Hardware

Computer Architecture & Von Neumann Architecture

- The central processing unit (CPU) (also known as a microprocessor or processor) is central to all modern computer systems

~~**The CPU consists of the following architecture:**~~

- **Processor:** The processor contains the Arithmetic and Logic Unit (ALU)
- **Control Unit:** The control unit controls the operation of the memory, processor and input/output devices
- **Arithmetic Logic Unit:** Carries out the logic system like calculations
- **System Clock:** The system clock is used to produce timing signals on the control bus

Busses: Carry data through components. The following are its types.

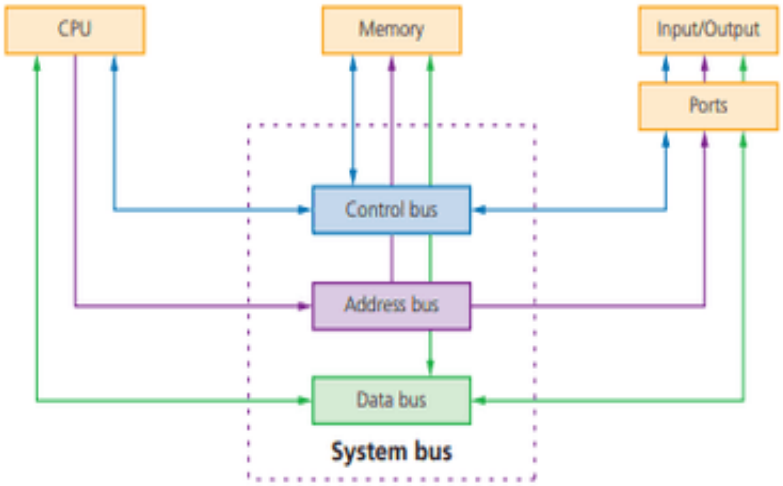
- *Address bus* – unidirectional
- *Data Bus* – bi-directional
- *Control Bus* – bi-directional

Immediate Access Store: Stores the instructions that are to be processed, which are fetched by the CPU

~~**The following registers also exist in the architecture:**~~

REGISTER	ABBREVIATION	DEFINITION
CIR	Current instruction registers	Stores the instruction the CPU is currently decoding or executing
MAR	Memory address register	Stores the Address of the instruction, copy it, and sends it to MDR

REGISTER	ABBREVIATION	DEFINITION
MDR	Memory data register	Stores the Data from the address received from the MAR and sends data to CIR
PC	Program counter	Stores the address of the next instruction to be fetched from memory
ACC	Accumulator	During calculations, data is temporarily held in it



The Fetch-Execute Cycle

1. PC contains the address of the next instruction to be fetched
2. This address is copied to the MAR via the address bus
3. The instruction of the address is copied into the MDR temporarily
4. The instruction in the MDR is then placed in the CIR
5. The value in the PC is incremented by 1, pointing to the next instruction to be fetched
6. The instruction is finally decoded and then executed

Stored Program Concept

- Instructions are stored in the main memory

- Instructions are fetched, decoded and executed by the processor
- Programs can be moved to and from the main memory

Memory Concept

- A computer’s memory is divided into partitions: Each partition consists of an address and its contents, e.g.

MEMORY LOCATION	CONTENT
10101010	01010110

Instruction Set:

An instruction set is a list of all the commands that a CPU can process, and the commands are machine code

Cores, Cache and Internal Clock

System’s Clock

The clock defines the clock cycle that synchronises all computer operations. **By increasing the clock speed, the computer's processing speed also increases.** This **doesn’t** mean that the computer's performance is increased, however.

Overclocking

Using a clock speed higher than the computer was designed for.

It leads to multiple issues.

- Operations become unsynchronised - (the computer would frequently crash and become unstable)
- can lead to serious overheating of the CPU

Length of Data Buses

The wider the data buses, the better the performance of the computer

Cache

Cache memory is located within the CPU itself

-- allows faster access to the CPU

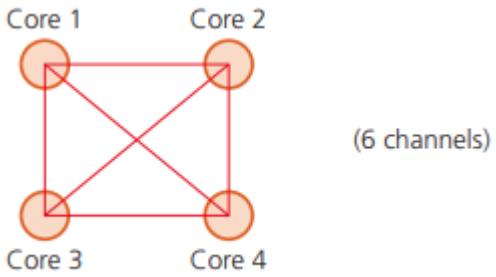
-- stores frequently used instructions and data that need to be accessed faster, which improves CPU performance

The larger the cache memory size, the better the CPU performance

Cores

The more cores in the CPU, the better and faster the performance

- But if any number of cores are used, it could possibly slow down the system performance as the communication between each core increases, and so do the data cables between each. Which in turn reduces the potential system performance.
- You might have heard about quad and dual cores, not septa or octa cores.



Input Devices

Two-dimensional Scanners:

- Used to input hard-copy documents
- The image is converted into an electronic form which can be stored in the computer
    - Document is placed on a glass panel
    - A bright light illuminates the document
    - A scan head moves across the document until the whole page is scanned. And image of the document is produced and sent to a lens using a series of mirrors
    - The lens focuses the document image
    - The focused image now falls onto a *charge couple device (CCD)* which consists of a numbers of integrated circuits
    - Software produces a digital image from the electronic form
- *Optical Character Recognition (OCR)* is a software which converts scanned documents into a text file format
- If the original document was a photo/image, then the scanned image forms an image file such as JPEG

Three-dimensional Scanners

- 3D scanners can scan solid objects and produce a three-dimensional image
- Scanners take images at several points, x, y and z (lasers, magnetic, white light)
- The scanned images can be used in *Computer Aided Design (CAD)* or to a 3D printer to produce a working model

Application of 2D Scanners at an Airport:

- Make use of (OCR) to produce digital images which represent the passport pages
- Text can be stored in ASCII format
- The 2D photograph in the passport is also scanned and stored as jpeg image
- The passenger's face is also photographed using a digital camera and compared using face recognition software
- Key parts of the face are compared (distance between eyes, width of nose)

Barcode readers/scanners

- A barcode is a series of dark and light parallel lines of varying thicknesses
- The numbers 0 -9 are each represented by a unique series of lines
- The left- and right-hand sides of the barcode are separate using guard bars
- Allows barcode to be scanned in any direction
    - Barcode is read by a red laser or red LED
    - Light is reflected back off the barcode; dark areas reflect little light which allows the bars to be read
    - Reflected light is read by sensors (photoelectric cells)
    - The pattern is generated, which is converted to digital

Quick Response (QR) Codes

- Another type of barcode is the QR codes
- Made up of a matrix of filled-in dark squares on a light background
- Can hold more storage (7000 digits)
- Advantages of QR codes:
    - No need for the user to write down the website address

- QR codes can store website addresses

Digital Cameras

- It is controlled by a microprocessor that adjusts the shutter speed, focuses the image, etc.
- Photo is captured when light passes through the lens onto a light sensitive cell
- The cell is made up of pixels
- The number of pixels determines the size of the file

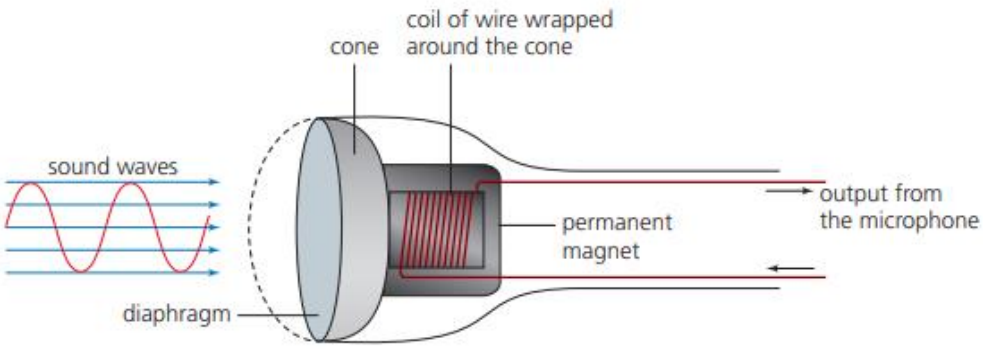
Keyboards

- Connected to a computer with a USB connection or by wireless connection
- Each character has an ASCII value and is converted into a digital signal
- Slow method
- Prone to errors

Pointing devices

- Mouse/trackball
  - Traditional; mechanical ball, connected by USB port
- Modern type; red LEDs to detect movement

Microphones

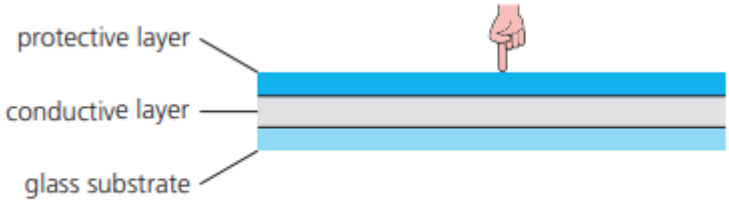


- Used to input sound to a computer
- When a microphone picks up sound, a diaphragm vibrates, producing an electric signal

- The signal goes to a sound card and is converted into digital values and stored in a computer
- *Voice recognition,* voice is detected and converted into digital

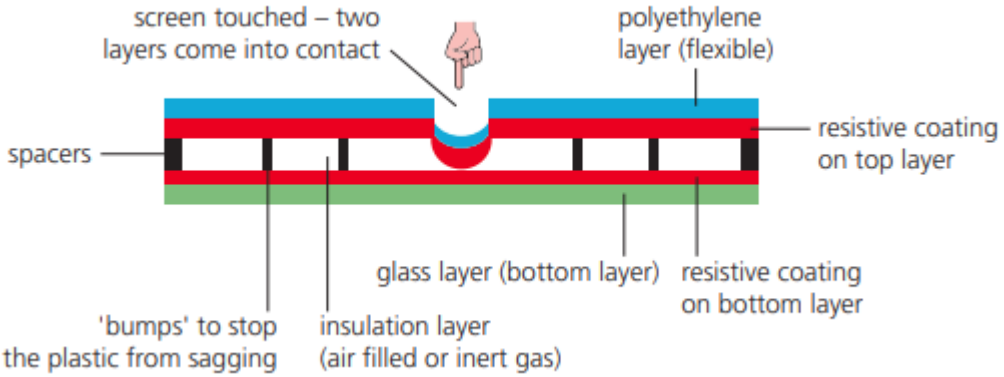
Touchscreens

Capacitive (medium cost tech)



- ▲ **Figure 3.32** Capacitive touch screen
    - Made up of many layers of glass
    - Creating electric fields between glass plates in layers
    - When the top layer of glass is touched, electric current changes
    - Co-ordinates where the screen was touched are determined by an on-board microprocessor
- Infra-red *heat* (expensive)
    - Use glass as the screen material
    - Needs a warm object to carry an input operation
- Infra-red *optical* (expensive)
    - Uses glass as screen material
    - Uses an array of sensors (grid form)
    - Point of contact is based on which grid co-ordinate is touched

- Resistive (inexpensive)

- 

    - The upper layer of polyester, the bottom layer of glass
    - When the top polyester is touched, the top layer and bottom layer complete a circuit
    - Signals are then sent out, which are interpreted by a microprocessor, determine where the screen was touched

Sensors

- Devices that read or measure physical properties
- Data needs to be converted to digital
- *Analogue-to-digital converter (ADC)* converts physical values into digital
- Sensors and their purposes:
    - Acoustic - These sensors act like a microphone that converts sound to electric pulses.
    - Accelerometer - These sensors measure an object's acceleration or deceleration and motion.
    - Flow - This sensor measures the flow of liquid or gas.
    - Gas - These sensors measure the amount/level of any gas in the environment.
    - Humidity - This sensor measures the water vapour in the air or any sample.

    - Infra-red (active) - This IR sensor uses an invisible infrared beam. When the beam is broken/disturbed, it changes the amount of infrared light reaching the detector.
    - Infra-red (passive) - These sensors detect the heat emitted by any type of object.
    - Level - This sensor detects the solids, liquids, or gas level.
    - Light - These devices use light-sensitive cells that generate electric current based on light brightness.
    - Magnetic field - This sensor detects the change in magnetic field.
    - Moisture - This type of sensor detects the water content wherever this sensor has been installed.
    - pH - This measures the acidity or alkalinity.
    - Pressure - This sensor measures the pressure applied
    - Proximity - This sensor detects the nearby objects around the sensor
    - Temperature - These sensors measure the temperature of the environment.
- (Note: You do not need to know the working principle of the sensor. But have an idea of their purposes.)

Control of Street Lighting

- The light sensor sends data to the ADC
- Digitised data and sends it to the microprocessor
- Microprocessor samples data every minute
- If data from sensor < value stored in memory:
    - Signal sent from microprocessor to street lamp
    - Lamp switched on

Output Devices

Inkjet Printers

- Used to print one-off pictures and documents

1. Data from the document sent to the printer driver
2. The printer driver ensures data is in the correct format
3. Check made by printer driver that the chosen printer is available
4. Data is sent to printer, and stored in a temporary memory (printer buffer)
5. A sheet of paper is fed; the sensor detects if the paper is available in the paper tray
6. The print head moves across paper printing text/image, four ink colours sprayed in the exact amount
7. Paper is advanced, so next line is printed
8. Repeated until the buffer is empty
9. Once it is done, the printer sends an interrupt to the processor (request for more data to be sent)

Laser Printers

- Used to print flyers, high quality
- Use dry powder ink (toner) and static electricity to produce text and images
- Prints the whole page in one go

1. (Steps 1-4 same as inkjet)
2. Printing drum is given a positive charge; as the drum rotates, the laser beam is scanned across it, removing the positive charge leaves negatively charged areas which match the text/image
3. The drum is then coated with positively charged *toner; it* only sticks to negatively charged parts of the drum
4. A negatively charged sheet is rolled over the drum

5. The toner on the drum now sticks to the paper to produce a copy of the page
6. Paper finally goes through a fuser (set of heated rollers); heat melts the ink so it is permanent
7. The discharge lamp removes all electric charge from the drum, ready to print next page

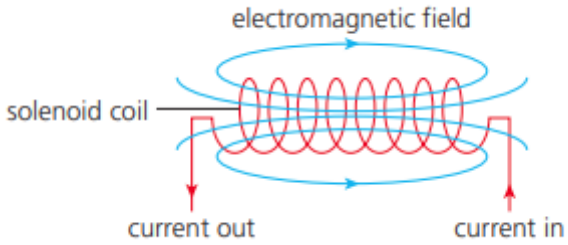
3D Printers

- Used for models of cars
- Produce solid objects that work
- Built up layer by layer, using powdered resin, ceramic powder
- A design is made using Computer-aided Design (CAD)

2D and 3D Cutters

- 3D cutters can recognise objects in x, y, z direction
- 3D laser cutters can cut; glass, crystal, metal, wood

Actuators



- The actuators convert electrical signals to mechanical processes.
- Used in many control applications involving sensors and devices (ADC and DAC)

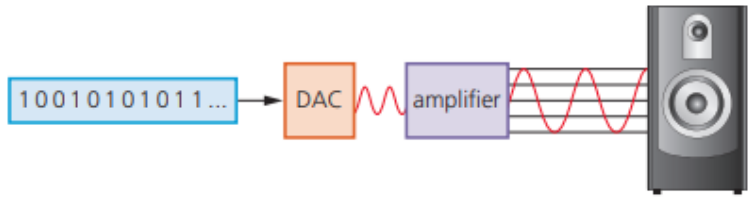
Loudspeakers/Headphones

(Loud) speakers

Loudspeakers are output devices that produce sound. When connected to a computer system, digitised sound stored on a file needs to be converted into sound as follows:

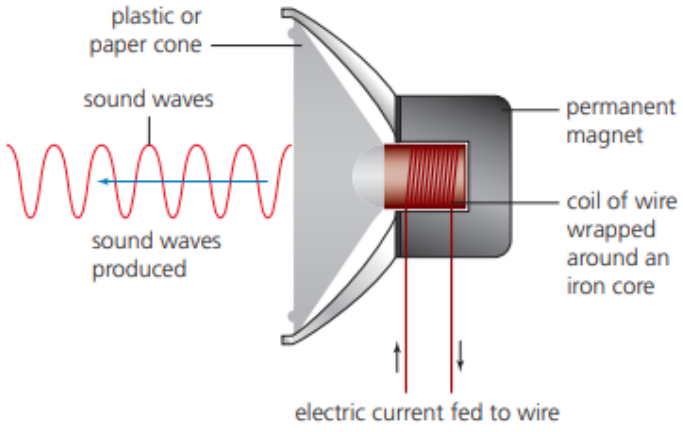
- The digital data is first passed through a digital to analogue converter (DAC) where it is changed into an electric current.
- This is then passed through an amplifier (since the current generated by the DAC will be very small); this creates a current large enough to drive a loudspeaker.
- This electric current is then fed to a loudspeaker where it is converted into sound.

The following schematic shows how this is done:



▲ **Figure 3.46** Digital to analogue conversion

As Figure 3.46 shows, if the sound is stored in a computer file, it must pass through a **digital to analogue converter (DAC)** to convert binary (digital) data into an analogue form (electric current) that can then drive the loudspeaker. Figure 3.47 shows how the loudspeaker converts the electric current into sound:



- Sound is produced by passing the digital data through a DAC then through an amplifier and then emerges from the loudspeaker
- Produced by voltage differences vibrating a cone in the speaker at different frequencies

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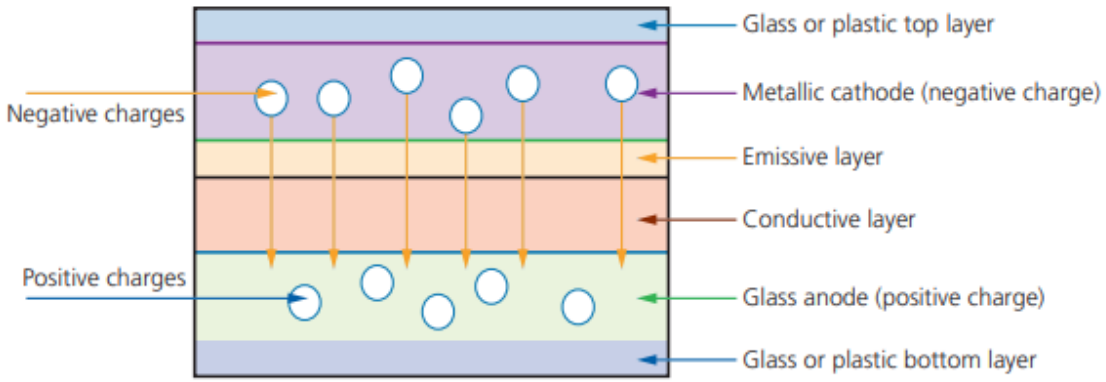
LCD and LED Monitors

- The front layer of the monitor is made up of *Liquid Crystal Display* (LCD), these tiny diodes are grouped together in threes as pixels (LCD doesn't emit any light)
- LCD monitors are backlit using *Light Emitting Diode (LED)* because:
    - LEDs reach their maximum brightness immediately
    - LEDs sharpens image (higher resolution), and CCFL has a yellow tint
    - LEDs improve the colour image
    - Monitors using LED are much thinner than CCFL
    - LEDs consume very little power
- Before LEDs, LCD monitors were backlit using CCFL
- CCFL uses two fluorescent tubes behind the LCD screen, which supplies the light source

Organic light emitting diodes (OLED)

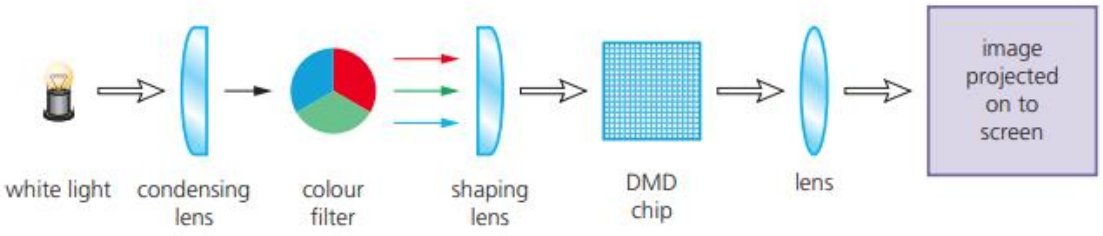
Newer LED technology is making use of **organic light emitting diodes (OLEDs)**. These use organic materials (made up of carbon compounds) to create semi-conductors that are very flexible. Organic films are sandwiched between two charged electrodes (one is a metallic **cathode** and the other a glass **anode**). When an electric field is applied to the electrodes, they give off light. This means that no form of backlighting is required. This allows for very thin screens. It also means that there is no longer a need to use LCD technology, since OLED is a self-contained system.



Light Projectors:

- Two common types of light projectors:
    - Digital Light Projector (DLP)
    - LCD Projector
- Projectors are used to project computer output onto larger screens/interactive whiteboards

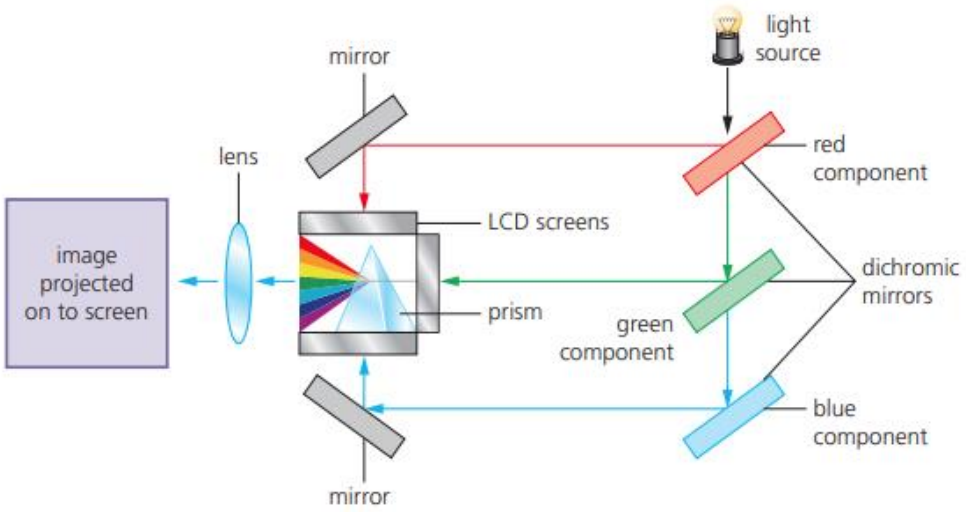
Digital Light Projectors (DLP)



▲ **Figure 3.37** A digital light projector (DLP)

- Uses millions of micromirrors
- the number of micromirrors and the way they are arranged on the DLP chip determines the resolution of the image
- When the micromirrors tilt towards the light source they are *on*
- When the micromirrors tilt away from the light source, they are *off*
- This creates a light or dark pixel on the projection screen
- A bright white light source passes through a colour filter on its way to the DLP chip
- White light splits into primary colours

LCD Projectors



▲ **Figure 3.38** LCD projector

- Older technology than DLP
- A powerful beam of white light is generated from a bulb
- This beam of light is then sent to a group of chromatic-coated mirrors; these reflect the light back at different wavelengths
- When the white light hits the mirrors, the reflected light has wavelengths corresponding to red, green, and blue
- These three different lights pass through three LCD screens; these screens show the image to be projected as millions of pixels in grayscale
- When the coloured light passes through the LCD screens, a red, green and blue version of the grey image emerges
- Finally, the image passes through the projector lens onto the screen

	Advantages	Disadvantages
Digital light projector (DLP)	higher contrast ratios	image tends to suffer from 'shadows' when showing a moving image
	higher reliability/longevity	
	quieter running than LCD projector	DLP do not have grey components in the image
	uses a single DMD chip, which mean no issues lining up the images	the colour definition is frequently not as good as LCD projectors because the colour saturation is not as good (colour saturation is the intensity of a colour)
	smaller and lighter than LCD projector	
	they are better suited to dusty or smoky atmospheres than LCD projectors	
LCD projector	give a sharper image than DLP projectors	although improving, the contrast ratios are not as good as DLPs
	have better colour saturation than DLP projectors	LCD projectors have a limited life (that is, the longevity is not as good as DLPs)
	more efficient in their use of energy than DLP technology – consequently they generate less heat	since LCD panels are organic in nature, they tend to degrade with time (screens turn yellow and the colours are subsequently degraded over time)

Memory, Storage Devices & Media

Primary vs. Secondary Storage

- The CPU directly accesses primary storage
- The CPU does not directly access secondary storage
- RAM, ROM, and cache memory are some examples
- HDD, SSD, DVD, memory stick, and Blu-ray disc are some examples

Primary Memory:

Random Access Memory (RAM)

- RAM is used by a system when it needs to store and access data immediately that is actively being used or processed by the user.
- Features of RAM

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

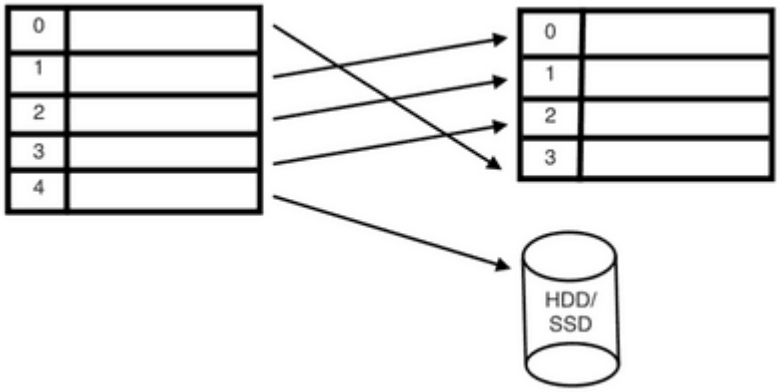
  - Volatile/temporary memory (contents lost if RAM is turned off)
  - Used to store; data, files
  - It can be written to or read from, and the contents of the memory can be changed
- The larger the size of the RAM, the faster the computer will operate
- RAM never runs out of memory and continues to run slow
- As RAM becomes full, the processor has to access the continually hard drive to overwrite old data on RAM with new data
- RAM is of two types:

DRAM (Dynamic RAM) and SRAM (Static RAM)

DRAM	SRAM
consists of a number of transistors and capacitors	uses flip flops to hold each bit of memory
needs to be constantly refreshed	doesn't need to be constantly refreshed
less expensive to manufacture than SRAM	has a faster data access time than DRAM
has a higher memory capacity than SRAM	CPU memory cache makes use of SRAM
main memory is constructed from DRAM	
consumes less power than SRAM	

Virtual memory

- When RAM runs out of memory, there is a problem with memory management; thus, the system has a high chance of crashing. This is why virtual memory comes into the picture.
- The virtual memory can be either HDD or SSD (these storages are discussed below)



- You may be expected to draw a diagram like the above.
- The main advantages of virtual memory are
    - They can be larger than the physical memory provided in the RAM.
    - Avoids the need to install/upgrade RAM, as it could be expensive
    - The system wastes no storage on unwanted/unused data.

Read Only Memory (ROM)

- Features of ROM
    - Non-volatile/permanent memories (contents remain even when ROM is turned off)
    - Used to store start-up instructions (basic input/output systems)
    - Data/contents of a ROM chip can only be read and cannot be changed

Secondary Storage:

Hard Disk Drives (HDD)

- Data is stored in a digital format on the magnetic surface of the disks (platter)
- A number of read/write heads can access all of the surfaces of the disk
- Each platter will have two surfaces which can be used to store the data
- Data is stored on the surfaces in sectors and tracks
- HDD has very slow data access compared to RAM

Solid-State Drive (SSD)

- There are no moving parts, and all data is received at the same time (not like HDD)
- Store data by controlling the movement of electrons within NAND chips, as 1s and 0s
- Non-volatile rewritable memory
- Benefits of using SSD rather than HDD:
    - More reliable (no moving parts)
    - Considerably lighter (suitable for laptops)
    - Lower power consumption
    - Run much cooler than HDDs
    - Very thin
    - Data access is faster than HDD
- Drawback – questionable longevity (20GB per day)

Off-Line Storage:

CD/DVD Disks

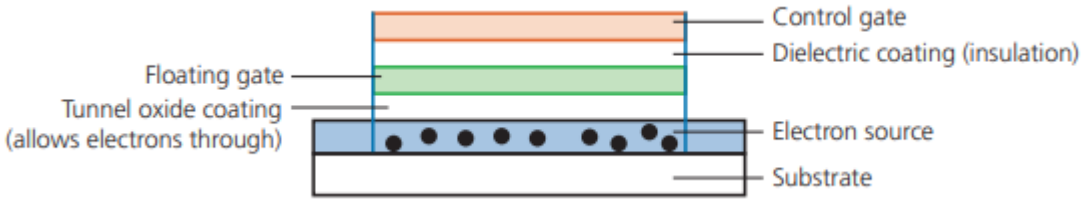
- Laser (red) light is used to read and write data on the surface of the disk.
- Use a thin layer of metal alloy to store data.
- Both systems use a single spiral track that runs from the centre of the disk to the edge
- DVD uses *Dual-Layering,* which increases the storage capacity (two individual recording layers)

Blu-ray Disks

▲ **Figure 3.67** Blu-ray disc

- Uses a blue laser to carry out read-and-write operations
- The wavelength of laser light is less than CD and DVD (stores up to five times more data than DVD)
- Automatically come with secure encryption (prevent piracy and copyright infringement)
- Used as backup systems

USB Flash Memory



- Very small, lightweight, and suitable for transferring files
- Small back-up devices for photo, music
- Solid state, so needs to be treated with care

Cloud Storage:

- Cloud storage is a method of data storage where data is stored on remote servers
- The same data is stored on more than one server in case of maintenance or repair, allowing clients to access data at any time. This is known as **data redundancy.**
- The following are its types:

  » Public cloud – this is a storage environment where the customer/client and cloud storage provider are different companies

» Private cloud – this is storage provided by a dedicated environment behind a company firewall; customer/client and cloud storage provider are integrated and operate as a single entity

» Hybrid cloud – this is a combination of the two above environments; some data resides in the private cloud, and less sensitive/less commercial data can be accessed from a public cloud storage provider

Benefits of using cloud storage	Drawbacks of using cloud storage
customer/client files stored on the cloud can be accessed at any time from any device anywhere in the world provided internet access is available	if the customer/client has a slow or unstable internet connection, they would have many problems accessing or downloading their data/files
there is no need for a customer/client to carry an external storage device with them, or even use the same computer to store and retrieve information	costs can be high if large storage capacity is required; it can also be expensive to pay for high download/upload data transfer limits with the customer/client internet service provider (ISP)
the cloud provides the user with remote back-up of data with obvious benefits to alleviate data loss/disaster recovery	the potential failure of the cloud storage company is always possible – this poses a risk of loss of all back-up data
if a customer/client has a failure of their hard disk or back-up device, cloud storage will allow recovery of their data	
the cloud system offers almost unlimited storage capacity	

Embedded Systems

Benefits	Drawbacks
they are small in size and therefore easy to fit into devices	it can be difficult to upgrade some devices to take advantage of new technology
compared to other systems, they are relatively low cost to make	troubleshooting faults in the device becomes a specialist task
they are usually dedicated to one task allowing simple interfaces and often no requirement for an operating system	although the interface can appear to be more simple (e.g. a single knob) in reality it can be more confusing (e.g. changing the time on a cooker clock can require several steps!)
they consume very little power	any device that can be accessed over the internet is also open to hackers, viruses, etc.
they can be controlled remotely using a mobile phone, for example	due to the difficulty in upgrading and fault finding, devices are often just thrown away rather than being repaired (very wasteful)
very fast reaction to changing input (operate in real time and are feedback orientated)	can lead to an increase in the 'throw away' society if devices are discarded just because they have become out-of-date
with mass production comes reliability	

- Combination of Hardware and Software which is designed to carry out a specific set of tasks.
- Embedded systems may contain -
    - Microcontrollers - CPU, RAM, ROM and other peripherals on one single chip
    - Microprocessor - Integrated circuit with CPU only
    - System on Chips (SoC) - microprocessor with I/O ports, storage and memory
- Process of Embedded Devices -
    - Input from the user is sent to the microprocessor (ADC needed if the data is analogue)
    - Data from the user interface is also sent to the microprocessor
    - Microprocessor then sends signals to actuators which is the output
- Non-programmable devices need to be replaced if they need a software update.
- Programmable devices have two methods of updating -
    - Connecting the device to a computer and downloading the update
    - Updating automatically via a satellite, cellular or Wi-Fi link

< centre>Advantages and Disadvantages of using embedded systems

Advantages	**Disadvantages**
Small in size, therefore can easily fit into devices	Can be difficult to upgrade
Low cost to make	The interface can be confusing sometimes
Requires very little power	Troubleshooting is a specialist's job
Very fast reaction to changing input	Often thrown away as difficult to upgrade and faults are harder to find

Advantages	Disadvantages
Dedicated to one task only	Increased garbage as they are thrown away
Can be controlled remotely	Any computerised system is prone to attacks

- Applications of Embedded devices -
    - GPS systems
    - Security Systems
    - Vending Machines
    - Washing Machines
    - Oven
    - Microwave

Network Hardware

Network Interface Card (NIC)

A network interface card (NIC) is needed to allow a device to connect to a network (such as the internet).

Media Access Control (MAC)

A MAC address comprises 48 bits which are shown as six groups of hexadecimal digits. The first six display the manufacturer’s code, and the second half shows the device serial number.

- These do not change and are primarily constant for every device
- there are two types of MAC addresses: the Universally Administered MAC Address (UAA) and the Locally Administered MAC Address (LAA)

The only difference between the two types is that UAA is made Universally and cannot be changed, but it is the opposite for LAA.

IP Addresses

- IP address allocation:
    - The network allocates IP addresses.
    - Two types of IP addresses: static and dynamic.
- Static IP addresses:
    - Assigned manually to a device.
    - Does not change over time.
- Dynamic IP addresses:
    - Assigned automatically by a DHCP (Dynamic Host Configuration Protocol) server.
    - Changes periodically or when the device connects to a different network.
- IPv4 (Internet Protocol version 4):
    - Widely used protocol.
    - Consists of four groups of decimal numbers separated by dots (e.g., 192.168.0.1).
    - Provides approximately 4.3 billion unique addresses.
- IPv6 (Internet Protocol version 6):
    - Developed to address the limitations of IPv4.
    - Uses eight groups of hexadecimal numbers separated by colons (e.g., 2001:0db8:85a3:0000:0000:8a2e:0370:7334).
    - Provides an extremely large number of unique addresses (approximately 340 undecillion).
- Differences between IPv4 and IPv6:
    - Address format: IPv4 uses a 32-bit address, while IPv6 uses a 128-bit address.
    - Address space: IPv4 provides approximately 4.3 billion addresses, whereas IPv6 offers around 340 undecillion addresses.

    - Address allocation: IPv4 addresses are allocated using DHCP or manually, while IPv6 addresses are primarily assigned using stateless autoconfiguration.

Routers

- Router functionality:
    - A router is a networking device that directs data packets between different networks.
    - It determines the most efficient path for data transmission.
- Sending data to a specific destination on a network:
    - A router examines the destination IP address of incoming data packets.
    - It uses routing tables to determine the next hop or the next router on the path to the destination.
    - The router forwards the data packet to the appropriate next hop.
- Router's role in IP address assignment:
    - A router can act as a DHCP server (Dynamic Host Configuration Protocol) and assign IP addresses to devices on a local network.
    - It dynamically allocates IP addresses from a predefined range to connected devices.
    - DHCP allows for automatic IP address configuration and simplifies network management.
- Connecting a local network to the Internet:
    - A router serves as the gateway between a local network and the internet.
    - It connects the local network to an internet service provider (ISP) network.
    - The router receives data packets from devices on the local network and forwards them to the internet.

- It also receives incoming data packets from the internet and routes them to the appropriate devices on the local network.