1. Hardware

CPU Computer processor unit

To a computer, the world consists of zeros and ones. Inside a processor, we can store zeros and ones using transistors. These are microscopic switches that control the flow of electricity depending on whether the switch is on or off. So the transistor contains binary information: a one if a current passes through and a zero if a current does not pass through.

Transistors are located on a very thin slice of silicon. A single silicon chip can contain thousands of transistors. A single CPU contains a large number of chips. Combined, these only cover a couple of square centimetres, but can hold several million transistors and process hundreds of millions of instructions per second.

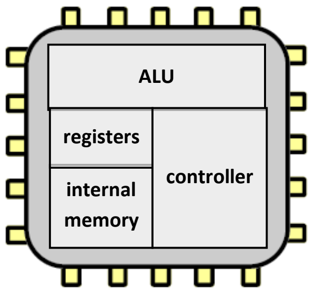
CPU (Central Processing Unit) Architecture

CPU architecture is a term that refers to the design of a Microprocessor, an integrated circuit, where the components of the CPU are combined as a single unit.

Components of the CPU

The **CPU** is the main component in a computer for processing data and instructions. It could be considered as the computing equivalent of the human brain. It is a hardware device that is made up of many sub components:

- controller
- ALU: arithmetic and logic unit
- registers
- internal memory



These components have specific functions.

Controller or control unit

The controller sends and receives signals from all parts of the computer. It ensures that all processes take place at the right time and in the correct order.

Arithmetic and logic unit (ALU)

The ALU is the part of the CPU that processes and manipulates data. It performs simple calculations on the data that is temporarily stored in the registers.

The ALU is also able to perform comparisons on data. It is these comparisons that allow programs to make use of *choice* – e.g. in a high-level language an IF statement.

Registers

A register is a storage location found on the CPU where data or control information is temporarily stored. Registers are usually much faster to access than internal memory, since they have to be accessed so often.

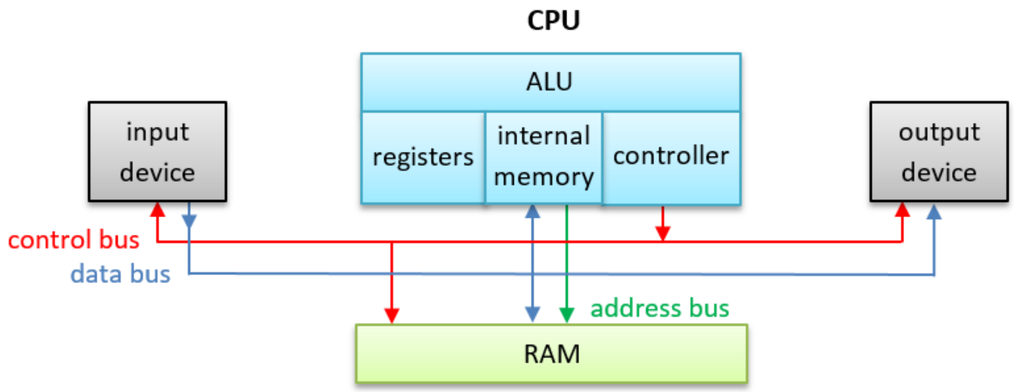
An accumulator is a common example of a register. This is the register used by the ALU to store the results of its calculations.

SUMMARY DEFINITIONS

Controller: manages the execution of instructions
ALU: processes and manipulates data
Register: fast access temporary data store
Internal memory: fast access memory on the CPU

Internal memory

Internal memory (*sometimes called level 1 cache memory*) is fast access temporary storage on the CPU. Data is moved from the registers to the internal memory when it is not being actively used. Data from internal memory can then either be written to RAM or called back into the registers for further processing.



Buses

Buses allow data to be transferred to different parts of the computer. There are three main buses used by the CPU.

1. Address bus. When data is saved or loaded from memory, the address at which it is to be stored or loaded from must be sent. The storage address of data always travels along an address bus.
2. Data bus. Data will then need to be moved between several parts of a computer. The path along which data travels is called a data bus.
3. Control bus. The controller uses the control bus to send control signals to different parts of the computer.

Von Neumann

Early computers were generally designed to carry out a specific task or calculation. Re-programming these custom built computers was very difficult and could even involve some re-wiring. In 1945 John von Neumann proposed storing the program instructions in the same memory as the data. This idea of a **stored program**, which is often referred to as 'Von Neumann' architecture, resulted in computers that could be more easily re-programmed and is the basis for the fetch-decode-execute cycle, fundamental to modern computer processing.

The fetch-decode-execute cycle

There are **three** steps to processing instructions given by a currently running program:

1. The fetch cycle takes the address required from memory, stores it in the instruction register, and moves the program counter on one so that it points at the next instruction.
2. The control unit checks the instruction in the instruction register. The instruction is decoded to determine the action that needs to be carried out.
3. The actual actions that happen during the execution cycle depend on the instruction itself.

CPU Performance and specification

When we use a computer, we want the instructions to be carried out very fast. As the instructions become more complicated (for example, creating a 3D animation or editing a video file), we demand more from the CPU. The technological advances we have seen in processor technology have largely been driven by the need for speed.

CPU Cache memory

Cache memory is a fast access type of memory that is very expensive. Due to its cost, only small amounts of cache memory are present in most computer systems. Cache memory improves the performance of the CPU as it is able to provide instructions and data to the CPU at a much faster rate than other system memory such as RAM. The more cache memory your system has, the better its performance is likely to be.

Clock speed

The speed at which a processor operates is called the clock speed. The faster the clock speed, the faster the computer is able to run the fetch-decode-execute cycle and therefore process more instructions.

The speed of the processor is measured in Hertz (Hz). One clock tick per second would be measured as 1 Hz. Therefore a processor that operates at 1,000 clock ticks per second would be a 1,000 Hz processor, also known as a 1 kHz processor.

At this stage, it is a good time to introduce *prefix multipliers* for clock speeds:

Prefix	Symbol	Multiplier	Power of 10
Kilo	k	1,000	10^3
Mega	M	1,000,000	10^6
Giga	G	1,000,000,000	10^9

A typical modern day home computer would have a 2.5 GHz processor. This means the clock speed of the processor runs at 2,500,000,000 Hz or clock ticks per second.

The clock speed inside the CPU can sometimes be changed. A processor can be set to run faster than its original design. By doing this however, it uses more energy and produces more heat. If this heat is not removed through cooling, the CPU can overheat, which will damage the CPU and shorten its lifespan. This is called *overclocking*.

INTERESTING FACT

Most CPUs are cooled using a fan mounted on a metal heat sync. Liquid cooling systems have been found to be more effective at cooling CPUs, although the water used in these systems conducts electricity and can therefore be dangerous. A computer designer, Seymour Cray, designed a computer cooling system that used artificial human blood to cool the CPU, as it does not conduct electricity

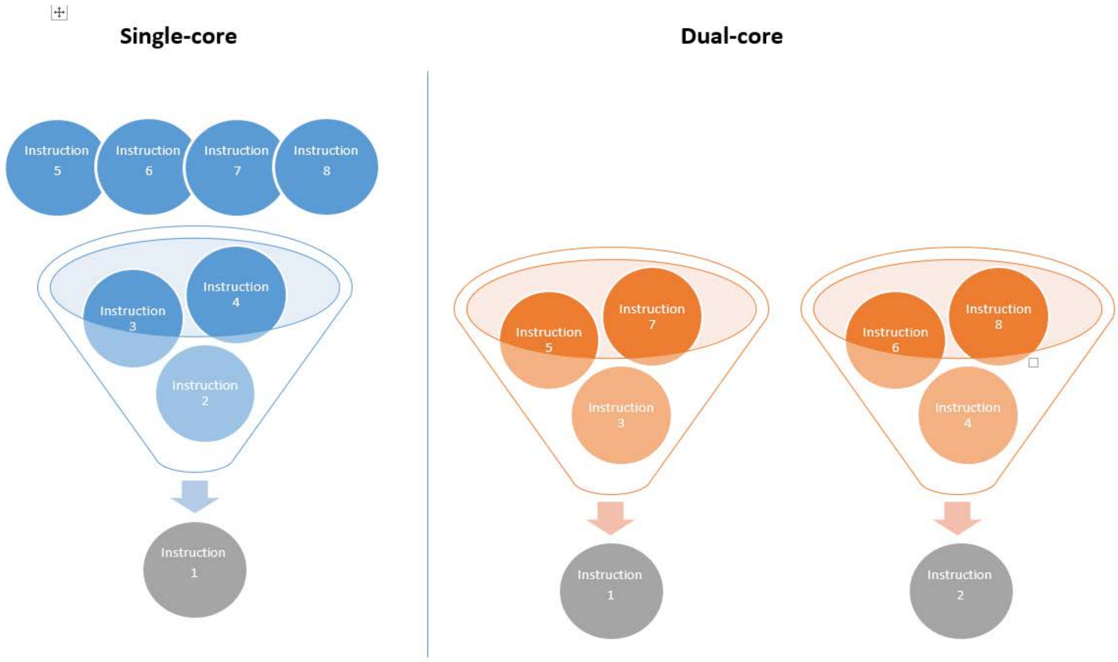
Some computer systems, especially mobile devices, set the clock speed of the CPU lower than its original design. This results in less power consumption, less heat being produced and will therefore increase the battery life of the device. This is called *underclocking*.

Some devices are able to change their own clock speed dynamically. For example, when your computer is idle, the clock speed may be set at a lower rate than if you were running a CPU intensive program, such as a computer game.

Number of cores

We have assumed that each CPU has only one core. However, this isn't always the case, as some CPU's have multiple cores. You may be familiar with the terms 'dual-core' and 'quad-core', so what exactly do these terms mean?

A core is the term used to describe the processing components within the CPU. Multi-core processors therefore have many processing components within the same CPU. Below is a diagram that illustrates a number of instructions waiting to be processed in single-core and dual-core CPUs.



In a single-core CPU each instruction is processed one after the other, whereas in a dual-core CPU, two instructions may be processed at the same time. In theory, a dual-core CPU should be able to process instructions twice as fast as a single-core CPU. However, this isn't always the case, as sometimes *Instruction 2* may need the result of *Instruction 1* before it can be processed.

In general, a computer running many programs at the same time will run faster on a multi-core processor than on a single-core processor.

INTERESTING FACT
Many high-end gaming consoles include CPUs with multiple cores. The Sony *Playstation 3* has an 8 core CPU.

RISC and CISC processors

There are two main types of processor, namely **Reduced Instruction Set Computer (RISC)** and **Complex Instruction Set Computer (CISC)**.

RISC processors can process a limited number of relatively simple instructions. To carry out more complex commands the problem is broken down into a longer list of simpler instructions. The advantage of this is that a RISC processor is able to process these simpler instructions quickly. Processing simpler instructions also requires less circuitry to decode and execute these instructions, which in turn means less power consumption and therefore less heat being generated.

CISC processors can process a large number of complex instructions. This allows the processor to understand and carry out complex tasks with only a few instructions. The advantage of this is that a CISC processor is able to process complex instructions, without having to break them down into many simpler instructions. Processing complex instructions however requires more circuitry to decode and execute these instructions, which in turn means more power consumption and therefore more heat being generated.

Input and Output

<table>
<tr>
<td>Input devices
An input device allows data, such as text, images, video or sound, to be entered into a computer system.</td>
<td>Output devices
There are many outputs created by a computer system. These include printed documents, on-screen data and sound.</td>
</tr>
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<td>

Common hardware input devices</td>
<td>

Common hardware output devices</td>
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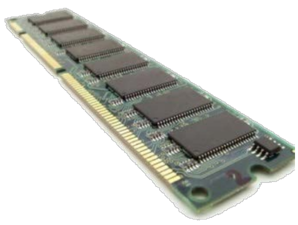
INTERESTING FACT
Doug Engelbart made the first computer mouse in 1964.
It was made out of wood!!

Primary storage

Random Access Memory (RAM)



RAM is used for the temporary storage of currently running programs and data. It consists of a large number of store locations each of which is identified by a unique address. The data in each store location can be changed. RAM is volatile – data is lost when the power is switched off.

Example: When you are working on a word-processed document, the program you are using and the data within the document are both stored in RAM.

Read-only Memory (ROM)

ROM is used for the permanent storage of data. The data in each store location cannot be changed. ROM is permanent –data is not lost when the power is switched off.

Example: ROM can be used for storing the programs such as the BIOS. The disadvantage of using ROM to store the BIOS is that it cannot be upgraded.

KEY INFORMATION
Basic Input Output System (BIOS): A low-level program that handles input and output operations relating to the keyboard and screen of the system. It provides an interface between the hardware and the operating system. One of its primary functions is loading and executing the *bootstrap loader* – the program that loads the operating system.

Flash memory

Flash memory is used for the permanent storage of data. However, the data stored in flash memory can be changed. Flash memory is permanent – data is not lost when the power is switched off.

Example: Flash memory can be used for storing the programs such as the BIOS, which is advantageous as the BIOS can be upgraded.

RAM Cache memory

RAM Cache memory is used for the temporary storage of frequently accessed data and instructions. It consists of a small number of store locations that can be accessed very quickly by the CPU; it is quicker than RAM. Cache memory is volatile – this means that data is lost when the power is switched off.

Summary of different types of memory

	Permanent	Volatile	Data can be changed	Speed
Cache memory		✓	✓	★★★★
ROM	✓			★★★
RAM		✓	✓	★★
Flash memory	✓		✓	★

Secondary storage

Secondary storage is also known as backing storage.

Data is written from memory to secondary storage when data is no longer being actively used, for retrieval at a later time.

INTERESTING FACT
The first commercial hard disk drives had the capacity to store approximately 5 MB and were the size of a dining room table. They were also called a *Winchester Drive*.

The time a computer takes to access data stored on secondary storage is **longer** than the time taken accessing data from memory.

Data Capacity

Data capacity is the amount of data a storage device can hold measured in Kilobytes (Kb), Megabytes (MB), Gigabytes (GB) and Terabytes (TB).

The most frequently used backing storage media are:

Media	Suitability	Typical capacity	Durability	Portability	Speed
 Flash drive	Moving relatively small files from work to home	2 GB – 64 GB	★★★★	✓	★★★★
 External hard drive	Backing up a home computer system	500 MB – 4 TB	★	✓	★★★
 CD/DVD/Blu-ray disk	Storing multimedia files	650 MB (CD) 9 GB (DVD) 50 GB (Blu-ray)	★★★	✓	★★
 Magnetic tape	Backing large commercial servers on multiple tapes	200 GB – 400 GB	★★	✓	★

Different types of data can create files that vary in size. In general, text based files are relatively small but audio and video files are much larger. Here are some typical file sizes.

File size	Typical contents
1 B	A single key stroke or a number from 0 to 255
70 B	One line of text
1 KB	A third of a page of text or a short email
8 KB	A school logo
30 KB	A basic web page
100KB	Maximum size for all elements of a web page
500 KB	A five page word processed document or a PDF for downloading
1 MB	One minute of audio when stored as an MP3
5 MB	DVD Movie
10 MB	HD Movie
25 MB	Blu-ray Movie
700 MB	Maximum amount of data on one CD-ROM

It is important to consider the type of data that is going to be stored when you are choosing a storage device.

Technologies such as: optical, magnetic, solid state, storage in the cloud

Optical

Optical storage media uses technology such as lasers. Laser beams are projected onto a CD/DVD or Blu-ray disk and if light is reflected back, then data is read as a 1 and if light is not reflected back, data is read as a 0. Lasers are used to read and write information to a disk.

> **KEY INFORMATION**
>
> **BInary digiT (BIT):** In computer systems, data is represented by either a 1 or a 0.

Magnetic

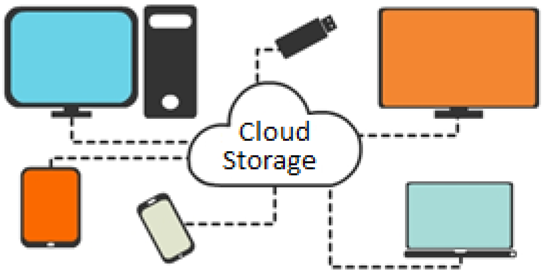
This technology is used in hard disks and tapes. Data is stored on a magnetic medium, which can be a disk or a tape, by writing data using a write-head. Data can then be read by the read-head.

Solid state

Solid state technology is used in storage media such as USB flash memory sticks. The technology is called solid state as it does not have any moving parts, such as a read-head in magnetic storage. Solid state storage technology is increasingly used to replace both magnetic and optical storage, especially in mobile devices, where its low power consumption and high speed access is advantageous.

Storage in the cloud

Storage in the cloud is a contemporary data storage facility that allows users to store their data on third-party servers. They can then access that data from many computing devices.



There are many **advantages** to this, such as maintenance tasks, backup and data replication. Purchasing additional storage devices becomes the responsibility of the cloud storage service provider.

A **disadvantage** of storage in the cloud is that an Internet connection is required to access the data. Some other disadvantages include the concern for some organisations that personal data held on a third-party server could be physically stored in a country where adequate data protection legislation does not exist. Another disadvantage is that users are solely reliant on the cloud storage provider when it comes to ensuring that their data is stored safely and can be retrieved at a later date.

Storage requirements

Computer systems can only store and process Binary digits, also known as BITs. A BIT is either a 1 or 0. When 8-bits are stored as a binary number, they are collectively called a byte.

	Symbol	Value
Byte	B	8 bits
Kilobyte	Kb	1024 bytes
Megabyte	MB	1024 Kb
Gigabyte	GB	1024 MB
Terabyte	TB	1024 GB
Petabyte	PB	1024 TB
Exabyte	EB	1024 PB
Zettabyte	ZB	1024 EB
Yottabyte	YB	1024 ZB

INTERESTING FACT

Half a byte (4 bits) is called a nybble.

Additional hardware components

Motherboard

The motherboard is the main circuit board of a computer. The CPU and ROM will be mounted on the motherboard, which also provides RAM expansion slots, USB ports, PCI slots for expansion cards and controllers for devices such as the hard drive, DVD drive, keyboard, and mouse.

Graphics Processor Unit GPU

A GPU is a microprocessor that performs the calculations needed to produce graphic images on screen. Initially the CPU performed these calculations, but as more complex applications were developed, such as 3D graphics and video quality animations, the GPU was introduced to offload those tasks from the CPU.

GPUs can be integrated within the circuitry of the motherboard, or provided on a dedicated graphics card.

Integrated GPU

An integrated GPU uses the computer's RAM. An integrated unit is cheaper than installing a dedicated GPU, it generates less heat and uses less power. They are perfect for general graphics processing such as watching or editing videos and word processing.

Dedicated GPU

A dedicated GPU has its own video memory. Dedicated cards provide the best visual experience and are used by people such as professional graphic designers and serious gamers, but they use more power and require a good cooling system.

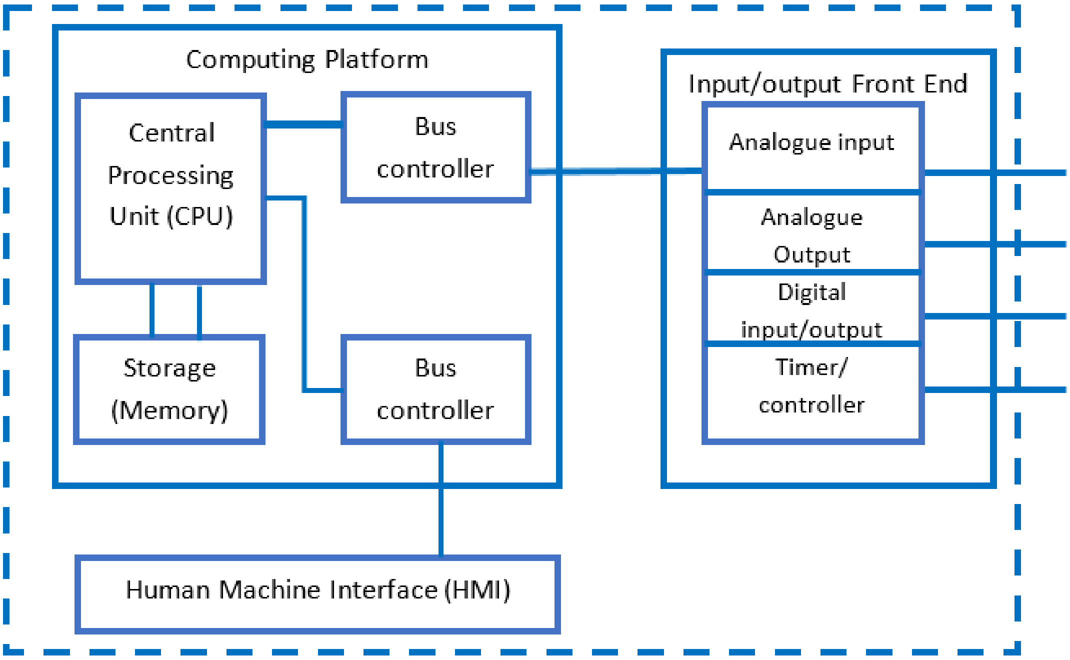
Sound cards

Sound cards may be on board (on the motherboard) or designed to fit a PCI slot. They enable the computer to output sound through speakers, to record sound from a microphone and to manipulate sound stored on a disk. Sound cards convert analogue input signals into digital data and reverse this process for audio output.

Embedded Systems

An embedded system is a combination of software and hardware that performs a specific task rather than a general-purpose computer that is designed to carry out multiple tasks.

Embedded systems are included as a part of a complete device often with hardware and mechanical parts. As the systems carry out specific tasks they can be designed to be small and have a low cost. Mass-production of embedded systems can save large amounts of money.



The software written for an embedded system is known as firmware. The instructions are stored in read-only memory or in Flash memory. The software runs with limited computer hardware resources, little memory and no peripherals.

Most embedded systems are reactive - they react to conditions such as temperature, weight, vibration and air quality. These systems detect external conditions and react to them by recording data, turning motors on or off, sounding an alarm or sending a message to another processor.

Reactive embedded systems often control real time events so must be completely reliable. For example, drivers rely of the anti-lock braking system of their car working correctly to avoid accidents on the road.

When an embedded system performs operations at high speed, and if it is very reliable, it can be used for real -time applications. If the size of the embedded system is very small and power consumption very low, then the system can be easily adapted for different situations.

INTERESTING FACT
98% of the microprocessors manufactured go into embedded systems.

Some examples of devices that incorporate embedded systems:

Electronics	Mobile phones, games consoles, printers, televisions, digital cameras
In the home	Washing machines, microwave ovens, refrigerators, dishwashers, air conditioners
Medical equipment	CT Scanners, Electrocardiogram (ECG), MRI Scanners, blood pressure monitors, heartbeat monitors
Cars	Electronic fuel injection systems, anti-lock braking systems, air-conditioner controls.