Hardware

A-Level Computer Science

Computers and their components

A general-purpose computer has four building blocks:

- **input devices** 输入设备—get data in (keyboard, mouse, microphone, scanner, sensors).
- **output devices** 输出设备—give results out (monitor, speakers, printer, actuators).
- **primary memory** 主存储器—fast memory the **processor** 处理器 (CPU) reaches directly (RAM and ROM). Holds the running program and its data.
- **secondary storage** 辅助存储器—slower, larger, keeps programs and data when not in use (hard disk, SSD, optical disc, USB stick).

A keyboard: a common input device for typing text and commands

Image: Logitech, Product image (www.logitech.com)

A mouse: a pointing input device

Image: Logitech, Product image (www.logitech.com)

A flatbed scanner: an input device that turns a paper page into a digital image

Image: Epson, Product image (epson.com)

A monitor: a common output device that displays the screen image

Image: Dell, Product image (www.dell.com)

Embedded systems

An **embedded system** 嵌入式系统 is a computer built **into another device** to do one fixed job (washing machine, microwave, car engine unit, thermostat).

- **benefits**: optimised for one task (low power, small, cheap); reliable; fast to start; cheap in volume.
- **drawbacks**: limited to its one task; hard to update (its **firmware** 固件 may need special tools); often not repairable; sometimes weak security.

Principal hardware devices

Laser printer

A **laser printer** 激光打印机 scans the page image onto a charged photosensitive **drum** 感光鼓. **Toner** 墨粉 sticks to the charged areas, transfers to the paper, and is melted on by a fuser. Fast, sharp, high-volume.

A laser printer: fast, sharp printing using a charged drum and toner

Image: Brother, Product image (www.brother-usa.com)

3D printer

A **3D printer** 3D 打印机 builds an object **layer by layer**: FDM melts plastic filament through a nozzle; stereolithography cures liquid resin with a UV laser. Used for prototypes and custom medical parts.

An FDM 3D printer builds an object layer by layer by melting plastic filament

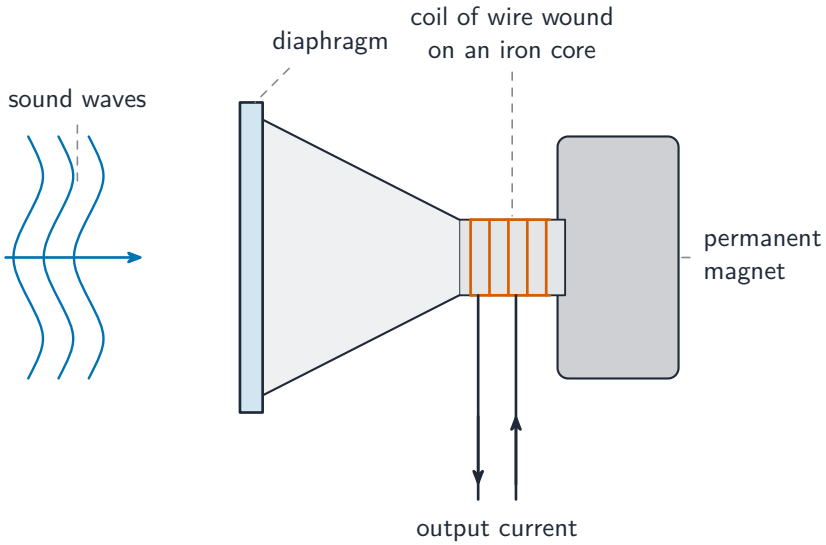
Image: Creality, Product image (store.creality.com)

Microphone and speakers

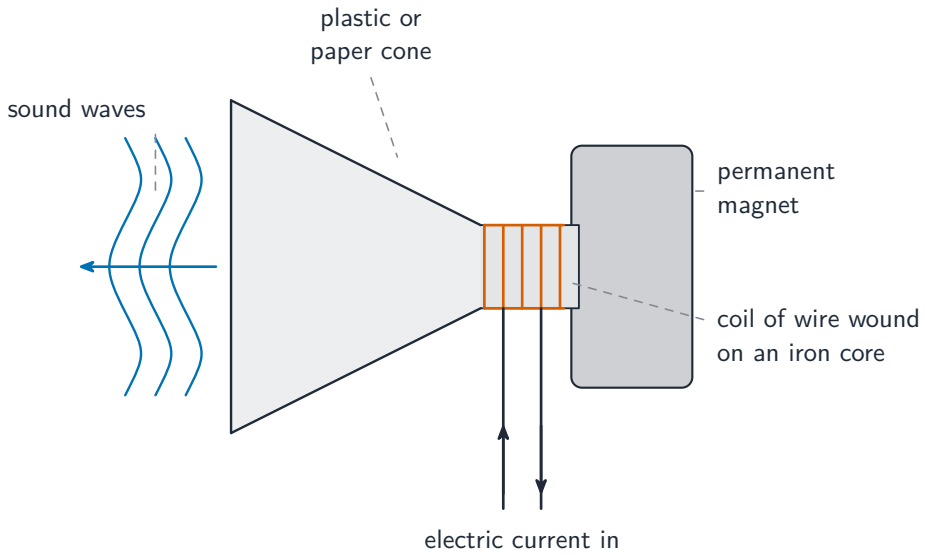
A **microphone** 麦克风 turns **sound into an electrical signal** (a diaphragm vibrates, changing **capacitor** 电容器 charge or coil position); the signal is digitised by an **analogue-to-digital converter** 模数转换器 (ADC). A speaker does the reverse — a varying signal drives a coil in a magnetic field, moving a cone to make sound.

A microphone turns sound into an electrical signal

Image: Logitech, Product image (www.logitechg.com)



Inside a microphone: sound vibrates the diaphragm and coil to produce a current



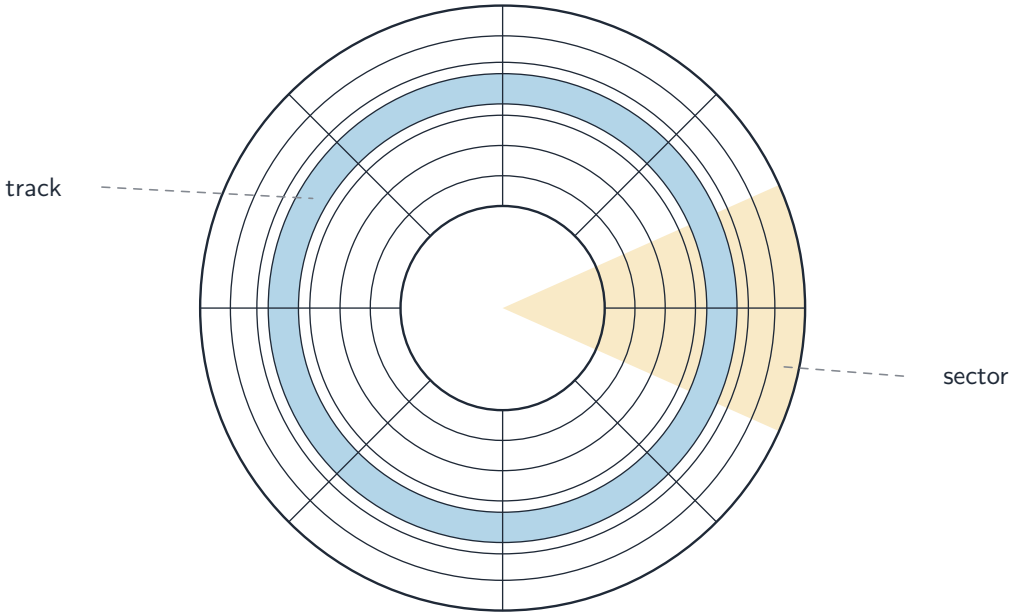
Inside a loudspeaker: a varying current in the coil moves the cone to make sound

Magnetic hard disk (HDD)

A **hard disk** 硬盘 stores data on spinning platters coated with magnetic material. Each platter has **tracks** 磁道 divided into **sectors** 扇区. A **read/write head** 读写头 floats just above and magnetises tiny regions (write) or senses them (read). Cheap per gigabyte, but slower than SSDs and has moving parts.

An opened hard disk: the actuator arm carries the read/write head over a platter

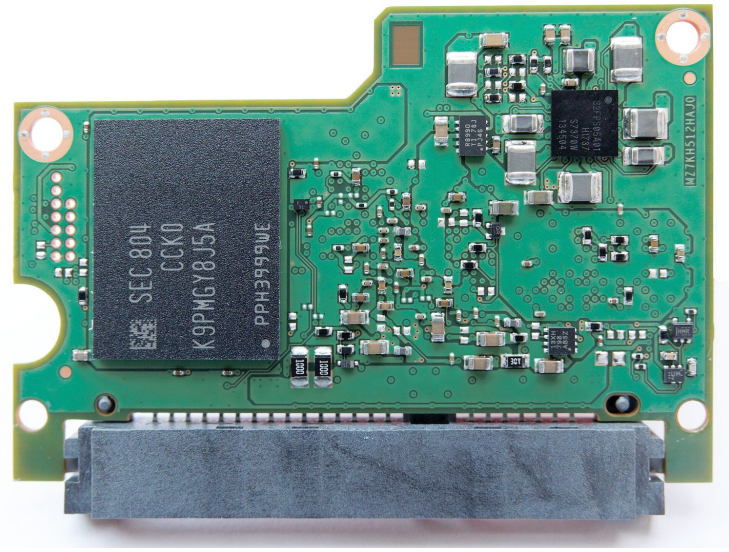
Image: Zzubnik, Public domain (commons.wikimedia.org)



Tracks and sectors on a hard disk platter

Solid-state (flash) memory

A **solid-state drive** 固态硬盘 stores data as charge in **transistors** 晶体管, with no moving parts. Faster random access than HDDs, tougher, lower power, but dearer per gigabyte; each cell wears out after many writes.



Inside an SSD: data is stored in flash memory chips, with no moving parts (compare the hard disk above)

Optical disc

A laser detects reflections from tiny pits on an **optical disc** 光盘 (CD, DVD, Blu-ray). Writing uses a stronger laser to change the surface's reflectivity.

An optical disc drive: a laser reads tiny pits on a CD, DVD or Blu-ray disc

Image: ASUS, Product image (www.asus.com)

Touchscreen

A **touchscreen** 触摸屏 senses contact. **Resistive** 电阻式: two conductive layers pressed together; works with anything but is less accurate. **Capacitive** 电容式: a finger disturbs a charge field; accurate, multi-touch, used in phones.

A touchscreen senses where a finger touches the glass

Image: Dell, Product image (www.dell.com)

Virtual reality headset

A **virtual reality** 虚拟现实 (VR) headset has two small displays (one per eye) and motion sensors (**accelerometer** 加速度计, **gyroscope** 陀螺仪) that track head movement so the scene shifts as you look around.

A virtual reality headset: two small displays and motion sensors track the head

Image: Meta, Product image (www.meta.com)

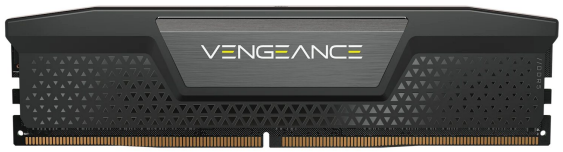
Buffers

A **buffer** 缓冲 is memory that **holds data temporarily** while it moves between devices of different speeds. Example: the CPU writes a document to a printer buffer quickly, then is free to do other work while the printer prints from the buffer at its own pace. Buffers stop the fast device waiting for the slow one (also used in streaming, the keyboard, and disk access).

RAM and ROM

- **RAM** 随机存取存储器 (Random Access Memory) —**volatile** 易失性 (loses data without power). Holds the OS, running programs and their data; read and written constantly.
- **ROM** 只读存储器 (Read-Only Memory) —**non-volatile** 非易失性 (keeps data without power). Usually written once; holds firmware needed at start-up (the BIOS / boot loader).

ROM starts the system; RAM then holds the active work.



A RAM module (DIMM) plugs into the motherboard as the computer's fast main memory

Image: Corsair, Product image (www.corsair.com)

SRAM vs DRAM

- **SRAM** 静态 RAM stores each bit in a **flip-flop** 触发器 of several transistors. Fast, but expensive and not dense. Used for CPU **cache** 高速缓存.
- **DRAM** 动态 RAM stores each bit as charge on a tiny capacitor. Cheaper and denser but slower, and must be **refreshed** 刷新 (rewritten) thousands of times a second. Used for main memory.

Use SRAM for small fast memory (cache); DRAM for large main memory.

PROM, EPROM and EEPROM

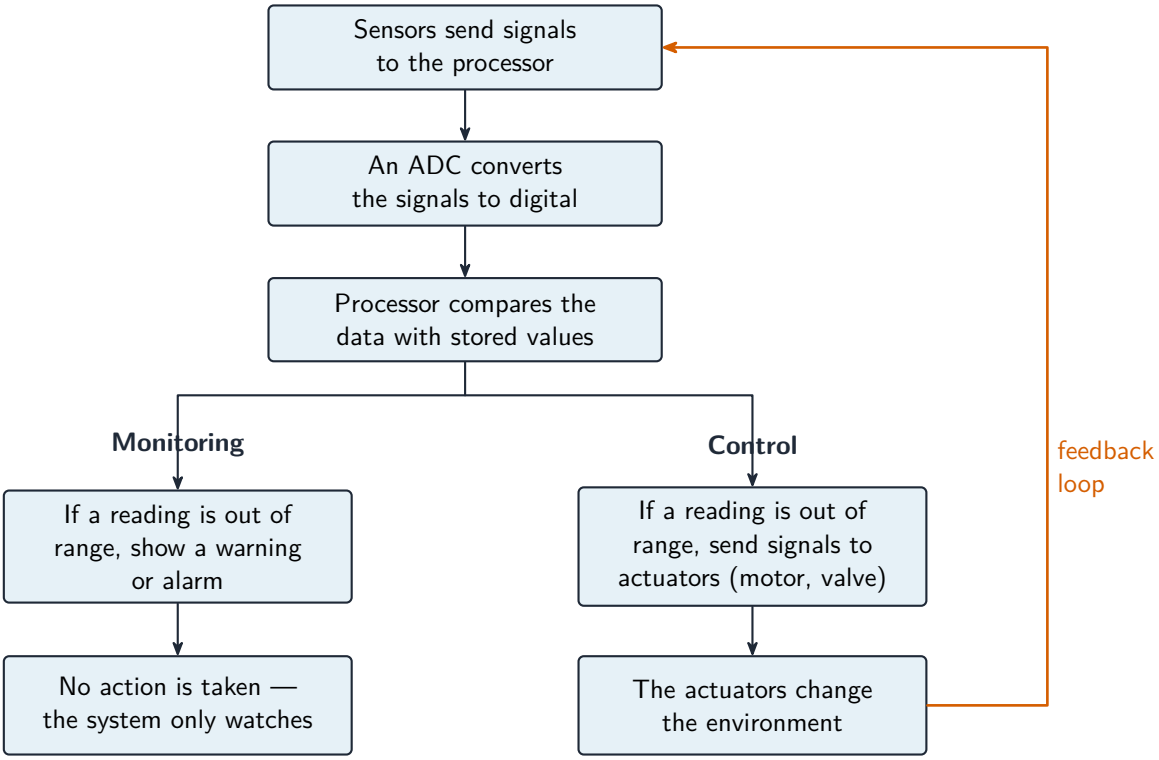
ROM variants you can program after manufacture:

- **PROM** —written **once** (fuses burned by a programmer); cannot be changed.
- **EPROM** —erased by **strong UV light** through a window, then rewritten (whole chip at once).
- **EEPROM** —erased and rewritten **electrically**, a byte at a time, in circuit. Flash memory is a derivative optimised for block erase.

Monitoring and control systems

Both read **sensors**; the difference is what they do next.

- **monitoring** 监控—collects and reports data but **takes no action** (a weather station logging readings).
- **control system** 控制系统—uses sensor data to **decide and act** through actuators, usually in a feedback loop (a thermostat turning a boiler on/off).



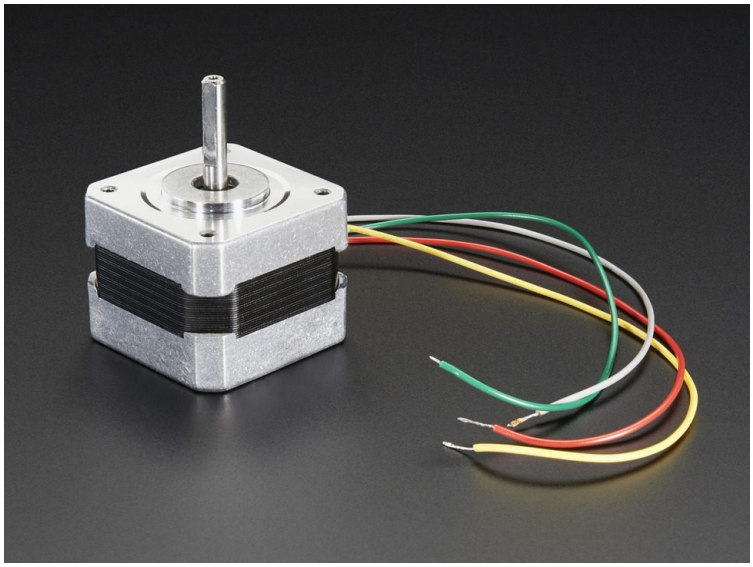
Monitoring reports data; a control system acts through a feedback loop

Sensors and actuators

A **sensor** 传感器 turns a physical quantity into a signal: temperature (a **thermistor** 热敏电阻 or thermocouple), pressure (strain gauge), infra-red, sound. Analogue signals need an ADC first. An **actuator** 执行器 does the reverse —turns a signal into an action (a motor, valve, heater, buzzer).

A thermistor: a temperature sensor whose resistance changes with heat

Image: SparkFun, Product image (www.sparkfun.com)



A small electric motor: an actuator that turns a signal into movement

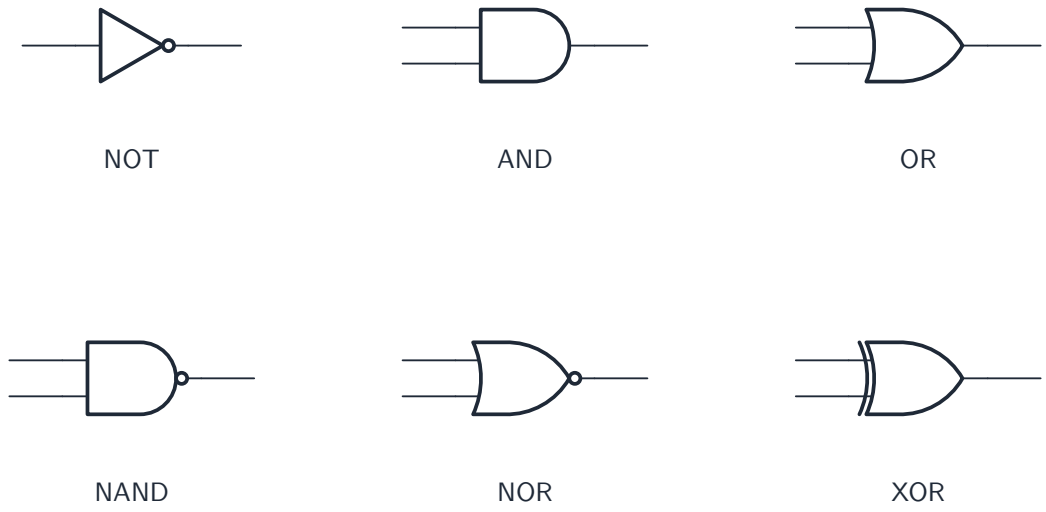
Image: Adafruit, Product image (www.adafruit.com)

Feedback

In a control system the actuator changes the environment, which the sensors then re-measure —a **feedback** 反馈 loop. Without feedback the system cannot correct itself or know when to stop (a thermostat with no temperature feedback would heat forever).

Logic gates

A **logic gate** 逻辑门 is a small circuit that does one **Boolean** 布尔 operation. Inputs and outputs are 0 (false, low) or 1 (true, high). Know the symbol, function and **truth table** 真值表 for each gate.



The symbols for the six logic gates

NOT (inverter)

A	NOT A
0	1
1	0

AND —output 1 only if all inputs are 1

A	B	A AND B
0	0	0
0	1	0
1	0	0
1	1	1

OR —output 1 if at least one input is 1

A	B	A OR B
0	0	0
0	1	1
1	0	1
1	1	1

NAND (NOT AND) —output 0 only when all inputs are 1

A	B	A NAND B
0	0	1
0	1	1
1	0	1
1	1	0

NOR (NOT OR) —output 1 only when all inputs are 0

A	B	A NOR B
0	0	1
0	1	0
1	0	0
1	1	0

XOR (Exclusive OR) —output 1 if the inputs are different

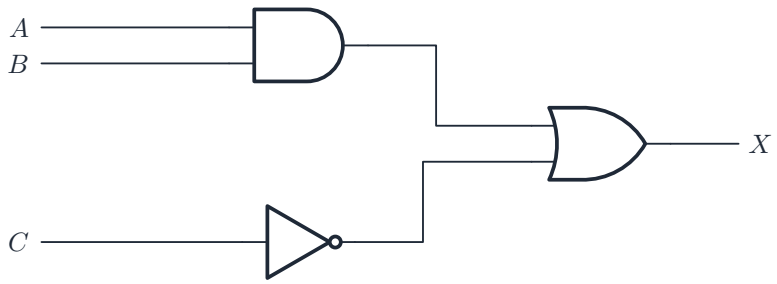
A	B	A XOR B
0	0	0
0	1	1
1	0	1
1	1	0

Logic circuits

A **logic circuit** 逻辑电路 is a network of gates that carries out a Boolean expression. You should be able to move between a problem statement, a logic expression, a truth table, and a circuit diagram.

From expression to circuit

Draw one gate per operator and wire them up. For $X = (A \text{ AND } B) \text{ OR } (\text{NOT } C)$: a NOT gate on C, an AND gate on A and B, then an OR gate on the two results.



Gates wired together to carry out a Boolean expression

From circuit to expression

Work forwards from the inputs, labelling each gate's output, until you reach the final output.

From circuit to truth table

For n inputs there are 2^n rows. List every input combination; for each, work out the internal gates then the output.

From truth table to expression (sum of products)

For each row that outputs 1, write an AND of the inputs (with NOT on any input that is 0 in that row); OR these together. Example: a table that is 1 only on $(A = 0, B = 1)$ and $(A = 1, B = 0)$ gives $\overline{A}B + A\overline{B}$, which is A XOR B.

From a problem statement

Turn the English into a Boolean expression first: ”A and B” → A AND B; ”A or B or both” → A OR B; ”exactly one of A and B” → A XOR B; ”neither A nor B” → A NOR B; ”not both” → A NAND B.