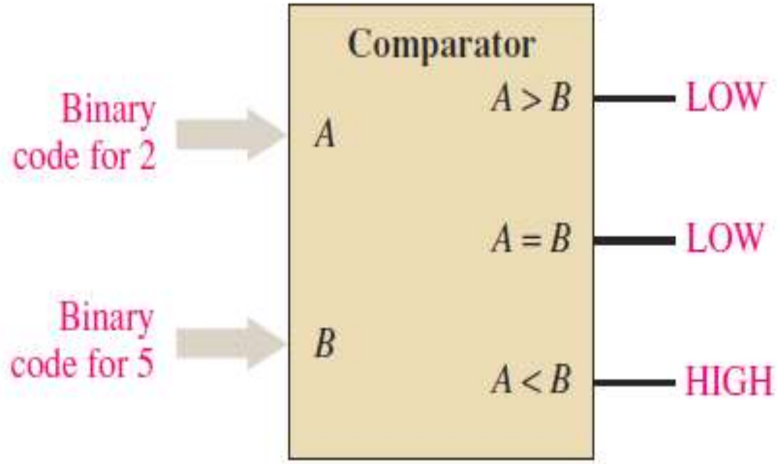
- **OR**



Example. Comparator

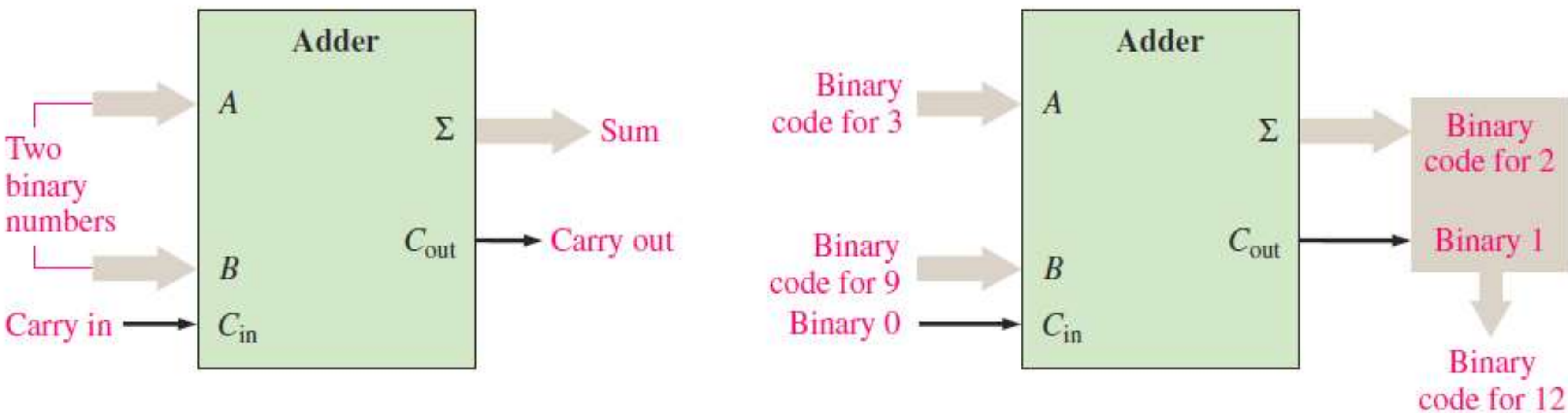


(a) Basic magnitude comparator



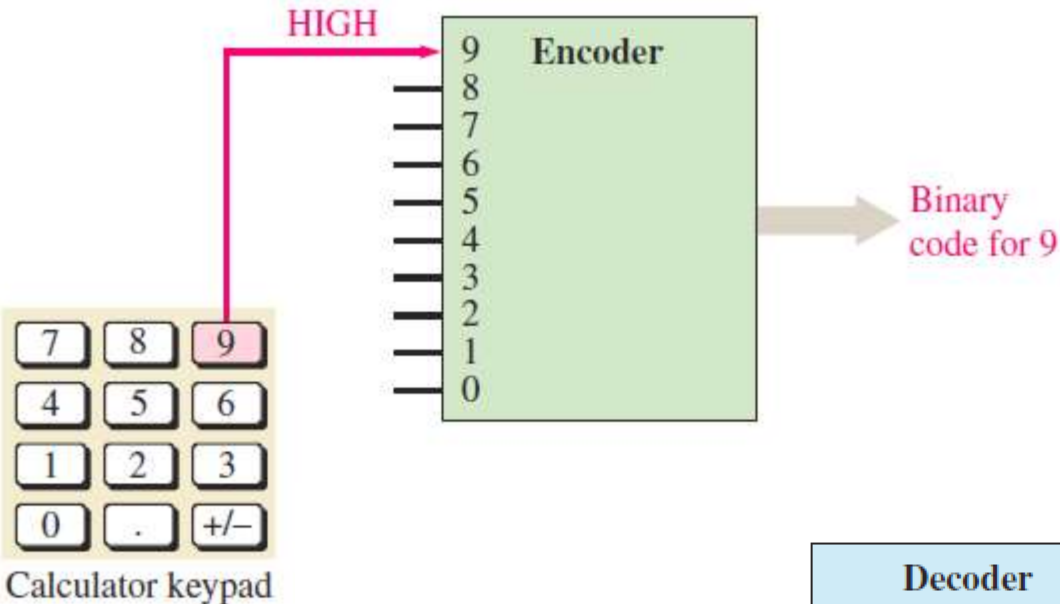
(b) Example: A is less than B ($2 < 5$) as indicated by the HIGH output ($A < B$)

Example. Adder

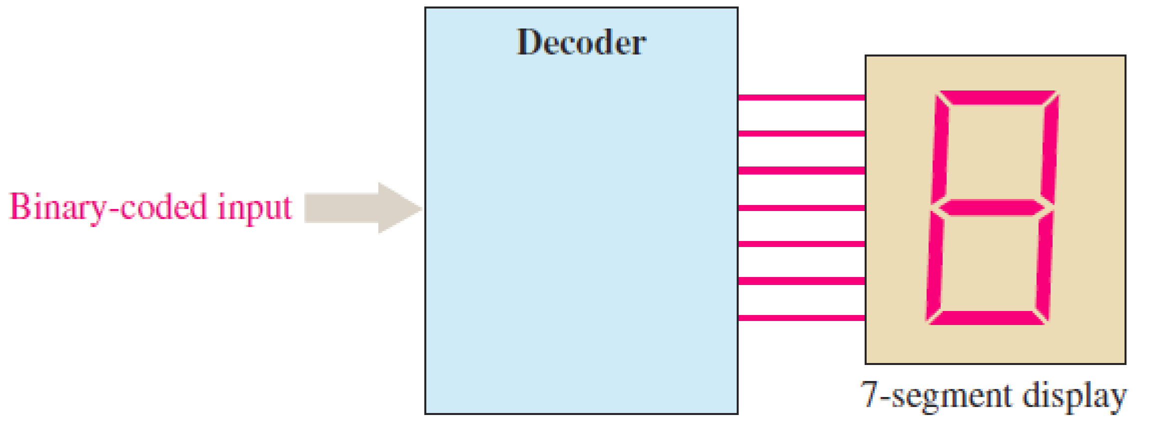


(a) Basic adder (b) Example: A plus B ($3 + 9 = 12$)

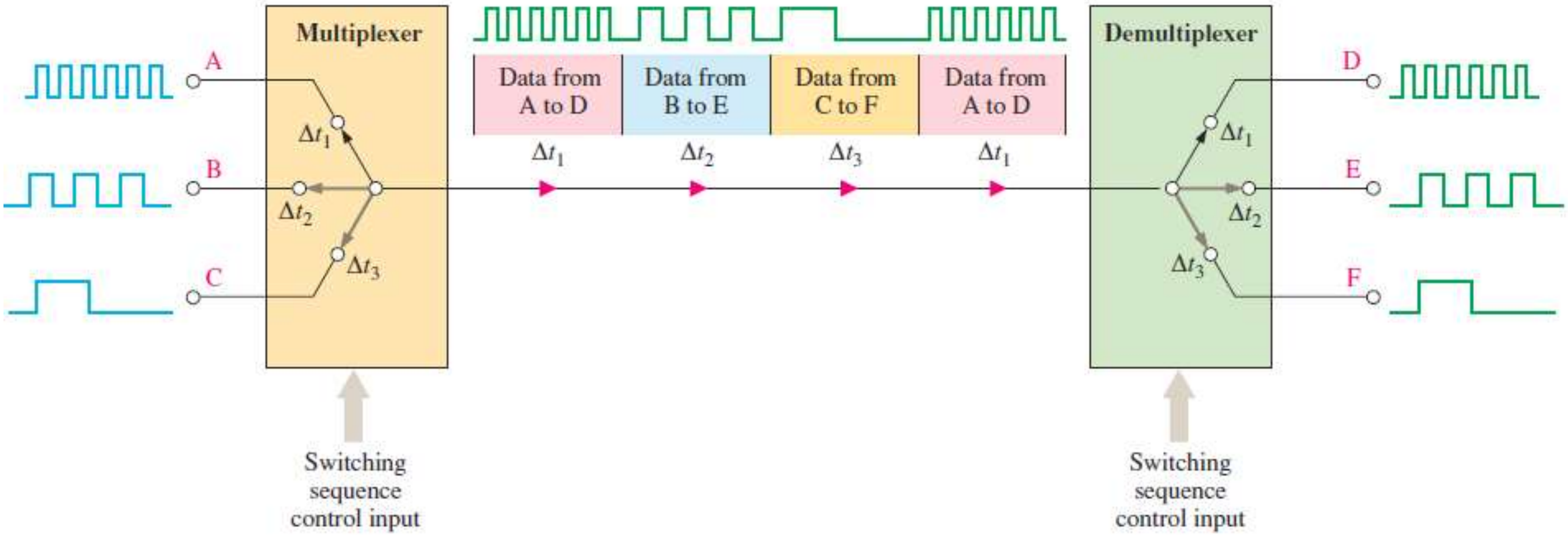
Example. Encoder and decoder



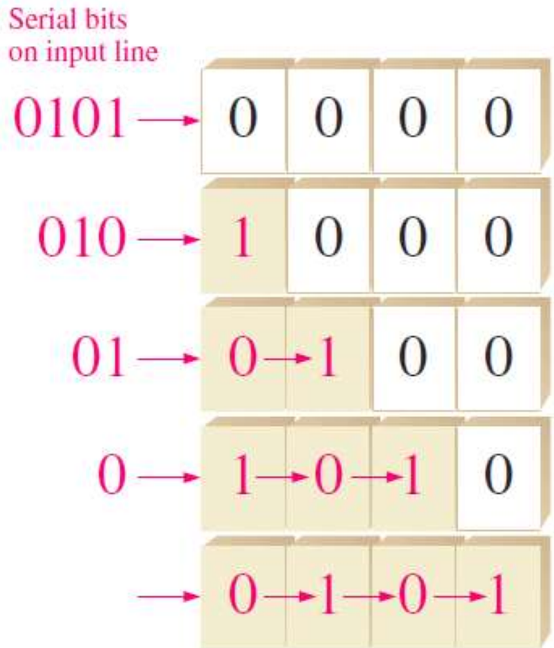
9:1001
8:1000
7:0111
6:0110
…
1:0001
0:0000



Example. multiplexing/demultiplexing



Example. Storage



Initially, the register contains only *invalid* data or all zeros as shown here.

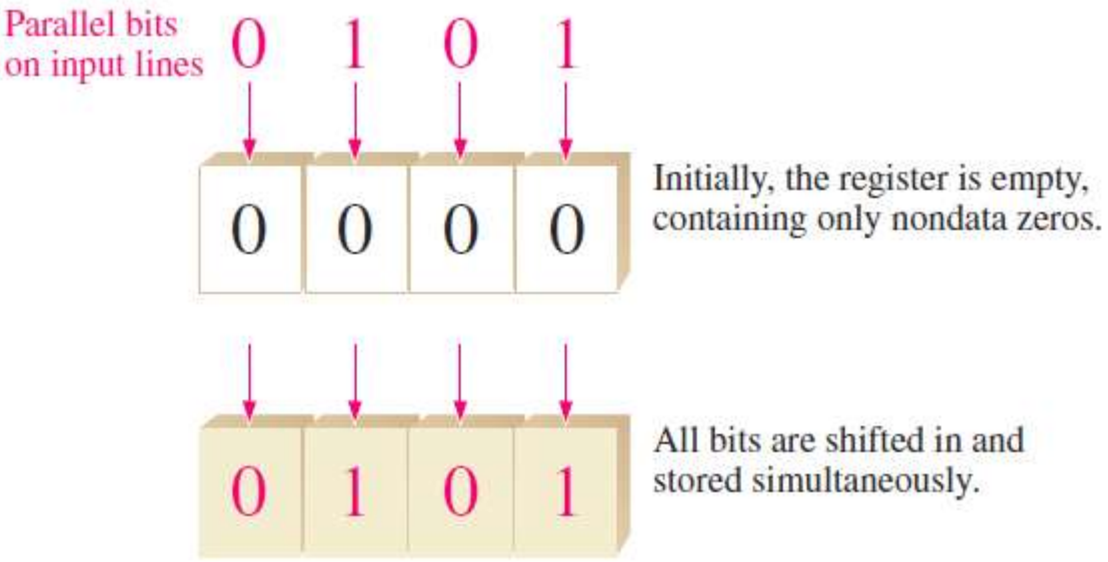
First bit (1) is shifted serially into the register.

Second bit (0) is shifted serially into register and first bit is shifted right.

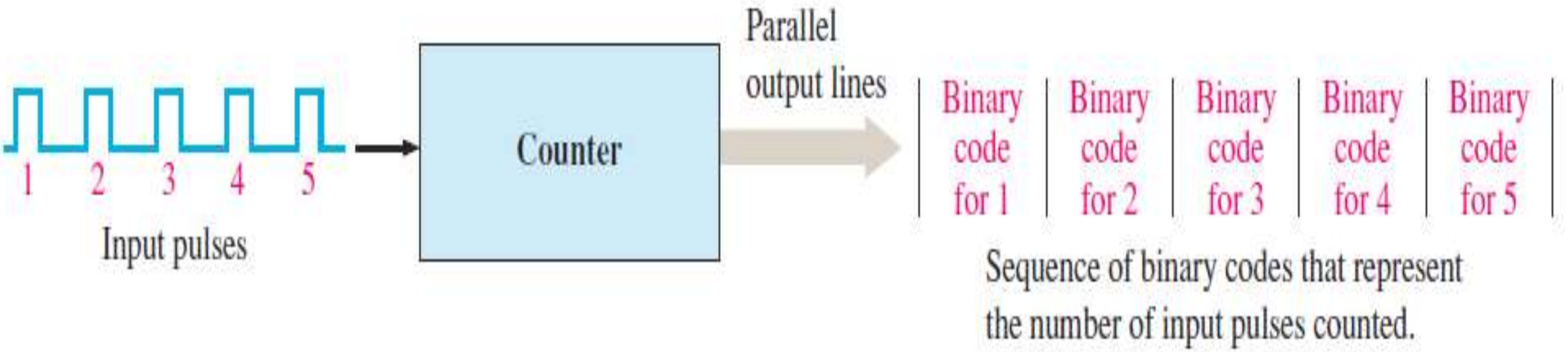
Third bit (1) is shifted into register and the first and second bits are shifted right.

Fourth bit (0) is shifted into register and the first, second, and third bits are shifted right. The register now stores all four bits and is full.

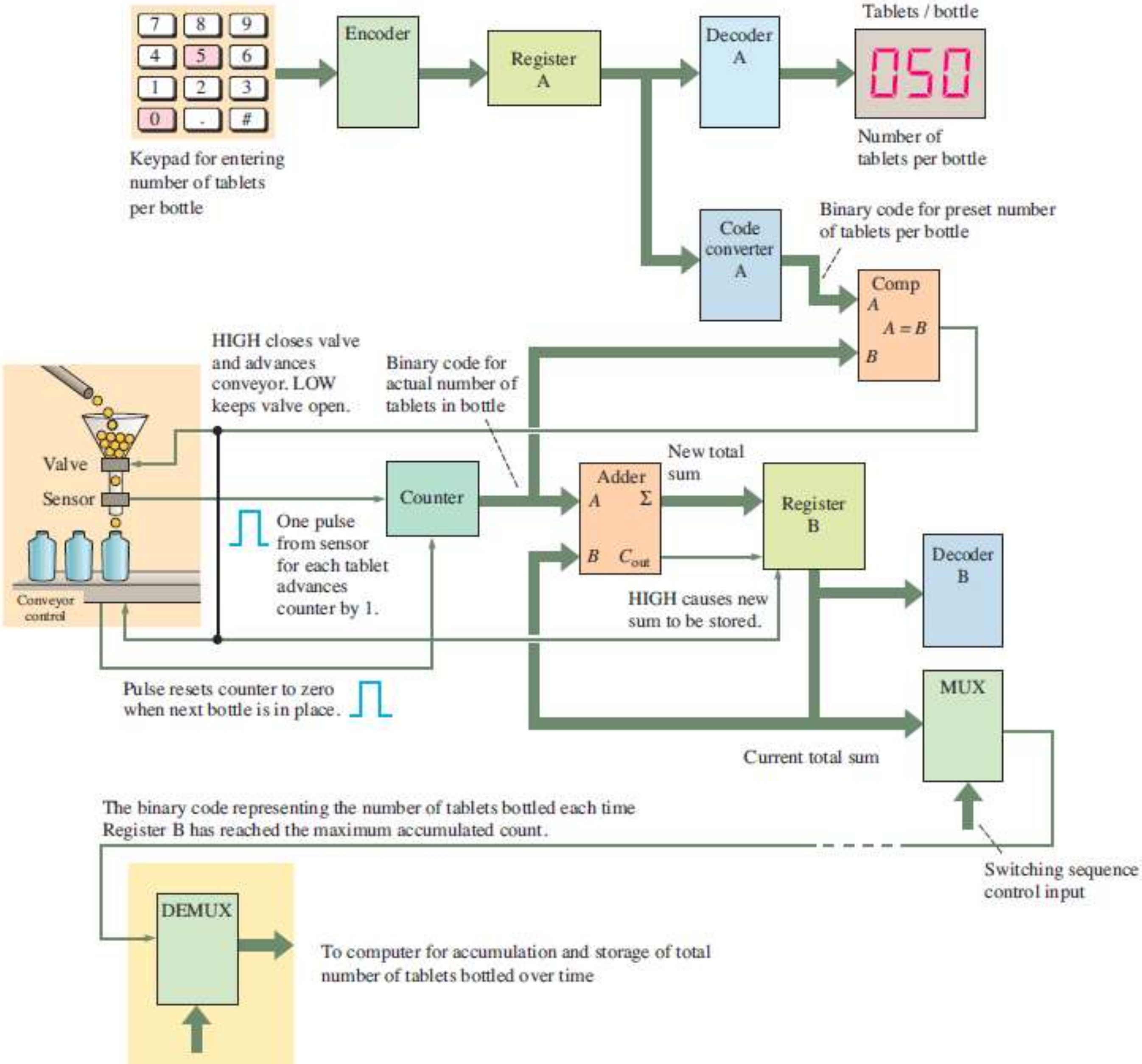
Example. Storage



Example. Counter



Tablet-bottling system



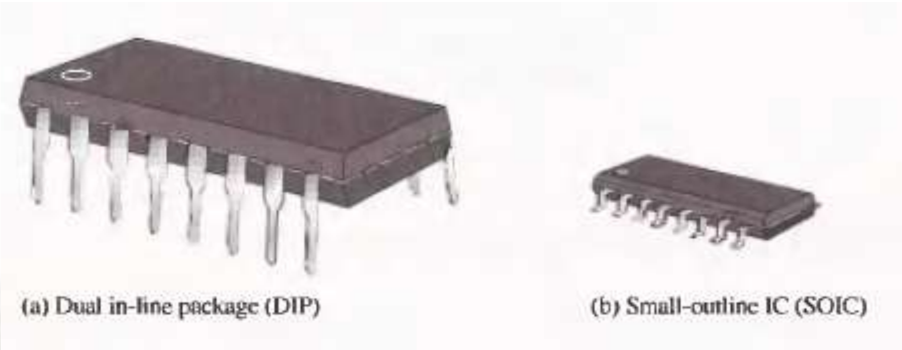
1-4 Overview of Integrated Circuits

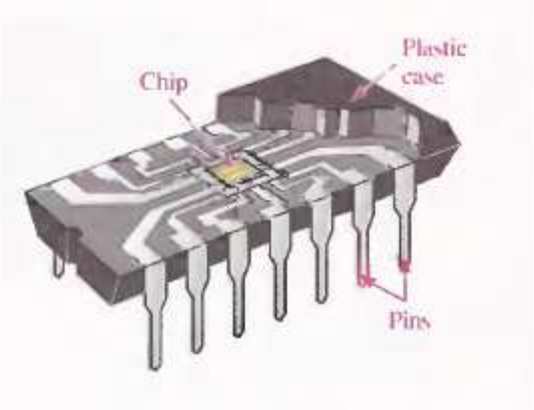
- Fixed-function Integrated Circuits
- Programmable Logic Circuits

Fixed-function Integrated Circuits

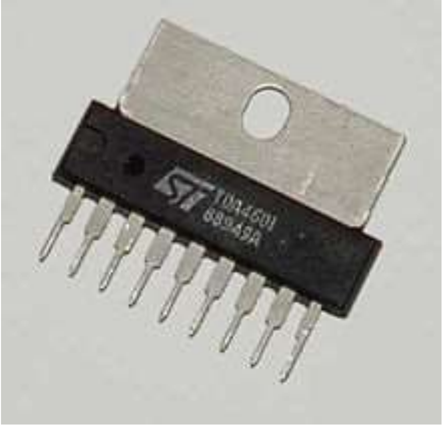
Fixed-function integrated circuits

- Constructed on a single small chip of silicon
- The logic functions are set by the manufacturer
- The logic cannot be altered

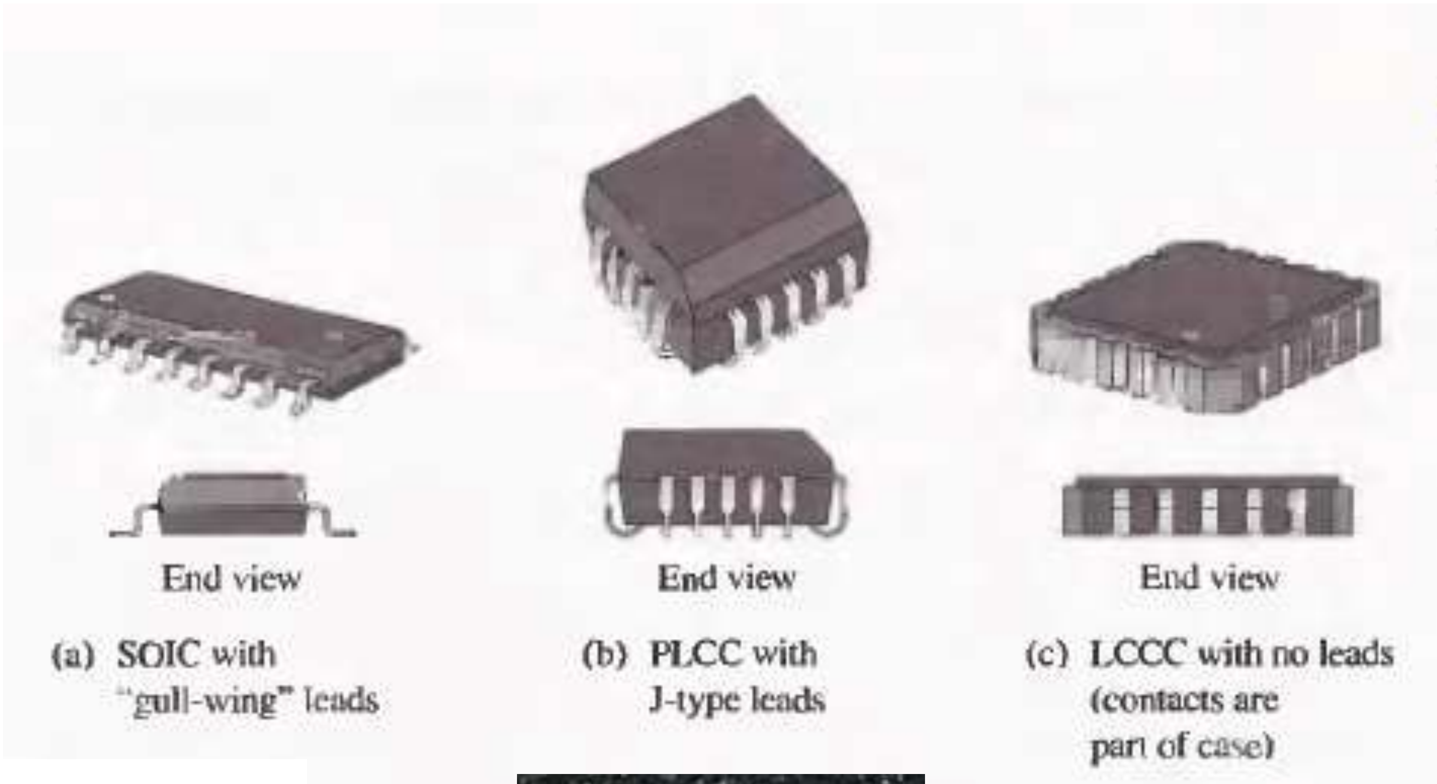




IC Packages



- **SIP: Single in-line package**
- **DIP: Dual in-line package**
- **SMT: Surface-mount technology**
  - SOIC: small-outline IC
  - PLCC: Plastic leaded chip carrier
  - LCCC: Leadless ceramic chip carrier
  - SSOP: Shrink small-outline package
  - TSSOP: Thin shrink small-outline package
  - TVSOP: Thin very small-outline package
  - BGA: ball grid array



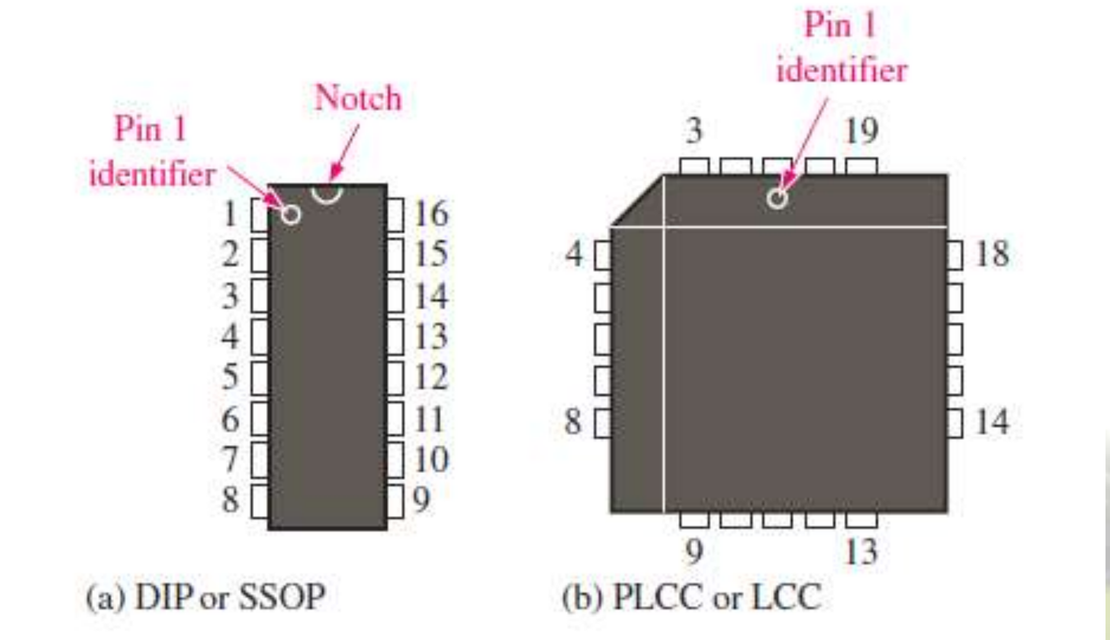
Bottom view of an Intel Embedded Pentium MMX, showing the blobs of solder

BGA ICs assembled on a PCB

Intel Mobile Celeron in a BGA2 package (FCBGA-479

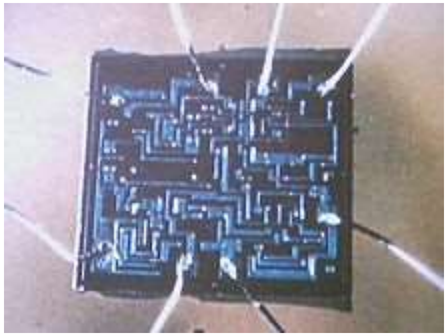
Pin Numbering

- Pin 1 is indicated by an identifier
- A small dot, a notch, or a beveled edge
- The dot is always next to pin 1.

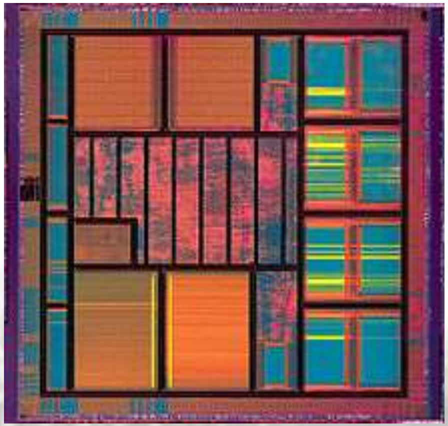


Complexity Classifications for Fixed-Function ICs

- **Small-scale integration (SSI)**
  - <10 equivalent gate circuits on a single chip
- **Medium-scale integration (MSI)**
  - 10~100
- **Large-scale integration (LSI)**
  - 100~10000
- **Very large-scale integration (VLSI)**
  - 10,000~100,000
- **Ultra large-scale integration (ULSI)**
  - >1000,000



A small-scale integrated circuit die, with bond wires attached

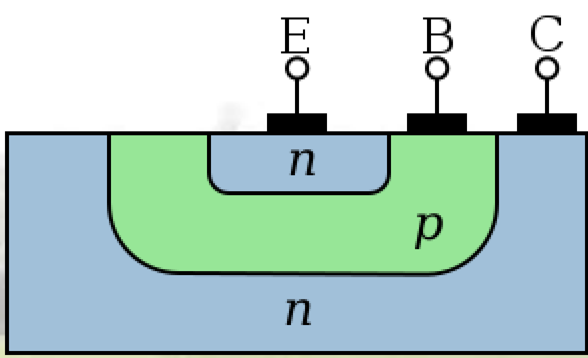


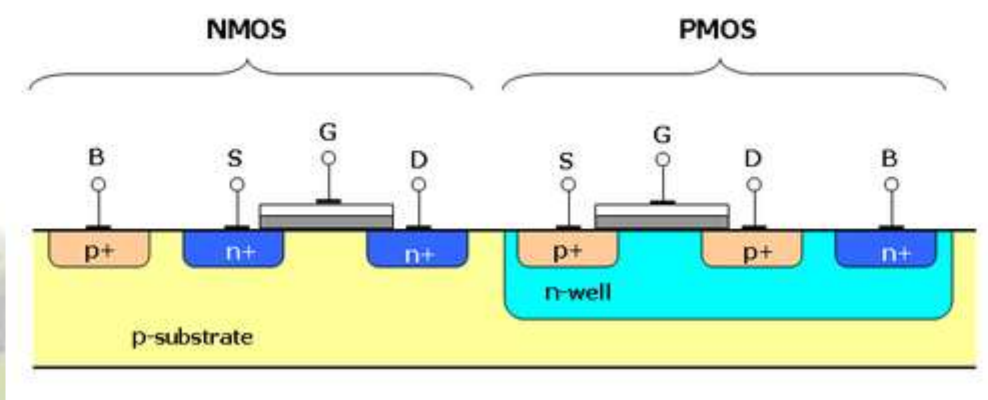
A VLSI integrated-circuit die

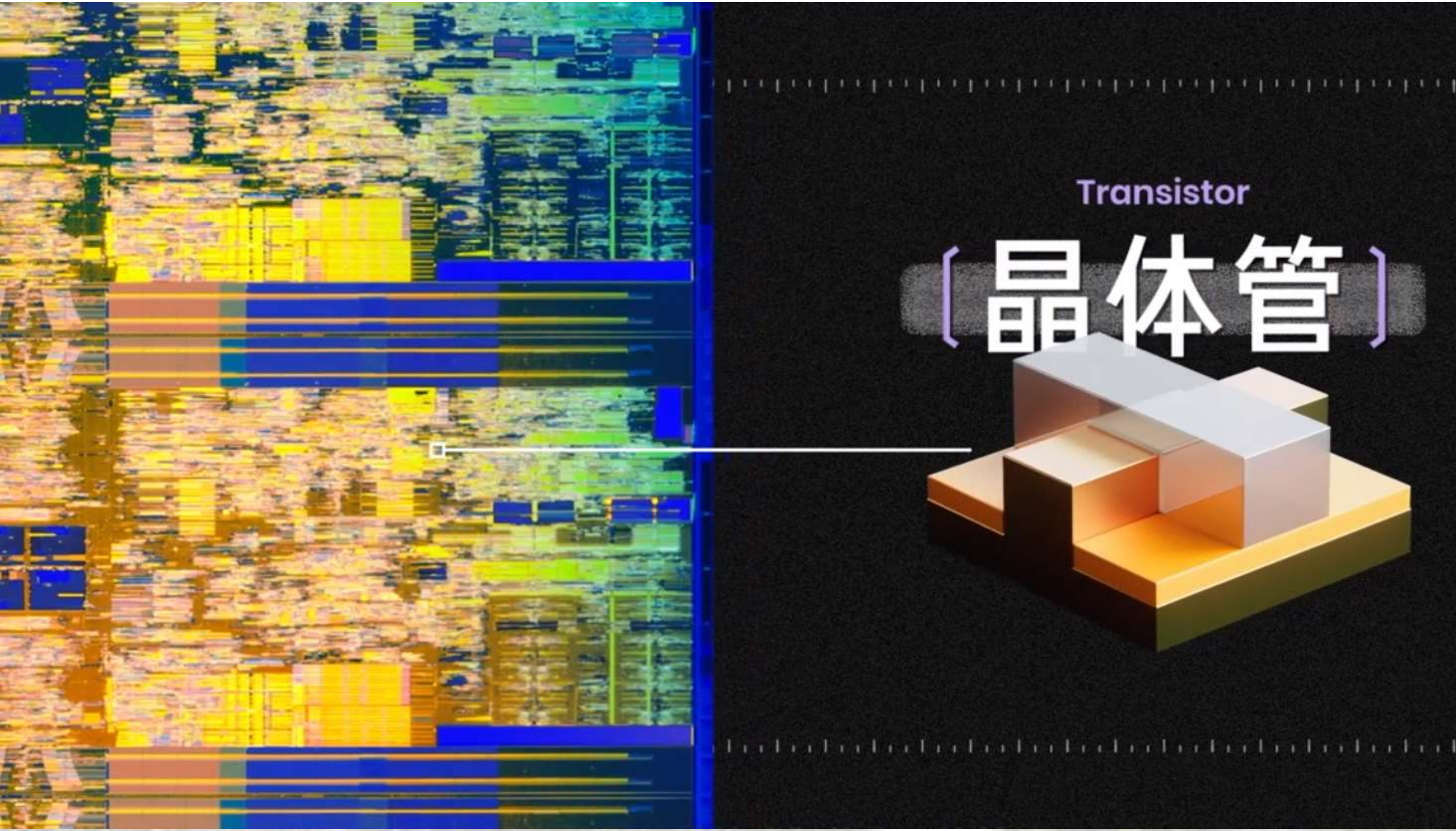
Semiconductor manufacturing processes
•10 µm — 1971 •3 µm — 1975 •1.5 µm — 1982 •1 µm — 1985 •800 nm (.80 µm) — 1989 •600 nm (.60 µm) — 1994 •350 nm (.35 µm) — 1995 •250 nm (.25 µm) — 1998 •180 nm (.18 µm) — 1999 •130 nm (.13 µm) — 2000 •90 nm — 2002 •65 nm — 2006 •45 nm — 2008 •32 nm — 2010 •22 nm — 2012 •14 nm — approx. 2014 •10 nm — approx. 2015 •7 nm — approx. 2020 •5 nm — approx. 2021

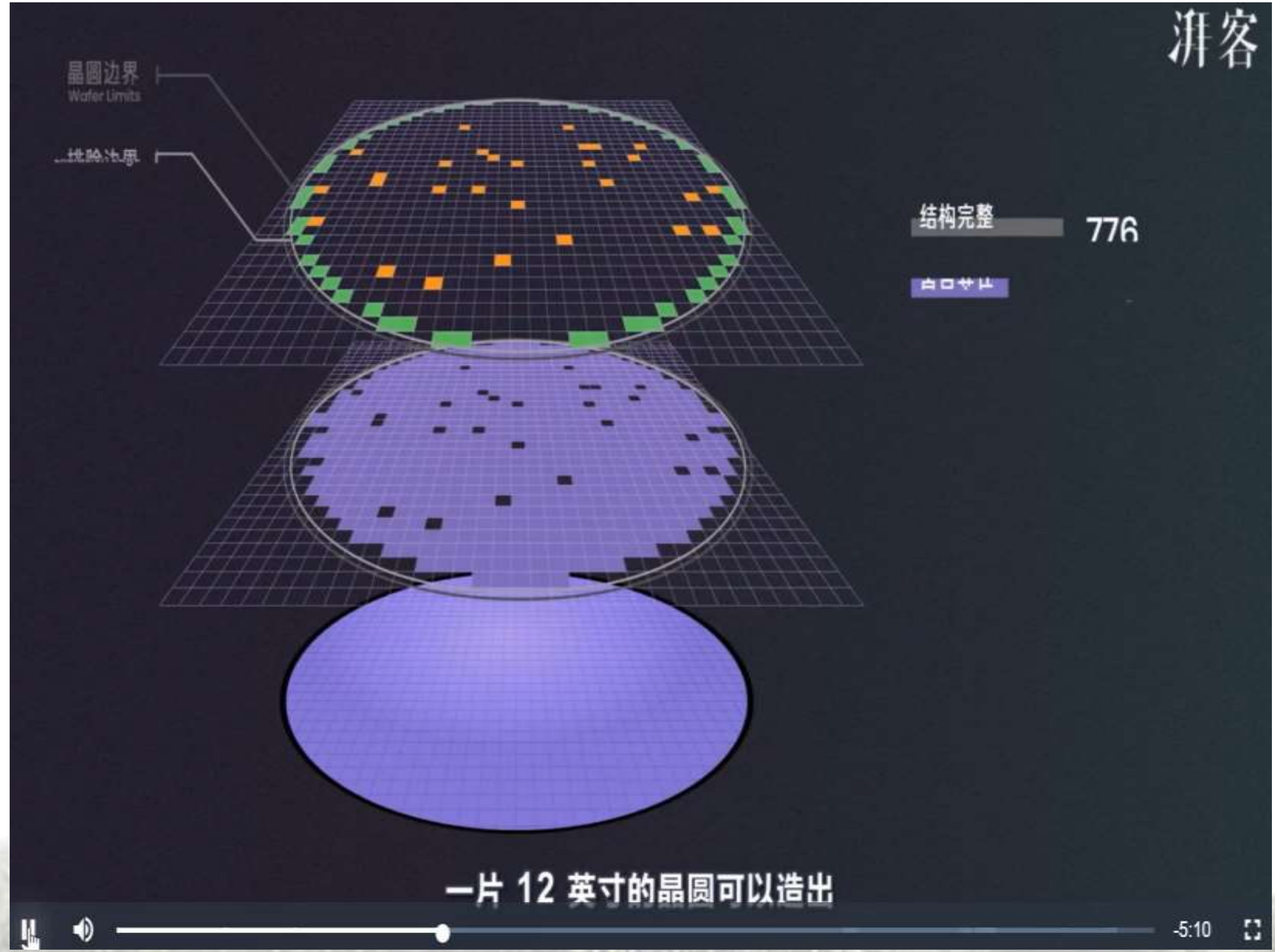
Integrated Circuit Technologies

- **CMOS (Complementary Metal-Oxide Semiconductor)**
  - Implemented with MOSFETs (Metal-Oxide Semiconductor Field-Effect Transistors)
- **TTL (Transistor-Transistor Logic)**
  - With bipolar junction transistors
- **BiCMOS**
  - Combination of both CMOS and TTL

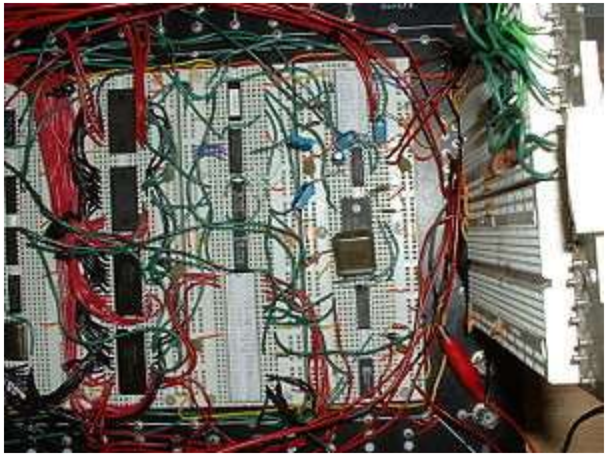





Transistor
晶体管



湃客
晶圆边界
Wafer Limits
结构完整
776
一片 12 英寸的晶圆可以造出
-5:10



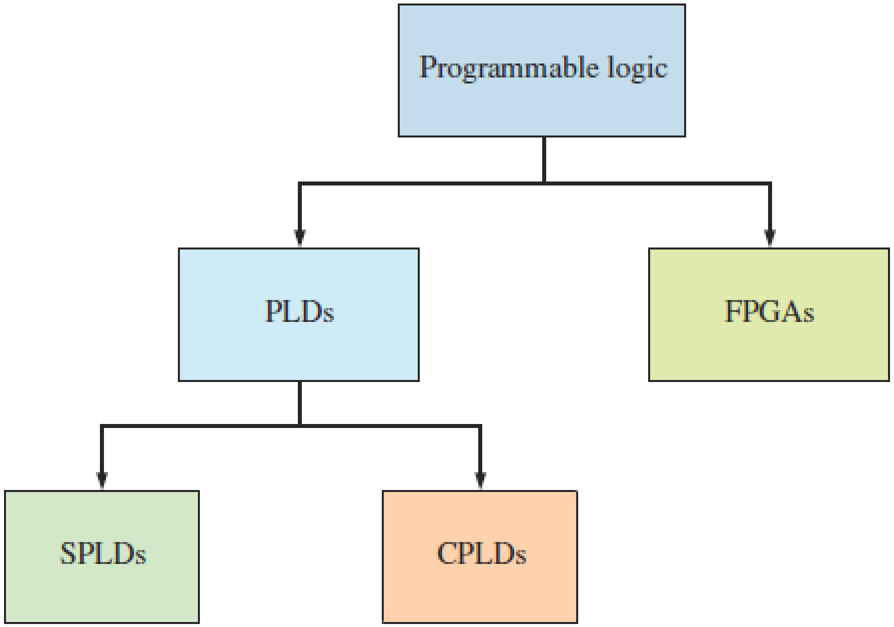
A Motorola 68000-based computer with various TTL chips mounted on protoboards

A micro ATX motherboard with some faulty capacitors

Programmable Logic Circuits

Types of Programmable Logic Devices

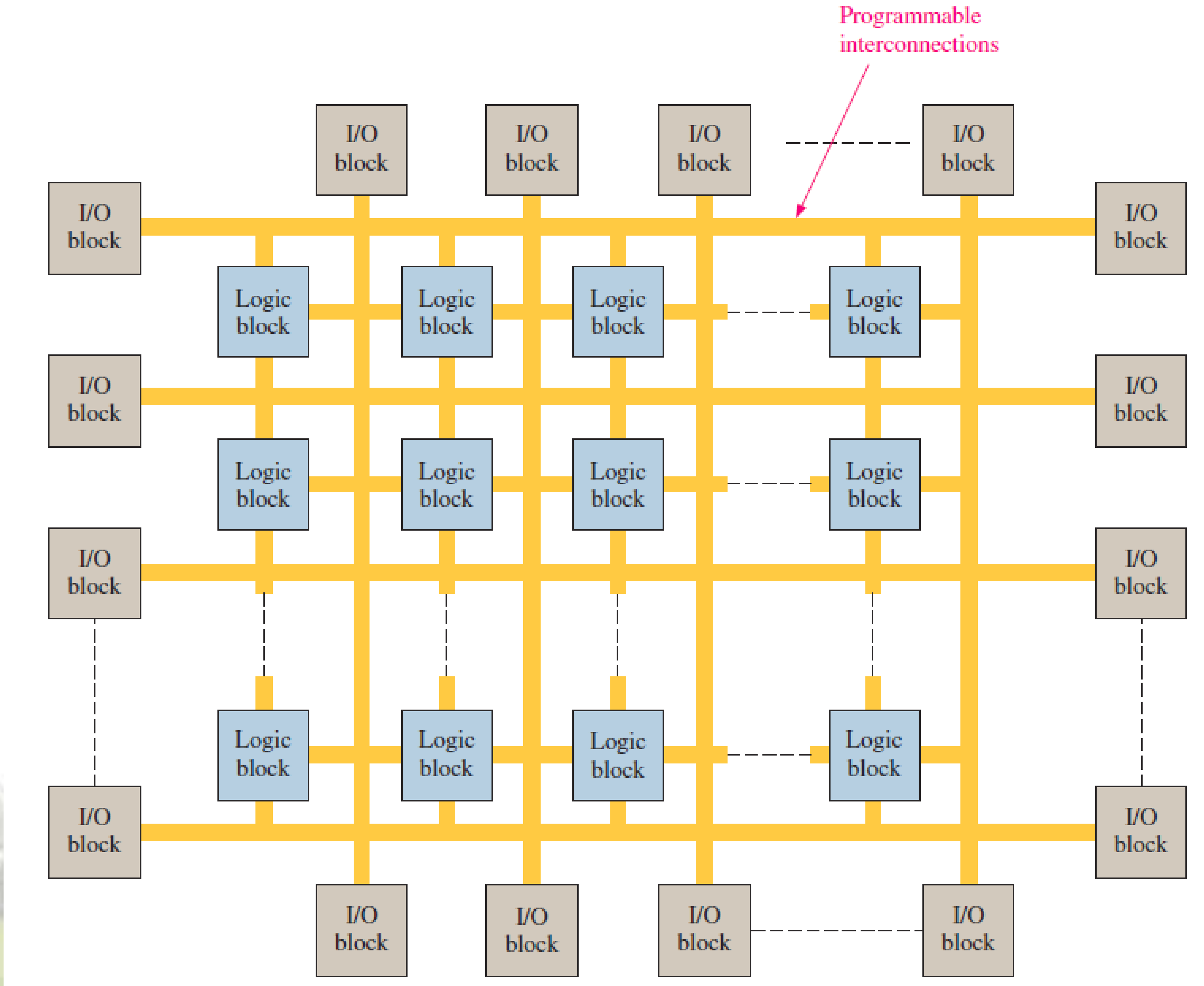
- PLD: Programmable Logic Device
- FPGA: Field Programmable Gate Array
- SPLD: Simple PLD
- CPLD: Complex PLDs



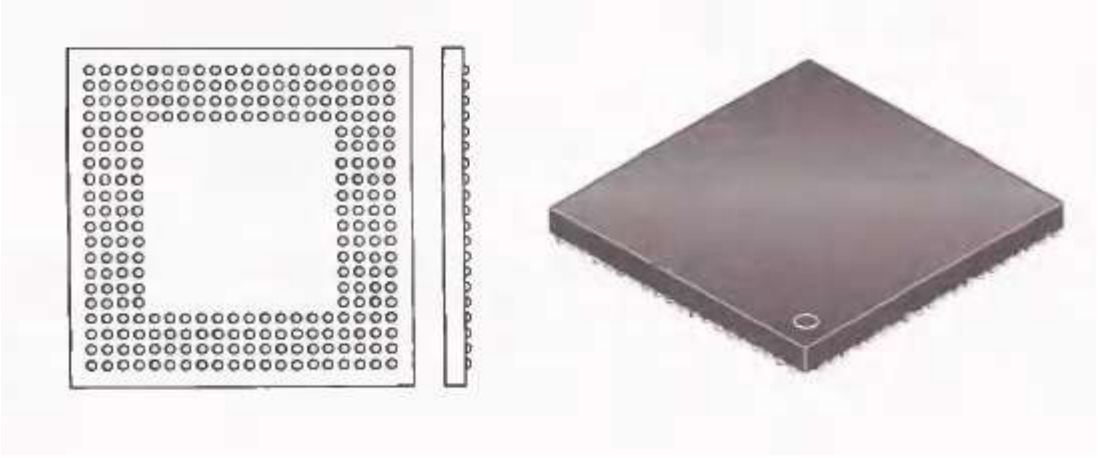
Typical package of SPLD

Typical CPLD packages

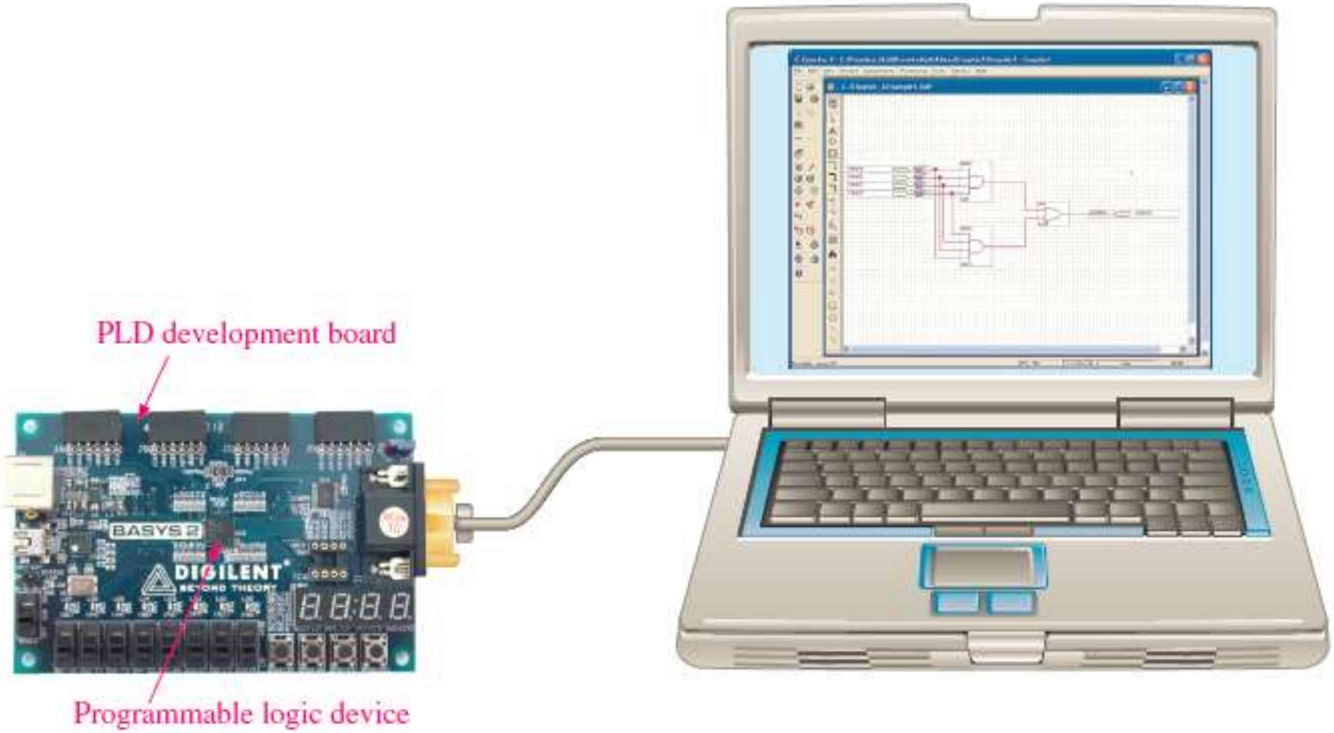
Basic structure of an FPGA

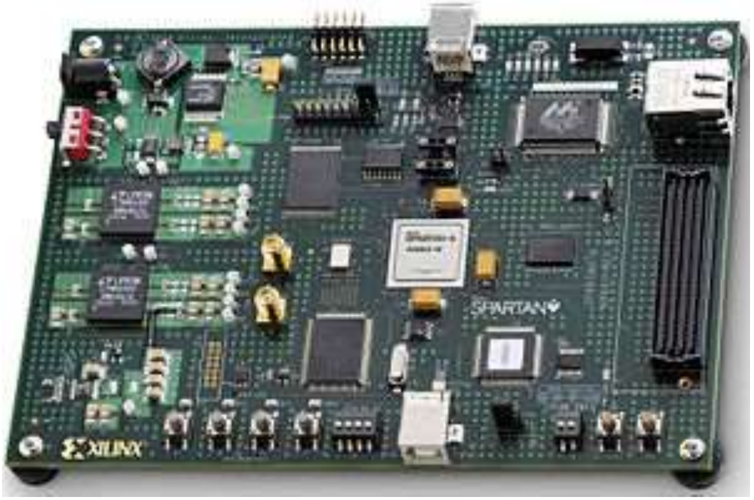


A typical ball-grid array package configuration



The Programming Process

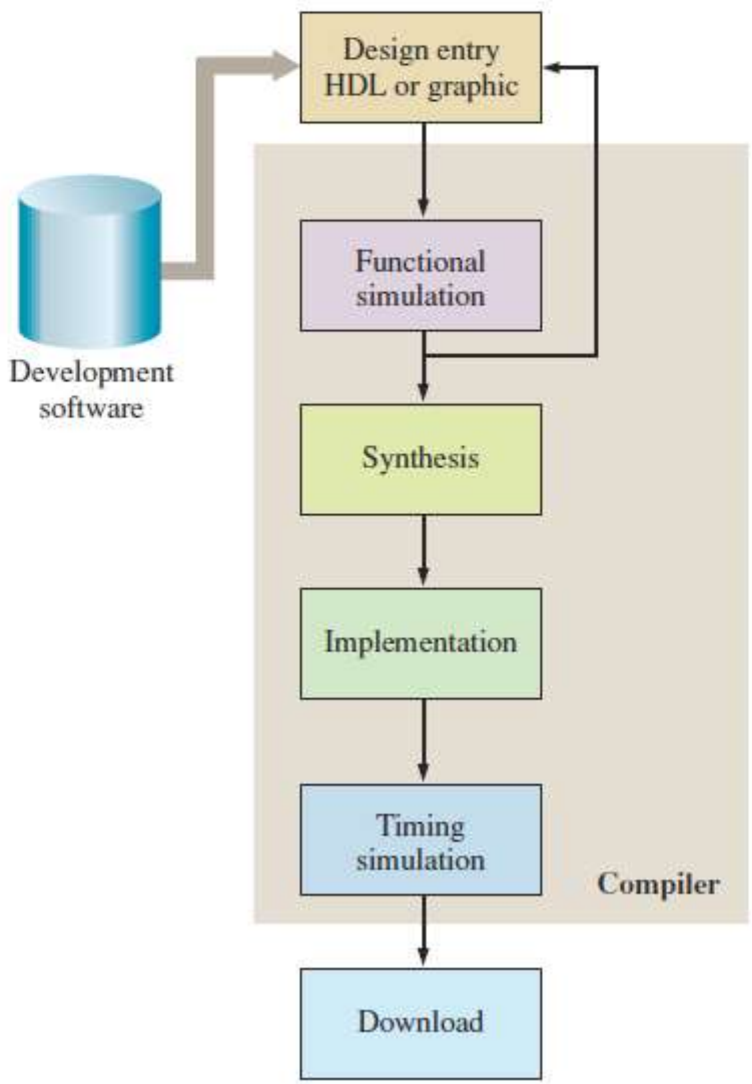




An example of a Xilinx Spartan 6 FPGA programming/evaluation board

An Altera Stratix IV GX FPGA

Basic programmable logic design flow block diagram



1-5 Test and Measurement Instruments

- **The Oscilloscope**

Signal generators

DC Power Supply

Digital Multimeter (DMM)

Summary

- Analog and digital
- Positional number systems
- Some basic concepts in digital design
- Basic logic operation
- Brief introduction of IC
- Test and measure instruments