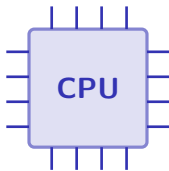


Hardware

AS Computer Science ■ Topic 3

A-Level Computer Science



What we will cover

3.1 Computers and their components: overview

3.1.1 Primary memory: RAM, ROM and their types

3.1.2 Secondary storage

3.1.3 Input and output devices, and buffers

3.1.4 Embedded systems, monitoring and control

3.2 The six logic gates

3.2.1 Reading a logic circuit

3.2.2 Building a logic circuit

Each part of this deck has the number of its exercise sheet and past-paper sheet.





The four building blocks



primary memory (RAM/ROM) is fast and direct; **secondary storage** is large and keeps data without power.



Microphone photo

Input and output devices



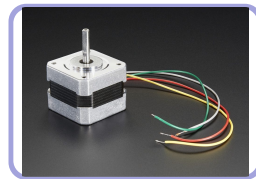
keyboard
input



monitor
output



laser printer
output



motor (actuator)
output

Laser printer : a charged **drum** attracts **toner** , which heat then fuses onto the paper.

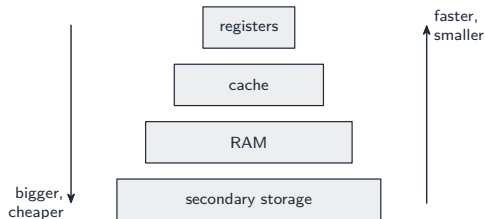
Why a computer needs secondary storage

RAM is **volatile**, small and expensive.

Secondary storage is:

- **non-volatile**: it keeps the operating system, the programs and the files when the power is off
- **large**, and cheap for each GB
- not read directly by the processor: data is copied into RAM first

Removable storage (USB drive, memory card, optical disc) **moves files** between computers and keeps a **backup** in a different place.





RAM and ROM

RAM

volatile , read/write
– running programs

ROM

non-volatile , read-only
– firmware

ROM: start-up firmware

power on: load

RAM: OS + programs run here

power off: RAM **cleared** ▪ ROM **kept**

RAM against ROM

RAM

volatile — lost at power off
read *and* write
holds running programs & data

ROM

non-volatile — kept at power off
read-only
holds start-up instructions

RAM is **volatile** working memory that the processor writes to; ROM holds what must survive a power cut, such as the bootstrap.

RAM is volatile working memory that loses everything at power-off; **ROM** is non-volatile and holds the start-up code.

What is held in RAM, and what in ROM?

Ask one question about each item: [does it change while the device is running?](#)

In a microwave oven	held in	because
the program that runs the cooking cycles	ROM	it never changes, and it must be there at switch-on
the cooking time the user has typed in	RAM	it changes with every use
the time that is left	RAM	it changes every second

ROM: start-up instructions (bootstrap) and **firmware** . **RAM:** the programs and data in use now, and the part of the operating system in use.

Memory variants

SRAM RAM

transistors in flip-flops;
fast, costly – CPU **cache**

DRAM RAM

capacitors, must be **refreshed**
thousands of times a sec-
ond; dense – main memory

ROM you can program later

PROM – written once, fuses burned

EPROM – UV light erases the whole
chip

EEPROM – erased electrically, a byte at
a time, in circuit (flash is its descendant)

SRAM or DRAM? Choose, and justify

	SRAM (static)	DRAM (dynamic)
a bit is stored in refresh access speed	a flip-flop (several transistors) not needed faster	one transistor and one capacitor needed: the charge leaks away slower
bits per chip, cost	fewer bits, dearer per bit	more bits, cheaper per bit
power used for	lower cache	higher (because of the refresh) main memory

A full answer has two parts: a **property**, and **why it suits the use**. “SRAM is faster, and cache must supply data to the processor with as little delay as possible.”

PROM, EPROM and EEPROM

	can it be erased?	how?	inside the device?
PROM	no: programmed once	–	–
EPROM	yes, many times	ultraviolet light ; the whole chip	no: the chip is taken out
EEPROM	yes, many times	an electrical signal; part of the contents	yes , in place

A smart TV receives a firmware update over the internet. Nobody opens the TV, so its firmware must be in **EEPROM**: only EEPROM is erased and rewritten electrically, in place.



“Describe the principal operation of ...”

One mark for each correct point, so write short sentences in this order:

- 1 name the **parts**;
- 2 say **what happens**, step by step, with the technical words;
- 3 finish with the **result**: how a 1 or a 0 is stored or read, or what comes out.

Describing what the device is *for* earns nothing. “A hard disk stores files” is not its operation.

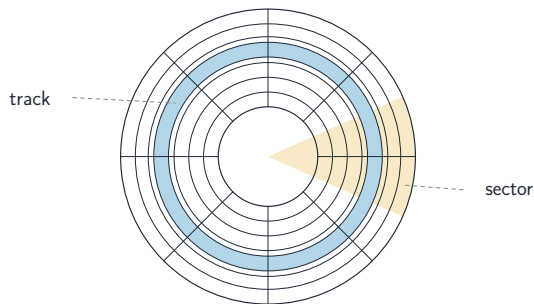
Magnetic hard disk

A **hard disk** stores bits as magnetised regions on spinning platters.

- a **read/write head** flies just above the surface
- data sits in concentric **tracks**, split into sectors
- cheap per GB, but mechanical – slower, and shock can crash the head



Tracks, sectors and the head



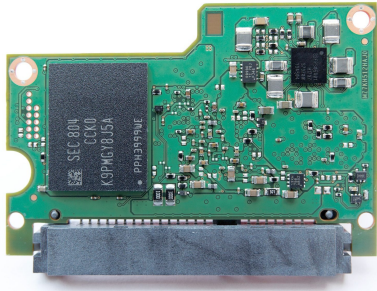
Access time is dominated by **seek** (moving the head to the track) and **latency** (waiting for the sector to arrive).

Data sits in concentric **tracks** divided into **sectors**; the head moves in and out while the platter spins, so access time is seek time plus rotational delay.

Magnetic hard disk: the marking points

- 1 One or more **platters**, each with a surface that can be **magnetised**.
- 2 The platters are on a **spindle** and spin at high speed.
- 3 Each surface is divided into **tracks**, and each track into **sectors**.
- 4 A **read/write head** on an **actuator arm** moves across the surface to the correct track.
- 5 **Write:** a current in the head makes a magnetic field that magnetises a tiny area in one of two directions, for 1 and 0.
- 6 **Read:** the magnetised areas pass under the head and produce a small changing current in it.

Solid-state and optical



solid-state drive : flash, no moving parts

SSD: faster, tougher, lower power – but dearer per GB and cells wear out.

Solid state (flash): how a bit is stored

- a grid of **transistors** , using **NAND** (or NOR) flash technology; **no moving parts**
- each cell has a **control gate** and a **floating gate**
- a voltage pushes electrons onto the floating gate, where an insulating layer **traps** them
- trapped electrons read as 0, no trapped electrons as 1; they stay without power
- data is erased and rewritten in **blocks**

Why an SSD in a laptop?

Faster access, robust when dropped, less power, lighter.

Why not everywhere?

Dearer per GB, and a limited number of erase cycles.

An optical disc

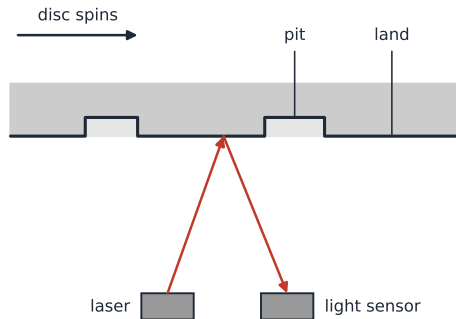


Pits and lands along a spiral track; a weak laser reads the reflections. The same drive **writes** with a stronger beam that burns the marks – CD, DVD and Blu-ray differ only in laser wavelength, and so in how small a pit can be.

Optical disc: reading and writing

- 1 A motor **spins** the disc, which has **one spiral track**.
- 2 A **laser** beam is focused on the track.
- 3 The track is made of **pits** and **lands**, which reflect the light differently.
- 4 A **light sensor** detects the reflected light.
- 5 A change between pit and land is read as 1; no change as 0.

Writing: a stronger laser heats spots in a dye layer, so that they reflect differently.



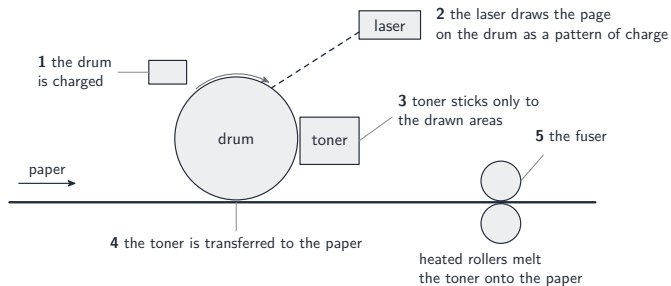
Choosing a storage device

	magnetic hard disk	solid state	optical disc
access speed	slow: moving parts	fast	slowest
capacity	very large	large	small
cost per GB	low	higher	low per disc
robustness	damaged by a knock	robust	scratches
power and noise	more	less	more

Ten years of CCTV video on a server: huge files, never moved, speed not important
⇒ magnetic hard disks. State the point *and* why it matters for this job.



Laser printer: six steps



1. the rotating drum is given a **charge**
2. the **laser** removes the charge at some points
3. **toner** sticks only to the drawn areas

4. the toner is **transferred** to the paper
5. the **fuser** **melts** the toner onto the paper
6. the charge is removed from the drum

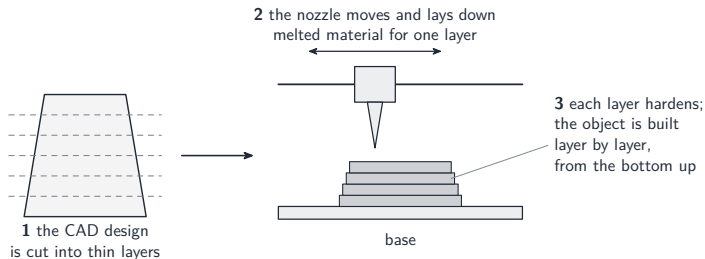
A 3D printer builds an object layer by layer



- **FDM** melts plastic filament through a moving nozzle
- **stereolithography** cures liquid resin with a UV laser
- either way the object grows one thin layer at a time

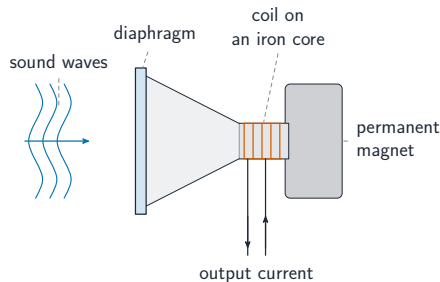
Used for prototypes, custom parts and medical models – anything where one item is wanted, not a thousand.

3D printer: from a design to an object



CAD design → cut into thin **layers** → the **nozzle** lays down melted material for one layer → the layer hardens → the next layer: the object is built **layer by layer**, from the bottom up (**additive manufacturing**).

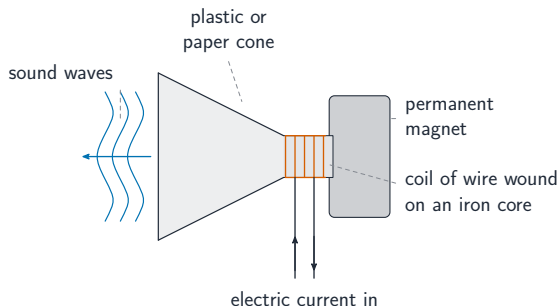
Microphone and loudspeaker



microphone : sound $\rightarrow$ signal

A **diaphragm** vibrates, changing a **capacitor** 's charge or a coil's position; an **analogue-to-digital converter** (ADC) digitises the signal. A loudspeaker runs the same parts backwards.

Inside the loudspeaker



A current in the coil sits in the magnet's field, so it is pushed in and out – the cone moves with it and pushes the air.

A current in the coil moves it in the magnet's field, the cone pushes the air, and you hear it. A microphone is the same parts run **backwards**.

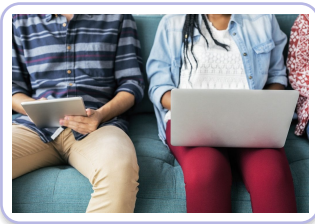
Input devices you should know



mouse – optical movement



scanner – reflected light



touchscreen – input *and* output

A **touchscreen** is both: **resistive** presses two conductive layers together (works with any object, less accurate); **capacitive** senses the change your finger makes to a charge grid (sharper, but needs skin or a special stylus).

Resistive or capacitive touchscreen?

	resistive	capacitive
layers	two conductive layers with a small gap	glass over a conductive layer that holds a charge
a touch	pressure pushes the layers together and completes a circuit	the finger takes a little charge, so the electric field changes
the position	calculated from the voltage at the point of contact	sensors at the corners measure the change
in use	works with a glove or a pen; cheaper	needs a bare finger; multi-touch; clearer

Virtual reality headset

- video is sent from the computer to the headset
- **two** slightly different images, one for each eye, make the scene look **3D**
- **lenses** focus and reshape the images
- sensors such as a **gyroscope** and an **accelerometer** detect the movement of the head
- the images are redrawn so that the view **follows the head**



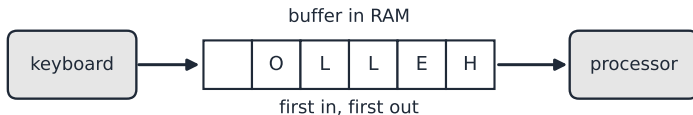
Buffers

A **buffer** holds data temporarily between devices of **different speeds**. The CPU writes to a printer buffer quickly, then works on; the printer prints from it at its own pace.



Buffers in exam questions

A **buffer** is a **temporary** storage area that holds data while it passes between two devices that work at **different speeds**. It is a **queue**: first in, first out.



printer: the computer sends the document quickly, then carries on **keyboard:** no key press is lost

streaming: video is downloaded ahead, so it plays smoothly



Embedded systems

An **embedded system** is a computer built into another device for one fixed job (washing machine, car engine, thermostat).

- + small, cheap, reliable, low power
- – locked to its one task; **firmware** updates may need special tools
- – often not repairable, and security is sometimes weak



“Explain why this is an embedded system”

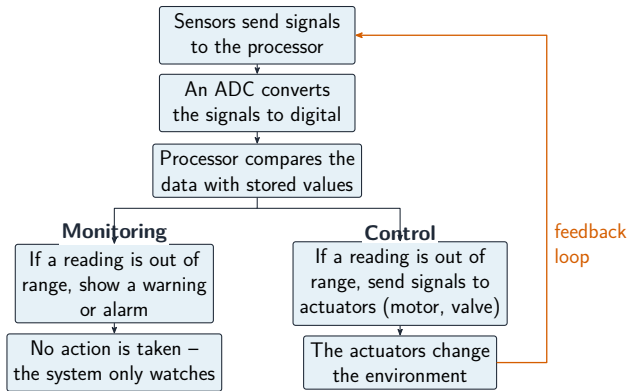
Make three points about [this](#) device:

- 1 it is a microprocessor system [inside a larger device](#);
- 2 it has [one dedicated task](#);
- 3 its program is in [ROM](#), and the user cannot install other software.

A laptop is not embedded: it is a general-purpose computer.

benefits	drawbacks
small, low power	hard to upgrade
cheap to mass-produce	hard to repair
reliable; starts at once	only one task
	can be hacked if never updated

Monitoring vs control



Both read **sensors** :

- **monitoring** : collects and reports, **takes no action** – a weather station logging readings
- **control** : **acts** via **actuators** in a **feedback loop**

Sensors and actuators

sensor	measures	used in
temperature	how hot or cold something is	an oven, a fridge, a greenhouse
pressure	a force pressing on an area	an alarm mat, a car tyre
infra-red	heat from a body, or a broken beam	an automatic door, a security light
sound	the loudness of a sound	a noise monitor, a glass-break alarm

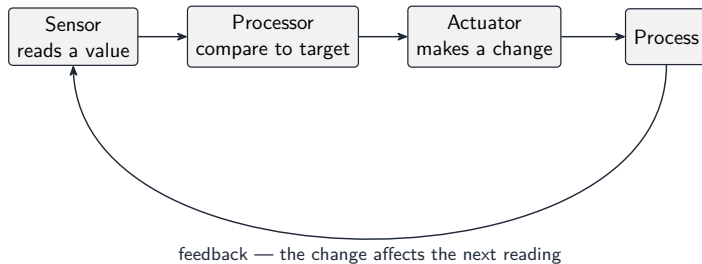
A sensor's signal is **analogue**, so an ADC converts it first. An **actuator** (motor, pump, valve, heater) turns the processor's signal into a **physical change**. There is no "weight sensor": weight is measured with a **pressure** sensor.

A sensor in a control system



A **thermistor** : its resistance falls as it warms, so a potential divider turns temperature into a voltage the ADC can read.

How a control system works: the answer in six steps



1. the **sensor** measures the value continuously
2. an **ADC** converts the reading to digital
3. it is **compared** with the **preset value**
4. too low: the **actuator** switches the heater on
5. high enough: the heater is switched off
6. **feedback** : the output changes the next reading;
repeat



Logic gates



NOT



AND



OR



NAND



NOR



XOR

A **logic gate** does one **Boolean** operation; inputs/outputs are 0 or 1. Know the symbol, function and **truth table** of each.

Truth tables

A	B	AND	OR	NAND	NOR	XOR
0	0	0	0	1	1	0
0	1	0	1	1	0	1
1	0	0	1	1	0	1
1	1	1	1	0	0	0

NOT: $0 \rightarrow 1, 1 \rightarrow 0$. **AND:** all 1. **OR:** any 1. **XOR:** inputs differ.

NAND, NOR and XOR: three quick rules

- **NAND**: work out AND, then **flip** every bit. The output is 0 only when both inputs are 1.
- **NOR**: work out OR, then **flip** every bit. The output is 1 only when both inputs are 0.
- **XOR**: the output is 1 when the two inputs are **different**. OR allows “both”; XOR does not.

NAND



NOR



XOR



A truth table for n inputs has 2^n rows, written by **counting up in binary**.

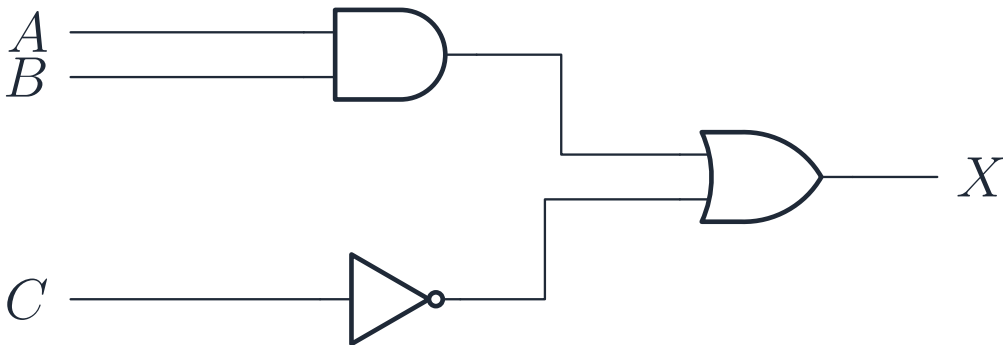


Logic circuits

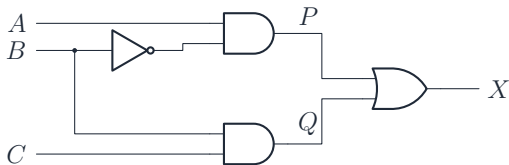
A **logic circuit** wires gates to do a Boolean expression – here

$$X = (A \text{ AND } B) \text{ OR } (\text{NOT } C).$$

Move freely between statement $\leftrightarrow$ expression $\leftrightarrow$ table $\leftrightarrow$ circuit.



From a circuit to an expression



Read from **left to right**, and name every gate's output:

1 $P = A \text{ AND NOT } B$ $Q = B \text{ AND } C$

2 $X = P \text{ OR } Q$

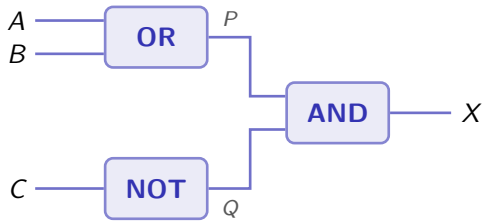
3 replace each name, **in brackets**:

$X =$

$$(A \text{ AND NOT } B) \text{ OR } (B \text{ AND } C)$$

The dot on the wire from B is a **junction**: one input that goes to two gates.

Worked example: from circuit to truth table



$$P = A \text{ OR } B, \quad Q = \text{NOT } C$$
$$X = P \text{ AND } Q$$

A	B	C	P	Q	X
0	0	0	0	1	0
0	0	1	0	0	0
0	1	0	1	1	1
0	1	1	1	0	0
1	0	0	1	1	1
1	0	1	1	0	0
1	1	0	1	1	1
1	1	1	1	0	0

Work **gate by gate**: add a column for every intermediate signal, then combine.

From an expression straight to a truth table

No circuit to look at, so the **brackets** give the order: one working column for each bracket.

$$X = (A \text{ OR } B) \text{ AND NOT } (A \text{ AND } B)$$

A	B	A OR B	A AND B	NOT (A AND B)	X
0	0	0	0	1	0
0	1	1	0	1	1
1	0	1	0	1	1
1	1	1	1	0	0

Fill one **whole column** at a time. The result is 1 when the inputs differ: three gates that do the job of one XOR gate.



From an expression to a circuit: three rules

- 1 One gate for each operator. Count the operators: NOT counts too.
- 2 Brackets first. The gate for a bracket is drawn on the left, and its output goes into the gate outside the bracket.
- 3 An input used twice is one input. Draw one wire, with a junction dot where it branches.



$X = (A \text{ AND } B) \text{ OR } C$: two operators, two gates. Draw the correct **shape**, and the small circle on NOT, NAND and NOR.

From a problem statement

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

Worked example. A machine's alarm X sounds when the guard is open ($A = 1$) **and** either the motor is running ($B = 1$) or the temperature is high ($C = 1$).

Worked example – English into Boolean

An alarm X sounds when the guard is open ($A = 1$) and either the motor runs ($B = 1$) or the temperature is high ($C = 1$). Write the expression and give the rows where $X = 1$.

- One clause at a time: “either B or C ” is $B + C$, and “ A and that” is $X = A \cdot (B + C)$.
- $X = 1$ needs $A = 1$ and at least one of B , C :
(1, 0, 1), (1, 1, 0) and (1, 1, 1) – three rows of eight.
- $A = 0$ can never sound the alarm, whatever B and C do.

Bracket the OR before ANDing it. $X = A \cdot B + C$ is a different circuit – one that sounds on a high temperature with the guard shut.

From a truth table to an expression

Look only at the rows where $X = 1$. Each of them becomes one term:

- an input that is 1 is written as itself; an input that is 0 as **NOT** that input
- the inputs of one row are joined with **AND**; the terms are joined with **OR**

$X = 1$ on the rows $ABC = 001, 010$ and 111 :

$$X = (\text{NOT } A \text{ AND NOT } B \text{ AND } C) \text{ OR } (\text{NOT } A \text{ AND } B \text{ AND NOT } C) \text{ OR } (A \text{ AND } B \text{ AND } C)$$

One term for each 1-row, and every term has **all three** inputs. The rows where $X = 0$ give nothing.



Exam tips

- Distinguish **RAM (volatile, read/write)** from **ROM (non-volatile, holds the bootstrap)**; SRAM (cache, faster) from DRAM (main memory, needs refreshing).
- For a **logic circuit**, build the Boolean expression gate by gate, then a truth table covering **every** input combination.
- Learn the symbol, expression and truth table for each gate (AND, OR, NOT, NAND, NOR, XOR).
- Explain a **buffer** (a temporary store bridging two different speeds) and the role of an interrupt.

Topic 3 – key takeaways

1

Components

input, output, primary memory,
secondary storage

2

Storage

HDD magnetic; SSD flash; optical
laser

3

Memory

RAM volatile; ROM non-volatile;
SRAM vs DRAM

4

Logic

six gates; build circuits from
expressions

Check yourself

- 1 Is RAM volatile or non-volatile?
- 2 Which memory is used for CPU cache?
- 3 A gate that outputs 1 only when inputs differ?
- 4 Monitoring or control: which acts on the data?



Answers 1. volatile 2. SRAM 3. XOR 4. control