Course Companion

IGCSE Computer Science

Every topic handout in one volume

全部专题讲义合集

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Data representation

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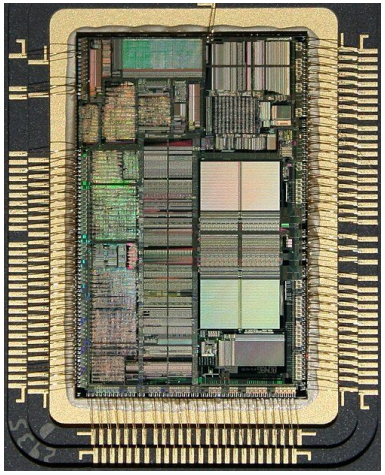
Why computers use binary

Digital computers represent data using two logical states, written as 1 and 0. A system that uses only two digits 数字 is called **binary** 二进制 (base 2).



Computers represent all data – numbers, text, sound and images – as binary strings of 0s and 1s

Every kind of data 数据 – numbers, text, sound and images – must be changed into binary before a computer can use it. The computer processes this binary using **logic gates** 逻辑门, and stores it in **registers** 寄存器 (small, fast stores inside the processor 处理器).



A microprocessor holds millions of tiny transistors, each a switch that is on (1) or off (0) – the physical basis of binary

Number systems

A **number system** 数制 is a way of writing numbers using a fixed set of digits. You need three of them.

System	Base	Digits used
Denary	10	0–9
Binary	2	0 and 1
Hexadecimal	16	0–9 then A–F

- **denary** 十进制 is the normal counting system (also called decimal).
- **binary** uses only 0 and 1.
- **hexadecimal** 十六进制 (hex) uses sixteen digits: 0–9, then A, B, C, D, E, F stand for 10, 11, 12, 13, 14, 15.

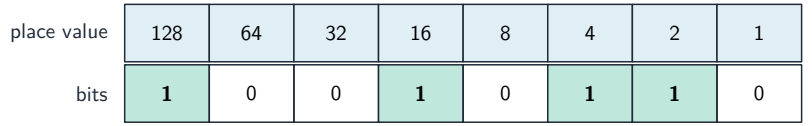
The **base** 基数 tells you how many different digits a system uses.

Place value

Each column in a number has a **place value** 位值. In binary the place values double from right to left. For an 8-bit number they are:

```
128  64  32  16  8  4  2  1
```


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$150 = 128 + 16 + 4 + 2 \Rightarrow$ `10010110`

An 8-bit place-value chart: the 1s sit under the values that add up to 150

One **bit** 位 is a single 0 or 1. Eight bits make one **byte** 字节. Four bits (half a byte) is a **nibble** 半字节.

Converting between number systems

Denary → binary. Write the place values. Put a 1 under each value you need so they add up to your number; put 0 under the rest.

Example: change denary 150 to binary. $150 = 128 + 16 + 4 + 2$.

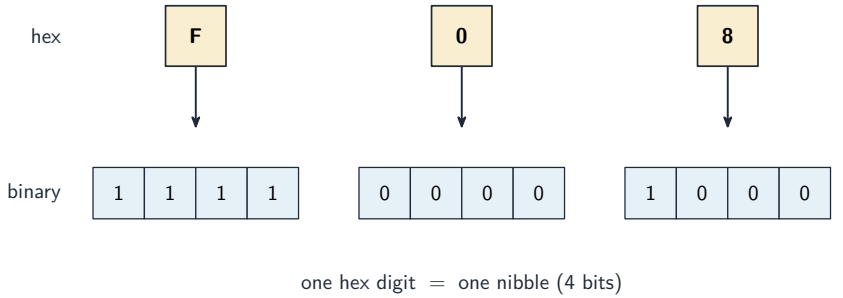
```
128 64 32 16 8 4 2 1
  1  0  0  1 0 1 1 0
```

So 150 = `10010110`.

Binary → denary. Add the place values where there is a 1. `10010110` $= 128 + 16 + 4 + 2 = 150$.

Hexadecimal → binary. Change each hex digit into its own 4-bit group (a nibble).

Example: hex F08. $F = 1111$, $0 = 0000$, $8 = 1000$, so F08 = `1111 0000 1000`.



Each hex digit maps to its own 4-bit nibble – F08 = 1111 0000 1000

Binary → hexadecimal. Group the bits into nibbles of 4, starting from the right. Change each nibble to one hex digit.

Denary → hexadecimal. The easy way is to change to binary first, then binary to hex.

This table helps with the hex letters:

Denary	Binary	Hex
10	1010	A
11	1011	B
12	1100	C
13	1101	D
14	1110	E
15	1111	F

Cambridge questions use binary numbers up to 16 bits long.

> **Worked example.** Convert denary 100 to 8-bit binary, then to hexadecimal.

$100 = 64 + 32 + 4$, so the binary is `01100100`. Splitting into nibbles, `0110 0100` = 6 and 4, so the hexadecimal is `64`.

> **Worked example (hexadecimal → denary).** Convert hex `2C` to denary. The hex place values are 16 and 1. `2` is worth $2 \times 16 = 32$ and `C` is 12, so `2C` $= 32 + 12 = 44$. Check through binary: `0010 1100` $= 32 + 8 + 4 = 44$.

Why hexadecimal is used

Hex is shorter than binary and easier for people to read and write. One hex digit replaces 4 binary digits, so you make fewer mistakes. The value does not change – hex is just a shorter way to show the same binary.

Computer scientists use hex for:

- MAC addresses and IPv6 addresses
- colour codes in HTML (for example `#FF0000` is red)
- **memory addresses** 内存地址 and error codes
- showing the contents of memory (a "memory dump")

Binary addition

You can add two 8-bit binary numbers, column by column from the right, just like denary. The rules for one column are:

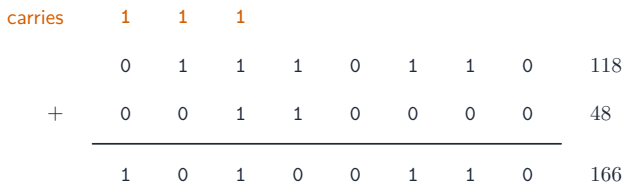
A	B	Result bit	Carry
0	0	0	0
0	1	1	0
1	0	1	0
1	1	0	1

When a carry also comes in, $1 + 1 + 1 = 1$ with a carry of 1.

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Example: add `01110110` (118) and `00110000` (48).

```
  0 1 1 1 0 1 1 0    (118)
+ 0 0 1 1 0 0 0 0    (48)
--------------------
  1 0 1 0 0 1 1 0    (166)
```

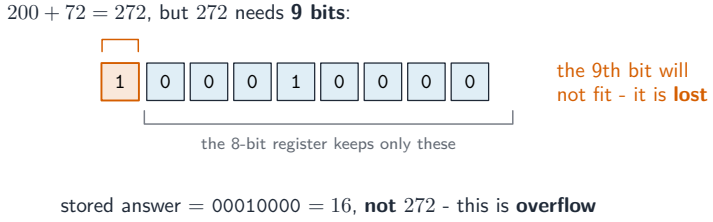


Adding column by column; the carries ripple to the left. 118 + 48 = 166

Overflow

When interpreted as an **unsigned** integer, an 8-bit register holds values from 0 to 255. If an addition gives a result above 255, the answer needs a 9th bit. The register cannot hold this extra bit, so it is lost. This is called **overflow** 溢出 (an overflow error). It happens when a value goes outside the limit the register can store.

Example: `11001000` (200) + `01001000` (72) = 272. In binary that is `1 00010000`, which needs 9 bits. The leading 1 will not fit in 8 bits, so the stored answer is wrong.



Adding 200 and 72 needs 9 bits, but an 8-bit register drops the ninth, so the answer is wrong

Logical binary shift

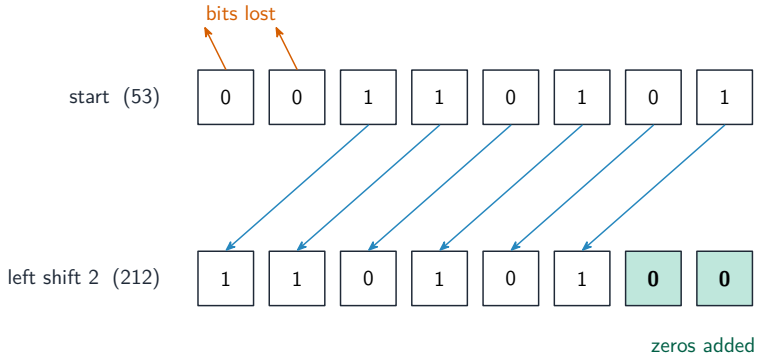
A **logical binary shift** 逻辑二进制移位 moves all the bits left or right by a number of places.

- Bits that move off the end of the register are **lost**.
- **Zeros** are added at the empty end.

For an unsigned integer, a **left shift** multiplies by 2 for each place moved **if no non-zero bit is lost**. A logical **right shift** gives the whole-number result of division by 2 for each place; the right-most bits (the **least significant bit(s)** 最低有效位) are lost.

Example: left shift `00110101` (53) by 2 places.

```
start:          0 0 1 1 0 1 0 1
left shift 2:   1 1 0 1 0 1 0 0
```



A left shift of 2: every bit moves 2 places left, the top bits are lost and zeros fill the right

The result is `11010100` (212), which is 53×4. The two left-most bits were lost and two zeros came in on the right. If a 1 is pushed off the end, that information is gone for good.

Worked example (right shift). Shift `10110100` (180) **right** by 3 places. Give the result in binary and denary, and say what effect the shift has.

```
start:          1 0 1 1 0 1 0 0
right shift 3:  0 0 0 1 0 1 1 0
```

The three right-most bits (`100`) are lost and three zeros enter on the left: `00010110` $= 16 + 4 + 2 = 22$. Shifting right 3 places divides by $2^3 = 8$: $180 \div 8 = 22.5$, and the shift keeps only the whole-number part, 22. The 0.5 was carried by the lost 1 bit.

> **Worked example (a left shift that goes wrong).** Shift `01100100` (100) left by 2 places. The result is `10010000` = 144, not 400: a 1 was pushed off the left end, and 400 is too large for 8 bits anyway. A left shift multiplies correctly only while no 1 bits are lost.

Two's complement

So far the numbers were positive. **Two's complement** 补码 lets an 8-bit register hold negative numbers too.

In two's complement, the left-most bit (the **most significant bit** 最高有效位, or MSB) has a *negative* place value:

```
-128  64  32  16  8  4  2  1
```

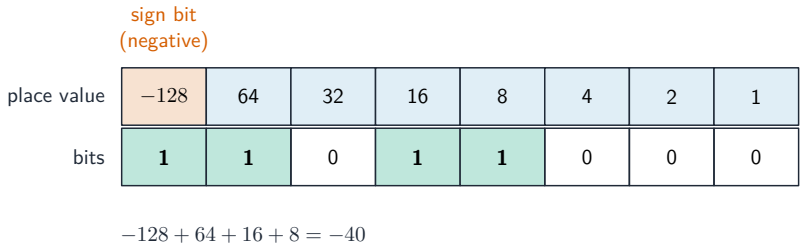
- If the MSB is 0, the number is zero or positive.
- If the MSB is 1, the number is negative.

To make a positive number negative: write the positive binary, flip every bit ($0 \leftrightarrow 1$), then add 1.

Example: make -40.

- $+40$ = `00101000`
- flip the bits = `11010111`
- add 1 = `11011000`

So -40 = `11011000`. Check by adding the place values: $-128 + 64 + 16 + 8 = -40$.



The most significant bit is worth −128, so 11011000 = −128 + 64 + 16 + 8 = −40

To read a negative two's complement number, just add the place values (the MSB counts as -128). The range of an 8-bit two's complement number is -128 to $+127$.

> **Worked example.** Convert the two's complement number `10011010` to denary. The MSB is 1, so the number is negative: $-128 + 16 + 8 + 2 = -102$. Check by the other method: flip the bits (`01100101`) and add 1 (`01100110` = 102), so the number is -102.

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Representing text

Computers store text by giving every character a number, then storing that number in binary. The set of characters a computer can use, together with their numbers, is a **character set** 字符集.

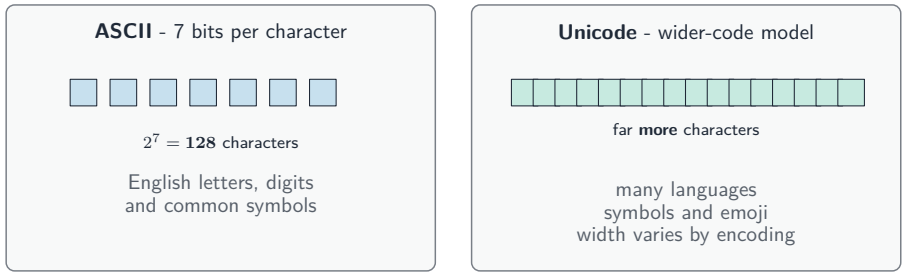
ASCII uses 7-bit character codes, giving $N = 2^b = 2^7 = 128$ different codes. It includes English letters, digits and common symbols; not all 128 codes are letters. **Unicode** represents a much greater range of characters, including different languages and **emoji** 表情符号.

Try it – encode a short message. This extract from ASCII gives A = 65, B = 66, C = 67 and space = 32. Write the four 7-bit groups for `CAB ` , including its final space. Then decode the groups `1000010 1000001 1000011`.

Worked answer. Look up each character, then convert its code to binary:

Character	Code	Seven bits
C	67	1000011
A	65	1000001
B	66	1000010
space	32	0100000

So `CAB ` is `1000011 1000001 1000010 0100000`. The second message decodes to `BAC`. A space has a code too; it is not an absence of stored data. The sender and receiver must use the same character-code mapping to interpret the message correctly.



ASCII has 128 codes. Unicode supports a much greater range; the wider row illustrates the syllabus model.

Why a larger range matters. ASCII cannot directly represent a Chinese name. Unicode includes Chinese characters as well as English characters and many other languages. For the syllabus comparison, explain that a greater range needs more distinct binary codes, requiring more bits per character than the 7-bit ASCII model.

Try it – compare stated storage models. Store the four characters `CAB ` using (A) 7 bits per character and (B) 16 bits per character. Assume the bits are packed with no padding or extra file information. Find the text data size in each model. The

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16-bit value is an assumption for this example, not a rule that all Unicode characters take 16 bits.

Worked answer. With the same number of characters, multiply by the stated bits per character:

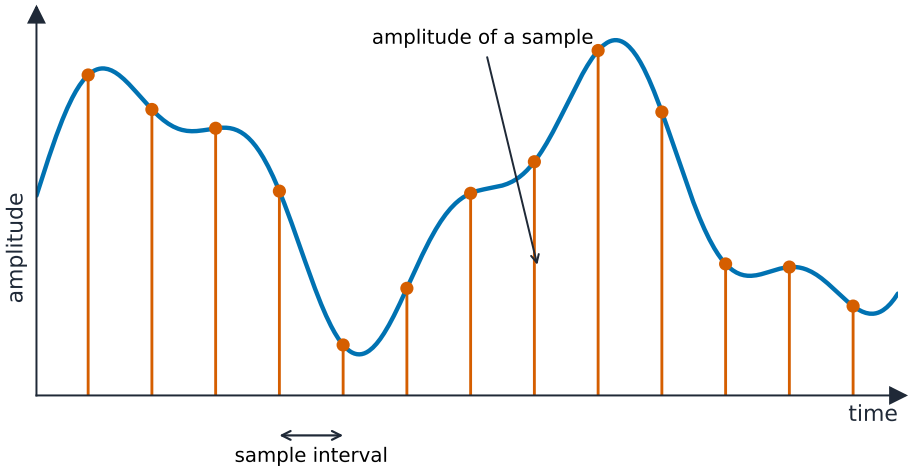
$$S = nb = 4 \times 7 \text{ bits} = 28 \text{ bits}$$

$$S = nb = 4 \times 16 \text{ bits} = 64 \text{ bits}$$

Model B uses more **storage** 存储 for this example because its stated code width is larger. Use the width given in an exam question. In real files, the encoding also matters: UTF-8 stores ASCII characters in the same bytes as an ASCII file, so Unicode text does not always occupy more bytes. You do not need the detailed UTF-8 rules for this syllabus comparison.

Representing sound

A **sound wave** 声波 is smooth and always changing. To store it, the computer measures the height of the wave at regular moments. This is called **sampling** 采样, and each measurement is a sample.



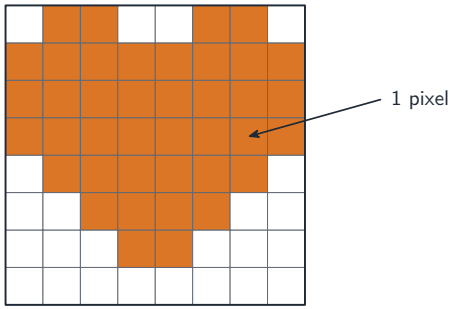
Sampling records the wave's height (amplitude) at regular moments

- **sample rate** 采样率 is the number of samples taken each second (measured in Hz).
- **sample resolution** 采样分辨率 is the number of bits used for each sample. The height of the wave at a sample point is its **amplitude** 振幅.

A higher sample rate and a higher sample resolution give a more accurate recording, but a larger file.

Representing images

A computer image is made of a grid of small dots called **pixels** 像素.



A bitmap is a grid of pixels; the resolution is how many pixels it has

- **resolution** 分辨率 is the number of pixels in the image (for example 1920×1080).
- **colour depth** 颜色深度 is the number of bits used to store the colour of each pixel.

A higher resolution and a higher colour depth give a better-quality image, but a larger file.

The colour depth decides how many different colours each pixel can be: with n bits there are 2^n colours. A colour depth of 1 bit gives 2 colours (black and white), 8 bits give $2^8 = 256$ colours, and 24 bits give over 16 million.

> **Worked example.** An image uses 64 different colours. What is the smallest colour depth it can have? Find the smallest n with $2^n \geqslant 64$: $2^6 = 64$, so **6 bits** per pixel. If it used 65 colours it would need 7 bits, because 6 bits can only make 64 different patterns.

Measuring data storage

Data storage is measured in the units below. A nibble is 4 bits and a byte is 8 bits; from the kibibyte upward, each unit is 1024 times the one before it (because $1024 = 2^{10}$, which fits binary).

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Unit	Equals
bit	a single 0 or 1
nibble	4 bits
byte	8 bits
kibibyte (KiB)	1024 bytes
mebibyte (MiB)	1024 KiB
gibibyte (GiB)	1024 MiB
tebibyte (TiB)	1024 GiB
pebibyte (PiB)	1024 TiB
exbibyte (EiB)	1024 PiB



Hard-disk platters: storage is measured in bytes – knowing file size needs width × height × colour depth for images

Calculating file size

Image file size (in bits) = resolution × colour depth = width × height × colour depth.

Example: an image is 1024×1024 pixels with a colour depth of 2 bytes (= 16 bits).

- bits = $1024 \times 1024 \times 16 = 16\,777\,216$ bits
- bytes = $\div 8 = 2\,097\,152$ bytes
- KiB = $\div 1024 = 2048$ KiB
- MiB = $\div 1024 = 2$ MiB



1024 × 1024 pixels × 16 bits; divide by 1024, not 1000, after the bytes

Bits to bytes is divide by 8; every step after that is divide by 1024

Sound file size (in bits) = sample rate × sample resolution × length in seconds.

These formulas count uncompressed data without file headers. The sound formula is for one channel; multiply by the channel count if a question specifies more channels.

Always divide by 1024 (not 1000) to change to KiB, MiB and so on. Give your answer in the unit the question asks for.

> **Worked example.** A sound is recorded for 30 seconds at a sample rate of 8,000 Hz with a sample resolution of 16 bits. Find the file size in kibibytes (KiB).

- bits = 8 000 × 16 × 30 = 3 840 000 bits
- bytes = 3 840 000 ÷ 8 = 480 000 bytes
- KiB = 480 000 ÷ 1024 ≈ 469 KiB

Compression

Compression 压缩 makes a file smaller. A smaller file:

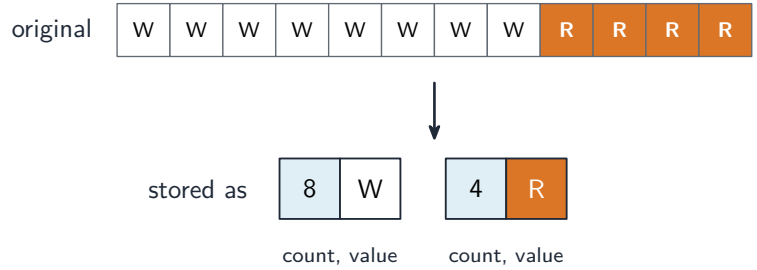
- uses less storage space,
- needs less **bandwidth** 带宽 (the amount of data a connection can carry),
- takes a shorter time to send (a shorter **transmission** 传输 time).

There are two types.

Lossless compression

Lossless 无损 compression makes the file smaller with **no permanent loss** of data. The original file can be rebuilt exactly.

One method is **run-length encoding** 行程编码 (RLE). It replaces a run of repeated values with one copy of the value and a count of how many times it repeats. For example `WWWWWWWW` (8 whites) is stored as "8 W". This works well when data has many repeats.



Run-length encoding stores each run once as a count and a value

> **Worked example.** One row of a black-and-white image is `B B B B B W W B B B B B B B B` (16 pixels). Compress it with RLE, and say whether it saved space if each count and each colour is stored in one byte.

The runs are 5 black, 2 white, 9 black, so the RLE data is `5 B 2 W 9 B`: 6 bytes instead of 16 bytes for the original (one byte per pixel). It saves space because the row has long runs. A row that changes colour at every pixel, `B W B W …`, would become `1 B 1 W 1 B 1 W …`, **twice** as large as the original: RLE only helps when data repeats.

Lossy compression

Lossy 有损 compression makes the file much smaller by **permanently removing** some data. The removed data cannot be got back. For example:

- reducing the resolution or colour depth of an image,
- reducing the sample rate or sample resolution of a sound.

Use lossless when you must keep every detail (text and program files). Use lossy for photos, music and video, where a small loss of quality is worth a much smaller file.

Exam tips

- Convert denary → binary by subtracting the place values (128, 64, 32 …); binary → denary by adding the place values that hold a 1.
- To convert to hex, group the binary into **nibbles** of 4 bits from the right; each nibble is exactly one hex digit.
- **Overflow** happens when a result is outside the chosen representation's range. Eight-bit unsigned integers hold 0–255; eight-bit two's complement holds −128–127.
- File size in bits: for an image, width × height × colour depth; for sound, sample rate × resolution × seconds. Divide by 8 for bytes, then by 1024 for each larger unit.

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- **Lossless** compression keeps every bit (text; run-length encoding); **lossy** permanently removes data (photos, music) for a much smaller file.

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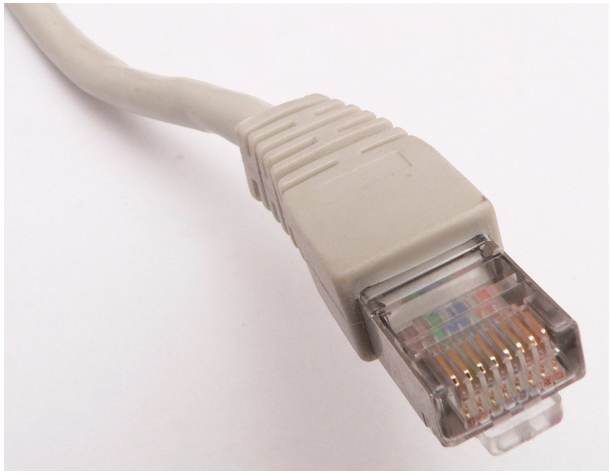
Data transmission

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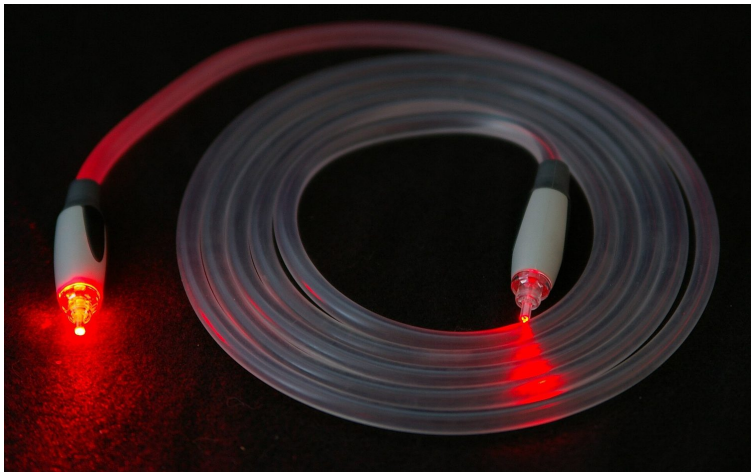
What is data transmission?

Data transmission 数据传输 means moving data from one place to another – for example from your computer to a website, or from a phone to a printer.

Data often travels along a cable. Two common ones are shown below.



An Ethernet cable with an RJ45 plug, often used to carry data on a wired network



A fibre-optic cable carries data as pulses of light along thin glass fibres

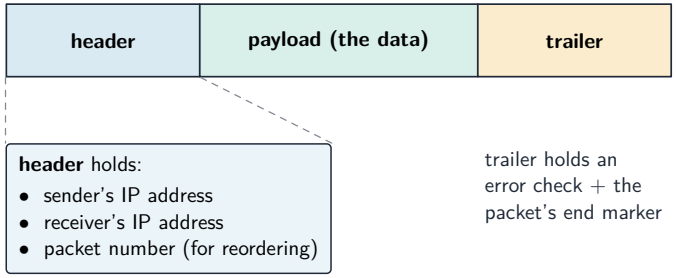
Before it is sent, the data is broken down into small, equal-sized pieces called **packets** 数据包. Each packet travels separately and they are put back together at the other end.

Using packets has benefits:

- if one packet is lost or damaged, only that packet is sent again, not the whole file;
- packets can take different routes, so a busy or broken route can be avoided;
- many users can share the same connection at the same time.

The structure of a packet

Every packet has three parts.



A packet has a header, a payload (the data) and a trailer; the header carries the addresses and packet number

Part	What it holds
packet header 包头	control information (see below)
payload 有效载荷	the actual data being carried
trailer 尾部	shows where the packet ends, plus an error check

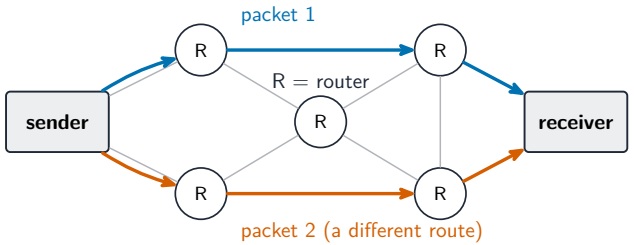
The **packet header** holds:

- the sender's IP address 地址 (where the packet came from),
- the receiver's IP address (where it is going),
- the **packet number** (so the packets can be put back in the right order).

Packet switching

Packet switching 数据包交换 is the way packets are sent across a network.

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Routers forward packets, and different packets can take different routes to the same receiver

- Special devices called **routers** 路由器 read each packet's header and choose the best route for it.
- Each packet may take its **own path**, so packets can travel different ways.
- Packets may **arrive out of order**.
- When the last packet has arrived, the packets are **reordered** using their packet numbers.

Methods of data transmission

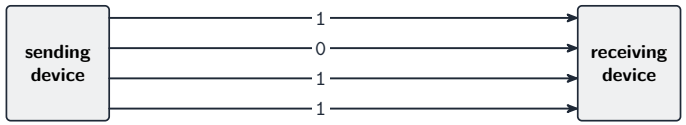
Serial and parallel

	Serial 串行	**Parallel 并行**
How	one bit at a time, down one wire	several bits at once, down several wires
Distance	good over long distances	good over short distances only
Cost	cheaper (fewer wires)	more expensive (more wires)
Errors	bits stay in order	bits can arrive at slightly different times over long wires

Serial sends one bit after another along a data path. **Parallel** sends several bits at the same time along separate data paths. With otherwise comparable timing, this can transfer more bits per clock cycle, but parallel transmission is not always faster than a modern serial link.



serial: one bit at a time, one wire

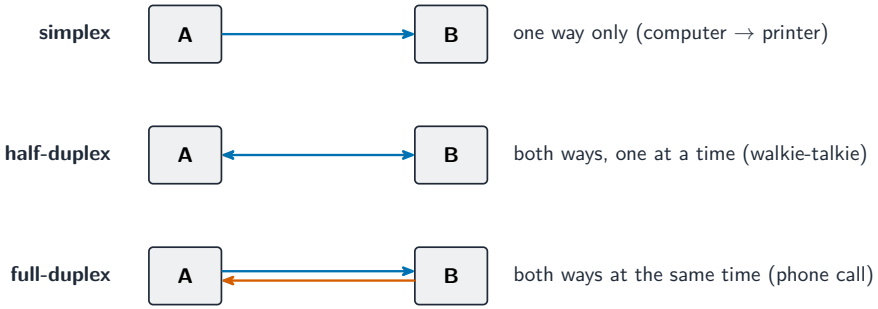


parallel: several bits at once, several wires

Serial sends one bit at a time down one wire; parallel sends several bits at once down several wires

Simplex, half-duplex and full-duplex

These describe the *direction* data can travel.



Simplex is one way only; half-duplex is both ways but one at a time; full-duplex is both ways at once

Method	Direction
simplex 单工	one direction only (e.g. computer → printer)
half-duplex 半双工	both directions, but only one at a time (e.g. walkie-talkie)
full-duplex 全双工	both directions at the same time (e.g. phone call)

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Choosing a method

The choice depends on the **distance**, the **speed** needed, the **cost**, and whether data must travel both ways at once.

> **Worked example.** A school connects (a) a computer to a printer in the same room, which only receives documents, and (b) two offices 200 m apart, which send files to each other all day. Suggest a method for each and justify it.

(a) **Serial, simplex**: data only needs to go from the computer to the printer, and serial needs a single cheap cable. (Parallel would also work over this short distance, but simplex is the key point: the printer never sends data back.)

(b) **Serial, full-duplex**: over 200 m, the bits on parallel wires could arrive at different times and become **skewed**, so serial is more reliable and cheaper. Full-duplex lets both offices send at the same time without waiting.

Always link the choice to a feature of the situation: a one-word answer earns no marks.

USB

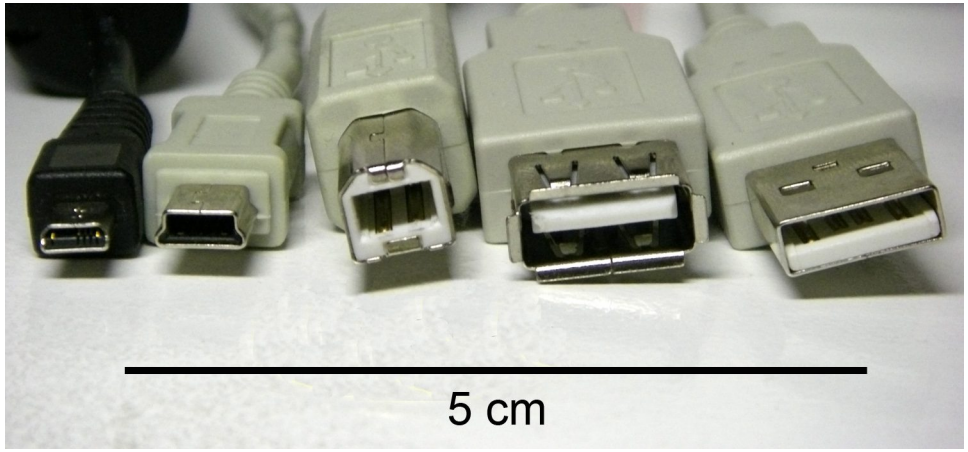
The **universal serial bus** 通用串行总线 (USB) is a common **interface** 接口 (a connection point) for joining devices to a computer.

Benefits:

- the same connector is used by many devices (one standard);
- the device is detected automatically and the correct driver is loaded;
- it carries power, so it can charge or run a device;
- the connector only fits one way, so it is hard to plug in wrongly.

Drawbacks:

- the cable can only be a limited length (a few metres);
- older USB versions are slower than newer ones;
- transfer speeds can be lower than some other connection types.



A few of the USB connector shapes. All use the same USB standard, so devices are detected automatically.

Why we check for errors

While data travels, **interference** 干扰 can change it. Three things can go wrong:

- **data loss** – some bits do not arrive;
- **data gain** – extra bits are added;
- **data change** – some bits are flipped.

So the receiver checks whether the data arrived correctly.

Error detection methods

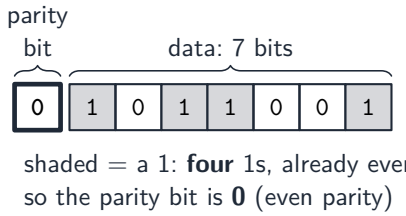
Parity check

A **parity check** 奇偶校验 adds one extra bit, the **parity bit** 奇偶校验位, to each byte. There are two types:

- **even parity** – the total number of 1s in the byte (including the parity bit) must be **even**;
- **odd parity** – the total number of 1s must be **odd**.

Example (even parity): the data `1011001` has four 1s, which is already even, so the parity bit is `0`:

```
parity bit + data
    0        1011001
```

A parity bit is added to make the number of 1s even (or odd)

To find an error: the receiver counts the 1s. If even parity was agreed but a byte arrives with an **odd** number of 1s, an error has happened during transmission.

A parity check cannot find every error. If two bits flip, the count may still look correct.

> **Worked example.** A single parity bit tells you *that* an error happened, but not *where*. A **parity block** 奇偶校验块 can find the exact bit. Several bytes are sent together, each with a row parity bit, and one extra **parity byte** 奇偶校验字节 at the bottom holds a parity bit for each column. Even parity is used below, and one bit was flipped during transmission. Find it.

```
          b1 b2 b3 b4 b5 | parity
byte 1     1  0  1  1  0 |   1
byte 2     0  1  1  0  1 |   1
byte 3     1  1  1  1  0 |   1    <- row: odd number of 1s
byte 4     0  0  1  1  0 |   0
------------------------------
parity     0  0  1  1  1 |   1
                ^ column b3: odd number of 1s
```

Row *byte 3* breaks even parity, and column *b3* breaks even parity. The flipped bit is where they cross: **byte 3, bit b3**. Changing it back from 1 to 0 repairs the data. With the stated single-bit-error assumption, the failed row and column locate the bit, so the receiver can correct it. Multiple-bit errors may escape detection or give an ambiguous result.

Checksum

A **checksum** 校验和 is a value worked out from all the data before sending. The receiver works out the checksum again from the data it received. If the two values do not match, an error has occurred and the data is resent.

The steps:

1. the sender calculates the checksum from the block of data, using an agreed algorithm;
2. the checksum is sent with the data;

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3. the receiver calculates the checksum again from the data it received, using the same algorithm;
4. it compares the two values: if they match, the data is accepted; if not, it asks for the data to be sent again.

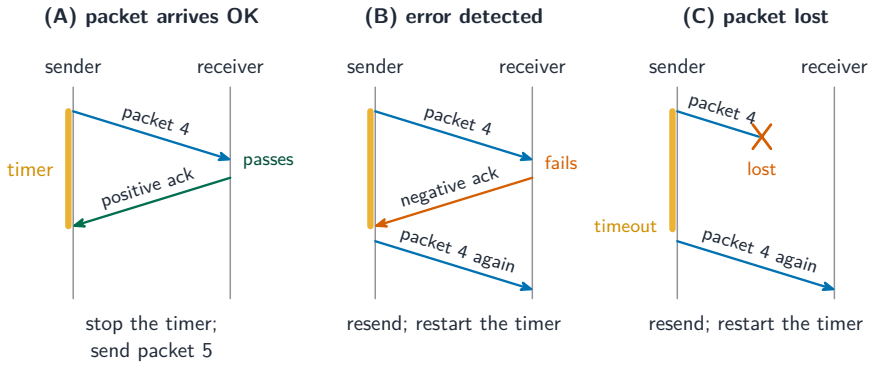
Echo check

In an **echo check** 回送校验, the receiver sends the data back to the sender. The sender compares it with the original. If they differ, an error happened. (This needs the data to be sent twice, so it is slow.)

Automatic Repeat reQuest (ARQ)

Automatic Repeat reQuest 自动重传请求 (ARQ) uses messages called **acknowledgements** 确认.

The syllabus calls this automatic repeat query; automatic repeat request is another name for the same method. The sender starts a **timeout** 超时 timer when it sends a packet. The receiver uses an error check on the received packet. If the check passes, it sends a **positive acknowledgement**. If an error is detected, it sends a **negative acknowledgement**.



ARQ: a positive acknowledgement moves on; a negative acknowledgement or a timeout makes the sender resend

Try it – packet 4. In three separate cases, packet 4 (A) passes the receiver's error check, (B) fails the check, or (C) never arrives. For each case, choose the receiver's response and the sender's next action.

Worked trace.

Case	Receiver	Sender
A	Sends a positive reply	Receives it; stops timer; can send next packet
B	Sends a negative reply	Receives it; resends packet 4; restarts timer
C	Has no packet to check	Timeout; resends packet 4; restarts timer

A negative reply can cause a repeat before the timer expires. If no positive acknowledgement arrives before timeout, the sender repeats the transmission. The timer handles silence, including a lost packet or a lost reply.

Transfer – a lost reply. Packet 4 arrives and passes its check. The receiver sends a positive acknowledgement, but this reply is lost. What does the sender do when its timer expires? Does timeout prove that packet 4 was damaged?

Answer. The sender resends packet 4 and restarts its timer. The receiver knows the packet arrived successfully, but the sender has no confirmation. Timeout does not tell the sender whether the packet or the reply was lost or delayed. ARQ requests another transmission; it does not itself repair damaged bits. It uses an error check to decide whether to accept a received packet.

Check digit

A **check digit** 校验码 is an extra digit placed at the end of a number, worked out from the other digits. It is used to find mistakes when a number is **typed in**.

When the number is entered, the check digit is calculated again and compared. Depending on the method, it can detect some of these errors; no check digit guarantees that every entry error is found:

- an **incorrect digit** entered,
- a **transposition error** 换位错误 (two digits swapped, e.g. 21 typed as 12),
- a digit **left out or an extra digit** added,
- a **phonetic error** (a digit that sounds similar, e.g. 13 and 30).

Check digits are used in **barcodes** 条形码 and ISBNs (book numbers).

> **Worked example (ISBN-13).** The first 12 digits of a book number are `978034083988`. Calculate the check digit. The ISBN-13 method multiplies the digits by **1, 3, 1, 3, ...** in turn, adds the results, and chooses the check digit that makes the total a multiple of 10.

Digit	9	7	8	0	3	4	0	8	3	9	8	8
Weight	1	3	1	3	1	3	1	3	1	3	1	3
Product	9	21	8	0	3	12	0	24	3	27	8	24

The total is 139. Divide by 10: the remainder is 9, and $10 - 9 = 1$, so the check digit is **1** (if the remainder is 0, the check digit is 0). The full number is `9780340839881`.

Now suppose the 9th and 10th digits are swapped when typed in: `...8 9 3 8 8...`. The products of those two digits become $9 \times 1 + 3 \times 3 = 18$ instead of $3 + 27 = 30$, so

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the total of the first 12 digits is 127, and $127 + 1 = 128$ is **not** a multiple of 10: the transposition error is detected.

Encryption

Why we need encryption

Encryption 加密 scrambles data so that it cannot be understood if it is **intercepted** 拦截 (caught) by the wrong person. The readable data is called **plaintext** 明文; after encryption it becomes **ciphertext** 密文.

Encryption does **not** stop data from being intercepted. It only stops the data from being understood.

Symmetric encryption

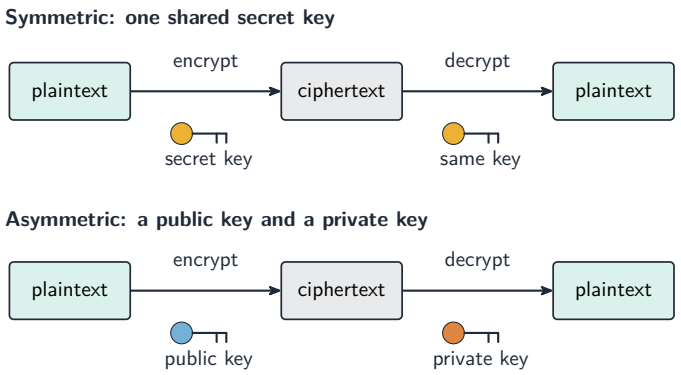
Symmetric encryption 对称加密 uses a single **key** 密钥 to both encrypt and decrypt the data. The sender and receiver must share this same secret key. The risk is that the key itself could be stolen while being shared.

Asymmetric encryption

Asymmetric encryption 非对称加密 uses two different keys:

- a **public key** 公钥 that anyone can have, used to encrypt;
- a **private key** 私钥 that is kept secret, used to decrypt.

Data encrypted with the public key can only be decrypted with the matching private key, so the private key never has to be shared. This is safer than sharing one secret key.



Symmetric uses one shared key; asymmetric uses a public key to encrypt and a private key to decrypt

Exam tips

- Data is sent in **packets** (a header with the addresses and packet number, a payload, and a trailer). Packets can take different routes and arrive out of order, then are reordered by their packet numbers.
- Match the transmission types: **serial** (one bit at a time, good over long distances) vs **parallel** (several bits at once, short distances); **simplex / half-duplex / full-duplex** describe the direction.
- A **parity bit** detects an odd number of flipped bits. A **parity block** locates the wrong bit when exactly one bit has flipped – the failed row and column cross there.
- Learn the error-detection methods and what each does: parity check, checksum, echo check, ARQ, and the check digit (for typed-in numbers).
- **Symmetric** encryption uses one shared key; **asymmetric** uses a public key to encrypt and a private key to decrypt, so no secret key is ever shared.

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Hardware

IGCSE Computer Science

The central processing unit (CPU)

The **central processing unit** 中央处理器 (CPU) is the part of the computer that processes data and carries out **instructions** 指令. It runs programs by repeating a cycle, billions of times each second. Its role is simple to state: the CPU **processes** the instructions and data that are input into the computer, so that the result can be output.

A **microprocessor** 微处理器 is a type of **integrated circuit** 集成电路 on a single chip. A CPU is usually built as a microprocessor; the small computers inside washing machines and cars are microprocessors too.

Most computers follow the **Von Neumann architecture** 冯 · 诺依曼体系结构: the program's instructions **and** its data are stored together in the same main memory (RAM), and the CPU fetches them one at a time, along the same buses, to process them.



A central processing unit (CPU): the chip that processes data and runs the instructions

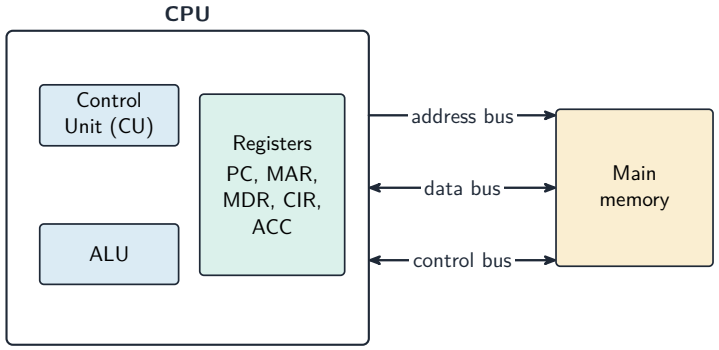
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Parts of the CPU

Part	What it does
arithmetic logic unit 算术逻辑单元 (ALU)	does calculations (add, subtract) and logical operations (compare)
control unit 控制单元 (CU)	sends control signals to manage all the parts and tell them what to do
registers 寄存器	very small, very fast stores that hold one piece of data at a time

The parts are joined by **buses** 总线 – sets of wires that carry information:

- the **address bus** 地址总线 carries memory addresses (one direction);
- the **data bus** 数据总线 carries data and instructions (both directions);
- the **control bus** 控制总线 carries control signals.



The CPU holds the control unit, the ALU and the registers; three buses link it to main memory

Special registers

These registers are used during the fetch–execute cycle.

Register	Purpose
program counter 程序计数器 (PC)	holds the address of the next instruction
memory address register 内存地址寄存器 (MAR)	holds the address to read from or write to
memory data register 内存数据寄存器 (MDR)	holds the data or instruction just fetched
current instruction register 当前指令寄存器 (CIR)	holds the instruction now being carried out
accumulator 累加器 (ACC)	holds the result of the ALU's calculations

The fetch–execute cycle

The **fetch–execute cycle** 取指执行周期 has three stages, repeated again and again:

1. **Fetch** – the instruction is copied from memory 内存 into the CPU (using the PC, MAR and MDR). The PC then increases by 1.
2. **Decode** – the control unit works out what the instruction means.
3. **Execute** – the instruction is carried out (the ALU may do a calculation, with the result going to the accumulator).

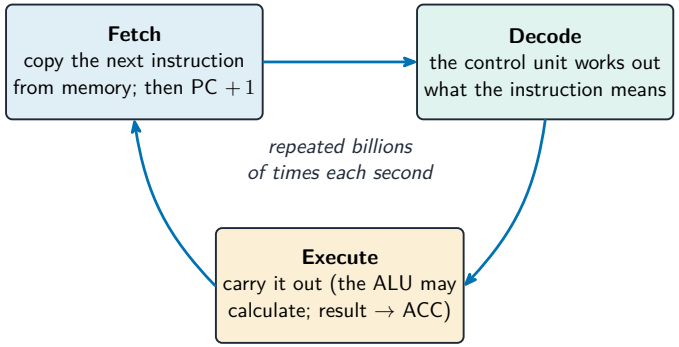
Exam questions often ask for the fetch stage **register by register**. Learn this order:

1. The address in the **PC** is copied to the **MAR**.
2. The address is sent along the **address bus** to RAM, and a read signal is sent along the **control bus**.
3. The instruction at that address is sent along the **data bus** to the **MDR**.
4. The instruction is copied from the MDR to the **CIR**.
5. The **PC** is incremented (increased by 1), so it points to the next instruction.

Then the **CU** decodes the instruction in the CIR, and it is executed: the CU sends signals, and the ALU does any calculation or comparison, storing the result in the **ACC**.

> **Worked example (4 marks).** *Describe the role of the MAR and the MDR in the fetch stage.* A full answer: "The MAR holds the address of the instruction to be fetched, copied from the PC (1). This address is sent along the address bus to RAM (1). The instruction stored at that address is sent along the data bus and stored in the MDR (1). The MDR then passes the instruction to the CIR (1)." Each mark is one register **and** what it holds or does.

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The processor repeats three stages: fetch the instruction, decode it, then execute it

Cache memory

Cache 高速缓存 is a small amount of very fast memory inside or close to the CPU. It stores data and instructions that the CPU uses often. The CPU can read from cache much faster than from main memory, so the computer runs faster.

What affects CPU performance

Feature	Effect
number of **cores** 核心	each core can run instructions on its own, so more cores can do more work at the same time
cache size	a larger cache holds more data ready for the CPU, so it waits less
clock speed 时钟速度	the number of cycles per second; a higher clock speed runs more instructions per second

> **Worked example.** Two computers are identical except that A has a 3.0 GHz single-core CPU with 2 MB of cache, and B has a 2.4 GHz quad-core CPU with 8 MB of cache. Which is better for video editing, and why? Video editing splits into many tasks that can run at the same time, so B's **four cores** can process several streams in parallel while A can only work on one at a time. B's larger **cache** also keeps more frequently used data close to the CPU, so it has to fetch from RAM less often. B is the better choice, even though A has the higher clock speed. Never answer on clock speed alone: weigh **cores, cache and clock speed** together, and tie each one to the job being done.

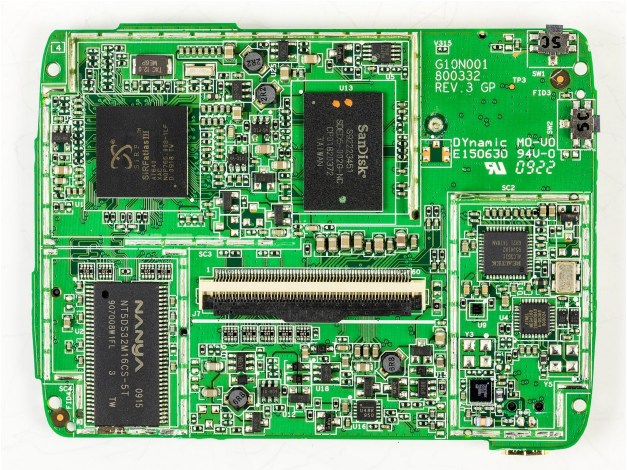
Instruction sets

An **instruction set** 指令集 is the list of all the commands a CPU can process. The commands are **machine code** 机器码 (binary). Each CPU family has its own instruction set, so a program in machine code for one type of CPU will not run on a different type.

Embedded systems

An **embedded system** 嵌入式系统 is a small computer built inside a larger device to do one fixed job. It is dedicated to that task, is usually small and low-cost, and has no general operating system. Examples: a washing machine, a microwave, a set-top box, a car's engine management, a security system, a lighting system and a vending machine.

This is different from a **general purpose computer** 通用计算机, such as a PC or a laptop, which can run many different programs to do many different jobs. To decide whether a device is embedded, ask: *does it do one dedicated function?*



The mainboard from inside a satnav: an embedded system is a small dedicated computer like this, built into a device to do one fixed job

Input devices

An input device sends data *into* the computer.

Device	How it works
barcode scanner 条形码扫描器	shines light at the bars and reads the pattern reflected back
QR code scanner 二维码扫描器	a camera reads a square pattern of black-and-white blocks
keyboard	pressing a key sends a code for that character
optical mouse 光电鼠标	a light and a sensor track movement across a surface
microphone	turns sound waves into an electrical signal
digital camera	a lens focuses light onto a sensor that records pixels
sensors 传感器	measure a physical quantity (such as temperature or light) and send it as data
touch screen 触摸屏	detects where your finger touches the screen
2D scanner 二维扫描仪	shines light across a flat document and records the reflected light as an image
3D scanner 三维扫描仪	uses lasers or light to measure the shape of a solid object from many angles, building a 3D model



A keyboard: each key press sends a code for that character

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An optical mouse: a light and a sensor track its movement on the desk



A flatbed scanner: it shines light across a page to copy it into the computer



A barcode scanner reads the pattern of bars and sends it to the computer

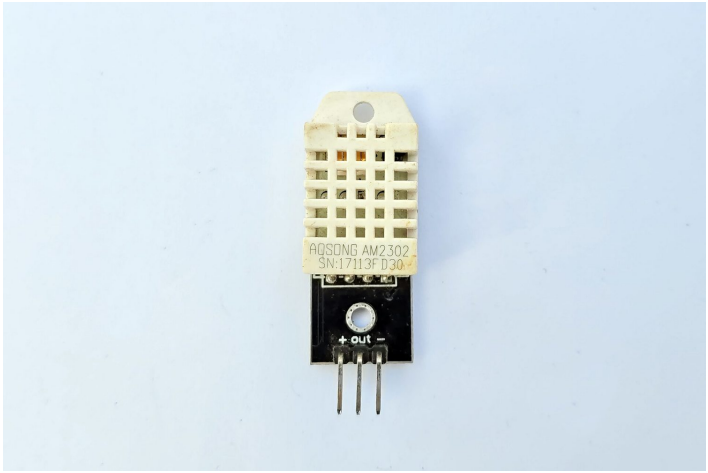


A digital camera: a lens focuses light onto a sensor that records the pixels

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A microphone turns sound waves into an electrical signal



A sensor measures a physical quantity (here, temperature) and sends it as data

A touch screen can work in three ways:

- **resistive** 电阻式 – two layers are pressed together where you touch;
- **capacitive** 电容式 – it senses the tiny electric charge of your finger;
- **infrared** 红外线 – your finger breaks a grid of light beams.

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A touch screen senses where your finger touches it

Sensors

A **sensor** is an input device that captures data from its surroundings. It measures one physical quantity and sends it to the computer, so that a system can **monitor** or **control** something without a person taking readings. Learn the data each one captures:

Sensor	Data it captures	When it is used
acoustic 声学	sound level	a noise alarm; a sound-activated light
accelerometer 加速度计	acceleration, movement and tilt	turning a phone screen; an airbag; a fitness tracker
flow 流量	how fast a liquid or gas moves through a pipe	water pipes; fuel pumps; a factory line
gas 气体	the amount of a gas (such as carbon monoxide or smoke)	a gas or smoke alarm; car exhaust tests
humidity 湿度	the amount of water vapour in the **air**	a greenhouse; a museum; a weather station
infra-red	infra-red radiation (body heat, or a broken beam)	an intruder alarm; a TV remote; an automatic tap
level 液位	how high a liquid is in a container	a water tank; a fuel tank; a drinking bowl

Sensor	Data it captures	When it is used
light 光	brightness	street lights that switch on at dusk; a screen's auto-brightness
magnetic field 磁场	the strength of a magnetic field	a door or window alarm; a phone's compass
moisture 水分	the amount of water in a **solid**, such as soil	watering plants in a field or greenhouse
pH	how acidic or alkaline a liquid is	a fish tank; a swimming pool; soil testing
pressure 压力	force pressing on it	a weighing scale; a floor mat by a door; tyre pressure
proximity 接近	how close an object is	car parking sensors; a robot vacuum; a drone avoiding a tree
temperature 温度	how hot or cold something is	air conditioning; an oven; a greenhouse

Two pairs are easy to mix up: **humidity** is water in the air, **moisture** is water in a solid such as soil; **level** measures how high a liquid is, **flow** measures how fast it moves.

> **Worked example (choosing a sensor).** *A farm's water bowl must refill when it is empty. Identify the most suitable sensor.* The system needs to know how high the water is, so the answer is a **level sensor**. A pressure sensor under the bowl could also work, but "level" fits the job best. Always match the sensor to the **quantity** the system needs to know.

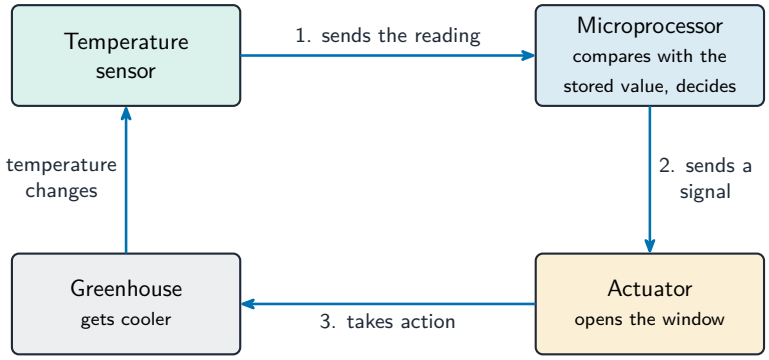
A sensor on its own only measures. In a control system, a **microprocessor** makes the decision and an **actuator** (an output device) acts. The loop repeats all the time. (Handout 6 covers automated systems in full.)

> **Worked example (6 marks).** *A train door must only close when no passenger is in the doorway. Explain how a sensor and a microprocessor are used.* A strong answer, one mark per point:

1. A **proximity** (or infra-red) sensor is placed by the door.
2. The sensor continually sends readings to the microprocessor; an analogue reading is converted to digital first.

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3. The microprocessor **compares** the reading with a **stored value** (for example, an object within 20 cm).
4. If the reading shows a person in the doorway, the door stays open (a warning may sound).
5. If the reading shows the doorway is clear, the microprocessor sends a signal to the **actuator** to close the door.
6. The process **repeats** continuously until the door has closed.



The same loop drives every control question: sensor reading, compare with a stored value, signal the actuator, repeat

Output devices

An output device sends data *out* of the computer to the user.

Device	How it works
actuator 执行器	turns an electrical signal into movement (e.g. a motor or valve)
LCD screen 液晶显示屏	liquid crystals in each pixel twist to let light through or block it; a backlight (usually LEDs) shines through them
LED screen	each pixel is made of tiny light-emitting diodes that give out their own light
DLP projector 数字光处理投影仪	a **projector** 投影仪 shines an enlarged image onto a screen; in a DLP one, millions of tiny mirrors on a chip tilt towards or away from the light to make each pixel bright or dark

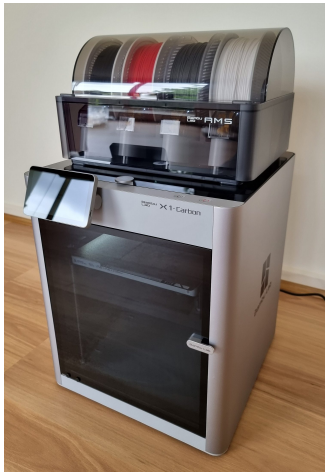
Device	How it works
LCD projector 液晶投影仪	a bright light shines through a liquid crystal panel, and a lens enlarges the image onto a screen
inkjet printer 喷墨打印机	sprays tiny drops of ink onto paper
laser printer 激光打印机	uses a laser and powder (toner) fixed onto paper by heat
3D printer	builds a solid object layer by layer
speaker 扬声器	turns an electrical signal into sound



An inkjet printer sprays tiny drops of ink onto the paper



A laser printer uses a laser and powder (toner) fixed onto paper by heat



A 3D printer builds a solid object layer by layer

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An LCD/LED monitor shows images using a grid of tiny coloured dots



A speaker turns an electrical signal into sound



Headphones turn an electrical signal into sound for one listener



An actuator such as a motor turns an electrical signal into movement

■ Describing how an output device works

A question such as "Describe how a laser printer works" is marked one point per correct step, in order, so learn each device as a short sequence.

Inkjet printer.

1. The printer **driver** turns the document into data the printer can use. The data is stored in the printer's **buffer** 缓冲区 (a small memory), so the computer can carry on with other work.

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2. The **print head** moves across the paper. Its tiny **nozzles** 喷嘴 spray drops of ink where the image needs them. A drop is pushed out either by heating the ink, which makes a bubble (**thermal bubble**), or by a crystal that changes shape when a current flows (**piezoelectric**).
3. A motor moves the paper up a little, and the head prints the next line, until the page is finished.

Laser printer.

1. The data is sent through the driver and stored in the printer's buffer.
2. A rotating **drum** 硒鼓 is given an electric charge. A laser beam scans across the drum and changes the charge wherever the page should be printed, leaving a pattern of the page on the drum.
3. The drum is coated with **toner** 墨粉 (a fine powder), which sticks only to the charged pattern.
4. Charged paper rolls past the drum, and the toner moves onto the paper.
5. The paper passes through a **fuser** 定影器 (hot rollers), which melts the toner so it is fixed to the paper.
6. A lamp removes the charge from the drum, ready for the next page.

3D printer. The object is designed with computer-aided design software, and the software splits it into thin horizontal **layers** 层. The printer then builds the object one layer at a time, for example by squeezing out melted plastic through a heated nozzle, and each layer hardens onto the one below.

Speaker. The digital sound data is changed to an analogue signal by a **digital-to-analogue converter** 数模转换器 (DAC) and amplified. The changing current flows through a coil next to a magnet, so the coil and the cone fixed to it move in and out, and the vibrating cone makes the sound waves.

Common mistake. Describing a laser printer as "a laser burns the image onto the paper". The laser never touches the paper: it only changes the charge on the drum, and the image is made of toner melted on by the fuser.

Primary storage: RAM and ROM

Primary storage 主存储器 is memory the CPU can use directly. There are two kinds.

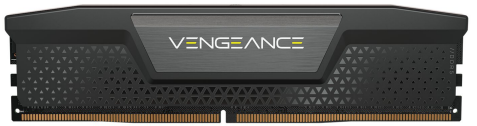
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RAM	ROM
volatile	non-volatile
can change	cannot change
running programs	startup (BIOS)

RAM is volatile and holds running programs; ROM is non-volatile and read-only

	RAM	**ROM**
Full name	**random access memory** 随机存取存储器	**read only memory** 只读存储器
Read/write	read and write	read only
Keeps data without power?	no – it is **volatile** 易失性	yes – it is **non-volatile** 非易失性
Holds	programs and data in use now	start-up instructions (how to boot the computer)

Both are needed: ROM tells the computer how to start, then RAM holds the programs you run.



A stick of RAM (random access memory): it holds the programs and data in use now

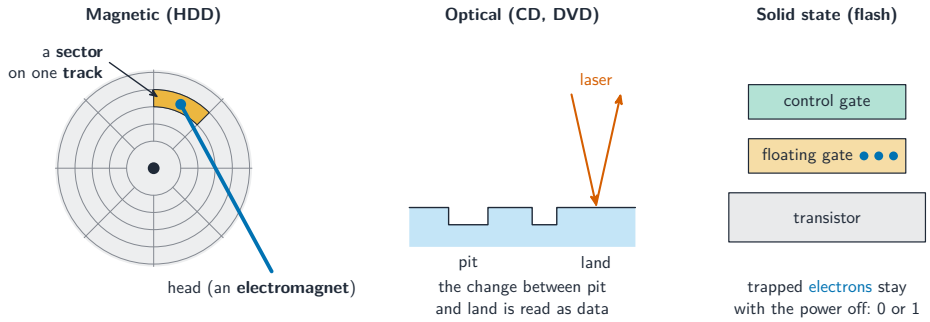
Secondary storage

Secondary storage 辅助存储器 keeps data permanently, even when the power is off. It is non-volatile and is used for long-term storage. There are three types.

Type	How it stores data	Examples
magnetic storage 磁存储	data is stored as magnetised spots on spinning disks	hard disk drive (HDD), magnetic tape
optical storage 光存储	data is stored as marks read by a laser	CD, DVD, Blu-ray
solid state storage 固态存储	data is stored in **flash memory** 闪存, with no moving parts	SSD, USB flash drive, SD card

How each one works. Questions ask you to *describe the operation* of each type:

- **Magnetic** – a hard disk has one or more **platters** 盘片 that spin. Each platter is divided into **tracks** 磁道 (rings) and **sectors** 扇区 (parts of a track). A read/write head, an **electromagnet** 电磁铁, moves across the platter: it magnetises tiny areas to write data and detects them to read it. Because it has moving parts, it is slower to access than solid state and can break if dropped.
- **Optical** – a laser burns **pits** 凹坑 into the disc surface; the flat areas between them are **lands** 平面. To read, a laser shines on the spinning disc: lands reflect light back, pits scatter it, and the changes are read as binary. CD, DVD and Blu-ray work like this; Blu-ray uses a blue laser with a shorter wavelength, so its pits are smaller and it holds more data.
- **Solid state (flash memory)** – data is stored in a grid of **transistors** 晶体管, using NAND or NOR technology. Each transistor has a **control gate** 控制栅 and a **floating gate** 浮栅. Electrons trapped on the floating gate store a 0 or a 1, and they stay there with the power off. There are no moving parts, so it is fast, quiet and robust.



Magnetic disks store data in sectors on tracks, optical discs as pits and lands, flash memory as electrons trapped on a floating gate



Inside a hard disk drive (HDD): the shiny disk spins and the arm reads the magnetised data

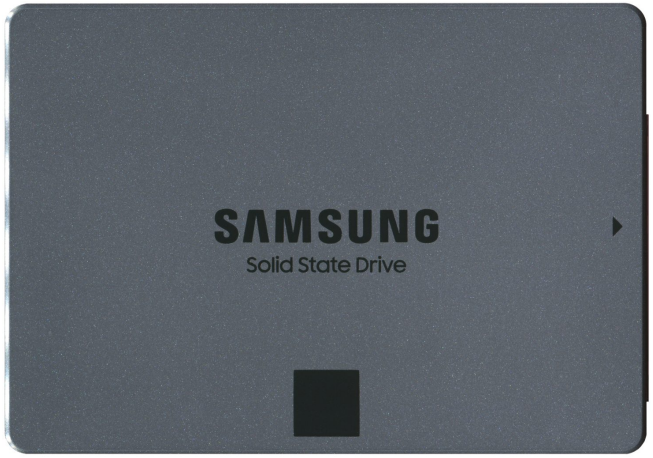


Magnetic tape stores data on a long magnetic strip; it is cheap for large backups

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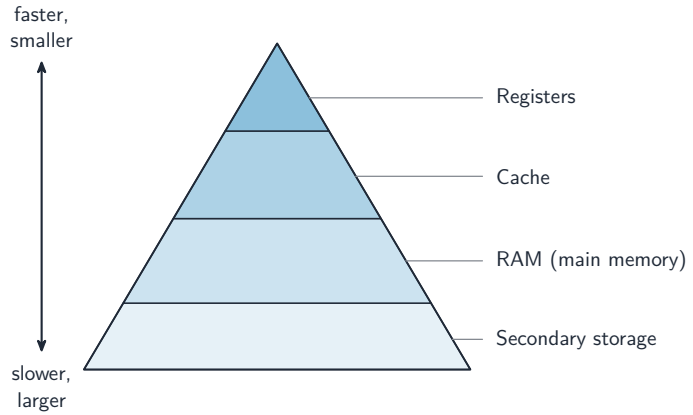
An optical disc such as a CD or DVD: a laser reads the marks on its shiny surface



A solid state drive (SSD) stores data in flash memory chips and has no moving parts



A USB flash drive stores data in flash memory and has no moving parts



Storage forms a hierarchy: registers and cache are fastest but smallest; secondary storage is slowest but largest

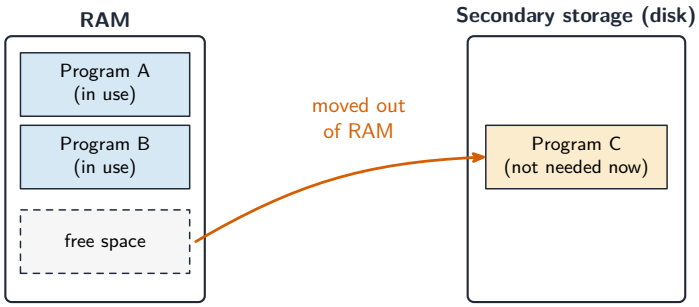
Virtual memory

When the RAM becomes full, the computer can use part of the secondary storage as extra, pretend RAM. This is called **virtual memory** 虚拟内存.

Virtual memory is created as an area of the secondary storage. Data is moved in blocks called **pages** 页: a page that is not needed right now is moved out of RAM into virtual memory, which frees space in RAM for other programs. When that page is needed again, it is moved back into RAM. This lets you run more programs than the

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RAM alone could hold. It is slower, because secondary storage is much slower than RAM.



This frees RAM, so more programs can run than RAM alone could hold — but it is slower, because the disk is much slower than RAM.

When RAM is full, data not in use is moved to the disk to free RAM – slower, but it lets more programs run

Cloud storage

Cloud storage 云存储 keeps your data on remote physical servers, reached over the internet, instead of on your own device.

- **Advantages**: reach it from anywhere on any device; no local storage hardware to buy or maintain; easy to share files and to back up automatically.
- **Disadvantages**: needs a working internet connection; an ongoing subscription cost; security and privacy depend on the provider; you rely on that provider staying available and in business.

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Data-centre server racks: cloud storage keeps your files on remote servers you reach over the network

Network hardware

Network interface card (NIC)

A **network interface card** 网络接口卡 (NIC) is the hardware that lets a device join a network and send and receive data. Each NIC has a built-in MAC address.

MAC address and IP address

- A **MAC address** (media access control 介质访问控制 address) is a number that identifies one physical device. The maker sets it, and it does not normally change. It is written in hexadecimal.
- An **IP address** (internet protocol 网际协议 address) is a number that identifies a device on a network. It is given by the network and can change.

So a MAC address stays with the device, while an IP address depends on the network the device is using.

There are two versions of IP address. **IPv4** is 32-bit, written as four denary numbers 0–255 (for example `192.168.0.1`); the newer **IPv6** is 128-bit, written as eight groups of hexadecimal separated by colons, giving vastly more addresses. An address is also either **static** 静态 (fixed, set by hand and never changing) or **dynamic** 动态 (handed out by the router/network each time the device connects, so it can change).

Router

A **router** 路由器 connects different networks together – for example, your home network to the internet. It reads the IP address in each packet and forwards it towards the right network.



A Wi-Fi router: network hardware forwards packets between devices and the wider Internet

Exam tips

- Learn the **fetch–decode–execute** cycle and the special registers: the **program counter** holds the address of the *next* instruction, the MAR/MDR carry the address/data, and the **accumulator** holds the ALU's result.
- CPU performance improves with more **cores**, a larger **cache**, and a higher **clock speed**.
- **RAM** is volatile (it loses its data with no power) and holds programs in use; **ROM** is non-volatile and read-only (the start-up instructions).
- For a "describe how the sensor and the microprocessor are used" question, write the loop: sensor sends reading → microprocessor **compares with a stored value** → signal to the **actuator** → **repeats**. Name the sensor that measures the right quantity (level, not flow, for a tank that empties).
- Say *Von Neumann*: instructions and data share the same memory. A microprocessor is an integrated circuit on a single chip.
- Match the secondary-storage types: **magnetic** (HDD, tape), **optical** (CD/DVD, read by a laser), **solid state** (SSD, USB, flash – no moving parts).
- A **MAC address** identifies the physical device and does not normally change; an **IP address** is given by the network and can change.

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Software

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Hardware and software

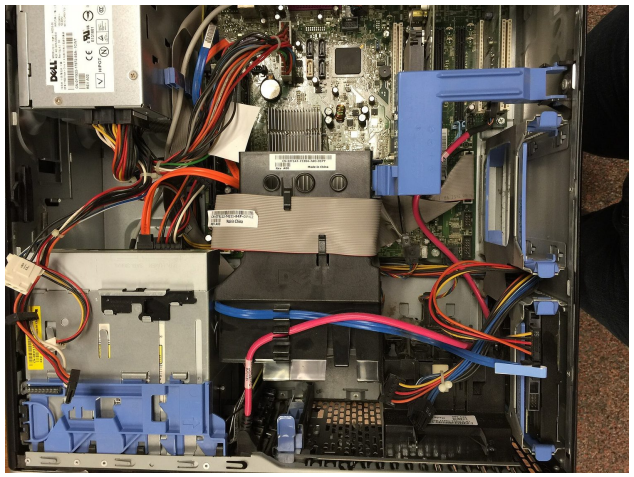
A computer system is made of two parts that work together.

hardware (physical parts)	software (programs)
CPU, keyboard, RAM	apps, the OS

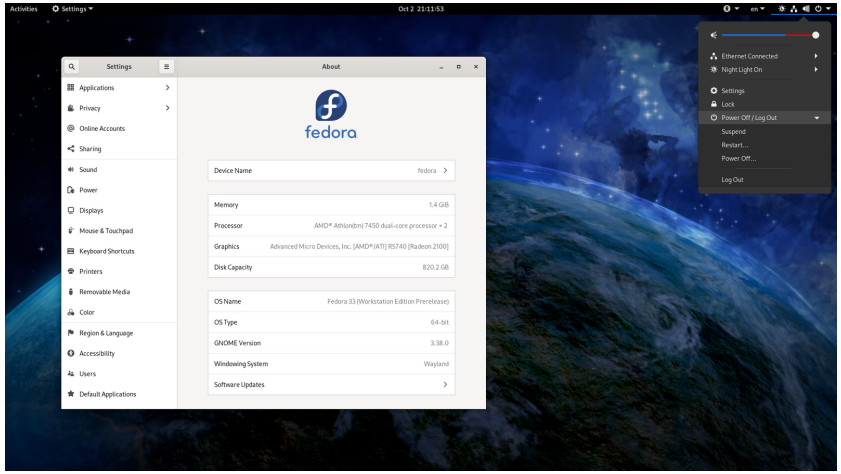
Hardware is the physical parts; software is the programs

- **Hardware** 硬件 is the **physical** 物理的 parts of the computer – the parts you can touch. Examples: the CPU, memory, keyboard, screen and hard disk.
- **Software** 软件 is the **programs** 程序 that control the computer and tell the hardware what to do.

Hardware cannot do anything useful on its own. Software needs hardware to run on. Both are needed.



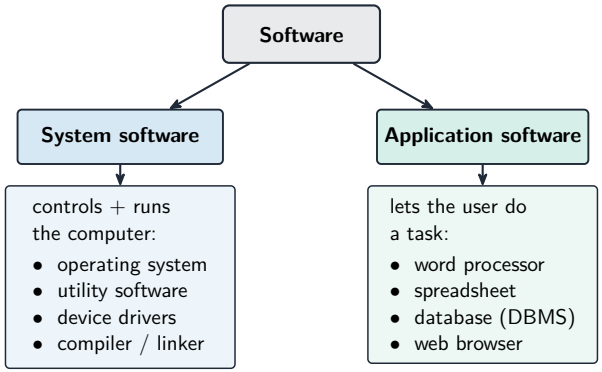
The motherboard and the parts attached to it are hardware – the physical parts you can touch



An operating system is software – the programs that tell the hardware what to do

Types of software

Software is split into two types.



Software divides into system software (runs the computer) and application software (lets the user do a task)

System software

System software 系统软件 controls the computer itself and gives a base for other programs to run on. Examples:

- **operating system** 操作系统 (see below);
- **compiler** 编译器 and **linker** 链接器 (tools that turn programs into a form the computer can run);
- **device driver** 设备驱动程序 – software that lets the operating system control a piece of hardware;
- **utility software** 实用程序 – small tools that look after the computer (for example anti-virus, backup, disk clean-up).

Below the operating system sits **firmware** 固件 – software stored permanently on ROM or flash that runs the moment the computer is switched on. The **BIOS** and the **bootloader** 引导程序 are firmware: they test the hardware and then load the operating system. So the layers stack up **hardware → firmware → operating system → application software**, each running on the layer below.

Application software

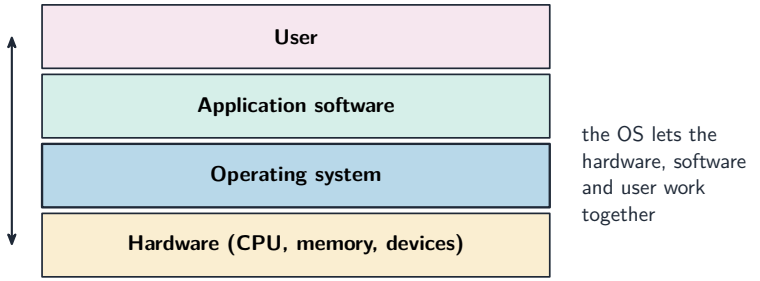
Application software 应用软件 lets the user do a useful task. Examples:

- **word processing** 文字处理 software (writing documents);
- **spreadsheet** 电子表格 software (working with numbers in a grid);
- **database management system** 数据库管理系统 (storing and searching data);
- **web browser** 网页浏览器 (viewing web pages).

	System software	Application software
Job	runs and manages the computer	helps the user do a task
Used by	the computer (in the background)	the user (directly)
Examples	operating system, drivers, utilities	word processor, browser, games

The operating system

An **operating system** (OS) is the main system software. It controls the whole computer and lets the hardware, the application software and the user work together. Without an OS the computer is very hard to use.



The operating system sits between the hardware and the application software and user, letting them work together

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The OS has many roles:

- **managing files** – saving, opening, naming, moving and deleting files;
- **handling interrupts** (see below);
- **providing a user interface** 用户界面 so the user can control the computer;
- **managing memory** – deciding what is kept in RAM and where;
- **managing peripherals** 外围设备 and their drivers – controlling devices like printers;
- **managing multitasking** 多任务处理 – letting several programs run at once;
- **providing a platform** 平台 for running application software;
- **managing security** – user accounts, passwords and access rights.

> **Worked example.** Identify the function of the operating system in each case: (a) a student saves an essay into a folder called *History*; (b) a printer driver sends a document to the printer; (c) music keeps playing while the student browses the web; (d) a student must log in before using a school computer.

(a) **managing files**; (b) **managing peripherals** and their drivers; (c) **managing multitasking** (the OS shares processor time and memory between the two programs); (d) **managing security** (user accounts and access rights). In an exam, name the function **and** link it to the example given.

Interrupts

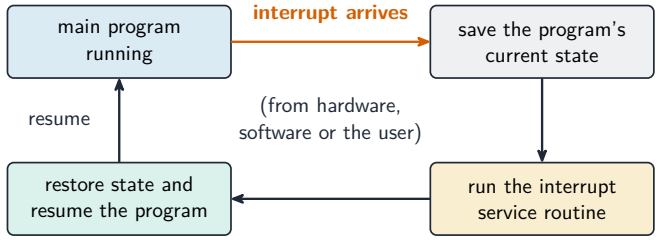
An **interrupt** 中断 is a signal sent to the **processor** 处理器 to tell it that something needs attention now.

An interrupt can come from three sources:

- **hardware** – for example a key is pressed, or a printer runs out of paper;
- **software** – for example a program tries to divide by zero;
- **the user** – for example the user presses a "cancel" key.

When an interrupt arrives, the processor **stops** what it is doing, saves its place, and **services** (deals with) the interrupt. When that is done, it goes back to what it was doing before. This lets the computer react quickly to important events.

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On an interrupt the CPU saves its place, runs the interrupt service routine, then restores its place and carries on

Interrupts have different **priorities** 优先级. The processor checks for interrupts at the end of each fetch–execute cycle. If an interrupt has a **higher** priority than the current task, the processor saves the current task and runs the **interrupt service routine** (ISR) for it. A lower-priority interrupt waits in a queue until the processor is free.

> **Worked example.** A student is typing a document while it prints, and the printer runs out of paper. Describe how the computer deals with this.

1. The printer sends a **hardware interrupt** to the processor.
2. At the end of its current cycle, the processor checks the interrupt's priority. It is higher than the current task, so the processor saves the state of the current task (the values in its registers).
3. It runs the ISR for the printer, which makes the OS show a message such as "Out of paper".
4. It then restores the saved state and carries on with the word processor, so the student can keep typing.
5. When paper is added, the printer sends another interrupt, and printing continues.

Programming languages

All computers process data using the **central processing unit** 中央处理器 (CPU). To make the CPU do work, people write **programs** in a **programming language** 编程语言. There are two kinds.

High-level languages

A **high-level language** 高级语言 is written in words that look a bit like English (for example Python). It is:

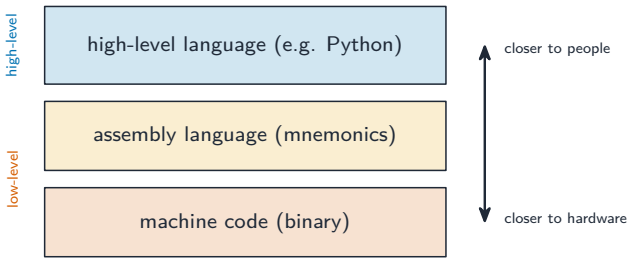
- **easy** for people to read, write and fix;
- **independent of the computer** – the same program can run on different types of computer.

Low-level languages

A **low-level language** 低级语言 is close to what the hardware actually uses. It includes:

- **machine code** 机器码 – instructions written in binary (0s and 1s), which the CPU runs directly;
- **assembly language** 汇编语言 – machine code written with short word codes (mnemonics) instead of binary.

A low-level language relates to the **specific** 特定的 type of CPU, so a program written for one CPU may not run on another. It is used when the programmer needs full control of the hardware or very fast, small code.



High-level languages are close to human language and run on any computer; low-level languages (assembly and machine code) are close to the hardware and tied to one type of CPU

Translators

The CPU can only run machine code. A high-level program must first be changed into machine code. The software that does this is a **translator** 翻译程序. There are three types: a compiler and an interpreter (for high-level code), and an assembler (for low-level code).

Compiler

A **compiler** translates the **whole** program into machine code **before** it is run. After translating, the machine code can be run many times without translating again.

- translation happens once, in full;
- it provides an error report for the whole source, with the translation errors it detects;
- the finished program runs fast and does not need the compiler to run.

Interpreter

An **interpreter** 解释器 translates and runs the program **one line at a time**.

- it stops at the **first error** it finds, which helps when testing;
- the program runs more slowly, because it is translated each time it runs;
- the interpreter must be present every time the program runs.

Use a **compiler** when you want to share a fast, finished program. Use an **interpreter** when you are writing and testing a program and want to find errors easily.

Worked comparison – when does execution happen?

> **Try it.** Use the syllabus's whole-program compiler and line-by-line interpreter models. Consider this short source description; it is not a program in a particular language.

Line	Source description
1	A valid instruction displays `Start`
2	An incomplete addition is missing a value after the plus sign
3	A valid instruction displays `Done`

Line 2 contains a translation error. What is displayed before that error is reported with each translator? Will line 3 execute? Explain the order of translation and execution.

Compiler trace. The whole source is translated before execution. The error in line 2 causes compilation to fail. An error report is provided for the whole source. The new program is not executed, so neither `Start` nor `Done` is displayed.

Interpreter trace. Line 1 is translated and executed, displaying `Start`. The interpreter encounters the error in line 2 and stops execution there. Line 3 is not reached, so `Done` is not displayed.

These traces illustrate the syllabus model; real language tools can combine approaches. A translator reports errors it can detect, not every mistake in the program's logic.

Transfer – development and release. A team wants to locate errors while testing short sections. Later, customers must run the finished program repeatedly without installing its translator. Choose a translator for each stage and explain why. In the **integrated development environment** 集成开发环境 (IDE), name one tool for entering source and one for investigating a reported error. Finally, decide whether successful translation proves that a calculated total is correct.

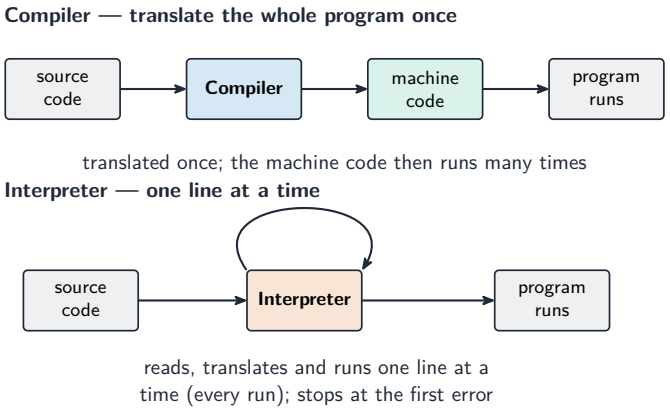
Worked answer. In the syllabus model, an interpreter suits development: line-by-line translation and execution stop at an encountered error, helping the team locate it. A compiler suits release: successful compilation creates an executable file that can be run repeatedly without the compiler. Unchanged source does not need translation again for every run. A **code editor** 代码编辑器 enters and changes source; **error diagnostics** 错误诊断 help locate and explain reported errors; the **run time environment** 运行时环境 lets the team test the program. A wrong total can still result from faulty logic

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after successful translation. Test with known inputs, compare actual and expected results, and investigate the calculation.

Assembler

An **assembler** 汇编器 translates a **low-level assembly-language** program (written in mnemonics such as `LDA`, `ADD`) into machine code. Each mnemonic becomes **one** machine instruction – a direct one-to-one translation, unlike a compiler or interpreter, which work on high-level code.



A compiler translates the whole program once into machine code; an interpreter translates and runs one line at a time

> **Worked example.** A team is writing a program. While developing it they want to find and fix errors quickly; when they ship it they want customers to run it fast without seeing the source code. Which translator suits each stage? While developing, use an **interpreter**: it translates and runs one line at a time and stops at the first error, so a mistake is easy to locate. To ship, use a **compiler**: it translates the whole program once into machine code, which then runs quickly with no translator present, and the customer receives only the executable rather than the source. The two are not rivals - name the **stage** and give the reason, because "a compiler is faster" on its own earns nothing.

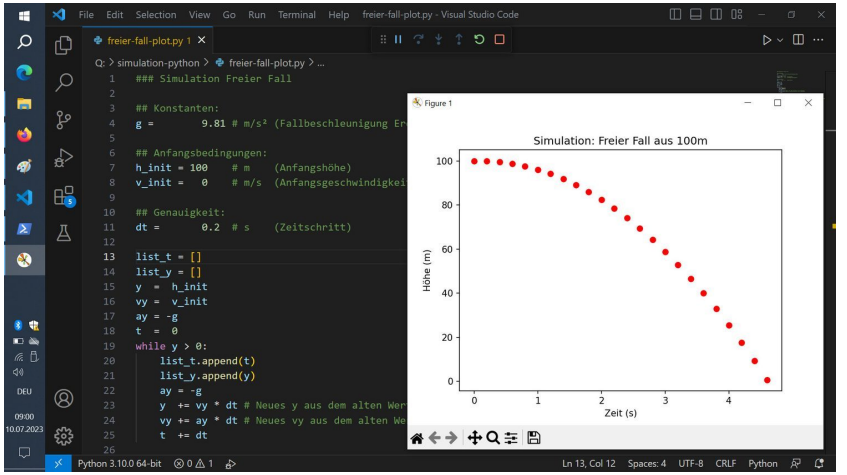
Integrated development environment (IDE)

An **integrated development environment** (IDE) is software that helps you write programs. It puts many useful tools in one place:

- a **code editor** – for typing in your program;
- a **run time environment** – for running the program to test it;

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- a **translator** – a compiler or interpreter to turn your code into machine code;
- **error diagnostics** – messages that help you find and understand mistakes;
- **auto-completion** 自动补全 and **auto-correction** 自动纠错 – the IDE finishes or fixes code as you type;
- **prettyprinting** 美化打印 – laying out the code neatly with colour and indentation so it is easy to read.



Source code in an editor: an IDE combines editor, debugger and run tools in one place

Exam tips

- **Hardware** is the physical parts; **software** is the programs. **System software** runs the computer (OS, drivers, utilities); **application software** does a task for the user.
- A **compiler** translates the whole program at once (the finished program runs fast, and all errors are reported at the end); an **interpreter** translates line by line (it stops at the first error, runs slower, and is needed every time).
- **High-level** languages are close to English and run on any computer; **low-level** languages (assembly, machine code) are tied to one type of CPU.
- An **interrupt** is a signal that makes the CPU stop, save its place, service the event, then carry on where it left off.
- Learn the operating system's roles: managing files, memory, peripherals, multi-tasking, security and the user interface.

The internet and its uses

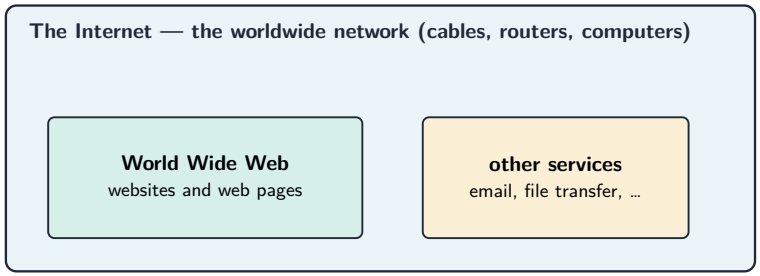
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The internet and the world wide web

People often mix up these two terms, but they are not the same.

- The **internet** 互联网 is the **infrastructure** 基础设施 – the huge worldwide network of computers and the cables, routers and connections that join them.
- The **world wide web** 万维网 (WWW) is a collection of **websites** 网站 and web pages that you view using the internet.

So the internet is the network; the web is one of the things you use *on* that network.



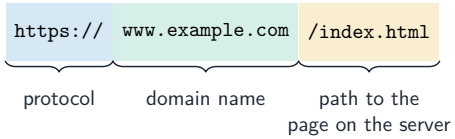
The internet is the worldwide network; the world wide web is one of the things you use on it



A router joins your home network to the internet and sends data to the right place

URL

A **uniform resource locator** 统一资源定位符 (URL) is a text-based address for a web page. You type it into a **web browser** 网页浏览器 to visit a page, for example `https://www.example.com/index.html`.



A URL has three parts: the protocol, the domain name, and the path to the page on the server

HTTP and HTTPS

Hypertext transfer protocol 超文本传输协议 (**HTTP**) is the set of rules for sending web pages between a web server and a browser. The browser sends a **request** for a page; the server sends back a **response** containing the HTML, images and other files.

Hypertext transfer protocol secure 超文本传输安全协议 (**HTTPS**) is HTTP with **encryption** 加密 added, using the **secure socket layer** 安全套接层 (**SSL**) protocol (or its newer form, TLS). Before any page is sent:

1. the browser asks the web server to identify itself;
2. the server sends its **digital certificate** 数字证书, which proves the website is genuine;
3. the browser checks the certificate; if it is valid, the two agree on a key, and every message after that is **encrypted**.

So if the data is intercepted, it cannot be understood. A browser shows a **padlock** in the address bar for an HTTPS site. Use HTTPS whenever you log in or pay online: with plain HTTP, a password would travel as readable text.

The web browser

A web browser is the program you use to view web pages. Its role includes:

- **rendering** 渲染 the **hypertext markup language** 超文本标记语言 (HTML) – turning the page's code into what you see;
- **displaying web pages** on the screen;
- **managing how a web page is presented** – its layout, text and images.

Its other functions:

- an **address bar** to type in a URL;

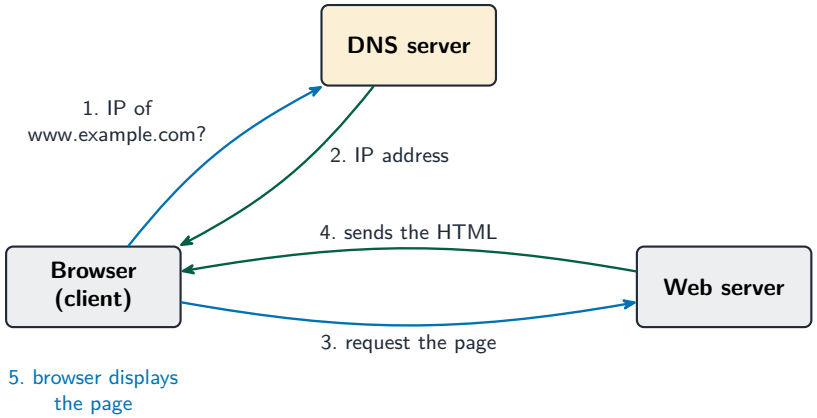
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- **navigation tools**: back, forward and refresh buttons, and hyperlinks;
- **multiple tabs**, so several pages can be open at once;
- **bookmarks** and **favourites**, to save the addresses of pages you want to visit again;
- **recording the user's history** of pages visited;
- **storing cookies** for the websites you visit.

How a web page reaches you

When you type a URL and press enter, several steps happen:

1. The browser needs the website's **IP address** 网际协议地址, but a URL uses a name, not a number.
2. The browser asks a **domain name service** 域名服务 (DNS) – a system that stores the IP address for each web address.
3. The DNS finds the matching IP address and sends it back to the browser.
4. The browser uses the IP address to contact the **web server** 网页服务器 that stores the page.
5. The web server sends the page's HTML back to the browser.
6. The browser turns the HTML into the page and displays it.



The browser asks a DNS for the site's IP address, then requests the page from the web server, which returns the HTML

If the DNS does not have the address, it asks another DNS server until the address is found.

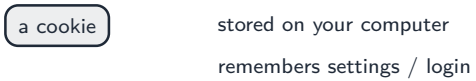


A data centre full of servers: powerful computers that store websites and send them to you

Worked example. Break down the URL `https://www.example.com/books/index.html`. `https` is the **protocol**, the set of rules used to transfer the page (the `s` means the transfer is encrypted). `www.example.com` is the **domain name**, which identifies the web server and which a DNS server turns into an IP address. `/books/index.html` is the **file path and file name** of the resource stored on that server. Name each part together with its **job**: an answer that says "the first bit" and "the last bit" describes the URL without ever explaining it.

Cookies

A **cookie** is a small text file that a website stores on your device. It lets the website remember things about you. There are two types.



A cookie is a small text file stored on your computer

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Type	Kept when you close the browser?	Used for
session 会话 cookie	no – deleted when you close the browser	short-term data, e.g. items in a shopping basket
persistent 持久 cookie	yes – saved on the device	remembering you between visits

Cookies are used to:

- **save personal details** so you do not type them again (such as login or address);
- **track user preferences** 用户偏好, such as your language or the things you like, so the site can suggest content;
- **hold the items in an online shopping cart** while you keep browsing (usually a session cookie);
- **store login details**, so you stay logged in when you come back (a persistent cookie).

> **Worked example.** A user adds three books to the shopping cart of an online shop, closes the browser, and opens the shop again the next day. The cart is empty, but the site still greets them by name. Explain. The cart was held in a **session cookie**, which was deleted when the browser closed. The user's name and login were stored in a **persistent cookie**, which stays on the device until its expiry date, so the site still recognises them.

Digital currency

A **digital currency** 数字货币 is money that exists only in **electronic form** 电子形式. There are no coins or notes. It is stored and moved between people using computers, and can be used to pay for things online.

Examples are cryptocurrencies such as Bitcoin. Payments can be made directly between two people, without a bank in the middle, and many digital currencies are **decentralised**: no single bank or government controls them.

A problem with digital money is trust: how do you stop someone spending the same money twice, or changing the records? Blockchain solves this.

Blockchain

A **blockchain** 区块链 is a **digital ledger** 数字账本 – a shared record of every **transaction** 交易. The record is copied across many computers, so no single person controls it and it is very hard to change.

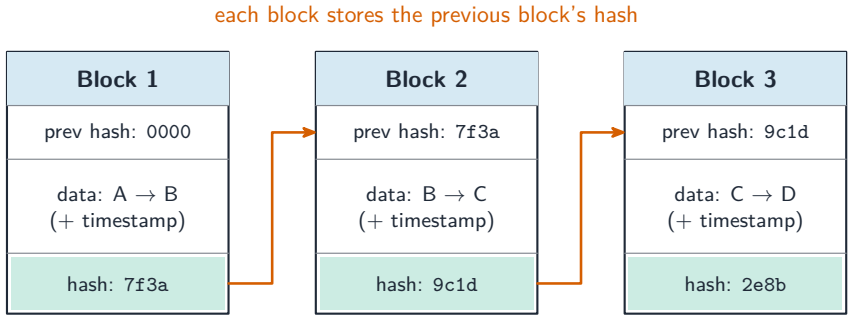
The transactions are kept in blocks joined in a chain. Each block holds:

- the **data** of the transaction (who paid whom, and how much);

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- a **timestamp** 时间戳 (the date and time);
- a **hash value** 哈希值 – a special code worked out from the block's contents.

Each block also stores the hash of the block before it. If someone changes an old block, its hash changes, so it no longer matches the next block. This breaks the chain and the change is spotted at once. This is how blockchain tracks transactions safely.



Each block stores the previous block's hash, chaining the blocks; changing one block breaks the chain

Cyber security threats

Cyber security 网络安全 means keeping computers, networks and data safe from attack. You must know these threats.

Threat	What it is
brute force attack 暴力破解	trying many passwords very quickly until the right one is found
data interception 数据拦截	"listening in" to steal data while it travels across a network
distributed denial of service 分布式拒绝服务 (DDoS) attack	flooding a server with so many requests that it cannot respond, so the website goes down
hacking 黑客攻击	gaining access to a computer system without permission
malware 恶意软件	harmful software (see the table below)
pharming 域名欺骗	secret code sends you to a fake website even when you type the correct address
phishing 网络钓鱼	fake emails or messages that trick you into giving away private details

Threat	What it is
social engineering 社会工程	tricking a person (not a computer) into breaking security, e.g. pretending to be the boss

The process and aim of each threat

An exam answer needs **how** the attack is carried out (the process) and **what** the attacker wants (the aim).

- **Brute force**: a program tries every possible password, or a list of common ones, one after another, until it finds the right one. Aim: to get into an account. Long passwords that mix letters, numbers and symbols take far longer to crack.
- **Data interception**: a **packet sniffer** collects the data packets travelling across a network, or a fake Wi-Fi hotspot is set up to capture them. Aim: to steal data such as passwords or card numbers.
- **DDoS**: the attacker infects many computers with malware, making a network of "bots" (a **botnet**). These are all told to send requests to one web server at the same time. Aim: to overload the server so that genuine users cannot reach the website.
- **Hacking**: a person gains unauthorised access to a computer or network, often by finding a weakness in its software. Aim: to steal, change or delete data, or to cause damage.
- **Phishing**: a fake email that seems to come from a trusted company contains a link to a fake website, where the user is asked to type in personal details. Aim: to steal those details.
- **Pharming**: malicious code is installed on the user's computer, or the records in a DNS server are changed, so that even the **correct** URL leads to a fake website. Aim: to collect the details typed in. Unlike phishing, the user does not have to click a link.
- **Social engineering**: the attacker manipulates a **person**, for example by phoning and pretending to be from the IT department, to make them reveal a password or open a file. Aim: to get past the security by using human trust.

Types of malware

Malware is any software made to harm a computer. The main types are:

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Malware	What it does
virus 病毒	attaches to a file and copies itself when the file is opened; can delete or damage data
worm 蠕虫	copies itself across a network on its own, without needing a file to be opened
Trojan horse 特洛伊木马	pretends to be useful software, but harms the computer once installed
spyware 间谍软件	secretly records what you do, such as the keys you press
adware 广告软件	floods you with unwanted adverts
ransomware 勒索软件	locks your files and demands payment to unlock them

Impact of the threats

These attacks can **steal personal data**, **delete or change files**, **stop a service from working**, cost money, and make users lose trust in a company. For example, a DDoS attack can make an online shop unusable, so it loses sales.



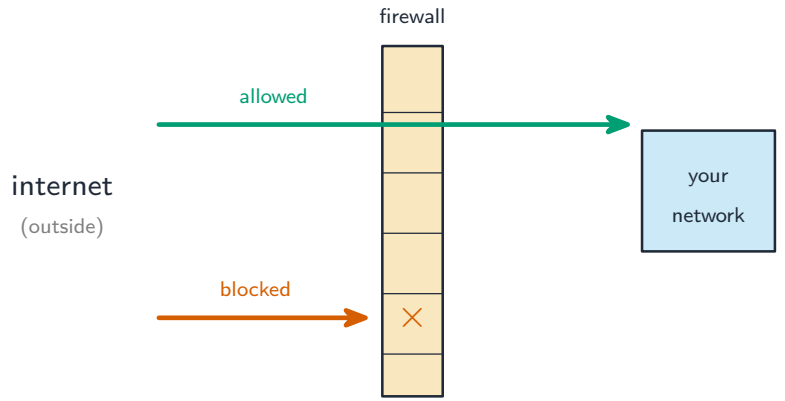
A padlock: cyber security locks data and systems against malware, phishing and unauthorised access

Keeping data safe

You can protect data using these methods.

- **access levels** 访问权限 – each user can only see or change the data they need, nothing more.
- **anti-malware** 反恶意软件 software, including **anti-virus** 杀毒软件 and **anti-spyware** 反间谍软件 – scans for and removes harmful software.
- **authentication** 身份验证 – proving who you are before you get access. Methods include:
  - **biometrics** 生物识别 (fingerprint or face),
  - a **password** 密码,
  - **two-step verification** 两步验证 (a code sent to your phone as well as a password).
- **automating software updates** – updates fix weak points (bugs) in software automatically.
- **checking the spelling and tone** of messages – bad spelling or an odd, urgent tone can show a message is fake (phishing).
- **checking the URL attached to a link** – a wrong or strange web address warns you the link is unsafe.
- **firewall** 防火墙 – checks data going in and out of a network and blocks anything not allowed.
- **privacy settings** 隐私设置 – control who can see your information online.
- **proxy server** 代理服务器 – sits between the user and the internet, hiding the user's IP address and filtering out unsafe content.
- **secure socket layer (SSL)** – encrypts the data sent between a browser and a web server (as in HTTPS), so intercepted data cannot be read.

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A firewall sits between the outside internet and your network, checking each connection and blocking any traffic that is not allowed

How a firewall works. It sits between a computer (or a whole network) and the internet. It examines every packet of data coming in and going out, and compares it with a set of **rules** set by the user or network manager: for example, which IP addresses, ports and programs are allowed. Traffic that does not meet the rules is **blocked**, and the firewall can warn the user. It can be software on the computer or a separate hardware device.

How a proxy server helps. Requests from the user go to the proxy first, and the proxy fetches the web page on the user's behalf. The web server only sees the proxy's IP address, so the user's is hidden. The proxy can block access to unsafe websites, and it can store (cache) popular pages to send them faster. It can also take the load of a DDoS attack, so the real web server stays online.

> **Worked example.** A student receives an email that says it is from their bank. It asks them to click a link and "confirm" their account number and password within 24 hours, or the account will be closed. (a) Identify the threat. (b) Give two ways the student can tell the email is fake. (c) Give one way the bank can reduce the harm if the password is stolen.

(a) **Phishing**. (b) The tone is **urgent** and threatening; check the **spelling** and the sender's address; check the **URL** behind the link (hover over it), which will not be the bank's real domain; a real bank does not ask for a password by email. (c) Use **two-step verification**: a code sent to the student's phone is needed as well as the password, so the stolen password alone is not enough.

Exam tips

- The **internet** is the worldwide network (the infrastructure); the **world wide web** is the pages you view on it – do not mix the two up.
- Learn how a page loads: the browser asks a **DNS** for the site's IP address, then requests the page from the **web server**, which returns the HTML.
- Match the malware types: **virus** (attaches to a file), **worm** (spreads by itself across a network), **Trojan horse** (pretends to be useful), **spyware**, **ransomware**.
- Match each threat to a defence: phishing/pharming → check the URL; brute force → strong passwords + two-step verification; interception → encryption; hacking/DDoS → a firewall.
- A **session** cookie is deleted when you close the browser; a **persistent** cookie is saved to remember you between visits.
- **HTTPS** = HTTP + **SSL** encryption: the server's digital certificate is checked, then all the data is encrypted, so intercepted data cannot be read.
- For a threat, describe the **process** and the **aim**; for a solution, say **how** it stops that threat.

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Automated and emerging technologies

IGCSE Computer Science

Automated systems

An **automated system** 自动化系统 combines software and hardware to sense and respond to data in its **environment** 环境, with little or no direct **human intervention** 人工干预 during normal operation. People may still need to set it up, supervise it or handle faults.

Examples of automated systems:

- a central heating 中央供暖 system;
- a chemical process 化学过程 in a factory;
- a **greenhouse** 温室 (for growing plants);
- a **car park barrier** 停车场道闸.

Sensors, microprocessors and actuators

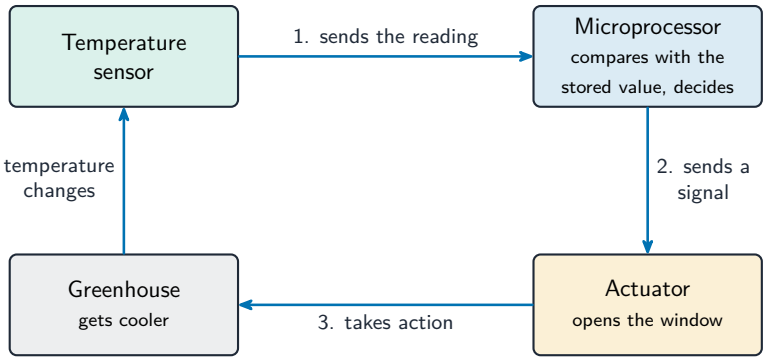
Three parts work together in an automated system.

Part	Job
sensor 传感器	measures a physical quantity (such as temperature or light) and sends the data
microprocessor 微处理器	compares the data with stored values and makes decisions
actuator 执行器	receives a signal and causes movement or action (such as opening a valve)

The cycle works like this:

1. The sensor sends data to the microprocessor.
2. The microprocessor compares this data with **stored values** 存储值 and makes a decision.
3. The microprocessor sends signals to the actuators to take action.

For example, in a greenhouse: a temperature sensor reads the heat; the microprocessor compares it with the wanted value; if it is too hot, the microprocessor signals an actuator to open a window.



A sensor feeds the microprocessor, which compares the reading with a stored value and signals an actuator; the loop then repeats

The syllabus names many **sensor types** 传感器类型, each reading one physical quantity – for example an **accelerometer** 加速度计 (movement or tilt), a **humidity** 湿度 sensor (water in the air), and a **proximity** 接近 sensor (a nearby object):

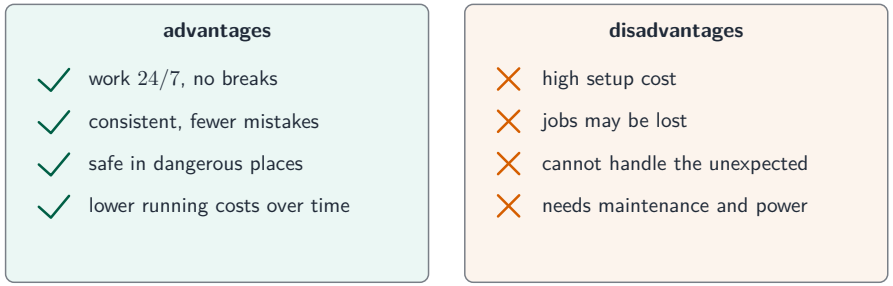
Sensor	Measures	Typical use
temperature	temperature	ovens, greenhouses, heating
light	brightness	automatic lights, cameras
pressure	force per unit area	alarm floor mats, touchscreens
infra-red / proximity	a nearby object	automatic doors, parking sensors
acoustic (sound)	sound level	noise monitors
humidity / moisture	water in air or soil	greenhouses, irrigation
gas	a gas being present	smoke and CO alarms
pH	acidity	pools, fish tanks
accelerometer	movement or tilt	phones, airbag triggers
magnetic field	magnetism	door contacts, compasses
flow / level	fluid flow or depth	pipes, tanks

To pick a sensor for a scenario, choose the one that reads the **right physical quantity**: a fish tank needs pH and temperature sensors; an automatic door needs an infra-red / proximity sensor.

Advantages and disadvantages

Automated systems are used in many situations, such as industry, transport, agriculture 农业 (farming), weather (gathering data), gaming and lighting.

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The advantages and disadvantages of automated systems



A camera drone: it can fly itself along a set route to collect data

Advantages	Disadvantages
work all day and night, without rest	cost a lot to buy and set up
faster and more **consistent** 一致的 than people	can break down and need expert repair
can work in places unsafe for people	may replace people's jobs
fewer human mistakes	cannot easily react to a situation they were not built for

Worked example. Describe how an automatic greenhouse holds the temperature at 25 °C. A **temperature sensor** continuously measures the temperature and sends its reading, converted to digital by an ADC, to the **microprocessor**. The microprocessor **compares** the reading with the stored value of 25 °C. If the temperature is above it, the microprocessor signals an **actuator** to open a window or switch on a fan; if it is below, it switches on a heater. The whole loop then **repeats continuously**. Two marks nearly always sit on the words "compares with a stored (pre-set) value" and "the process repeats" - a description that stops at "the sensor tells the computer" leaves them behind.

Applying it to a scenario

An exam question names one scenario, and the marks go to advantages and disadvantages that fit **that** scenario, not a general list.

Scenario	How it works	Advantage	Disadvantage
Lighting: street lights	a light sensor reads the light level; below the stored value, the microprocessor switches the lights on	lights are on only when needed, so less energy is wasted	a faulty or dirty sensor can leave a street dark
Transport: driverless train	sensors read speed and position; the microprocessor controls the motors and brakes	trains run closer together and on time; no driver error	very expensive to build, and passengers may not trust it
Weather: automatic weather station	temperature, humidity, pressure and wind sensors take readings at set times and send them to a computer	collects data day and night in remote places	equipment in remote places is hard to reach and repair
Agriculture: irrigation	a soil-moisture sensor reads the soil; if it is too dry, an actuator opens a water valve	water is used only when the soil needs it	high cost to set up for a small farm
Industry: a chemical plant	sensors measure temperature and pressure; actuators open valves to keep them safe	reacts faster than a person to a dangerous change	a software fault could cause an accident if nobody is watching

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Worked example. A city installs automatic street lights. Give **one** advantage and **one** disadvantage. Advantage: the lights switch on only when the light sensor shows it is dark, so the city saves electricity and money. Disadvantage: if the sensor fails, the lights may stay off at night, which is unsafe for drivers and walkers. Each answer names something about street lights; "it is expensive" or "it saves time" with no link to the scenario usually earns no mark.

Robotics

Robotics 机器人技术 is the branch of technology that deals with the design, building and operation of **robots** 机器人.

A robot has these characteristics:

- a **physical structure** 物理结构 (a mechanical 机械的 body, such as arms);
- **electrical components** 电子元件 (motors, sensors and wiring);
- **programmable instructions** 可编程指令 – it follows a program that can be changed.

What robots do

Robots can perform many roles, for example:

- **factory equipment** 工厂设备 – building cars, welding, moving heavy parts;
- **domestic appliances** 家用电器 – such as a robotic **vacuum cleaner** 吸尘器;
- **transport** – self-driving cars, driverless trains, and robots that move goods in warehouses;
- **agriculture** – robots that pick fruit, weed crops or milk cows, and drones that spray crops;
- **medicine** – robot arms that help surgeons make very small, steady cuts;
- **entertainment** – moving robots in theme-park rides and films, and camera drones.



An industrial robot arm. It follows a program and can be reprogrammed to do a new job.



A robot vacuum cleaner: a home robot that drives itself around to clean the floor

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Advantages	Disadvantages
do dull or dangerous jobs	expensive to buy and maintain
work quickly and accurately	can replace human workers
do not get tired or bored	a fixed-program robot has a **lack of independent decision-making** 缺乏独立决策 – its responses are limited by its program

A fixed-program robot is limited by the instructions and responses built into its control system. Robots using AI may adapt within their design, but unexpected situations can still require human help.

> **Worked example.** A hospital uses a robot to assist in surgery. Give one advantage and one disadvantage. Advantage: the robot arm does not shake or get tired, so it can make very precise, small cuts, and patients may recover faster. Disadvantage: the robot is very expensive to buy and maintain, and surgeons must be trained to use it.

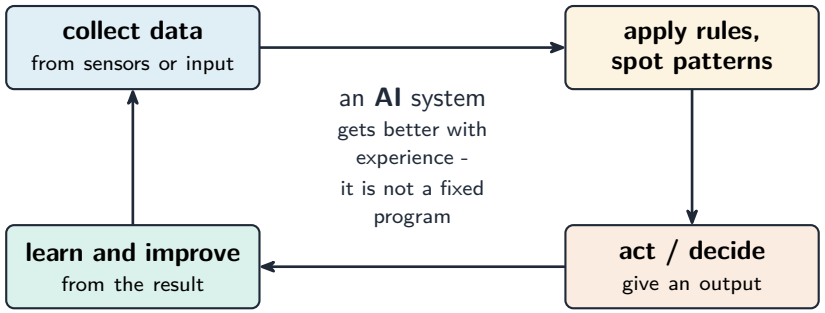
Artificial intelligence

Artificial intelligence 人工智能 (AI) is the **simulation** 模拟 of human intelligence by computer systems. This means a computer doing tasks that normally need human thinking.

Characteristics of AI

AI systems may use the following features. A particular system need not learn or adapt: for example, an expert system can apply a fixed set of rules.

- they **collect data** and the **rules** 规则 for using that data;
- they have the ability to **reason** 推理 (work things out using the rules);
- they have the ability to **draw conclusions** 得出结论, which may be **approximate** 近似的 (a best guess) or **definite** 确定的 (certain);
- they have the ability to **learn** 学习 from data;
- they have the ability to **adapt** 适应 – to change their behaviour as they get new data.



One learning-system example: collect data, apply rules or a model, act, and use feedback to update behaviour

Examples of AI

- **expert systems** 专家系统 – software that gives advice like a human expert (for example, helping a doctor with a diagnosis);
- **natural language processing** 自然语言处理 – understanding human speech or text;
- **self-driving cars** 自动驾驶汽车.



A self-driving car: sensors on the car let a computer steer it with no driver

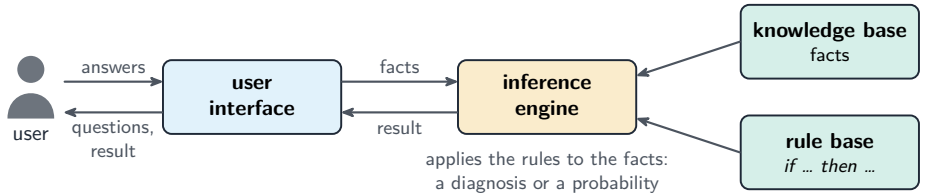
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Inside an expert system

An **expert system** stores human expertise and reasons from it. It has four parts:

- a **knowledge base** 知识库 – the stored facts about the subject;
- a **rule base** 规则库 – the "if… then…" rules a human expert would apply;
- an **inference engine** 推理引擎 – applies the rules to the facts to reach a conclusion;
- a **user interface** 用户界面 – asks the user questions and shows the result.

The interface collects facts from the user; the inference engine runs the rule base against the knowledge base; and the system outputs a diagnosis or a probability – as used to help a doctor diagnose an illness or to find a car fault.



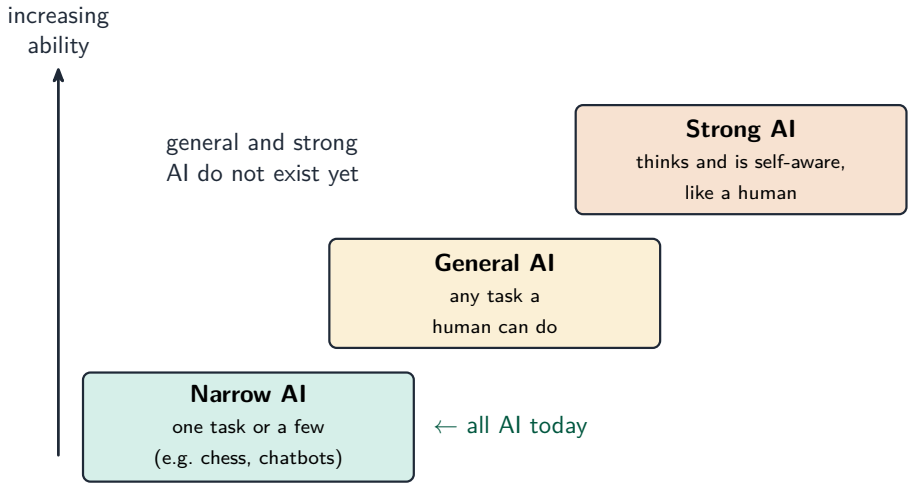
Inside an expert system: the inference engine applies the rules to the facts

Machine learning

Machine learning 机器学习 is a program that improves its own performance from **experience**, without being explicitly reprogrammed. It finds patterns in data and adapts: a search engine gets better at ranking results, a voice assistant recognises spoken commands more accurately, and a robot vacuum gradually learns the layout of a room.

Narrow, general and strong AI

Type	What it means
narrow AI 弱人工智能	designed for a particular task or limited domain (for example, a chess program)
general AI 通用人工智能	a proposed system with broad capability across many intellectual tasks
strong AI 强人工智能	in this course's terminology, a proposed system with human-like understanding and awareness



Course categories: task-focused narrow AI, proposed broad general capability, and proposed human-like awareness. These labels describe capabilities rather than date the status of every current system.

Exam tips

- Learn the control loop: a **sensor** measures a quantity → the **microprocessor** compares it with a stored value → an **actuator** takes action; then the loop repeats.
- Do not confuse the parts: a **sensor** sends data *in*; an **actuator** causes movement *out*.
- A robot follows **programmable instructions**; a fixed-program robot cannot decide for itself when something unexpected happens.
- For an advantage or disadvantage, **name the scenario** in your answer: say what it means for that factory, farm, street or hospital.
- **AI** simulates human thinking: it collects data and rules, reasons, draws conclusions, and can learn and adapt.
- Know the AI levels: **narrow** (one task or a limited area), **general** (a proposed system that can handle a broad range of tasks), **strong** (a proposed system with human-like understanding and awareness).

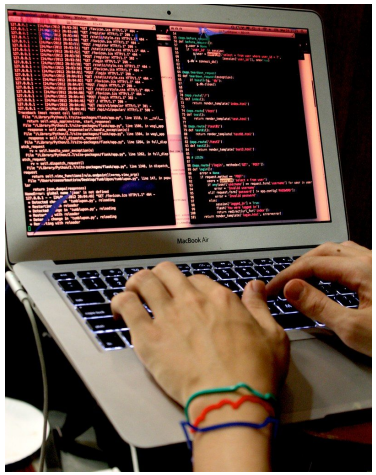
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Topic 07

IGCSE Computer Science

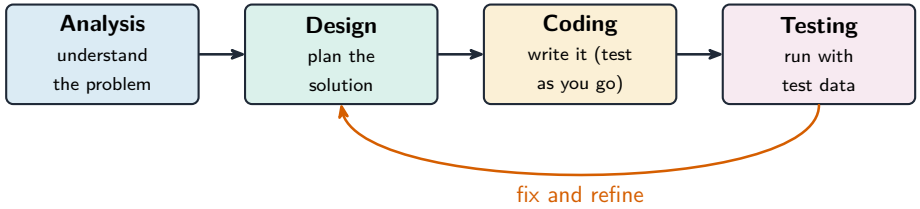
The program development life cycle

The **program development life cycle** 程序开发生命周期 is the set of stages used to make a program. There are four stages.

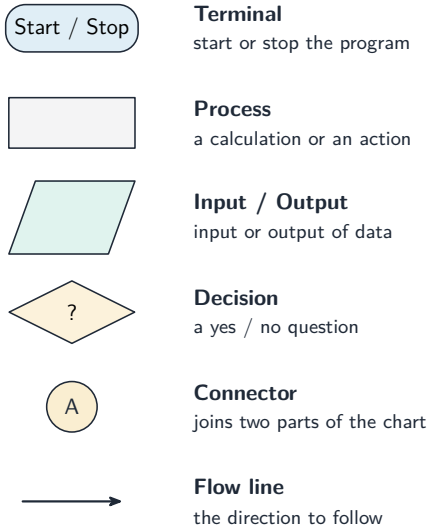


Software is written by programmers, who follow the development life cycle

Stage	What you do
analysis 分析	study the problem and work out what is needed
design 设计	plan how the program will work
coding 编码	write the program code and test it as you go
testing 测试	run the finished program with test data to find errors



The four stages of program development; testing feeds back to fix and refine the design



A program flowchart sets out the steps and decisions of a program during the design stage

Analysis

In analysis you understand the problem. Two key skills help:

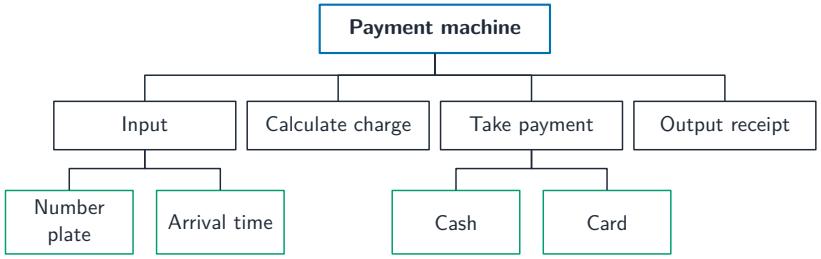
- **abstraction** 抽象 – keep only the important details and ignore the rest;
- **decomposition** 分解 – break a big problem into smaller, easier parts.

Design

In design you plan the solution, often using decomposition. You can show the parts as **sub-systems** 子系统 in a **structure diagram** 结构图 (a chart that splits a system into smaller boxes).

> **Worked example.** A car park has a payment machine. The driver types in the car's number plate, the machine works out how long the car has stayed and the charge, the driver pays by cash or card, and a receipt is printed. Draw a structure diagram.

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A structure diagram for the car park payment machine: each box is a sub-system, and each lower level splits its parent into smaller parts

The whole system goes in the top box. Each box on the next level is one job the system does, and a box can be split again (paying splits into **cash** and **card**). Read across a level from left to right in the order the jobs happen. A structure diagram shows the **parts**, not the order of decisions or loops: that is what a flowchart or pseudocode is for.

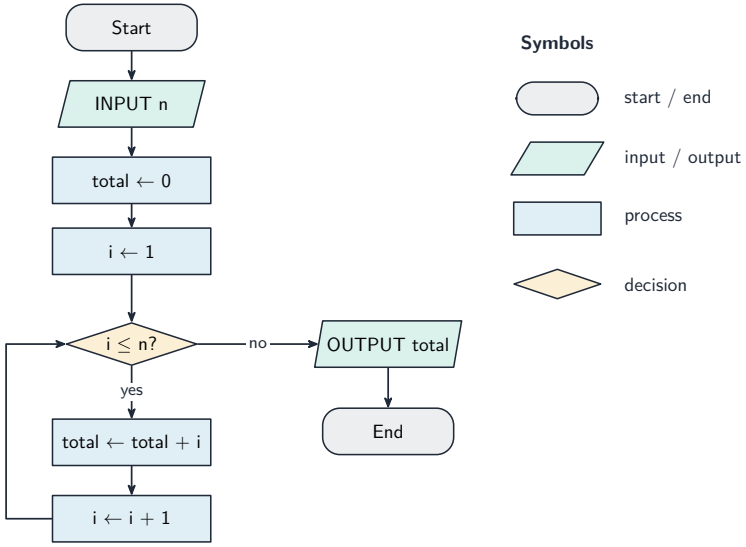
Coding and testing

In **coding** you write the program code. You use **iterative testing** 迭代测试 – test small parts again and again as you build them. In **testing** you run the whole program with **test data** 测试数据 to check it works.

Design tools

You can plan a solution in three main ways.

- a **structure diagram** – shows the parts of a system and how they fit together;
- a **flowchart** 流程图 – a diagram using boxes and arrows to show the steps in order;
- **pseudocode** 伪代码 – steps written in simple, code-like English (not a real language).



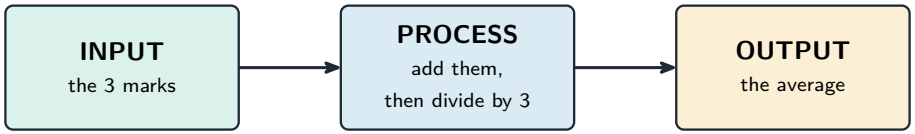
A flowchart for the sum algorithm, using the standard symbols (start/end, input/output, process, decision)

Algorithms

An **algorithm** 算法 is a set of steps, in the right order, that solves a problem. Every algorithm can be split into three parts:

- **input** 输入 – the data that goes in;
- **processing** 处理 – the work done on the data;
- **output** 输出 – the result that comes out.

This is called decomposition into inputs, processes and outputs. For example, for "find the average of three marks": the inputs are the three marks; the processing is adding them and dividing by 3; the output is the average.



Every algorithm decomposes into input, processing and output – here, finding the average of three marks

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Validation and verification

When data is entered, you check it to reduce mistakes.

Validation 验证 checks that the data is **sensible** and follows the rules. It cannot check that the data is true, only that it is allowed.

Validation check	What it checks
range check 范围检查	the value is between a lowest and highest allowed value
length check 长度检查	the number of characters is allowed (e.g. a password ≥ 8)
type check 类型检查	the data is the right type (e.g. a number, not letters)
presence check 存在性检查	something has actually been entered (not left blank)
format check 格式检查	the data is in the right pattern (e.g. a date as dd/mm/yyyy)
check digit 校验码	an extra calculated digit helps detect errors when a number is entered

Verification 核实 checks that data was **copied or entered correctly** (no mistakes while typing it in). Two methods:

- **visual check** 目视检查 – a person compares the typed data with the original;
- **double entry** 双重输入 – the data is entered twice and the two copies are compared.

validation: is it allowed?
range, length, type, presence, format, check digit
age = 250: rejected by a range check

verification: was it copied correctly?
visual check or double entry
typed 34 instead of 43: both allowed, only verification can catch it

Validation stops data that is not allowed; verification catches allowed data that was typed wrongly

Writing a validation routine

An exam often asks you to write the code for a check. Use a loop that asks again **until** the input is acceptable, and give the user a message when it is not.

Worked example. Write pseudocode to input a test mark, which must be a whole number from 0 to 100 (a range check), and to keep asking until a valid mark is entered.

```
DECLARE Mark : INTEGER
REPEAT
    OUTPUT "Enter a mark from 0 to 100"
    INPUT Mark
    IF Mark < 0 OR Mark > 100
      THEN
        OUTPUT "Invalid: the mark must be from 0 to 100"
    ENDIF
UNTIL Mark >= 0 AND Mark <= 100
```

The `UNTIL` condition is the **accepted** range, and the `IF` condition is its opposite. Notice `OR` in the `IF`: a mark cannot be below 0 **and** above 100 at the same time, so `AND` there would never be true.

Other checks follow the same pattern, with a different condition:

Check	Condition for a valid value
length check (password of at least 8 characters)	`LENGTH(Password) >= 8`
presence check (a name must be entered)	`Name <> ""`
range check (age 16 to 65)	`Age >= 16 AND Age <= 65`

A type check is usually done by the language itself, for example when an input is stored in an `INTEGER` variable.

Trace tables

A **trace table** 追踪表 records the value of each variable as an algorithm runs, step by step. It helps you:

count	total	output
1	5	
2	12	
3	20	20

A trace table records each variable's value as the program runs

- check that an algorithm works correctly;
- work out **what an algorithm does** by following it with given data.

Example: trace this algorithm with the input 5.

```
INPUT N
Total ← 0
FOR I ← 1 TO N
    Total ← Total + I
NEXT I
OUTPUT Total
```

i	total	OUTPUT
1	1	
2	3	
3	6	
4	10	
5	15	15

The trace shows the algorithm adds up 1 to n. With input 5 the output is 15.

Worked example. Trace this algorithm and give the output.

```
X ← 20
Count ← 0
WHILE X > 1
    X ← DIV(X, 2)
    Count ← Count + 1
ENDWHILE
OUTPUT Count
```

`DIV` gives only the whole-number part of a division. Take one row per pass: x becomes 10 (count 1), then 5 (count 2), then 2 (count 3), then 1 (count 4). Now `x > 1` is false, so the loop stops and the output is **4**. Two habits protect these marks: test the condition **before** each pass rather than after, and write a new row for **every** pass - trying to hold the values in your head is what makes traces go wrong.

Finding and correcting errors

A common question gives an algorithm with errors and asks you to find and correct them. Read it line by line and ask: is every variable given a starting value? Is each loop the right length? Is each comparison the right way round? Is the output in the right place?

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Worked example. This algorithm should input 10 numbers and output the largest. Find the three errors and correct them.

```
Largest ← 1000
FOR Count ← 1 TO 9
    INPUT Number
    IF Number < Largest
      THEN
        Largest ← Number
    ENDIF
    OUTPUT Largest
NEXT Count
```

- Line 1: `Largest ← 1000` starts too high, so no number would replace it. Correction: `Largest ← -1000` (or input the first number and use it as the start).
- Line 2: the loop runs only 9 times. Correction: `FOR Count ← 1 TO 10`.
- Line 4: `<` finds the smallest. Correction: `IF Number > Largest`.

There is also a problem with the `OUTPUT`: inside the loop it prints the largest so far after every input. Moving it after `NEXT Count` prints only the final answer. For each error, give the **line**, say what is wrong, and write the **corrected line** in full.

Test data

Test data is data you use to test a program. There are four types you must know.

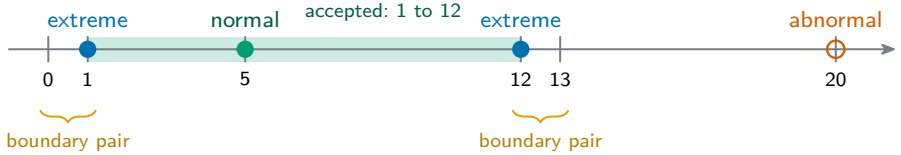
Type	Meaning	Example (age 0–120 allowed)
normal 正常数据	sensible data that should be accepted	25
abnormal 异常数据	wrong data that should be rejected	-4 or “cat”
extreme 极端数据	the largest and smallest values still allowed	0 and 120
boundary 边界数据	the values on each side of a limit (one allowed, one not)	120 and 121

Worked example. A program accepts the number of people booking a table, from 1 to 12. Give test data of each type, with the expected result.

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Type	Test data	Expected result
normal	5	accepted
abnormal	20 (or “six”)	rejected, with an error message
extreme	1 and 12	accepted
boundary	12 and 13 (or 0 and 1)	12 accepted, 13 rejected

Always give the **expected result** with the data: a test is only useful if you know what should happen. Extreme data is the edge value itself; boundary data is a pair, one value each side of the limit.



Test data on one line: extreme values sit on the limits, boundary pairs straddle them

Standard methods of solution

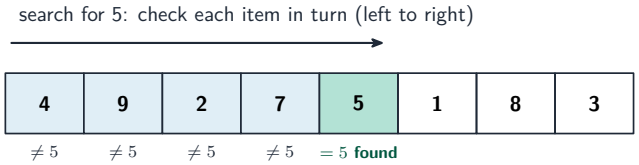
You must know these common algorithms.

Linear search

A **linear search** 线性查找 compares each item with the target, starting at the beginning. Stop when the value is found or the list ends. The list does not need to be sorted. The following example uses positions 1 to 4.

```
DECLARE List : ARRAY[1:4] OF INTEGER
DECLARE I, SearchValue : INTEGER
DECLARE Found : BOOLEAN
List[1] ← 8
List[2] ← 3
List[3] ← 5
List[4] ← 1
INPUT SearchValue
Found ← FALSE
I ← 1
WHILE I <= 4 AND NOT Found
    IF List[I] = SearchValue
      THEN
        Found ← TRUE
    ENDIF
    I ← I + 1
ENDWHILE
OUTPUT Found
```

Worked comparison. Searching for 5 compares 8, 3 and then 5: three comparisons, with `Found` becoming `TRUE`. The fourth item is not checked. Searching for 9 compares all four values; `Found` stays `FALSE`. Stop before trying to read position 5, which is outside this array.



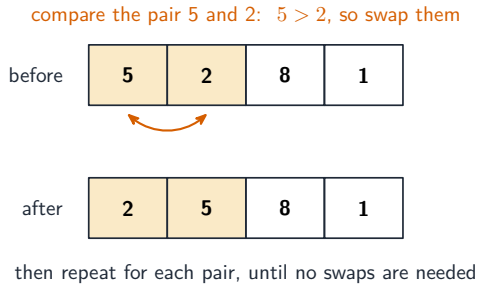
Another example: linear search checks each item in turn from the start until it finds the value

Bubble sort

A **bubble sort** 冒泡排序 puts a list in order. Compare neighbouring values and swap them if the left value is greater. A single pass is not enough in general. This complete version repeats passes until a whole pass makes no swaps.

```
DECLARE List : ARRAY[1:4] OF INTEGER
DECLARE I, Temp : INTEGER
DECLARE Swapped : BOOLEAN
List[1] ← 8
List[2] ← 3
List[3] ← 5
List[4] ← 1
REPEAT
    Swapped ← FALSE
    FOR I ← 1 TO 3
        IF List[I] > List[I + 1]
          THEN
            Temp ← List[I]
            List[I] ← List[I + 1]
            List[I + 1] ← Temp
            Swapped ← TRUE
        ENDIF
    NEXT I
UNTIL NOT Swapped
OUTPUT List[1], ", ", List[2], ", ", List[3], ", ", List[4]
```

Worked passes. Start with `8, 3, 5, 1`. In the first pass the list becomes `3, 8, 5, 1`, then `3, 5, 8, 1`, then `3, 5, 1, 8`. This puts the largest value last but leaves the rest unsorted. The second pass ends at `3, 1, 5, 8`; the third at `1, 3, 5, 8`. The fourth makes no swaps and confirms that this version can stop. Reset `Swapped` to `FALSE` at the start of every pass; set it to `TRUE` on any swap.



One comparison in another example: bubble sort swaps neighbours that are out of order, then continues through the pass

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Totalling and counting

Totalling 求和 adds each required value to a running total: `Total ← Total + Value`. **Counting** 计数 adds 1 for each required item: `Count ← Count + 1`. Initialise both to zero before processing the values.

Worked example. Four attempted inputs are −20, 4, 50 and 6. Accept a value only if it is greater than −20 and less than 50. This example processes four attempts, not four accepted values.

```
DECLARE I, Count : INTEGER
DECLARE Value, Total : REAL
Total ← 0
Count ← 0
FOR I ← 1 TO 4
    INPUT Value
    IF Value > -20 AND Value < 50
      THEN
        Total ← Total + Value
        Count ← Count + 1
    ENDIF
NEXT I
IF Count > 0
  THEN
    OUTPUT Total, ", ", Count, ", ", Total / Count
  ELSE
    OUTPUT "No accepted values"
ENDIF
```

Attempted value	Total after attempt	Count after attempt
−20	0	0
4	4	1
50	4	1
6	10	2

The strict limits reject −20 and 50. Both updates belong inside the acceptance test, so rejected attempts change neither total nor count. The average of the accepted values is:

$$\text{Average} = \frac{\text{Total}}{\text{Count}} = \frac{10}{2} = 5$$

Do not divide by four: only two values were added. If no value is accepted, the count is zero and an average cannot be calculated; output a message instead of dividing by zero.

Transfer to a fixed number of accepted values. If a task asks for 50 accepted values, rather than four attempts, replace the fixed `FOR` loop with `WHILE Count <`

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`50` and close it with `ENDWHILE`. Keep the same input and acceptance test inside it. Rejected inputs leave `Count` unchanged, so another input is requested. On completion `Count` is 50, although the number of attempts may be greater. Output the total and calculate the average as `Total / Count`.

Maximum, minimum and average

The **maximum** 最大值 is the largest value and the **minimum** 最小值 is the smallest. The **average** 平均值 is the total divided by the number of values. For a non-empty list, initialise both from its first item. For each remaining item, replace the maximum if the new value is larger, and replace the minimum if it is smaller.

> **Worked example.** The list is −8, −3, −12, −5. Starting the maximum at zero would fail: no list item is greater than zero, so the algorithm would output a number that is not in the list. Starting from −8 works without assuming that the data is positive.

Value just considered	Maximum so far	Minimum so far
−8 (initialisation)	−8	−8
−3	−3	−8
−12	−3	−12
−5	−3	−12

```
DECLARE List : ARRAY[1:4] OF INTEGER
DECLARE I, Maximum, Minimum, Total : INTEGER
List[1] ← -8
List[2] ← -3
List[3] ← -12
List[4] ← -5
Maximum ← List[1]
Minimum ← List[1]
Total ← List[1]
FOR I ← 2 TO 4
    IF List[I] > Maximum
      THEN
        Maximum ← List[I]
    ENDIF
    IF List[I] < Minimum
      THEN
        Minimum ← List[I]
    ENDIF
    Total ← Total + List[I]
NEXT I
OUTPUT Maximum, ", ", Minimum, ", ", Total / 4
```

The maximum is −3 and the minimum is −12. The average uses all four values:

$$\text{Total} = \sum \text{Value} = (-8) + (-3) + (-12) + (-5) = -28$$

$$\text{Average} = \frac{\text{Total}}{\text{Count}} = \frac{-28}{4} = -7$$

The average lies between the minimum and maximum; this is a useful check, not proof that the calculation is correct. Initialising from the first item requires a non-empty list. Handle an empty list separately before trying to read that item.

Exam tips

- The four life-cycle stages: analysis → design → coding → testing. **Abstraction** keeps only what matters; **decomposition** splits a problem into parts.
- **Validation** checks data is *sensible* (range, length, type, presence, format checks); **verification** checks it was *copied correctly* (a visual check or double entry).
- Learn the four test-data types: **normal** (accepted), **abnormal** (rejected), **extreme** (the largest/smallest still allowed), **boundary** (either side of a limit).
- A **trace table** (every variable's value at each step) shows what an algorithm does.
- To write a validation routine, put the input in a `REPEAT … UNTIL` loop whose `UNTIL` condition is the **valid** data.
- When you correct an error, quote the line and write the whole **corrected line**.
- Know the standard algorithms: **linear search** (check each item in turn) and **bubble sort** (swap side-by-side pairs until no swaps are needed).

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Programming

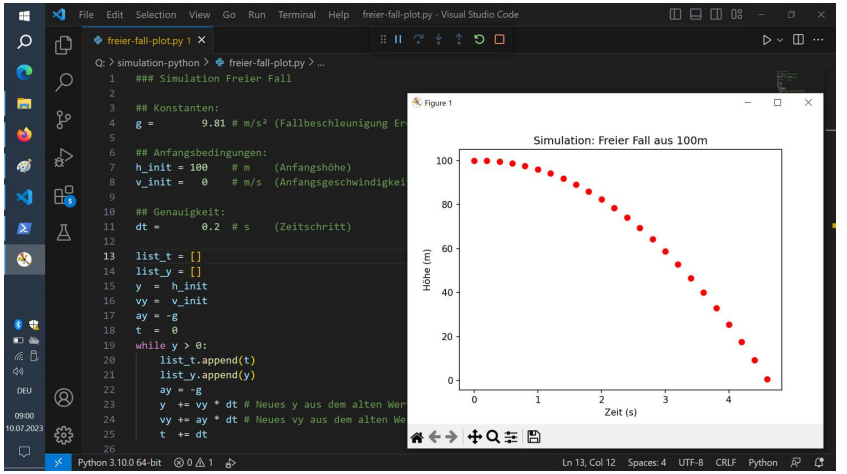
IGCSE Computer Science

Variables and constants

A **variable** 变量 is a named store that holds a value which **can change** while the program runs. A **constant** 常量 is a named store whose value is **fixed** and does not change.



A variable is a named store whose value can change



Variables and constants are named stores for values, set in the program's code

You should **declare** 声明 them (say their name and type) before use:

```
DECLARE Score : INTEGER
DECLARE Name : STRING
CONSTANT Pi ← 3.142
```



While a program runs, its variables are held in the computer's memory (RAM)

Use a constant for a value that never changes (like Pi), so it is set in one place and is easy to read.

Data types

A **data type** 数据类型 says what kind of value a variable holds. You must know five basic types.

integer	whole number: 7
real	decimal: 3.5
char	one letter: 'A'
string	text: "hello"
boolean	true or false

The basic data types: integer, real, char, string and boolean

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Type	Holds	Example
integer 整数	a whole number	`42`, `-7`
real 实数	a number with a decimal point	`3.14`, `-0.5`
char 字符	a single character	`'A'`, `'?'`
string 字符串	a sequence of characters	`"Hello"`
Boolean 布尔值	one of two values	`TRUE` or `FALSE`

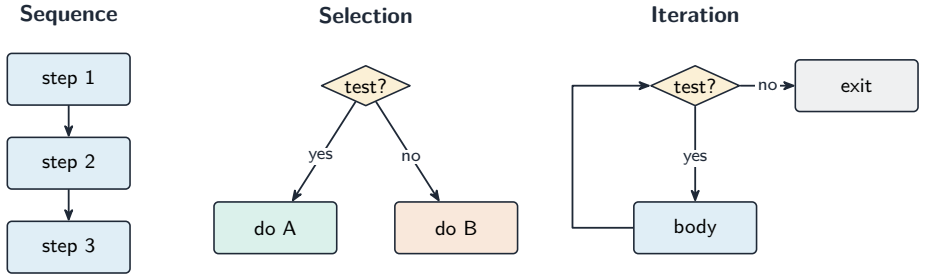
Input and output

Input 输入 reads a value from the user. **Output** 输出 shows a value on the screen.

```
OUTPUT "What is your name?"
INPUT Name
OUTPUT "Hello ", Name
```

The three basic structures

Every program is built from three control structures.



The three control structures: sequence runs steps in order, selection chooses a branch, iteration repeats a body

Sequence

Sequence 顺序 means the steps run one after another, in order, from top to bottom.

```
INPUT Length
INPUT Width
Area ← Length * Width
OUTPUT Area
```

Selection

Selection 选择 chooses which steps to run, based on a condition. Use an `IF` statement, or a `CASE` statement when there are many choices.

```
IF Score >= 50
  THEN
    OUTPUT "Pass"
  ELSE
    OUTPUT "Fail"
ENDIF
```

```
CASE OF Grade
    'A' : OUTPUT "Excellent"
    'B' : OUTPUT "Good"
    OTHERWISE OUTPUT "Keep trying"
ENDCASE
```

Iteration

Iteration 迭代 (a loop 循环) repeats steps. There are three kinds.

A **count-controlled loop** 计数循环 repeats a fixed number of times:

```
FOR I ← 1 TO 5
    OUTPUT "Hello"
NEXT I
```

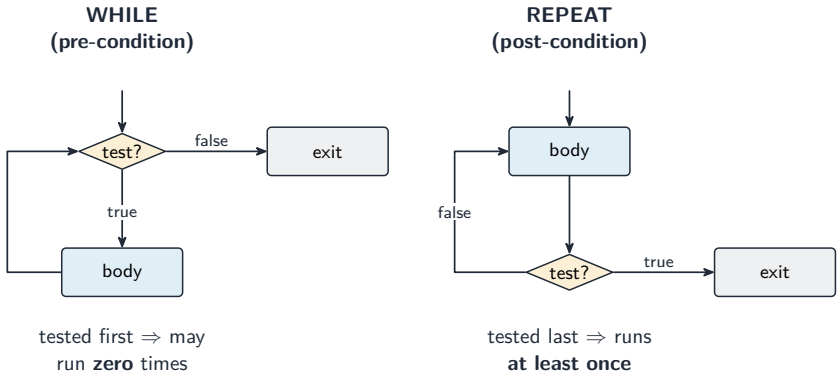
A **pre-condition loop** 前测循环 checks the condition **before** each repeat, so it may run zero times:

```
WHILE Answer <> "stop" DO
    INPUT Answer
ENDWHILE
```

A **post-condition loop** 后测循环 checks the condition **after** each repeat, so it always runs **at least once**:

```
REPEAT
    INPUT Password
UNTIL Password = "secret"
```

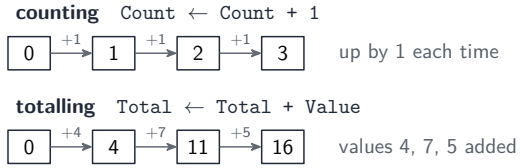

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A pre-condition (WHILE) loop tests before the body, so it may run zero times; a post-condition (REPEAT) loop tests after, so it runs at least once

Totalling and counting

- **totalling** 求和 – keep adding values to a running total: `Total ← Total + Value`.
- **counting** 计数 – add 1 to a counter each time: `Count ← Count + 1`.



A counter counts up by 1; a total builds a running sum

```
total <- 0
count <- 0
FOR each value (4, 7, 5)
  total <- total + value
  count <- count + 1
```

total keeps a running sum;
count adds 1 each pass -
a **trace table** follows both

value	total	count
start	0	0
4	4	1
7	11	2
5	16	3

A trace table follows a totalling and counting loop pass by pass

```
Total ← 0
FOR I ← 1 TO 10
    INPUT Mark
    Total ← Total + Mark
NEXT I
OUTPUT Total
```

Worked example. A program must read 5 marks, then output the total and the average.

```
Total ← 0
FOR I ← 1 TO 5
    INPUT Mark
    Total ← Total + Mark
NEXT I
Average ← Total / 5
OUTPUT Total, Average
```

Two lines carry the marks. `Total ← 0` must sit **before** the loop: put it inside and the total resets on every pass, so the program outputs only the last mark. And `Average ← Total / 5` must sit **after** the loop, because the total is not complete until every mark has been added. Initialise before, calculate after - that ordering is what the question is really testing.

Operators

Arithmetic operators

Operator	Meaning
`+ - * /`	add, subtract, multiply, divide
`^`	raised to the power of
`MOD`	the **remainder** 余数 after division
`DIV`	the whole-number part of a division

For example, `17 MOD 5` is 2, and `17 DIV 5` is 3.

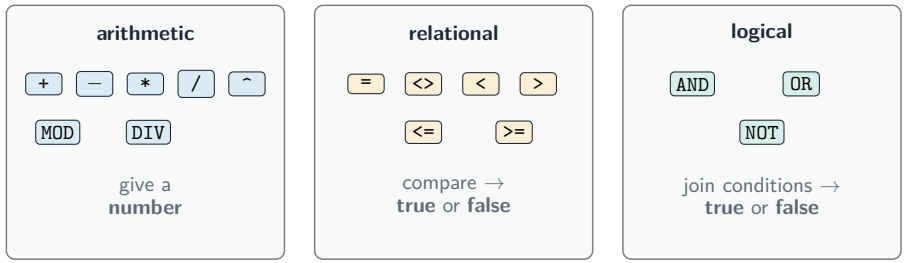
Relational operators

These compare two values and give a Boolean result: `=`, `<`, `<=`, `>`, `>=`, and `<>` (not equal to).

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Logical operators

These join conditions: `AND` (both must be true), `OR` (at least one must be true), `NOT` (reverses true/false).

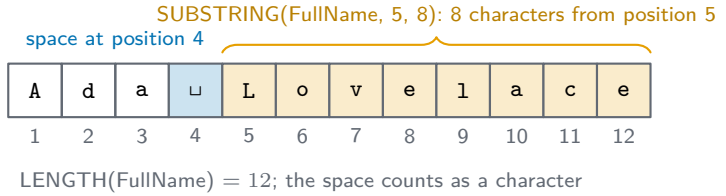


The three families of operators: arithmetic, relational and logical

```
IF Age >= 13 AND Age <= 19
  THEN
    OUTPUT "Teenager"
ENDIF
```

String handling

A string is made of characters. Useful operations:



Positions start at 1 and the space is a character: the surname is the 8 characters from position 5

- **length** 长度 – the number of characters in the string;
- **substring** 子串 – a smaller part taken from the string;
- **upper case** 大写 – change letters to capitals;
- **lower case** 小写 – change letters to small letters.

```
name ← "Computer"
OUTPUT LENGTH(name)          // 8
OUTPUT SUBSTRING(name, 1, 4) // "Comp"
OUTPUT UCASE(name)           // "COMPUTER"
OUTPUT LCASE(name)           // "computer"
```

(The first character may be counted as position 0 or position 1, depending on the language.)

In exam pseudocode the first character is at position 1, and `SUBSTRING(name, start, length)` takes `length` characters starting at `start`.

Worked example. Output the surname from a full name such as `"Ada Lovelace"`.

```
FullName ← "Ada Lovelace"
Position ← 0
FOR I ← 1 TO LENGTH(FullName)
    IF SUBSTRING(FullName, I, 1) = " "
      THEN
        Position ← I
    ENDIF
NEXT I
OUTPUT SUBSTRING(FullName, Position + 1, LENGTH(FullName) - Position)
```

1. `LENGTH(FullName)` is 12 (the space counts as a character).
2. The loop checks one character at a time; the space is at position 4, so `Position` is 4.
3. The surname starts at position 5 and has $12 - 4 = 8$ characters: `SUBSTRING(FullName, 5, 8)` is `"Lovelace"`.

Nested statements

A **nested statement** 嵌套语句 is one control structure placed **inside** another. You can nest selection and iteration.

```
FOR I ← 1 TO 3
    IF MOD(I, 2) = 0
      THEN
        OUTPUT I, " is even"
      ELSE
        OUTPUT I, " is odd"
    ENDIF
NEXT I
```

You will not have to write more than three levels of nesting.

Procedures and functions

To avoid repeating code, you can break a program into named blocks.

- A **procedure** 过程 is a named block of code that does a task. You run it with `CALL`.
- A **function** 函数 is like a procedure, but it **returns a value** back to where it was called.

A **parameter** 参数 is a named input in a procedure or function; a call supplies its value. Exam questions use up to three parameters.

```
PROCEDURE Greet(PersonName : STRING)
    OUTPUT "Hello ", PersonName
ENDPROCEDURE

CALL Greet("Sam")
```

```
FUNCTION Square(N : INTEGER) RETURNS INTEGER
    RETURN N * N
ENDFUNCTION

Answer ← Square(5)   // answer is 25
```

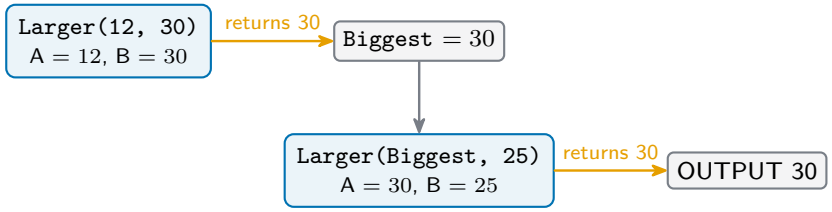
Worked example. Write a function that returns the larger of two numbers, and use it.

```
FUNCTION Larger(A : INTEGER, B : INTEGER) RETURNS INTEGER
    DECLARE Result : INTEGER
    IF A > B
      THEN
        Result ← A
      ELSE
        Result ← B
    ENDIF
    RETURN Result
ENDFUNCTION

Biggest ← Larger(12, 30)
OUTPUT Larger(Biggest, 25)
```

`Larger(12, 30)` returns 30, which is stored in `Biggest`; `Larger(30, 25)` returns 30, which is output. `A`, `B` and `Result` are **local**: they exist only while the function runs. A function's result must be **used**, in an assignment or an output; a procedure is run on its own line with `CALL` and gives nothing back.

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A, B and Result are local: they exist only while each call runs

Each function call returns a value that must be used: stored in Biggest, then output

Local and global variables

- A **local variable** 局部变量 is declared inside a procedure or function. It can only be used there.
- A **global variable** 全局变量 is declared in the main program. It can be used anywhere.

Local variables are safer, because they cannot be changed by mistake from another part of the program.

Library routines

A **library routine** 库程序 is a ready-made piece of code you can use. You must know these:

Routine	What it does
`MOD`	gives the remainder of a division
`DIV`	gives the whole-number part of a division
`ROUND`	rounds a real number to a number of decimal places
`RANDOM`	gives a random number

Call	Result
`MOD(17, 5)`	2
`DIV(17, 5)`	3
`ROUND(3.14159, 2)`	3.14
`ROUND(7.46, 1)`	7.5
`RANDOM()`	a random real number from 0 to 1

`MOD(Number, 2) = 0` tests whether a number is even; `DIV(Seconds, 60)` and `MOD(Seconds, 60)` split 135 seconds into 2 minutes and 15 seconds.

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Writing a maintainable program

A **maintainable** 可维护的 program is easy for other people to read and change later. To make one:

- use **meaningful identifiers** 有意义的标识符 – clear names for variables, constants, arrays, procedures and functions (`totalScore`, not `x`);
- add **comments** 注释 to explain what parts of the code do;
- use procedures and functions to split the work into small blocks.

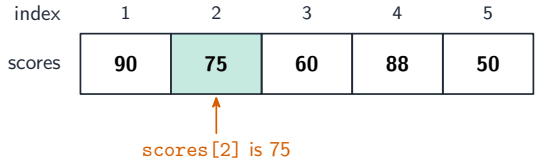
Arrays

An **array** 数组 is a single variable that holds **many values** of the same type, found by an **index** 索引 (a position number).

One-dimensional arrays

A **one-dimensional (1D) array** 一维数组 is like a single list.

```
DECLARE Scores : ARRAY[1:5] OF INTEGER
Scores[1] ← 90
Scores[2] ← 75
OUTPUT Scores[1]
```



A 1D array holds many values in one variable; each is found by its index

You can use a loop to fill or read an array:

```
FOR I ← 1 TO 5
    INPUT Scores[I]
NEXT I
```

Worked example. Find the highest score in `Scores` and its position. `Scores` holds 90, 75, 98, 61, 98.

```
DECLARE Scores : ARRAY[1:5] OF INTEGER
Scores[1] ← 90
Scores[2] ← 75
Scores[3] ← 98
Scores[4] ← 61
Scores[5] ← 98

Highest ← Scores[1]
Place ← 1
FOR I ← 2 TO 5
    IF Scores[I] > Highest
      THEN
        Highest ← Scores[I]
        Place ← I
    ENDIF
NEXT I
OUTPUT "Highest ", Highest, " at position ", Place
```

I	Scores[I]	> Highest?	Highest	Place
start			90	1
2	75	no	90	1
3	98	yes	98	3
4	61	no	98	3
5	98	no	98	3

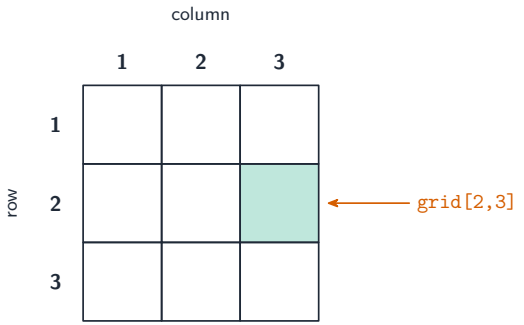
The output is `Highest 98 at position 3`. Starting `Highest` at the first element, not at 0, makes it work for negative values too; with `>=` instead of `>`, the **last** 98 would be found (position 5).

Two-dimensional arrays

A **two-dimensional (2D) array** 二维数组 is like a table with rows and columns. It uses two indexes.

```
DECLARE Grid : ARRAY[1:3, 1:3] OF INTEGER
Grid[1, 1] ← 5
Grid[2, 3] ← 8
```


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A 2D array is a table; each value is found by two indexes, [row, column]

You read a 2D array with a loop inside a loop (nested iteration).

Worked example. `Marks[1:3, 1:2]` holds two test marks for each of three students (rows). Output each student's total.

	Column 1	Column 2
Row 1	12	15
Row 2	9	11
Row 3	14	18

```
DECLARE Marks : ARRAY[1:3, 1:2] OF INTEGER
Marks[1, 1] ← 12
Marks[1, 2] ← 15
Marks[2, 1] ← 9
Marks[2, 2] ← 11
Marks[3, 1] ← 14
Marks[3, 2] ← 18

FOR Row ← 1 TO 3
    Total ← 0
    FOR Col ← 1 TO 2
        Total ← Total + Marks[Row, Col]
    NEXT Col
    OUTPUT "Student ", Row, ": ", Total
NEXT Row
```

The outer loop picks a student; the inner loop adds that student's two marks. The output is 27, 20 and 32. `Total ← 0` must be **inside** the outer loop: placed before it, the totals would run on to 27, 47 and 79.

A complete scenario program

The last question on Paper 2 asks you to write a whole program for a scenario, using arrays. Marks are given for each required part, so plan the parts before you write.

> **Worked example.** A weather station records the midday temperature for each of the 7 days of a week. Write a program that:
>
> - inputs the 7 temperatures into an array, accepting only values from −20 to 50;
> - outputs the average temperature for the week;
> - outputs how many days were above that average, and which day was the hottest.

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Plan. (1) declare the array and variables; (2) a loop of 7 inputs, each with a validation loop; (3) a running total, then the average; (4) a second loop to count days above the average and find the highest; (5) outputs with messages.

```
DECLARE Temps : ARRAY[1:7] OF REAL
DECLARE Day, AboveCount, HotDay : INTEGER
DECLARE Total, Average : REAL

Total ← 0
FOR Day ← 1 TO 7
    OUTPUT "Enter the temperature for day ", Day
    INPUT Temps[Day]
    WHILE Temps[Day] < -20 OR Temps[Day] > 50 DO
        OUTPUT "Invalid: enter a value from -20 to 50"
        INPUT Temps[Day]
    ENDWHILE
    Total ← Total + Temps[Day]
NEXT Day

Average ← Total / 7
OUTPUT "Average temperature: ", ROUND(Average, 1)

AboveCount ← 0
HotDay ← 1
FOR Day ← 1 TO 7
    IF Temps[Day] > Average
      THEN
        AboveCount ← AboveCount + 1
    ENDIF
    IF Temps[Day] > Temps[HotDay]
      THEN
        HotDay ← Day
    ENDIF
NEXT Day

OUTPUT "Days above average: ", AboveCount
OUTPUT "Hottest day: ", HotDay, " at ", Temps[HotDay]
```

Why it scores. Each required part is there and easy to find: the validation loop **re-asks** until the value is in range (an `IF` would check only once); the total is added **after** the value is valid; the average is found **after** the loop, not inside it; the count starts at 0 and the hottest day starts at day 1, so it is always a real reading. The days above average need a **second** loop, because the average is not known until every value has been entered.

Common mistakes. Dividing by 7 inside the first loop; comparing with the average before it exists; starting the highest at 0 (wrong if every temperature is negative); and

outputs with no message saying what each number is.

File handling

A program can store data in a **file** 文件 so it is kept after the program stops. You must **open** the file, use it, then **close** it.

```
OPENFILE "data.txt" FOR WRITE
WRITEFILE "data.txt", "Hello"
CLOSEFILE "data.txt"

OPENFILE "data.txt" FOR READ
READFILE "data.txt", Line
CLOSEFILE "data.txt"
```

You can read and write single items of data or a whole line of text. Always close a file when you have finished with it.

Worked example. Save the five values of `Scores` to a file, one per line, then read the first one back.

```
DECLARE Scores : ARRAY[1:5] OF INTEGER
Scores[1] ← 90
Scores[2] ← 75
Scores[3] ← 98
Scores[4] ← 61
Scores[5] ← 98

OPENFILE "scores.txt" FOR WRITE
FOR I ← 1 TO 5
    WRITEFILE "scores.txt", Scores[I]
NEXT I
CLOSEFILE "scores.txt"

OPENFILE "scores.txt" FOR READ
READFILE "scores.txt", FirstScore
CLOSEFILE "scores.txt"
OUTPUT FirstScore
```

Each `WRITEFILE` adds one line, so the file holds five lines; reading starts at the top, so `FirstScore` is the first score. Opening a file `FOR WRITE` starts it empty: anything already in it is lost.

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Exam tips

- For the long scenario question, list the required parts first, then make sure each one appears in your code, with **comments or messages** that show where.
- A **variable** can change while the program runs; a **constant** is fixed. Learn the five data types: integer, real, char, string, Boolean.
- Every program is built from three structures: **sequence**, **selection** (IF / CASE), and **iteration** (loops).
- A **WHILE** loop tests *before* the body, so it may run zero times; a **REPEAT ... UNTIL** loop tests *after*, so it always runs at least once.
- `MOD` gives the remainder and `DIV` the whole-number part of a division: `17 MOD 5` is 2, `17 DIV 5` is 3.
- A **function** returns a value; a **procedure** does not. A **local** variable works only inside its block; a **global** one works anywhere.

Databases

IGCSE Computer Science

What is a database?

A **database** 数据库 is an organised store of data, kept so that it is easy to search, sort and update. At IGCSE you work with a **single-table database** 单表数据库 – all the data is held in one table.



A library card catalogue is a database on paper – records you can search and sort by index



Large modern databases are stored on servers in data centres

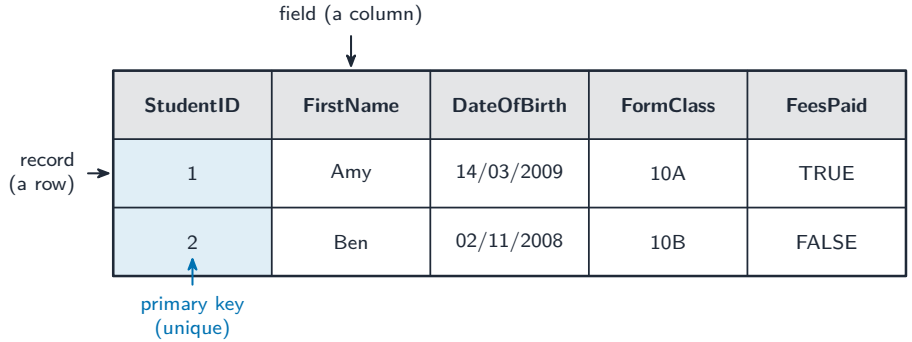
Records and fields

A database table is made of records and fields.

- A **record** 记录 is one row in the table – all the data about one thing (for example one student).
- A **field** 字段 is one column in the table – one piece of data that every record has (for example "First name").

StudentID	FirstName	DateOfBirth	FormClass	FeesPaid
1	Amy	14/03/2009	10A	TRUE
2	Ben	02/11/2008	10B	FALSE

Here each **row** is a record, and each **column** is a field.



Each row is a record and each column is a field; the primary key (StudentID) is unique for every record

Data types for fields

Each field stores one **data type** 数据类型. You choose the type that best fits the data.

field	Name	Initial	Member	Age	Height	Joined
record	Amy	'M'	TRUE	42	1.62	14/03/2009
data type	*text/ alphanumeric*	*character*	*Boolean*	*integer*	*real*	*date/time*

Each field in a record holds one data type

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Data type	Used for	Example
text/alphanumeric 文本	letters, digits and symbols	“10A”, “Amy”
character 字符	a single character	’M’
Boolean 布尔值	one of two values	TRUE / FALSE
integer 整数	a whole number	42
real 实数	a number with a decimal point	3.5
date/time 日期时间	a date or a time	14/03/2009

Worked example. Choose the data type for each field of a `Member` table.

Field	Example	Data type	Why
MemberID	M0042	text	it has a letter
Phone	07712 345678	text	starts with 0; never used in sums
Age	15	integer	a whole number
Fee	12.50	real	has a decimal point
Gender	F	character	one character
Paid	TRUE	Boolean	only two values
Joined	01/09/2025	date/time	a date

A phone number looks like a number, but it is a common exam trap: stored as an integer it would lose its first `0`, and no one adds phone numbers together.

The primary key

A **primary key** 主键 is a field that holds a **unique** 唯一的 value for every record. No two records can have the same primary key, so it lets you pick out exactly one record.

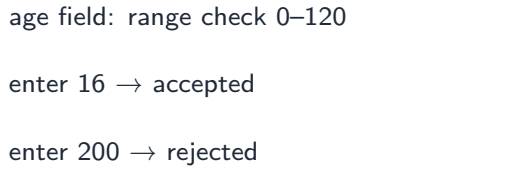
In the table above, `StudentID` is a good primary key because every student has a different number. A field like `FormClass` would be a bad primary key, because many students share the same class.

Worked example. Which field of the `Member` table above should be the primary key? `MemberID`, because each member is given a different one. `Age`, `Fee` and `Joined` repeat; even a name such as `Surname` is a poor choice, because two members can share a surname. A good answer names the field **and** says it is unique for every record.

Validation in a database

When data is put into a database, **validation** 验证 checks make sure it is sensible – for example a range check on an age field, or a presence check so a field is not left empty. (You saw these checks in topic 7.)

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A range check accepts sensible values and rejects the rest

Field	Suitable check	Rejects
Age	range check, 11 to 18	200
Surname	presence check	an empty field
Phone	length check, 11 characters	0771234
Fee	type check, a number	“twelve”
Joined	format check, DD/MM/YYYY	2025-9-1

Worked example (designing a table). A dance school wants to store, for each pupil: a pupil number, the pupil’s name, date of birth, the grade of their last exam (1 to 8), whether they have paid this term, and the monthly fee. Define a suitable single-table database.

Field	Data type	Validation
PupilID (primary key)	text, e.g. “D0153”	presence check; format check (D + 4 digits)
PupilName	text	presence check
DateOfBirth	date/time	format check, DD/MM/YYYY
LastGrade	integer	range check, 1 to 8
PaidThisTerm	Boolean	type check, TRUE/FALSE
MonthlyFee	real	range check, greater than 0

Give the table a name (here `Pupil`), one field for each item of data, a data type for each field, and say which field is the primary key and why: `PupilID` is different for every pupil, while two pupils could share a name or a date of birth.

Structured Query Language (SQL)

Structured Query Language 结构化查询语言 (SQL) is a language used to **query** 查询 a database – to pick out the records you want. You must understand and complete SQL scripts.

SELECT, FROM and WHERE

- `SELECT` says **which fields** to show.
- `FROM` says **which table** to use.
- `WHERE` gives a **condition** 条件, so only matching records are shown.

```
SELECT name
FROM students
WHERE age > 15
```

gets the names of students older than 15

SELECT picks fields, FROM names the table, WHERE sets the condition

```
SELECT FirstName, FormClass
FROM Student
WHERE FeesPaid = TRUE;
```

This shows the first name and class of every student who has paid the fees.

Use `*` to select **all** fields:

```
SELECT *
FROM Student
WHERE FormClass = '10A';
```

ORDER BY

`ORDER BY` sorts the results. Use `ASC` for **ascending** 升序 (smallest first, A→Z) or `DESC` for **descending** 降序 (largest first, Z→A).

```
SELECT FirstName, DateOfBirth
FROM Student
ORDER BY DateOfBirth ASC;
```

AND and OR

Join conditions with `AND` (both must be true) or `OR` (at least one must be true).

Conditions use these comparison operators:

Operator	Meaning	Example
`=`	equal to	`FormClass = '10A'`
`<>`	not equal to	`FormClass <> '10A'`
`>` and `<`	greater than, less than	`Height > 100`
`>=` and `<=`	greater than or equal to, less than or equal to	`Price <= 5.00`

```
SELECT FirstName
FROM Student
WHERE FormClass = '10A' AND FeesPaid = FALSE;
```

SUM and COUNT

- `SUM` adds up the values in a number field.
- `COUNT` counts how many records match.

```
SELECT COUNT(StudentID)
FROM Student
WHERE FeesPaid = FALSE;
```

This counts how many students have not paid. `SUM` works the same way but adds a number field instead of counting rows.

```
SELECT SUM(Fee)
FROM Member
WHERE Paid = TRUE;
```

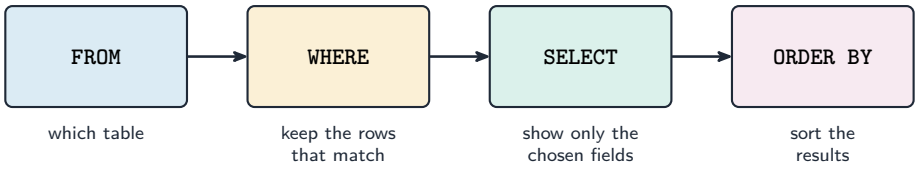
This adds up the `Fee` of every member who has paid and shows one number. `SUM` needs a number field (integer or real); `COUNT` can count any field.

Working out the output

To find the output of an SQL script, read it in this order:

1. `FROM` – which table;
2. `WHERE` – keep only the records that match the condition;
3. `SELECT` – show only the chosen fields;
4. `ORDER BY` – put the results in order.

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Read an SQL query in this order: FROM (which table), WHERE (which rows), SELECT (which fields), ORDER BY (sort)

Following these steps, you can write down exactly which rows and columns the query returns.

Worked example. The `Plant` table:

PlantID	Name	Type	Height	Price
P01	Rose	shrub	120	8.50
P02	Basil	herb	30	2.00
P03	Holly	shrub	300	15.00
P04	Mint	herb	40	1.50
P05	Lavender	shrub	60	6.00

Give the output of:

```
SELECT Name, Price
FROM Plant
WHERE Type = 'shrub' AND Height < 200
ORDER BY Price DESC;
```

1. `FROM`: the `Plant` table.
2. `WHERE`: shrubs are P01, P03 and P05; Holly is 300 tall, so only Rose and Lavender pass.
3. `SELECT`: only `Name` and `Price`.
4. `ORDER BY Price DESC`: the dearest first.

Name	Price
Rose	8.50
Lavender	6.00

`SELECT COUNT(PlantID) FROM Plant WHERE Type = 'herb';` would give `2`, and `SELECT SUM(Price) FROM Plant WHERE Type = 'herb';` would give `3.50`.

With **OR** instead, more records pass: `SELECT Name FROM Plant WHERE Type = 'herb' OR Price > 10;` gives Basil, Holly and Mint (the two herbs, and Holly because its price is over 10). A record that meets **both** conditions is still shown only once.

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Worked example. A `Book` table has the fields `Title`, `Author`, `Price` and `InStock`. Write a query showing the title and price of every book by Orwell that is in stock, cheapest first.

```
SELECT Title, Price
FROM Book
WHERE Author = 'Orwell' AND InStock = TRUE
ORDER BY Price ASC;
```

Build it in the reading order: `FROM` names the table; `WHERE` keeps only the matching records, and because there are two conditions they need `AND`; `SELECT` shows only the two fields asked for; `ORDER BY … ASC` sorts them. Text values go in **quotes**, and only the fields the question asks for belong in `SELECT` - adding `Author` just because you filtered on it is the commonest way to lose a mark here.

Exam tips

- A **record** is a row (all the data about one thing); a **field** is a column (one item that every record has).
- A **primary key** must be *unique* for every record, so it picks out exactly one record (StudentID, not FormClass).
- Learn the SQL parts: `SELECT` (which fields), `FROM` (which table), `WHERE` (the condition), `ORDER BY` (sort, ASC or DESC).
- Read a query in the order **FROM → WHERE → SELECT → ORDER BY** to work out its output.
- `COUNT` counts the matching records; `SUM` adds up a number field.
- To design a table, give each field a name, a data type and a validation check, and justify the primary key.
- `<>` means "not equal to"; text values need quotes, numbers and TRUE/FALSE do not.

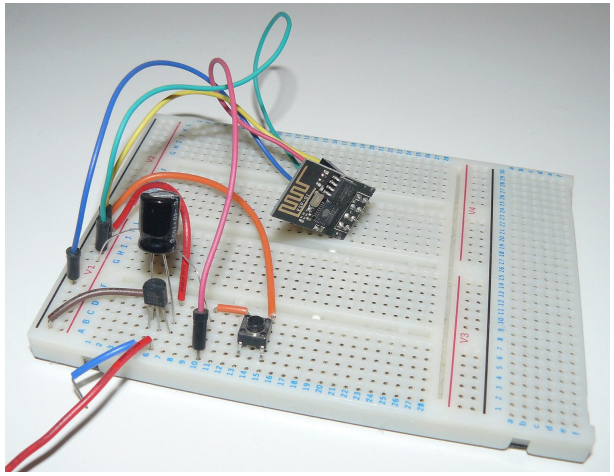
Boolean logic

IGCSE Computer Science

What is Boolean logic?

Boolean logic 布尔逻辑 works with values that are either **true** or **false**. In electronics these are shown as **1** (true) and **0** (false). A **logic gate** 逻辑门 takes one or more of these inputs and gives one output, following a fixed rule.

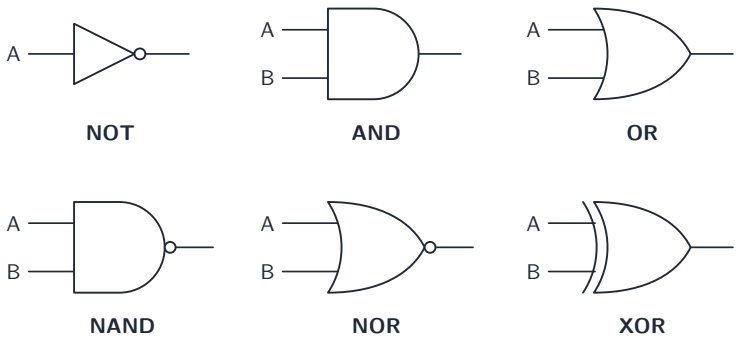
A **truth table** 真值表 lists every possible set of inputs and the output for each. You build it by writing out all the input combinations.



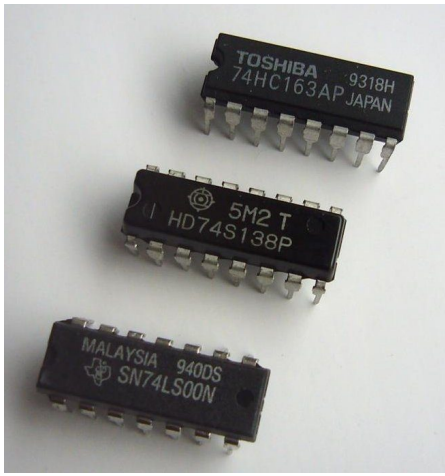
Logic gates are built from electronic circuits like this one, where each gate switches on 1s and 0s

The six logic gates

You must know six gates. `NOT` has one input; all the others have two inputs (A and B).



The six logic gates. A small circle on the output means the result is inverted (NOT, NAND, NOR)



A real logic chip: inside are logic gates like the ones on this page

NOT gate

The **NOT gate** 非门 reverses the input. Output is 1 when the input is 0.

A	Output
0	1
1	0

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AND gate

The **AND gate** 与门 gives output 1 **only when both** inputs are 1.

A	B	A · B
0	0	0
0	1	0
1	0	0
1	1	1

AND

AND outputs 1 only when both inputs are 1

A	B	Output
0	0	0
0	1	0
1	0	0
1	1	1

OR gate

The **OR gate** 或门 gives output 1 when **at least one** input is 1.

A	B	A+B
0	0	0
0	1	1
1	0	1
1	1	1

OR

OR outputs 1 when either input is 1

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A	B	Output
0	0	0
0	1	1
1	0	1
1	1	1

NAND gate

The **NAND gate** 与非门 is AND followed by NOT. The output is the **opposite** of AND.

A	B	Output
0	0	1
0	1	1
1	0	1
1	1	0

NOR gate

The **NOR gate** 或非门 is OR followed by NOT. The output is the **opposite** of OR.

A	B	Output
0	0	1
0	1	0
1	0	0
1	1	0

XOR gate

The **XOR gate** 异或门 (exclusive OR) gives output 1 when the inputs are **different**.

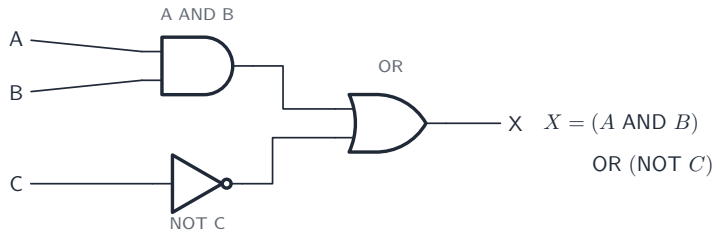
A	B	Output
0	0	0
0	1	1
1	0	1
1	1	0

Logic expressions

A **logic expression** 逻辑表达式 writes a circuit using letters and gate words. The usual way to write the gates:

Gate	In words
NOT A	NOT A
A AND B	A AND B
A OR B	A OR B
A NAND B	A NAND B, the same as NOT (A AND B)
A NOR B	A NOR B, the same as NOT (A OR B)
A XOR B	A XOR B

For example, the expression `(A AND B) OR (NOT C)` means: do A AND B, do NOT C, then OR the two results together.

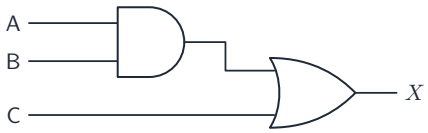


The expression X = (A AND B) OR (NOT C) drawn as a logic circuit

Logic circuits

A **logic circuit** 逻辑电路 joins gates together to carry out a task. The output of one gate can become the input of another. At IGCSE a circuit has up to **three inputs** and **one output**.

$X = (A$ **AND** $B)$ **OR** C



Building the circuit for X = (A AND B) OR C – the AND gate's output feeds the OR gate

You must be able to move between four forms:

- a **problem statement** 问题陈述 (a description in words),
- a logic expression,
- a logic circuit,
- a truth table.

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From a problem statement to a circuit

Read the statement and pick out the conditions and the logic words (and, or, not). For example:

> An alarm (X) sounds when the door is open (A) AND the system is switched on (B).

This is `X = A AND B`, so you draw one AND gate with inputs A and B.

Some words point to the other gates:

The statement says...	Gate
"either A or B, **but not both**", "exactly one of"	XOR
"**neither** A nor B"	NOR
"**not both** A and B"	NAND
"A is **off**", "A is **not** on"	NOT A

For example, "a hall light (X) is on when exactly one of the two switches (A, B) is up" is `X = A XOR B`; "a warning light (X) is on when neither the brake (A) nor the clutch (B) is pressed" is `X = A NOR B`.

Completing a truth table from a circuit or expression

To fill in a truth table:

1. Write **all** the input combinations. For three inputs there are 8 rows (000 up to 111).
2. Work out each gate's output in order, one column at a time.
3. The last column is the final output.

3 inputs ⇒ $2 \times 2 \times 2 = 8$ rows

A	B	C
0	0	0
0	0	1
0	1	0
0	1	1
1	0	0
1	0	1
1	1	0
1	1	1

list **every** combination - count up in binary, from 000 to 111

the last column flips every row, the next every two rows, the first every four

Three inputs give eight rows: every combination counted in binary

A	B	C	A AND B	(A AND B) OR C
0	0	0	0	0
0	0	1	0	1

A	B	C	A AND B	(A AND B) OR C
0	1	0	0	0
0	1	1	0	1
1	0	0	0	0
1	0	1	0	1
1	1	0	1	1
1	1	1	1	1

Adding a middle "working" column for each gate makes the final output easy to fill in. Always draw the circuit exactly as the statement says, **without simplifying** it.

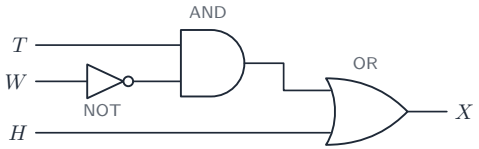
> **Worked example.** Complete the truth table for `X = (A AND B) OR (NOT C)` for the row A = 1, B = 0, C = 0. Work **outwards from the brackets**, one gate at a time. First `A AND B` = 1 AND 0 = **0**, because AND needs both inputs to be 1. Next `NOT C` = NOT 0 = **1**. Finally OR the two results: 0 OR 1 = **1**. So X = **1**. Give each intermediate gate **its own column** rather than trying to do the whole expression in one step: with three inputs there are $2^3 = 8$ rows, and those intermediate columns are where the method marks live even if the final answer slips.

> **Worked example (all four forms).** A greenhouse fan (X) switches on if the temperature is high (T) and the window is **not** open (W), or if the humidity is high (H).

Step 1: expression. "and the window is not open" is `T AND NOT W`; "or" joins H: `X = (T AND NOT W) OR H`.

Step 2: circuit. W goes through a NOT gate first; its output and T go into an AND gate; the AND output and H go into an OR gate.

$X = (T$ **AND NOT** $W)$ **OR** H



The greenhouse fan: one NOT, one AND and one OR gate

Step 3: truth table. Eight rows, with a working column for each gate:

T	W	H	NOT W	T AND NOT W	X
0	0	0	1	0	0
0	0	1	1	0	1

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T	W	H	NOT W	T AND NOT W	X
0	1	0	0	0	0
0	1	1	0	0	1
1	0	0	1	1	1
1	0	1	1	1	1
1	1	0	0	0	0
1	1	1	0	0	1

Step 4: check against the words. Whenever H = 1 the fan is on (rows 2, 4, 6, 8); otherwise it is on only for T = 1, W = 0 (row 5). Five rows give X = 1.

Going the other way, **from a circuit to an expression**, start at the inputs and write each gate's output on its wire, then join them at the last gate. Use brackets around each gate's result so the order is clear.

> **Worked example (circuit to expression).** In a circuit, A and B go into a NAND gate; B and C go into an XOR gate; the outputs of these two gates go into an AND gate, whose output is X. Write the expression. Label each wire as you go: the NAND output is `(A NAND B)`, the XOR output is `(B XOR C)`, so `X = (A NAND B) AND (B XOR C)`. For the row A = 1, B = 1, C = 0: A NAND B = **0** (both inputs are 1), so X = 0 whatever the XOR gives.

■ From a truth table to an expression or circuit

Look only at the rows where the output is **1**. For each of those rows, write the inputs joined by AND, putting NOT in front of any input that is 0. Then join the row terms with OR.

> **Worked example.** Write a logic expression for this truth table, and describe the circuit.

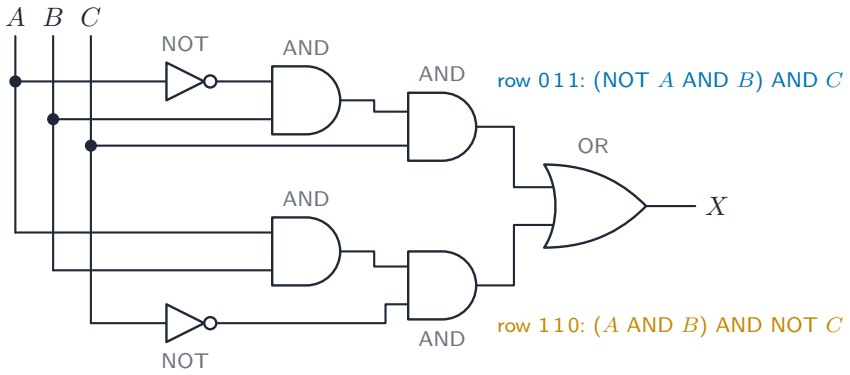
A	B	C	X
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	1
1	0	0	0
1	0	1	0
1	1	0	1
1	1	1	0

X = 1 in two rows. Row `0 1 1`: A is 0, so it is `(NOT A AND B) AND C`. Row `1 1 0`:

C is 0, so it is `(A AND B) AND NOT C`. Join them with OR:

`X = ((NOT A AND B) AND C) OR ((A AND B) AND NOT C)`

The circuit follows the expression: two NOT gates (for A and for C), four two-input AND gates (each row term needs two, because gates have at most two inputs), and one OR gate to combine the two terms. Check one row: for `0 1 1`, the first term is (1 AND 1) AND 1 = 1, so X = 1, as in the table.



One AND term for each row where X = 1, joined by an OR gate

An expression made this way is not always the shortest one, but it is always correct, and the exam does not ask you to simplify it.

Exam tips

- Learn all six gates and their truth tables: **NOT**, **AND**, **OR**, **NAND** (NOT AND), **NOR** (NOT OR), **XOR** (output 1 when the inputs are different).
- Build a truth table with *all* input rows (2 inputs → 4 rows, 3 inputs → 8), counting up in binary, and add a working column for each gate.
- Turn a problem statement into a logic expression by picking out the AND / OR / NOT words, then draw it exactly as written – **do not simplify** it.
- NAND and NOR give the *opposite* output to AND and OR; a small circle on a gate's output means the result is inverted.
- From a truth table, take each row with output **1**, AND its inputs (with NOT for each 0), then OR the row terms together.
- "Exactly one" or "but not both" means **XOR**; "neither … nor" means **NOR**.

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