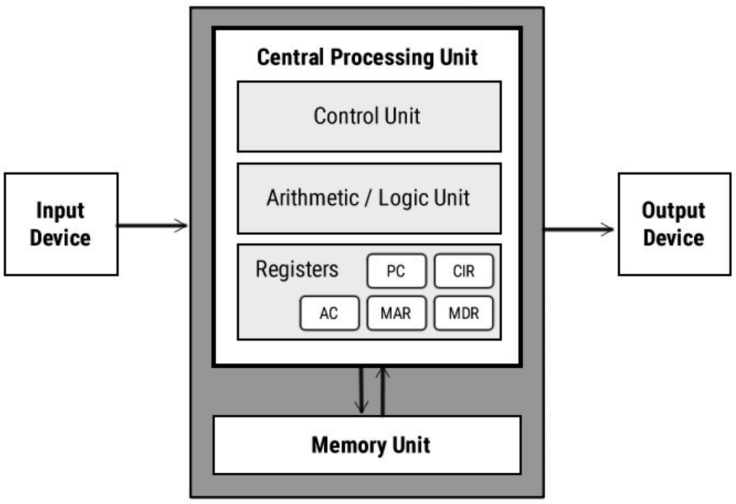
Von Neumann Architecture

Von Neumann architecture is based on the stored-program computer concept, where instruction data and program data are stored in the same memory. This design is still used in most computers produced today.



- the concept of a central processing unit (CPU or processor)
- the CPU was able to access the memory directly
- computer memories could store programs as well as data
- stored programs were made up of instructions which could be executed in sequential order.

The Central Processing Unit (CPU) is often referred to as the brain of a computer, and it plays a crucial role in the **overall functioning of the system**. The CPU is very often installed as an **integrated circuit** on a single microchip. The CPU has the responsibility for the execution or processing of all the instructions and data in a computer application.

The CPU consists of:

1. **control unit (CU):** The CPU includes a control unit that coordinates and manages the activities of other components in the computer, ensuring that instructions are executed in the correct sequence. The control unit reads an instruction from memory. The address of the location where the instruction can be found is stored in the Program Counter (PC).

   Note: system clock is used to produce **timing signals** on the control bus to ensure this vital synchronisation takes place and the **RAM** holds all the data and programs needed to be accessed by the CPU.

2. **arithmetic and logic unit (ALU):** The CPU is capable of performing arithmetic operations (addition, subtraction, multiplication, and division) and logical operations (comparisons, AND, OR) to process data.

3. **registers and buses:** Registers are small, fast storage units within the CPU that hold temporary data and control information. Buses, on the other hand, are communication pathways connecting the CPU, memory, and devices for transferring data and control signals.

current instruction register (CIR)	this register stores the current instruction being decoded and executed
accumulator (ACC)	this register is used when carrying out ALU calculations; it stores data temporarily during the calculations
memory address register (MAR)	this register stores the address of the memory location currently being read from or written to
memory data register (MDR)	this register stores data which has just been read from memory or data which is about to be written to memory
program counter (PC)	this register stores the address where the next instruction to be read can be found

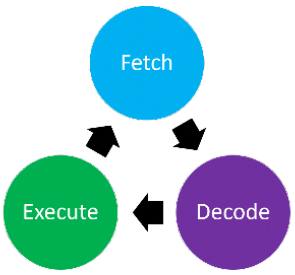
Address Bus	the address bus carries addresses throughout the computer system. Between the CPU and memory, the address bus is unidirectional
Data bus	The data bus is bidirectional (allowing data to be sent in both directions along the bus). This means data can be carried from CPU to memory (and vice versa) and to and from input/output devices.
Control bus	The control bus is also bidirectional. It carries signals from the control unit (CU) to all the other computer components.

Fetch–Decode–Execute cycle

Video

To carry out a set of instructions, the CPU first of all fetches some data and instructions from memory and stores them in suitable registers. Both the **address bus** and **data bus** are used in this process. Once this is done, each instruction needs to be decoded before finally being executed. This is all known as the Fetch–Decode–Execute cycle.

- **Fetch:** Both data and instruction can be stored in MDR. In the Fetch–Decode–Execute cycle, the next instruction is fetched from the memory address currently stored in the MAR and the instruction is stored in the MDR. The contents of the MDR are then copied to the Current Instruction Register (CIR). The PC is then incremented (increased by 1) so that the next instruction can then be processed.



- **Decode:** The instruction is then decoded so that it can be interpreted in the next part of the cycle.
- **Execute:** The CPU passes the decoded instruction as a set of control signals to the appropriate components within the computer system. This allows each instruction to be carried out in its logical sequence.

Cores, cache and internal clock

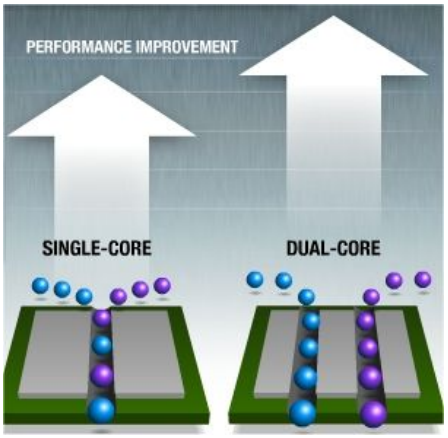
Factors that determine the performance of a CPU:-

- **The width of the address bus and data bus:** A wider address bus allows for increased memory capacity and improved multitasking, contributing to better overall performance. A wider data bus results in faster data transfer, enhancing the computer's processing speed and efficiency.

- **Overclocking:** Overclocking is the practice of boosting the clock speed of computer components like the CPU or GPU beyond their default settings to gain increased performance. It involves running hardware at higher speeds than intended by the manufacturer. While it can enhance performance, it also generates more heat and carries potential risks such as reduced lifespan and system instability.

- **Use of Cache memory:** Cache stores frequently used instructions and data, facilitating quick retrieval and reducing the need to access slower RAM. When the CPU needs to read memory, it first checks the cache for the required data; if found, this avoids the slower process of fetching from main memory (RAM).

- **number of cores:** The use of a different number of cores can improve computer performance. One core is made up of an ALU, a control unit and the registers. However, doubling the number of cores doesn't necessarily result in a doubling of overall computer performance.



Instruction set

In a computer system, instructions are a set of operations which are decoded in sequence. Each operation will instruct the ALU and CU (which are part of the CPU). An operation is made up of an opcode and an operand. These commands, written in machine language, represent the fundamental operations and tasks that the CPU can perform. Each instruction corresponds to a specific operation, such as arithmetic calculations, data movement, or control flow.

Example:

ADD A,B: This instruction adds the values stored in memory locations A and B and stores the result in register A, **LOAD A, 100:** Loads the value from memory address 100 into register A.

Embedded systems

An embedded system is a combination of **hardware** and **software** which is designed to carry out a **specific set of functions**. An embedded system is used to perform a **dedicated function**, e.g. domestic appliances, cars, security systems, lighting systems or vending machines.

This is different to a general purpose computer that is used to perform many different functions, e.g. a personal computer (PC) or a laptop.

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 is difficult
they are usually dedicated to one task allowing simple interfaces and often no requirement for an operating system	sometimes confusing interfaces
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

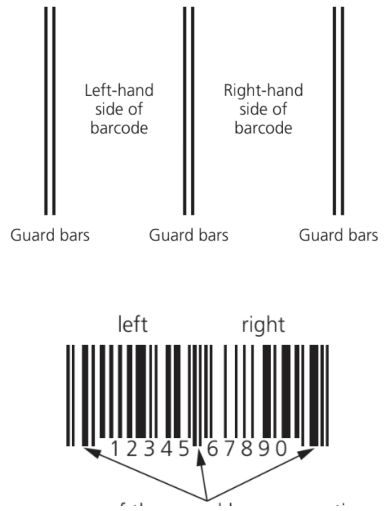
Examples of the use of embedded systems:

- **Motor vehicles:** Engine Control Unit (ECU), Anti-lock Braking System (ABS), Airbag System, Infotainment System, Advanced Driver Assistance Systems (ADAS), GPS System, Keyless Entry System etc.
- **Security systems**: Surveillance Cameras, Motion Sensors, Alarm Systems, Video Doorbells, Fire and Smoke Detectors etc.
- **Lightning systems**: LED Technology, Motion Sensors, Dimming Capabilities, Color-changing Options, Timers and Scheduling, Occupancy Sensors etc.
- **Vending machines:** Payment Systems, Product Dispensing Mechanism, Product Inventory Control, User Interface, Cooling/Heating Systems, Remote Monitoring etc.

Input and output devices

Input devices

1. **Barcode scanners (readers):** A barcode is a series of dark and light parallel lines of varying thickness. The numbers 0 to 9 are each represented by a unique series of lines. The example we shall use adopts different codes for digits appearing on the left and for digits appearing on the right of the barcode:



- the barcode is first of all read by a red laser or red LED (light emitting diode)
- light is reflected back off the barcode; the dark areas reflect little or no light, which allows the bars to be read
- the reflected light is read by sensors.
- as the laser or LED light is scanned across the barcode, a pattern is generated, which is converted into digital data

Advantages to the management of using barcodes:

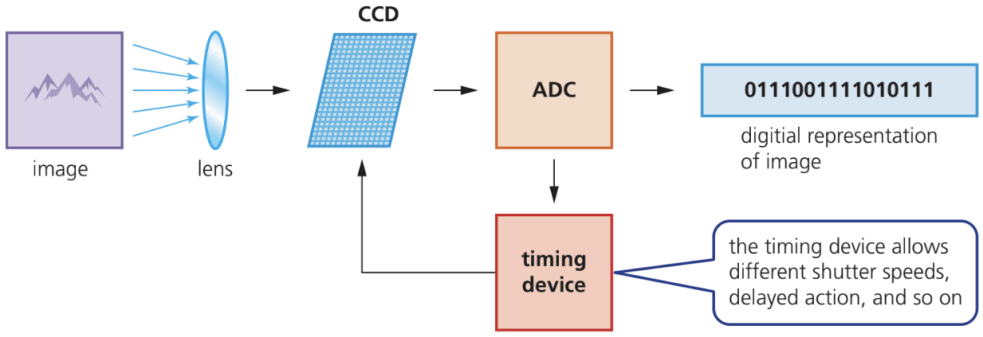
- much easier and faster to change prices on stock items
- much better, more up-to-date sales information/sales trends
- no need to price every stock item (this reduces time and cost to the management)
- allows for automatic stock control
- possible to check customer buying habits more easily by linking barcodes to, for example, customer loyalty cards.

2. **Quick response (QR) codes:** Quick Response (QR) codes are two-dimensional barcodes that store information such as URLs, text, or contact details. Scannable by devices like smartphones, they offer a quick and efficient way to access information.

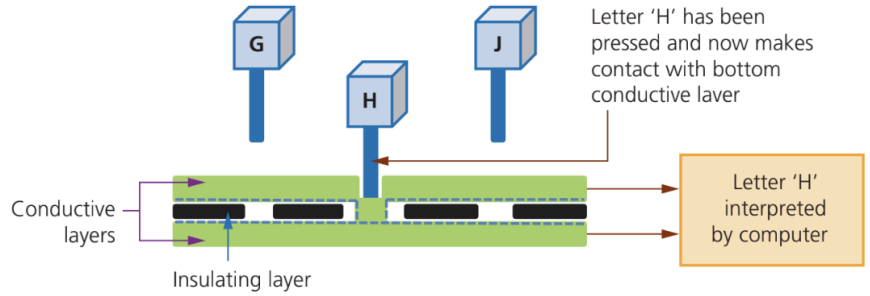
Advantages of QR codes compared to traditional barcodes:

- They can hold much more information
- QR codes are easier to read; they don't need expensive laser or LED (light emitting diode) scanners like barcodes – they can be read by the cameras on smartphones or tablets
- It is easy to transmit QR codes either as text messages or images
- It is also possible to encrypt QR codes which gives them greater protection than traditional barcodes.

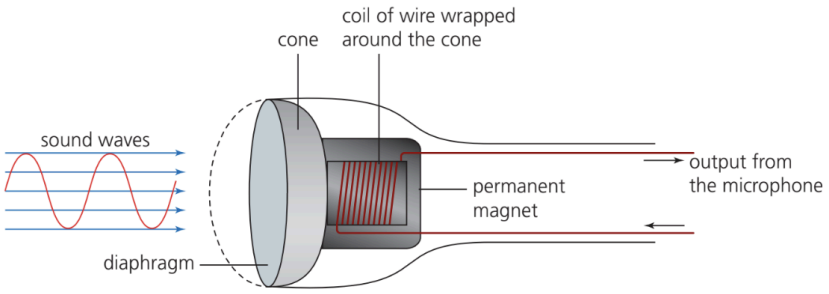
3. **Digital cameras:** Digital cameras are electronic devices that capture and store images in digital format. They use sensors to convert light into electrical signals (using ADC), producing digital photographs. These cameras often include features like autofocus, zoom lenses, and various shooting modes. Images can be previewed on a digital screen and transferred to computers or other devices for storage, editing, and sharing.

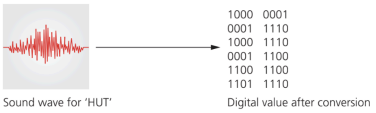


4. **Keyboards:** Keyboards are by far the most common method used for data entry. They are used as the input devices on computers, tablets, mobile phones and many other electronic items. The keyboard is connected to the computer either by using a USB connection or by wireless connection. In the case of tablets and mobile phones, the keyboard is often virtual or a type of touch screen technology. **Example:** When 'H' key is pressed and this completes a circuit

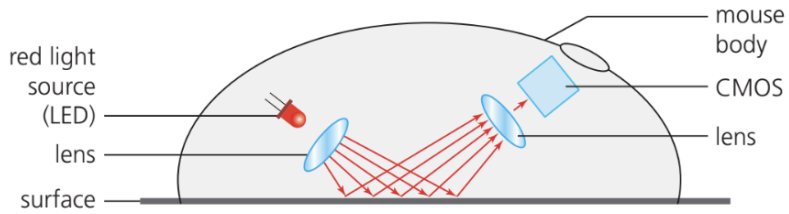


5. **Microphones:** Microphones are either built into the computer or are external devices connected through the USB port or using Bluetooth connectivity. Figure shows how a microphone can convert sound waves into an electric current. The current produced is converted to a digital format so that a computer can process it or store it (on, for example, a CD).





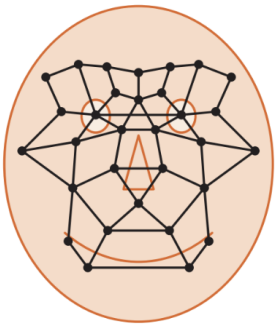
6. **Optical mouse:** An optical mouse is a computer input device that uses optical sensor technology to detect movement. Instead of a traditional ball mechanism, it employs an LED light and a sensor to track changes in surface texture and movement. As the mouse moves, the sensor captures these changes and sends corresponding signals to the computer, allowing the cursor on the screen to move accordingly.



7. **2D and 3D scanners:** 2D Scanners are the most common form and are generally used to input hard copy (paper) documents. The image is converted into an electronic form that can be stored in a computer. Computers equipped with optical character recognition (OCR) software allow the scanned text from the document to be converted into a text file format.

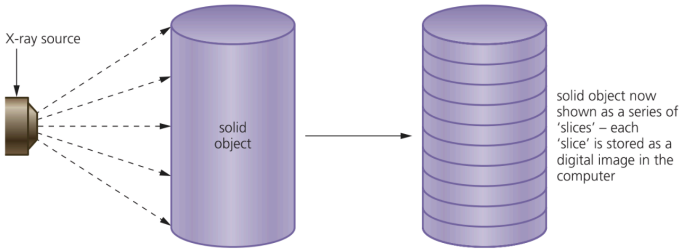
   3D scanners scan solid objects and produce a three-dimensional image. Since solid objects have x, y and z coordinates, these scanners take images at several points along these three coordinates. A digital image which represents the solid object is formed.

   Application of 2D scanners at an airport: 2D scanners are used at airports to read passports. They make use of OCR technology to produce digital images which represent the passport pages. At many airports the two-dimensional photograph in the passport is scanned and stored as a JPEG image. The passenger's face is also photographed using a digital camera. The two digital images are compared using face recognition/detection software. Key parts of the face are compared.

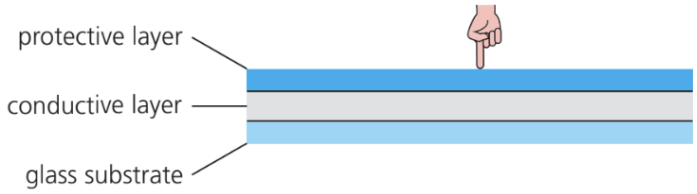


- distance between the eyes
- width of the nose
- shape of the cheek bones
- length of the jaw line
- shape of the eyebrows

   Application of 3D scanning – computed tomographic (CT) scanners: Computed tomographic (CT) scanners are used to create a 3D image of a solid object. This is based on tomography technology, which basically builds up an image of the solid object through a series of very thin 'slices'. Each of these 2D 'slices' make up a representation of the 3D solid object.



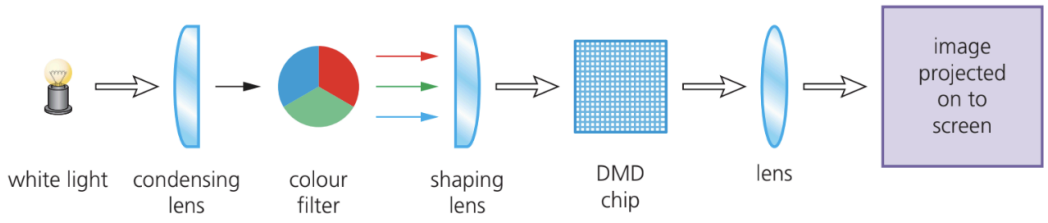
8. **Touch screens:** Touch screens are display screens that can detect and respond to touch input from fingers or styluses. These screens use various technologies, including capacitive, resistive, infrared, or surface acoustic waves, to detect touch interactions. Users can directly interact with the display by tapping, swiping, pinching, or performing other gestures to control applications, navigate menus, or input data. Touch screens are widely used in smartphones, tablets, laptops, interactive kiosks, and other devices, providing an intuitive and user-friendly interface.



Output devices

1. **Actuators:** Actuators are devices or components that convert input signals or energy into physical motion or mechanical action. Actuators are commonly used in engineering, automation, robotics, and numerous other applications. Actuators are fundamental in translating control signals into motion. They are often used with **sensors**.

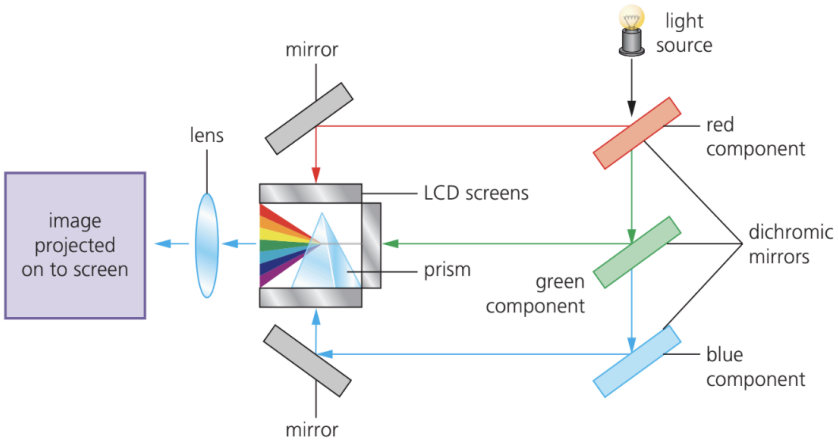
2. **Digital light processing (DLP) projector:** A Digital Light Processing (DLP) projector is required for various reasons, primarily due to its unique technology and advantages in delivering high-quality images in a wide range of applications.



Advantages:

- higher contrast ratios
- higher reliability/longevity
- quieter running than LCD projector
- smaller and lighter than LCD projector

3. **Liquid crystal display (LCD) projector:** A Liquid Crystal Display (LCD) projector is a type of video projector that uses liquid crystal panels to project images onto a screen or surface. LCD projectors are driven by their ability to provide high-quality, versatile, and cost-effective solutions for various visual display needs. Their popularity spans across different sectors, including education, business, entertainment, and personal use.



Advantages:

- give a sharper image than DLP projectors
- have better colour saturation than DLP projectors
- more efficient in their use of energy than DLP technology – consequently they generate less heat

4. **Inkjet printers:** Inkjet printers are composed of key components, including a print head with nozzles that spray ink droplets onto paper to create characters, and ink cartridges that hold coloured inks (blue, yellow, magenta) and black ink.

Some systems may use separate cartridges for each colour and black, while others use a single cartridge with all colours. A stepper motor and belt move the print head assembly horizontally across the page. Additionally, there is a paper feed mechanism that automatically supplies pages to the printer when needed. These components work together to enable the precise deposition of ink onto paper, producing high-quality prints of text and images.

Features:

- High-Quality Printing
- Versatility and Colour Accuracy
- Home and Small Office Use
- Photo Printing and Affordability

5. **Laser printers:** Laser printers are a type of printer that uses laser technology to produce high-quality prints. Laser printers are known for their speed, efficiency, and cost-effectiveness, making them an ideal choice for offices, businesses, and users with high-volume printing requirements.

   Laser printers use dry powder ink rather than liquid ink and make use of the properties of static electricity to produce the text and images. Unlike inkjet printers, laser printers print the whole page in one go.

Features:

- fast printing speeds
- High-Volume Printing
- Network Printing
- Monochrome and Color Printing

6. **3D printer:** 3D printers are used to produce solid objects that actually work. They are primarily based on inkjet and laser printer technology. The solid object is built up layer by layer using materials such as: powdered resin, powdered metal, paper or ceramic.

   3D printing is regarded as being possibly the next 'industrial revolution' since it will change the manufacturing methods in many industries.

Features:

- 3D printers can be used to create rapid prototypes
- Models can be transmitted digitally
- Used to create 3D image of any object

7. **LCD screens:** LCD screens, consisting of millions of tiny liquid crystals arranged in a matrix of pixels, are widely utilized in devices such as TVs, monitors, tablets, and phones. Unlike LED screens, LCD screens require backlighting to illuminate the display. Despite this requirement, LCD screens are known for their low power consumption, running at a cool temperature.

Features:

- They are used for TVs, monitors, tablets and phones
- They have low power consumption and run at a cool temperature
- They do not suffer image burn or flicker issues
- They provide bright images and colours
- They are cheaper to produce than LED screens

8. **LED Screens:** LED screens, comprised of tiny light-emitting diodes (LEDs), distinguish themselves by not requiring backlighting, resulting in a thinner and lighter design that can be easily mounted on walls. This characteristic has led to the increasing replacement of LCD displays in various devices, including TVs, monitors, laptops, and mobile devices.

Features:

- An LED screen is made up of tiny LEDs
- They do not need backlighting
- They have better image quality and a longer life span
- can be used to create very large screens
- They consume very little power

9. **(Loud) speakers:** (Loud) speakers are devices designed to convert electrical signals into audible sound waves, providing an essential component for audio reproduction in various applications. In audio systems, loudspeakers are used in a range of settings, from home entertainment and professional audio setups to public address systems and concerts.

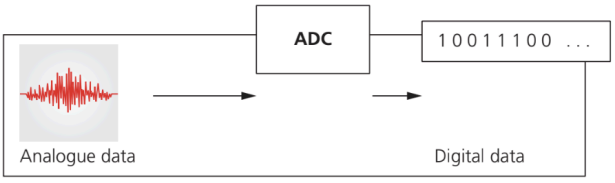
Features:

- Speakers are used to take digital sounds or recordings and output them as sound waves which can be heard by humans.
- The digital data is changed into an electric current using a digital to analogue converter (DAC).
- It is then passed through an amplifier to create a current large enough to drive a loudspeaker.
- The loudspeaker converts the current into a sound wave.

Sensors

A **sensor** is a device or instrument that **detects** and **measures physical properties** or **changes** in the environment and converts them into **signals** or data that can be interpreted, displayed, or used for control purposes.

Sensors play a crucial role in various applications by providing information about the surrounding conditions. However, computers cannot make any sense of these physical quantities so the data needs to be converted into a digital format. This is usually achieved by an **analogue to digital converter (ADC)**. This device converts physical values into discrete digital values.



When the computer is used to control devices (output devices like motor), it is necessary to use a **digital to analogue converter (DAC)** since these devices need analogue data to operate

Types of sensors:

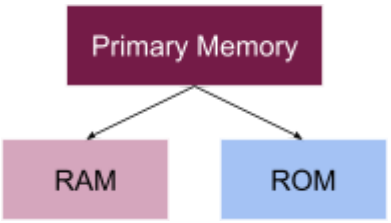
Sensor	Description	Example
Temperature	measures temperature of the surroundings by sending signals; these signals will change as the temperature changes Type of Data: Ambient temperature	• control of a central heating system • control/monitor a chemical process • control/monitor temperature in a greenhouse
Moisture	measure the level of moisture or water content in soil, building materials, or other substances Type of Data: Moisture or water content in soil or other substances	• control/monitor moisture levels in soil in a greenhouse • monitor the moisture levels in a food processing factory
Humidity	this is slightly different to moisture; this measures the amount of water vapour in Type of Data: Moisture content in the air	• monitor humidity levels in a building • monitor humidity levels in a factory manufacturing microchips • monitor/control humidity levels in the air in a greenhouse
Light	these use photoelectric cells that produce an output depending on the brightness of the light Type of Data: Ambient light levels	• switching street lights on or off depending on light levels • switch on car headlights automatically when it gets dark
Infrared	detect infrared radiation, commonly used in motion detectors, temperature measurement, and proximity sensing Type of Data: Infrared radiation	• turn on car windscreen wipers automatically when it detects rain on the windscreen • security alarm system (detects body heat)

Pressure	measure the force exerted on a surface per unit area Type of Data: Force exerted on a surface per unit area	• weighing of lorries at a weighing station • measure the gas pressure in a nuclear reactor
Acoustic/sound	these are basically microphones that convert detected sound into electric signals/pulses Type of data: Sound waves or vibrations	• pick up the noise of footsteps in a security system • detect the sound of liquids dripping at a faulty pipe joint
Gas	they use various methods to detect the gas being monitored and produce outputs that vary with the oxygen or carbon dioxide levels present Type of Data: Presence and concentration of gases in the air	• monitor pollution levels in the air at an airport • monitor oxygen and carbon dioxide levels in a greenhouse • monitor oxygen levels in a car exhaust
pH	measure the acidity or alkalinity of a solution Type of Data: Acidity or alkalinity of a solution	• monitor/control acidity levels in the soil in a greenhouse • control acidity levels in a chemical process
Magnetic field	these sensors measure changes in magnetic fields Type of Data: Strength and direction of magnetic fields	• detect magnetic field changes (for example, in mobile phones and CD players) • used in anti-lock braking systems in cars
Accelerometer	measure acceleration and motion of an application Type of Data: Acceleration, changes in motion, tilt, or vibration	• used in cars to measure rapid deceleration and apply airbags in a crash • used by mobile phones to change between portrait and landscape mode
Proximity	these sensors detect the presence of a nearby object Type of Data: Presence or absence of an object within a certain range	• detect when a face is close to a mobile phone screen and switches off screen when held to the ear
Flow (rate)	measure the flow rate of a moving liquid or gas and produce an output based on the amount of liquid or gas passing over the sensor Type of Data: Rate of fluid (liquid or gas) flow	• used in respiratory devices and inhalers in hospitals • measure gas flows in pipes (for example, natural gas)
Level	measure the level or depth of a substance (liquid or solid) Type of Data: Level or depth of a substance (liquid or solid)	• monitor levels in a petrol tank in a car • in a pharmaceutical process where powder levels in tablet production need to be monitored • leak detection in air conditioning

Data storage

Primary Memory

Primary memory is the part of the computer memory which can be accessed directly from the CPU; this includes **random access memory (RAM)** and **read- only memory (ROM)** memory chips. Primary memory allows the CPU to access applications and services temporarily stored in memory locations.



RAM	**RAM** is volatile memory, which means that the information temporarily stored in the module is erased when you restart or shut down your computer. Because the information is stored electronically on transistors, when there is no electric current, the data disappears. Each time you request a file or information, it is retrieved either from the computer's storage disk or the internet. The data is stored in RAM, so each time you switch from one program or page to another, the information is instantly available. When the computer is shut down, the memory is cleared until the process begins again. Volatile memory can be changed, upgraded, or expanded easily by users.
ROM	**ROM** stands for non-volatile memory in computers., which means the information is permanently stored on the chip. The memory does not depend on an electric current to save data, instead, data is written to individual cells using binary code. Non-volatile memory is used for parts of the computer that do not change, such as the initial boot-up portion of the software, or the firmware instructions that make your printer run. Turning off the computer does not have any effect on ROM. Non-volatile memory cannot be changed by users.

Secondary Memory

Secondary storage refers to storage devices or media that are not directly accessed by the Central Processing Unit (CPU) for day-to-day operations. Unlike primary storage (such as RAM), which is volatile and used for temporary storage, secondary storage provides more permanent and non-volatile storage of data. Secondary storage retains its contents even when the power is turned off, making it suitable for long-term storage.

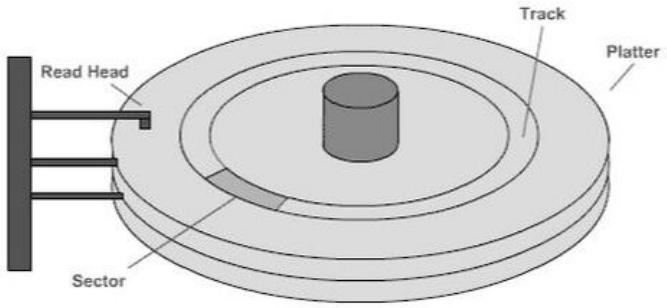
Types of secondary storage

There are three types of secondary storage - **magnetic**, **solid state** and **optical**

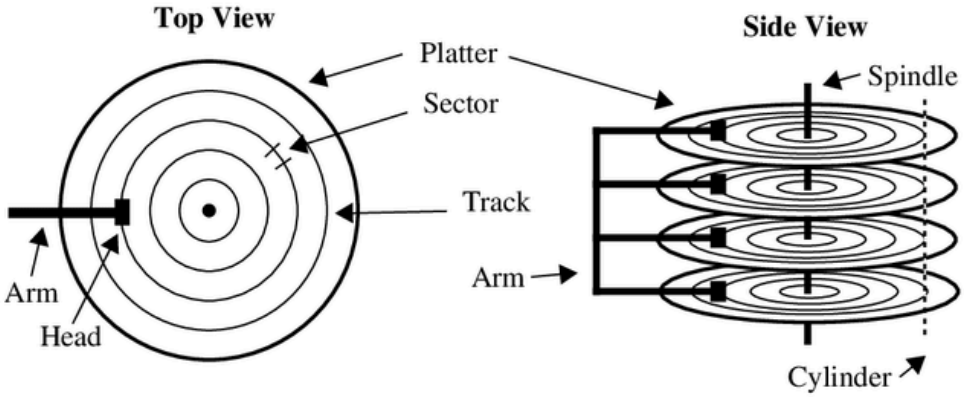
1. Magnetic

- Magnetic hard disk drives have been the main type of internal secondary storage in personal computers for many years however solid state drives are increasingly popular due to their durability, low power consumption and high read/write speeds
- A magnetic hard disk is made up of several metal discs coated with a magnetic material

- These are called platters
- Iron particles on each platter are magnetised to represent a 0 or 1



- Each platter is divided by concentric circles creating several tracks and wedge shaped sectors. Where they intersect is a track sector
- The hard drive spins the metal disk(s) at a high speed (typically around 5400-7200 RPM) using a motor.



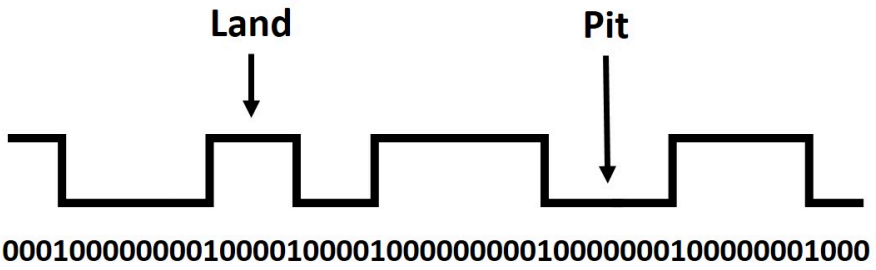
- A read/write arm, controlled by an actuator, moves the head over the surface of the disc to the location of the data.
- The data is read/written using electromagnets

2. Solid-State Drive (SSD)

- Solid State secondary storage is made of transistors that are arranged in a grid layout
- It uses NAND and NOR gates in electrical circuits to persistently control the flow of electrons
- Current flowing is 1, no current is 0 - which is how electrical flow can represent binary values
- A NOR gate will produce an output (1) only when both inputs are 0
- A NAND gate will take in two inputs and produce an output (1/electrical current) as long as both inputs are not 1

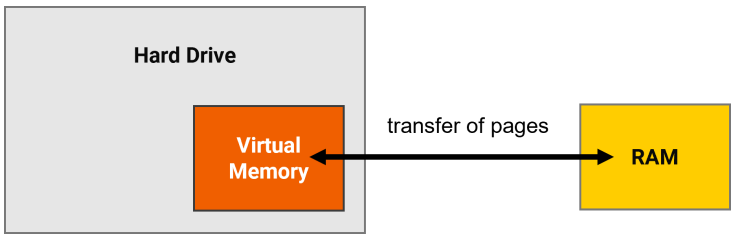
3. Optical Drive (CD/ DVD)

- Optical devices include CDs, DVDs and Blu-rays
  - Blu-rays have the largest capacity
  - CDs have the lowest capacity
  - CD-R are read-only (you cannot save data on to them)
  - CD-RW can be written to and read from
  - DVD-RW can be written to and read from
- All optical devices work by shining a laser at the disk and processing the reflection
- An arm moves the laser across the surface of the disk
- In CD-Rs a laser burns the data, permanently on to the disk, by creating pits and lands
- The laser is also used to read the data from the pits and lands
- When the laser light hits the point where the pit changes into a land or vice versa the light scatters and is not reflected back as well. This is captured by a sensor and can be interpreted as a change in the binary value



Virtual Memory

One of the problems associated with memory management is the case when processes **run out of RAM**. If the amount of available RAM is exceeded due to multiple programs running, it is likely to cause a system crash. This can be solved by utilising the hard disk drive (or SSD) if we need more memory. This is the basis behind virtual memory. Essentially RAM is the physical memory, while virtual memory is **RAM + swap space on the hard disk or SSD**.



All of this will continue to occur until RAM is no longer being over-utilised by the competing programs running in memory. In computer operating systems, paging is used by memory management to store and retrieve data from HDD/SSD and copy it into RAM.

The main benefits of virtual memory are:

- programs can be larger than physical memory and still be executed
- there is no need to waste memory with data that isn't being used
- it reduces the need to buy and install more expensive RAM memory