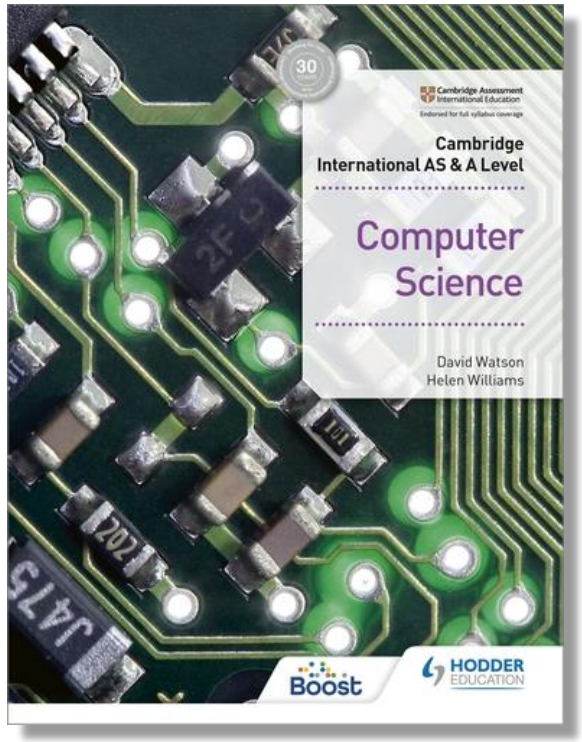
GCE AS LEVEL

In the context of CIE 9618 syllabus

CAMBRIDGE International Examinations

Chapter 3
Hardware

3.1 Computers and their components
3.2 Logic Gates and Logic Circuits



3. Hardware

LEARNING OBJECTIVES:

1. Primary storage/memory devices
2. Secondary storage (including removable devices)
3. The benefits and drawbacks of embedded systems
4. Hardware devices used as input, output and storage
5. The differences between RAM, ROM, SRAM, DRAM, PROM and EPROM
6. The use of RAM, ROM, SRAM and DRAM in a range of devices
7. Monitoring and control systems
8. The use of logic gates: NOT, AND, OR, NAND, NOR and XOR
9. The construction and use of truth tables
10. The construction of logic circuits, truth tables and logic expressions from a variety of logic information

3.1 Computers and their components

KEY TERMS: (1/3)

- Memory cache – high speed memory external to processor which stores data which the processor will need again.
- Random access memory (RAM) – primary memory unit that can be written to and read from.
- Read-only memory (ROM) – primary memory unit that can only be read from.
- Dynamic RAM (DRAM) – type of RAM chip that needs to be constantly refreshed.
- Static RAM (SRAM) – type of RAM chip that uses flip-flops and does not need refreshing.
- Refreshed – requirement to charge a component to retain its electronic state.
- Programmable ROM (PROM) – type of ROM chip that can be programmed once.
- Erasable PROM (EPROM) – type of ROM that can be programmed more than once using ultraviolet (UV) light.
- Hard disk drive (HDD) – type of magnetic storage device that uses spinning disks.
- Latency – the lag in a system; for example, the time to find a track on a hard disk, which depends on the time taken for the disk to rotate around to its read-write head.

3.1 Computers and their components

KEY TERMS: (2/3)

- Fragmented – storage of data in non-consecutive sectors; for example, due to editing and deletion of old data.
- Removable hard disk drive – portable hard disk drive that is external to the computer; it can be connected via a USB part when required; often used as a device to back up files and data.
- Solid state drive (SSD) – storage media with no moving parts that relies on movement of electrons.
- Electronically erasable programmable read-only memory (EEPROM) – read-only (ROM) chip that can be modified by the user, which can then be erased and written to repeatedly using pulsed voltages.
- Flash memory – a type of EEPROM, particularly suited to use in drives such as SSDs, memory cards and memory sticks.
- Optical storage – CDs, DVDs and Blu-ray TM discs that use laser light to read and write data.
- Dual layering – used in DVDs; uses two recording layers.
- Birefringence – a reading problem with DVDs caused by refraction of laser light into two beams.
- Binder 3D printing – 3D printing method that uses a two-stage pass; the first stage uses dry powder and the second stage uses a binding agent.
- Direct 3D printing – 3D printing technique where print head moves in the x, y and z directions. Layers of melted material are built up using nozzles like an inkjet printer.

3.1 Computers and their components

KEY TERMS: (3/3)

- Digital to analogue converter (DAC) – needed to convert digital data into electric currents that can drive motors, actuators and relays, for example.
- Analogue to digital converter (ADC) – needed to convert analogue data (read from sensors, for example) into a form understood by a computer.
- Organic LED (OLED) – uses movement of electrons between cathode and anode to produce an on-screen image. It generates its own light so no back lighting required.
- Screen resolution – number of pixels in the horizontal and vertical directions on a television/computer screen.
- Touch screen – screen on which the touch of a finger or stylus allows selection or manipulation of a screen image; they usually use capacitive or resistive technology.
- Capacitive – type of touch screen technology based on glass layers forming a capacitor, where fingers touching the screen cause a change in the electric field.
- Resistive – type of touch screen technology. When a finger touches the screen, the glass layer touches the plastic layer, completing the circuit and causing a current to flow at that point.
- Virtual reality headset – apparatus worn on the head that covers the eyes like a pair of goggles. It gives the user the 'feeling of being there' by immersing them totally in the virtual reality experience.
- Sensor – input device that reads physical data from its surroundings.

3.1.1 Common Input Devices

- There are many different input devices that can be used to enter data for the computer to process.
- Some of the more common devices, and their primary purpose, are listed below.

	Device	Purpose
1	Keyboard	Allows a user to enter character data (numbers, letters, and symbols). It often has function keys or special purpose keys to perform common user tasks such as sending signals to control the volume or to switch between windows.
2	Mouse	Allows a user to 'point and click' to select icons, or to position the cursor on the screen.
3	Trackpad	Offers the same functionality as a mouse but the user controls the movement of the cursor using their fingers. It is commonly found on laptop computers.

3.1.1 Common Input Devices

	Device	Purpose
4	Graphics tablet	Also known as a drawing tablet, this is used to create digital drawings with a special Stylus by pressing the tip on the tablet surface.
5	Microphone	Captures analogue sound waves and converts them into electronic signals. Common uses include capturing your voice whilst talking to a friend online, or recording live music that can be stored digitally.
6	Flatbed scanner	Allows users to scan a physical document such as a photograph, handwritten note, or important letter and save it as a digital bitmap image.
7	OMR scanner	OMR stands for optical mark recognition. This technology is often used to input the answers or marks that a candidate has made on a multiple choice test paper.
8	Magnetic stripe card reader	Things such as hotel door access cards contain a magnetic strip that holds data. This input device is capable of reading that data.

3.1.1 Common Input Devices

	Device	Purpose
9	Smart card reader	Reads the data from an embedded integrated circuit (IC) chip. Most retail shops have smart card readers that read data taken from the chip found on a customers bank card to enable a transaction to take place.
10	NFC reader	Reads the data from an NFC (near field communication) tag. A common use of this technology is contactless payment in shops. Here, an NFC reader uses radio waves to read data from a bank card or mobile phone when the two devices are close to each other.
11	Touchscreen	A display screen is usually listed as an output device, but touchscreens are designed so that the same device can be used to input data. The input device allows the user to use their finger or a stylus to select icons, use an on-screen keyboard, and perform navigation tasks.

3.1.2 Common Output Devices

- There are many different devices that output data in different ways.
- Some of the more common devices, and their primary purpose, are listed below.

	Device	Purpose
1	Inkjet printers	• Inkjet printers use liquid ink to produce black-and-white or colour prints. High-end inkjet printers can often handle specialist paper and print at very high resolutions (with the ability to show a large amount of detail). • Liquid ink produces rich colours, making this type of printer the most suitable for printing photographs. • The cost of ink is a key factor to take into account. Printer ink is often cited as being one of the most expensive commodities in the world, with small cartridges being the most expensive. • Inkjet printers are usually the printer of choice in the home because of their low upfront cost. They are also preferred by photographers and for print studios because of their superior colour production.

3.1.2 Common Output Devices

	Device	Purpose
2	Speakers	A speaker connected to a computer is a device that generates sound waves from data being received from a sound card. Speakers are often built into devices but can also be connected as external peripherals.
3	Laser printers	• Laser printers are frequently used in the workplace. They print a whole page at a time, so are usually faster than inkjet printers. High-specification laser printers are capable of producing hundreds of pages per minute. • Laser printers do not use liquid ink. Instead, they use powdered ink called **toner**. • The quality produced by a laser printer is generally very good for text, but not so good for photo-quality images, as it is difficult to produce deep, rich colours.

3.1.2 Common Output Devices

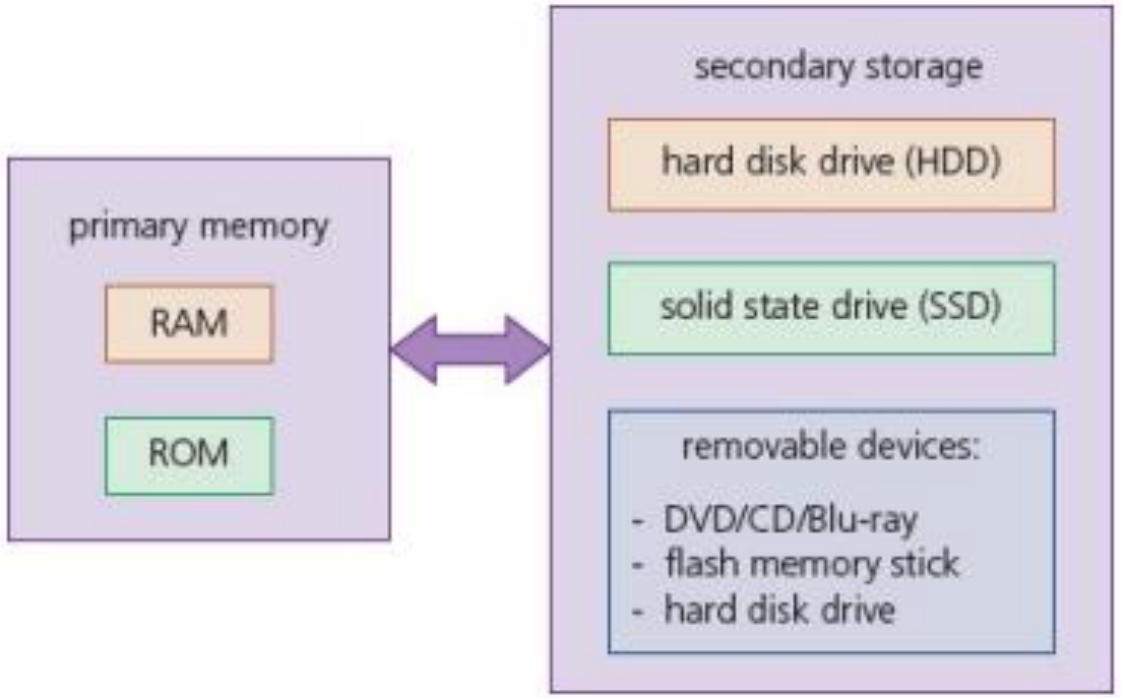
	Device	Purpose
4	Plotters	• A plotter is a device that uses one or more pens to draw an image. Pens are lifted or applied to the paper as required, to produce very precise drawings. Plotters are often large devices that can handle very wide paper, sometimes on a drum to allow repeated layers to be printed. • Plotters are commonplace in engineering and architectural practices.
5	3D printers	• 3D printing allows for three-dimensional designs on a computer to be printed in solid form. • 3D printers use **filament**, usually in the form of plastic-based resin, which is heated and printed layer (slice) by layer to form a solid object. • The potential for 3D printing is very exciting. Scientists are already exploring the use of special 3D printers — bioprinters — to make living body parts.

3.1.2 Common Output Devices

	Device	Purpose
6	Display screens	1. Most computers have some form of display, often either a stand-alone monitor or a built-in screen. **2. LCD screens** (liquid crystal display) are low cost, and are the most common display found in offices and on standard desktop and laptop computers. They are rapidly being superseded by **LED displays**. LED (light-emitting diode) technology uses less power than LCD, so LED displays are cheaper and more environmentally friendly to run. 3. A variant on traditional LED displays is **OLED screens** (organic light-emitting diode), which are currently being developed. OLEDs are lighter and more flexible than LED displays, which means that OLEDs are a good option for mobile devices such as phones and tablets.

3.1.3 Types of memory

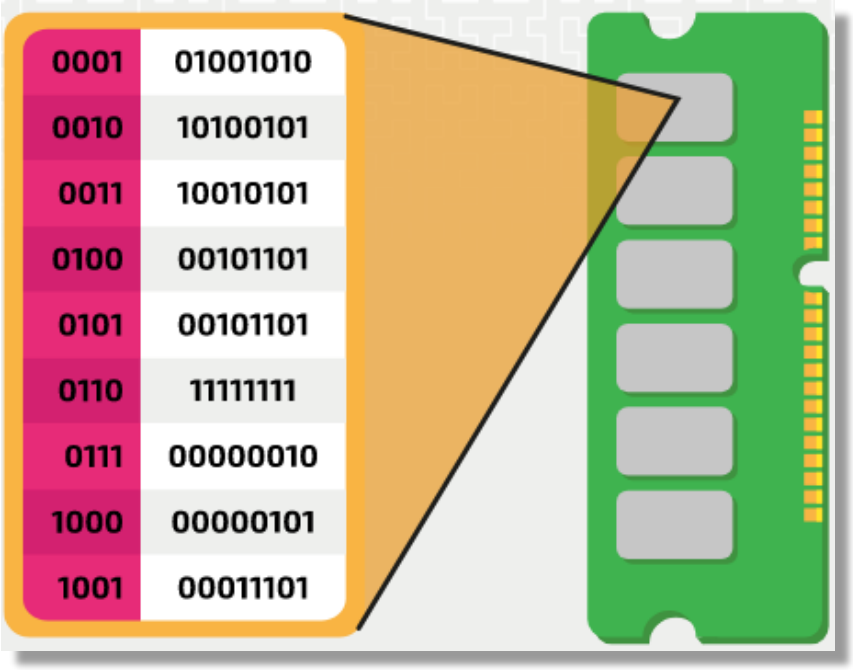
- Computers need memory and storage.
- Memory is like a computer's direct access.
- It's for working, temporary things, and important data.
- Storage keeps apps, files, and data.
- Stored data can be changed or read.
- Storage is bigger than memory for big stuff.
- Removable storage moves data between computers.
- It helps keep data safe in another place.
- New tech like 'data drop' and cloud storage are changing things.
- Internal memory has parts like registers and cache.
- Cache stores data the processor will use again.



3.1.3 Types of memory

Random Access Memory (RAM):

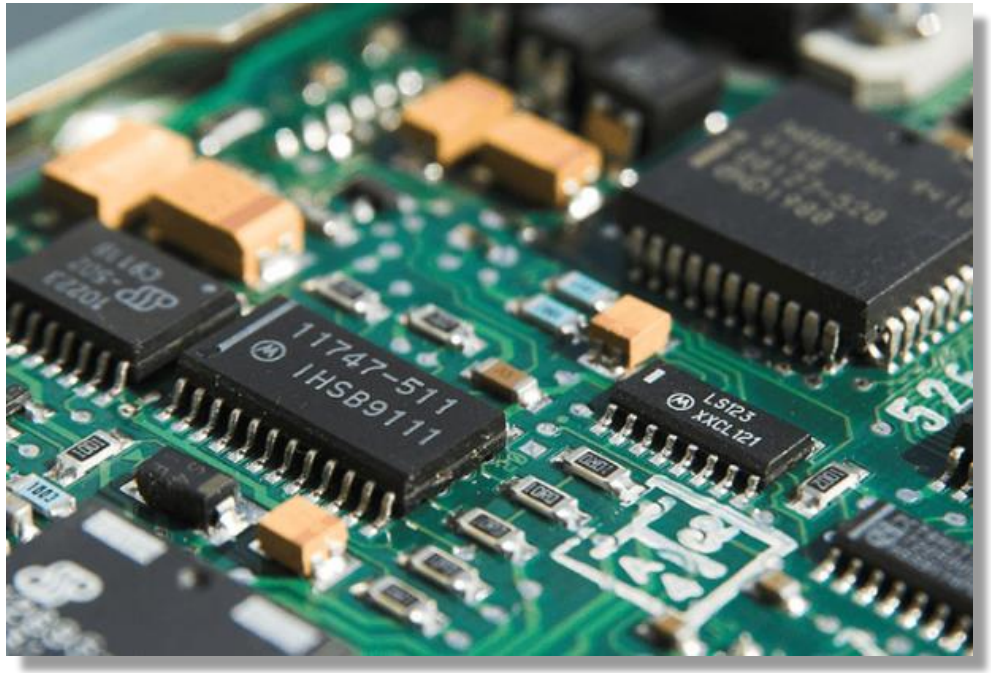
- RAM holds data and instructions in a computer.
- Programs need to be loaded into RAM for execution.
- RAM is faster than secondary storage.
- Processor gets instructions from RAM for execution.



3.1.3 Types of memory

Read Only Memory (ROM):

- ROM stores boot sequence (BIOS).
- Unlike RAM, it keeps data even when power is off.
- ROM's contents are set by the manufacturer.
- It's read-only, crucial for computer system.
- BIOS checks core components, stored in ROM.
- Boot sequence loads OS from storage to RAM.
- OS manages computer operation, memory, storage, and input/output.



3.1.3 Types of memory

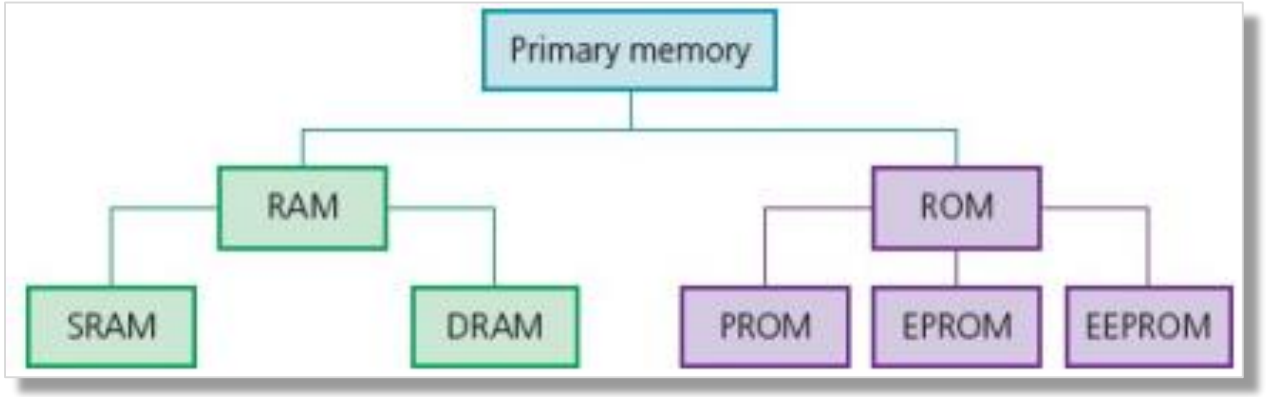
RAM vs ROM:

RAM	ROM
• temporary memory device • volatile memory • can be written to and read from • used to store data, files, programs, part of OS currently in use • can be increased in size to improve operational speed of a computer	• permanent memory device • non-volatile memory device • data stored cannot be altered • sometimes used to store BIOS and other data needed at start up

3.1.3 Types of memory

Structure of primary memory:

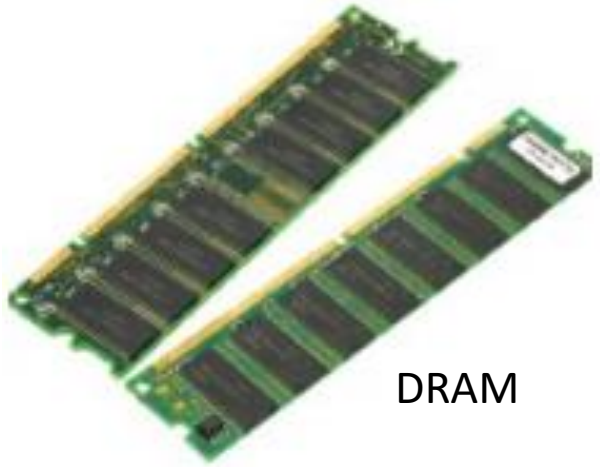
- All computer systems come with some form of RAM.
- Access any location independently.
- Faster data access than secondary devices.
- RAM can be written, read, and changed.
- Used for data, files, apps, and OS.
- Data lost when computer is off.
- More RAM = faster computer.
- RAM never runs out, but slows down.
- Larger RAM reduces secondary data access.



3.1.3 Types of memory

Static RAM and Dynamic RAM (SRAM and DRAM):

- Two main types: DRAM and SRAM.
- DRAM is dynamic and cheaper.
- Made of capacitor and transistor.
- Capacitor stores charge for bit value.
- Transistor acts as a switch to set/change value.
- Needs frequent refresh to maintain charge.
- SRAM is static and faster.
- Uses flip-flops, no need for refresh.
- Faster access but more expensive.
- Used for speed-dependent areas.
- Both are volatile, need constant power.



DRAM

SRAM

3.1.3 Types of memory

SRAM vs DRAM:

SRAM	DRAM
• uses flip-flops to hold each bit of memory • does not need to be constantly refreshed • has a faster data access time than DRAM • processor memory cache makes use of SRAM • if accessed at a high frequency, power usage can exceed that of DRAM	• consists of a number of transistors and capacitors • needs to be constantly refreshed • less expensive to manufacture than SRAM • has a higher memory capacity than SRAM • main memory is constructed from DRAM • consumes more power than SRAM under reasonable levels of access, as it needs to be constantly refreshed

3.1.3 Types of memory

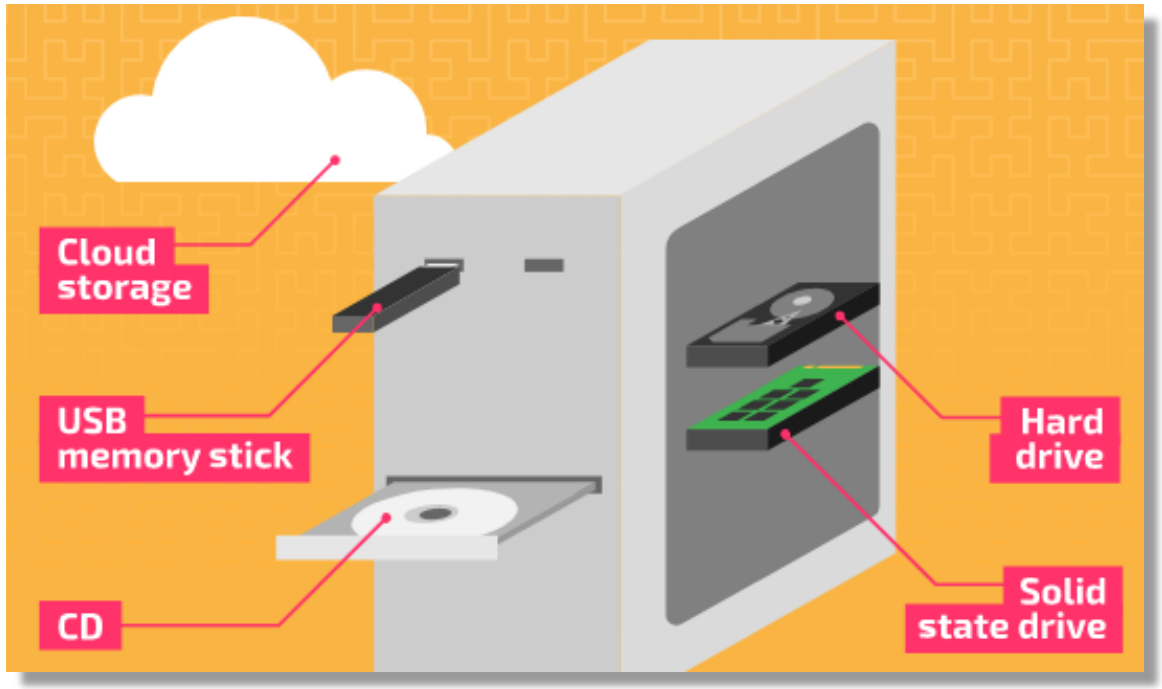
PROM, EPROM, EEPROM:

- PROM (Programmable Read-Only Memory):
  - Can be written to once after manufacturing
  - Used when production volume is low
  - Supplier writes data to the circuit
  - Common in microcontrollers, games consoles, phones, and RFID tags
- EPROM (Erasable Programmable Read-Only Memory):
  - Contents can be changed by erasing with ultraviolet light
  - Requires special equipment and expertise
- EEPROM (Electrically Erasable Programmable Read-Only Memory):
  - Bytes can be erased electronically and device reprogrammed
  - Used in smart cards and keyless systems
  - Some EEPROMs have security features against hacking

3.1.4 Types of storage

The need for Secondary Storage:

- Secondary storage is high capacity, low cost, for file storage, and reliable; type chosen depends on budget and usage.
- Types of Secondary Storage:
  - Internal storage: inside the computer case.
  - External storage: portable, for file transfer or when internal upgrade isn't possible.
- Common Secondary Storage Types:
  - Magnetic (hard) disk
  - Solid-state disk
  - Optical disc



3.1.4 Types of storage

Comparing and choosing secondary storage:

- Criteria to Think About:
  - Capacity: How much storage it has.
  - Speed: How fast you can access files.
  - Cost: Price and cost per GB.
  - Portability: Can you move it around?
  - Compatibility: Does it fit your system?
- Longevity and Reliability:
  - Technology Changes: Old devices may become outdated.
  - Reliability: Storage can fail or get corrupted.
  - MTTF: Disk reliability measured by mean time to failure.
  - Backup: Important data should be backed up.
  - Cloud Storage: Easy solution for most users.

3.1.4 Types of storage

Capacity of Secondary Storage Devices:

	Typical capacity	Notes
• Magnetic hard disk	1TB	Max. capacity is around 16TB
• Solid-state disk	256GB	Max. capacity is around 8TB
• CD	Standard form is 700MB	
• DVD	Standard form is 4.7GB	• Dual-layer: 8.5GB • Double-sided: 9.4GB
• Blu-ray Disc	Standard form is 25GB	Triple-Layer: 100GB

3.1.4 Types of storage

Magnetic Hard Disk:

- Magnetic Disk: Often called a hard disk.
- Different from Floppy Disks: Floppy disks were used in the 1980s.
- HDD: Hard disk drive. Mechanical with moving parts.
- Protected and Sealed: HDDs are sealed units, safe from damage.
- Data Representation: Magnetized dots on metal platter.
- Read-Write Process: Disk spins fast for data access.
- Rotation Speed: Faster spin, quicker data retrieval.
- Speed Values: Standard: 5,400 rpm, 7,200 rpm. High-spec: 15,000 rpm.
- Access Speeds: Standard: 80-200MB/s.
- Factors Affecting Speed: Configuration, file size, fragmentation.
- Fragmentation: File parts in different places, linked.
- Full Disk: Slower writing and accessing.
- Advantages of Magnetic Disk: High capacity, low cost.
- Best for: Desktops, laptops with low cost priority.

3.1.4 Types of storage

Solid-State Disk:

- SSD Abbreviation: Stands for solid-state disk, also interpreted as drive or device.
- Electronic Device: Uses flash memory, no moving parts.
- Advantages of SSDs: Faster access, no mechanical failure, less energy, less heat.
- Limited Lifespan: Finite writes, 'leakage' if not powered.
- Not for Long-Term Archiving: Unsuitable for long-term data storage.
- Cost Comparison: SSD more expensive per GB than magnetic storage.
- Enclosure: Similar to magnetic drives, can upgrade or add.
- Suitable for Frequent Access: Good for frequently used files, OS.
- Hybrid Systems: Increasingly common to have both magnetic and SSD.

3.1.4 Types of storage

Optical Disks:

- Optical Discs: Different types like CD, DVD, Blu-ray.
- CD-ROM and DVD-ROM: Read-only memory for music, films, software.
  - Mass-Produced: Many copies made in factories.
- CD/DVD-ROMs: Used for software, becoming less common.
- CD-R and DVD-R: Recordable for archiving data.
  - Archiving: Permanent copy, can't overwrite.
- CD-RW and DVD-RW: Rewritable for backing up files.
  - Backing Up: Temporary copy, can be overwritten.
  - Modern Backups: High-speed tape, cloud storage.

3.1.5 Embedded Operating Systems

EMBEDDED OPERATING SYSTEMS:

- Used in specific-purpose devices like phones, washing machines
- Provide a reliable platform for specific applications
- Aim for hardware reliability and efficient resource use
- May sacrifice flexibility for these benefits

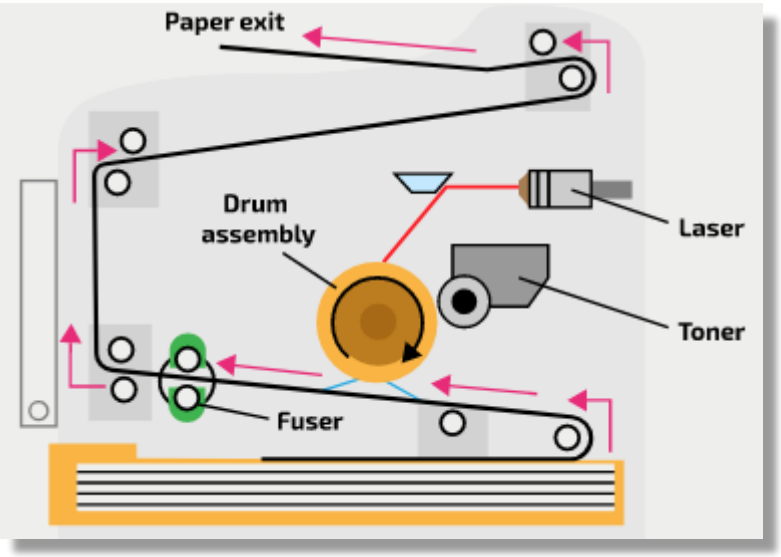
3.1.5 Embedded Operating Systems

EMBEDDED OPERATING SYSTEMS:

ADVANTAGES	DISADVANTAGES
• Compact size, fits easily into devices • Affordable to produce • Dedicated to one task, simple interfaces, no need for an operating system • Low power consumption • Fast response to changing input (real-time operation) • Reliable with mass production	• Limited upgradeability for new technology • Specialized troubleshooting for device faults • Deceptively simple interfaces can be confusing in practice (e.g., changing a cooker clock time) • Vulnerability to hackers and viruses when accessible over the internet • Tendency to discard devices instead of repairing due to upgrade and fault issues (wasteful)

3.1.6 Principal Operations of Hardware Devices

Laser Printer Operation:

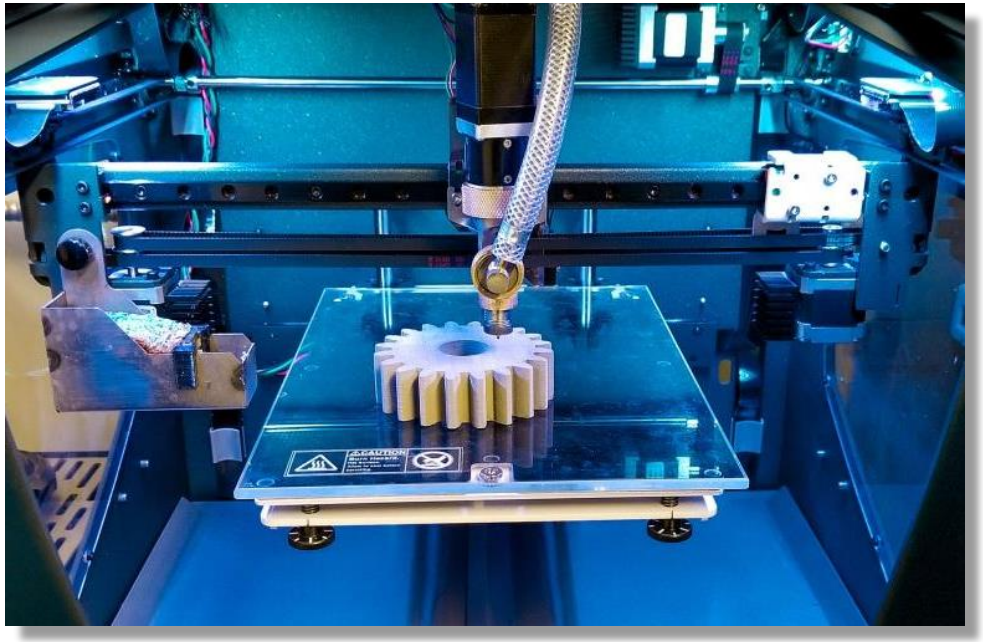


- Create a bitmap image of the page.
- Apply negative charge to the print drum.
- Laser changes polarity on the drum according to the image.
- Drum exposed to positively charged toner.
- Toner attracted to negatively charged areas on the drum.
- A sheet of paper passes under the drum, toner transfers to paper.
- Fusing (heating) stage makes toner stick to paper.
- Color printouts use four toner cartridges: Cyan, Magenta, Yellow, Black. Each toner applied in turn for the correct color print.

3.1.6 Principal Operations of Hardware Devices

3D Printer Operation:

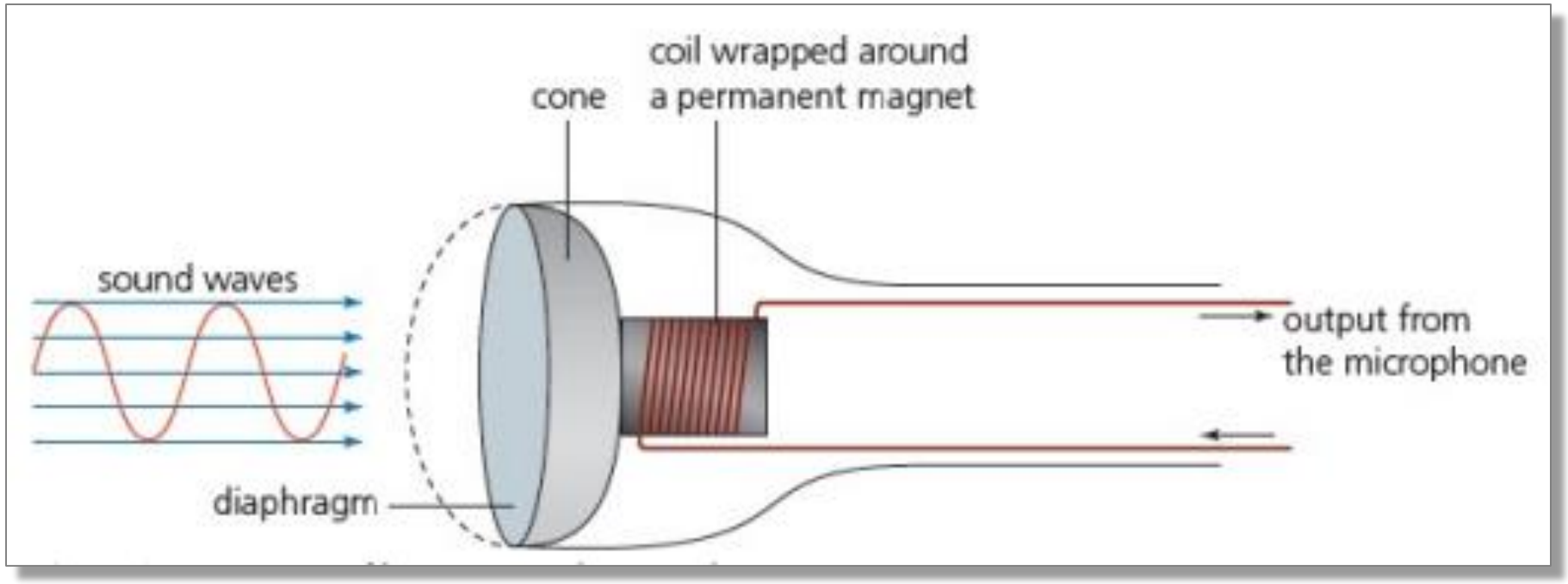
- Process starts from saved digital file that holds the blueprint of object to be printed
- Object is then built by sequentially adding layers of a material (e.g. polymer resin) until object created
- Object is then cured (e.g. resin-made objects are hardened by UV light)



3.1.6 Principal Operations of Hardware Devices

Microphone Operation:

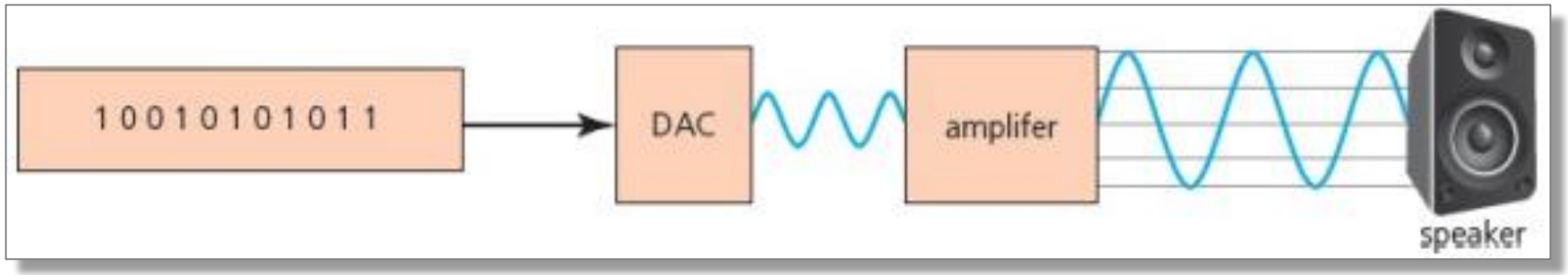
- Incoming sound waves enter wind screen and cause vibrations about a diaphragm
- Vibrations cause coil to move past a magnetic core
- Electrical current generated which is then digitized



3.1.6 Principal Operations of Hardware Devices

Speakers Operation:

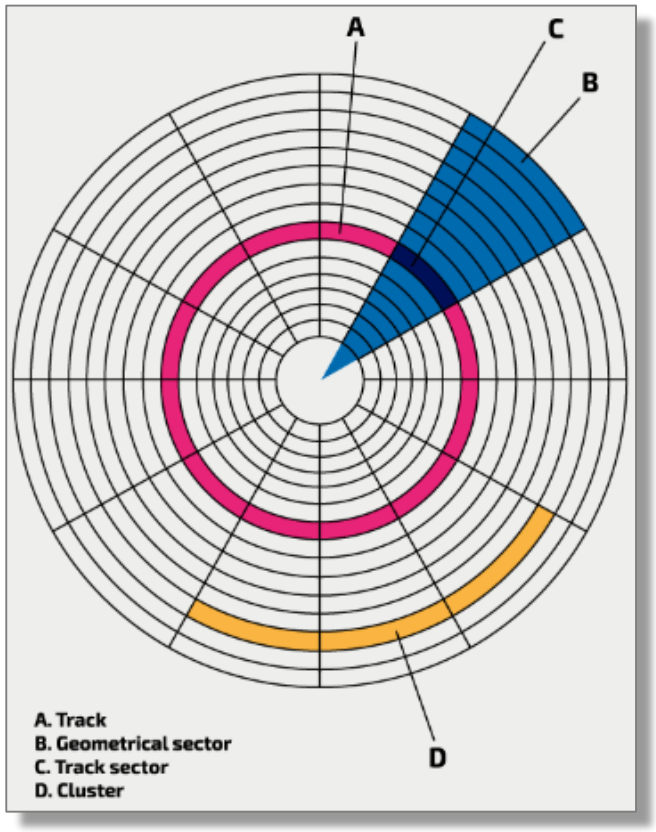
- Takes electrical signals and translates into physical vibrations to create sound waves
- Electric current in voice coil generates an electromagnetic field
- Change in digital audio signal causes current direction to change which changes field polarity
- Electromagnet is either attracted or repelled to a permanent magnet, causing a diaphragm that is attached to the coil to vibrate
- Vibration transmitted to air in front of speaker
- Degree of vibration determines amplitude and frequency of sound wave produced



3.1.6 Principal Operations of Hardware Devices

Magnetic Hard Disk Operation:

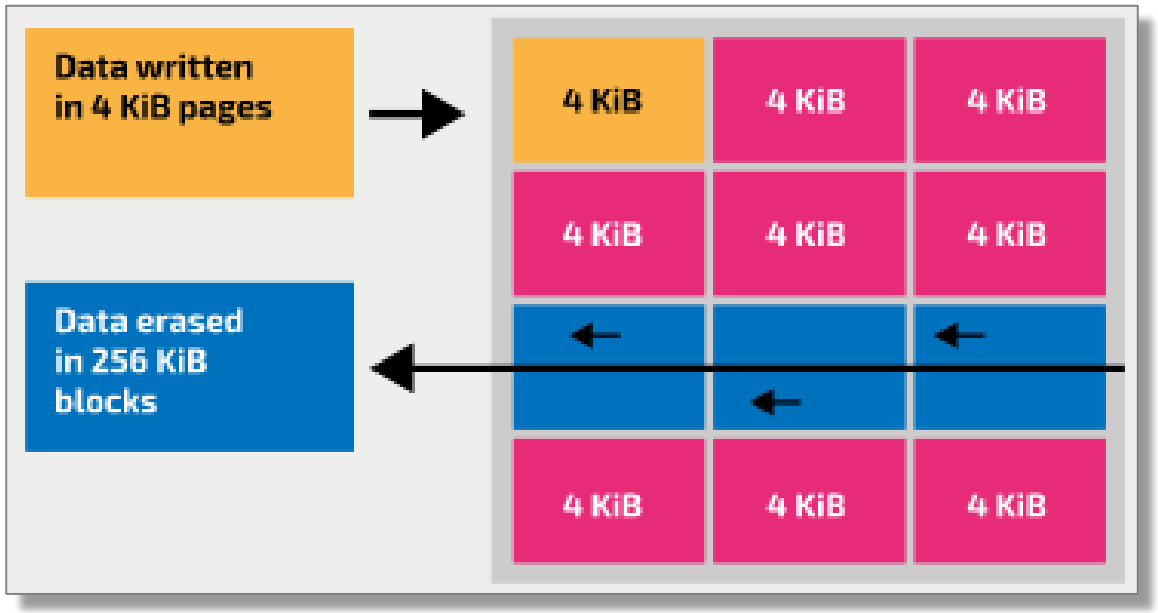
- Hard disk has platters whose surfaces are covered with a magnetisable material.
- Platters are mounted on central spindle and rotated at high-speed
- Surface of platters divided into concentric tracks & sectors, where data is encoded as magnetic patterns
- Each surface is accessed by read/write heads
- When writing, current variation in head causes magnetic field variation on disk
- When reading, magnetic field variation from disk produces current variation in read head



3.1.6 Principal Operations of Hardware Devices

Solid State (Flash) Memory Operation:

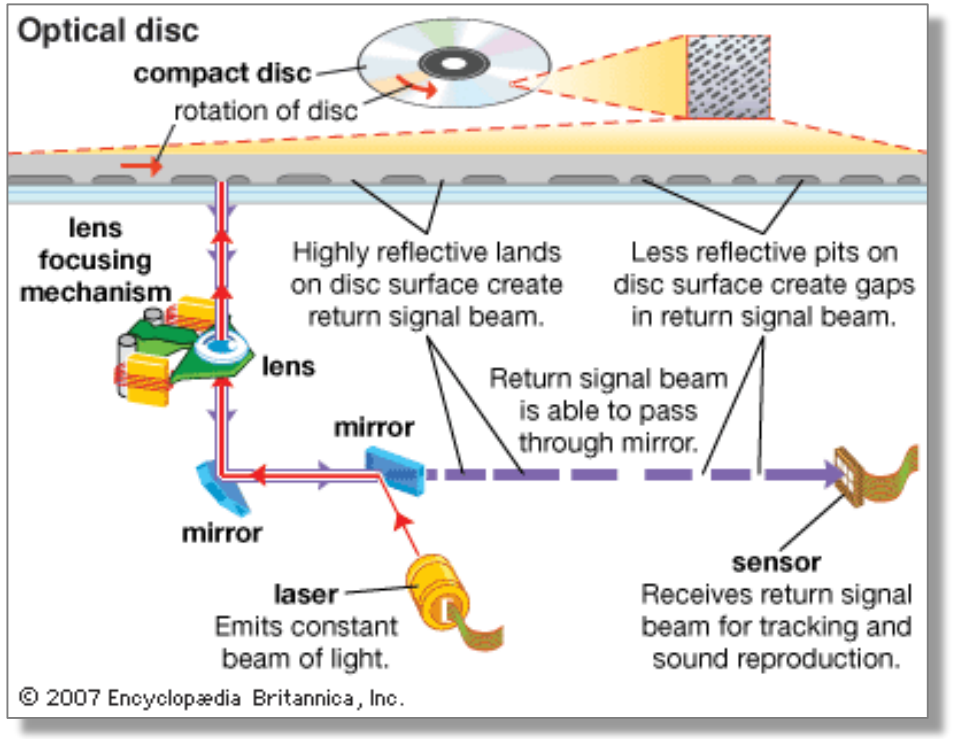
- Most use NAND-based flash memory
- Consist of a grid of columns & rows that has 2 transistors at each intersection
- Two transistors:
  - Floating Gate: stores electrons and the presence or absence of charge represents either 1 or 0
  - Control Gate: controls charge flow for read/write



3.1.6 Principal Operations of Hardware Devices

Optical Disk Reader/Writer Operation:

- Disc surface has reflective metal layer and is spun
- Tracking mechanism moves laser assembly
- Lens focuses laser onto disc
- Laser beam shone onto disc to read/write
- Tracks have sequences of amorphous and crystalline states on the metallic layer
- When reading, the reflected light from the different states on the track are encoded as bit patterns



- When writing, laser changes surface to crystalline and amorphous states along the track, which correspond to 1s or 0s

3.1.6 Principal Operations of Hardware Devices

Touch Screen Operation:

- Considered as both an input & output device
- 2 types:

Resistive	capacitive
Consists of two charged plates	Made from materials that store electric charge
Pressure causes plates to touch, completing circuit	When touched, charge transferred from finger
Point of contact registered with coordinates used to calculate position	

3.1.6 Principal Operations of Hardware Devices

Virtual Reality Headset Operation:

- Include 2 lenses, (LCD) display, circuit board with sensors, cover, and foam padding
- The display offers a simulation of a 3D environment, generated by a 3D graphics package
- Users can navigate within the virtual environment by moving their head or using controllers

3.1.7 Use of Buffers

Buffers:

- Buffer employed for data movement between computer processes
- Majority of buffers implemented in software
- Buffers utilized when data reception rate differs from processing rate

How Buffering can improve the performance of a Computer system?

- Buffering for Balanced CPU and I/O Speeds:
- Buffering aids when CPU and I/O devices have similar speeds
- Ensures CPU and I/O devices work at full speed, preventing idle moments

3.1.8 Monitoring and Control Systems

Monitoring System:

- Monitors external state of computer system
- No changes made to environment, so no feedback

Control System:

- Regulates behavior of other devices or systems
- Event-driven system: Controller responds to events by changing system state
- Time-driven system: Controller takes action at specific time points

3.1.8 Monitoring and Control Systems

Hardware Components in a System:

- Sensor: Measures an analogue property and sends it to processing unit as electrical or optical signal.
- Actuators: Turn heavy appliances on/off (e.g., heater, fan).
- ADC (Analog-to-Digital Converter): Converts analogue signals to digital signals.
- Transmission Cable: Transfers signals.

Feedback Systems:

- System output affects sensor input.
- Ensures system operates within criteria.
- System output affects subsequent inputs, potentially changing system actions.
- Enables automatic adjustment of conditions in continuous process.

3.2 Logic Gates and Logic Circuits

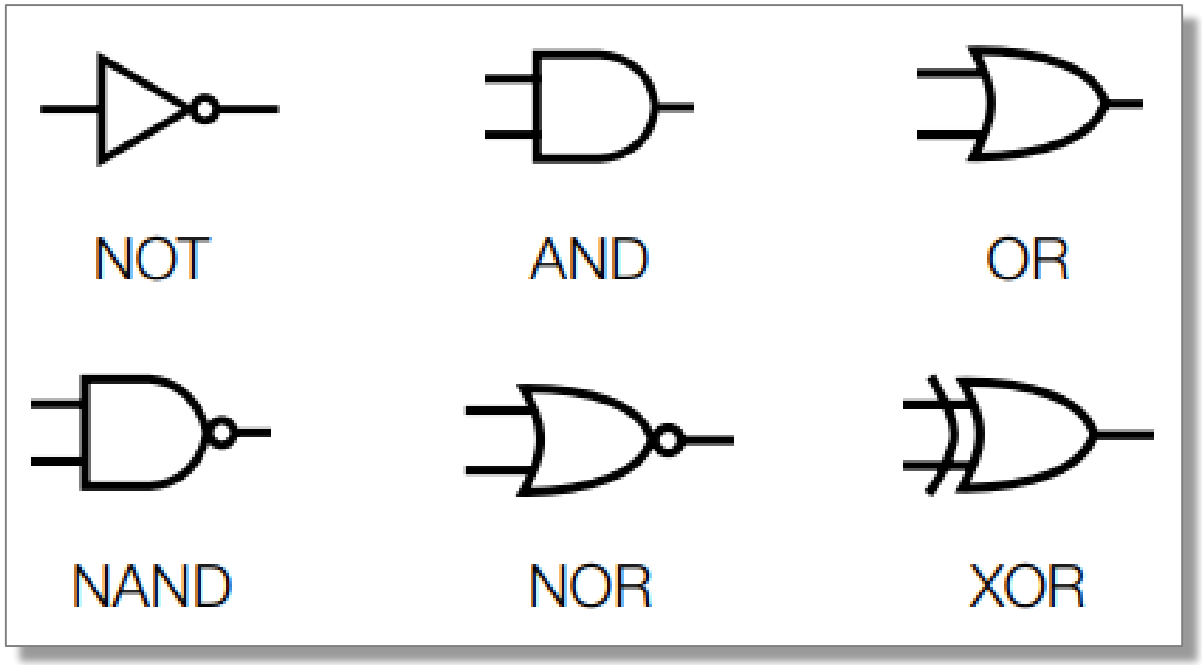
KEY TERMS:

- Logic gates – electronic circuits which rely on ‘on/off’ logic. The most common ones are NOT, AND, OR, NAND, NOR and XOR.
- Logic circuit – formed from a combination of logic gates and designed to carry out a particular task. The output from a logic circuit will be 0 or 1.
- Truth table – a method of checking the output from a logic circuit. They use all the possible binary input combinations depending on the number of inputs; for example, two inputs have 2^2 (4) possible binary combinations, three inputs will have 2^3 (8) possible binary combinations, and so on.
- Boolean algebra – a form of algebra linked to logic circuits and based on TRUE and FALSE.

3.2.1 Logic Gates

Logic Gates:

- Electronic circuits in computers consist of many logic gates.
- Logic gates process binary inputs and create binary outputs.
- Logic circuits are made by combining multiple logic gates.
- These circuits have a specific function.
- Truth tables are used to check logic gate or circuit outputs.



3.2.2 Truth Tables

Logic Gates:

- Truth tables are used to track logic gate or circuit output.
- The NOT gate is the only one with one input; the other gates have two inputs.
- When making truth tables, all possible combinations of 1s and 0s are considered.
- NOT gate (one input): 2^1 (2) binary combinations.
- Other gates (two inputs): 2^2 (4) binary combinations.
- Logic circuits can have more than 2 inputs.
- For instance, three inputs: 2^3 (8) binary combinations.
- For four inputs, there are 24 (16) possible binary combinations.
- The number of possible binary combinations is always a multiple of 2.

3.2.2 Truth Tables

Logic Gates:

- In logic circuits, inputs can exceed 2.
- For instance, 3 inputs: possible 2^3 (8) binary combinations.
- And with 4 inputs: possible 2^4 (16) binary combinations.
- The number of possible binary combinations is always a multiple of 2.

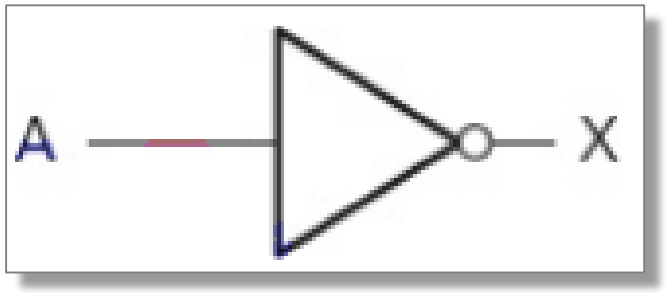
Inputs	
A	B
0	0
0	1
1	0
1	1

Inputs		
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

Inputs			
A	B	C	D
0	0	0	0
0	0	0	1
0	0	1	0
0	0	1	1
0	1	0	0
0	1	0	1
0	1	1	0
0	1	1	1
1	0	0	0
1	0	0	1
1	0	1	0
1	0	1	1
1	1	0	0
1	1	0	1
1	1	1	0
1	1	1	1

3.2.3 Functions of the 6 Logic Gates

NOT Gate:



Description

- The output, X, is 1 if the input A is NOT 1

How to write this

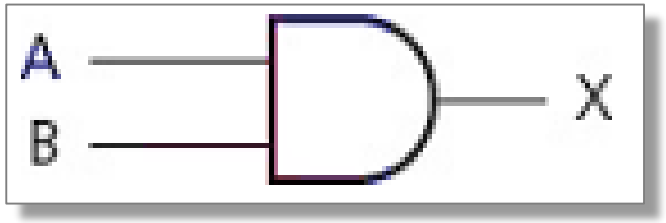
- X = NOT A (Logic notation)
- X = $\bar{A}$ (Boolean algebra)

Truth table

Input	Output
A	X
0	1
1	0

3.2.3 Functions of the 6 Logic Gates

AND Gate:



Description

- The output, X, is 1 if input A is 1 and input B is 1

How to write this

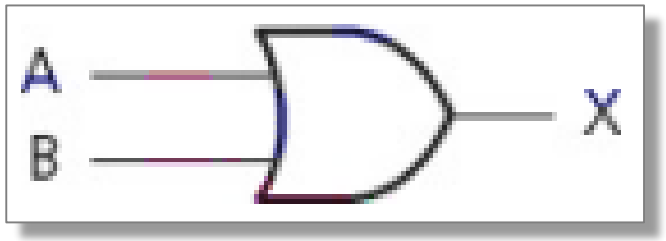
- X = A AND B (Logic notation)
- X = A.B (Boolean algebra)

Truth table

Inputs		Output
A	**B**	**X**
0	0	0
0	1	0
1	0	0
1	1	1

3.2.3 Functions of the 6 Logic Gates

OR Gate:



Description

- The output, X, is 1 if input A is 1 or input B is 1

How to write this

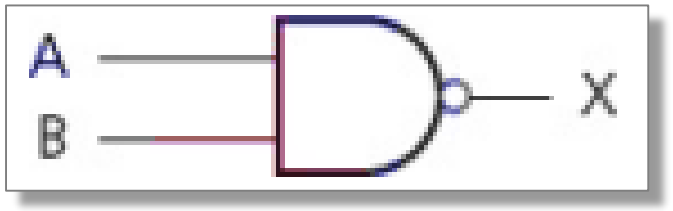
- X = A OR B (Logic notation)
- X = A + B (Boolean algebra)

Truth table

Inputs		Output
A	B	X
0	0	0
0	1	1
1	0	1
1	1	1

3.2.3 Functions of the 6 Logic Gates

NAND Gate *(NOT AND)*:



Description

- The output, X, is 1 if input A is NOT 1 or input B is NOT 1

How to write this

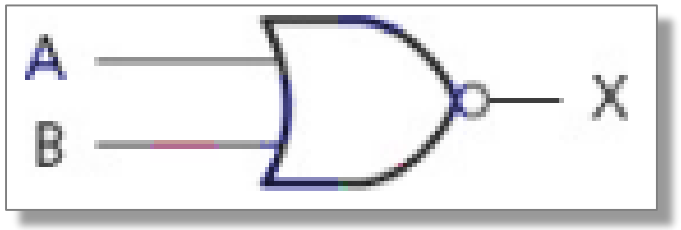
- X = A NAND B (Logic notation)
- $X = \overline{A.B}$ (Boolean algebra)

Truth table

Inputs		Output
A	**B**	**X**
0	0	1
0	1	1
1	0	1
1	1	0

3.2.3 Functions of the 6 Logic Gates

NOR Gate *(NOT OR)*:



Description

- The output, X, is 1 if: input A is NOT 1 and input B is NOT 1

How to write this

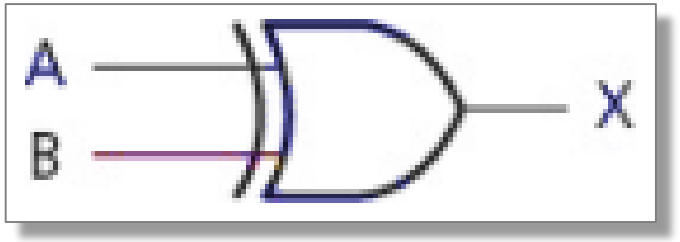
- X = A NOR B (Logic notation)
- $X = \overline{A + B}$ (Boolean algebra)

Truth table

Inputs		Output
A	B	X
0	0	1
0	1	0
1	0	0
1	1	0

3.2.3 Functions of the 6 Logic Gates

XOR Gate *(NOT OR)*:



Description

- The output, X, is 1 if (input A is 1 AND input B is NOT 1)
  OR (input A is NOT 1 AND input B is 1)

How to write this

- X = A XOR B (Logic notation)
- $X = (A.\overline{B}) + (\overline{A}.B)$ (Boolean algebra)

Truth table

Inputs		Output
A	**B**	**X**
0	0	0
0	1	1
1	0	1
1	1	0