CAIE Computer Science IGCSE

3 - Hardware

Advanced Notes

3.1 Computer architecture

Role of the CPU

At the heart of every computer is a Central Processing Unit (CPU) which processes instructions and data that are input into the computer so that the result can be output.

Microprocessors

A microprocessor is a type of integrated circuit that contains the CPU (and sometimes other components) on a single chip.

CPU Components

Units

Unit	Function
Arithmetic Logic Unit (ALU)	Performs mathematical calculations and logical operations as required.
Control Unit (CU)	The control unit marshals and controls the operation of the fetch-execute cycle, coordinating the operation of the CPU and sending commands to other components - for instance, requesting that the arithmetic logic unit perform a calculation. It also decodes instructions.

Registers

Registers are fast-to-access storage locations, used to store small amounts of data needed temporarily by the CPU during processing.

Register	Function
Program Counter (PC)	Stores the address of the next instruction to be fetched from memory. It increments during each fetch-execute cycle to point to the next instruction.
Memory Address Register (MAR)	Stores the address of the data to be fetched or the address where the data is to be stored.
Memory Data Register (MDR)	Stores the data that is being fetched from or written to memory. It acts as a buffer between main memory and the CPU.
Current Instruction Register (CIR)	Stores the instruction currently being decoded and executed by the CPU. When an instruction is fetched, it is copied from the MDR to the CIR prior to decoding.
Accumulator (ACC)	Stores the results of calculations or operations carried out by the Arithmetic Logic Unit (ALU). Also temporarily holds data being processed.

Note: data is the actual value or instruction being stored, used, or processed whereas an address is a location in memory where data is stored.

Buses
A bus is a collection of wires through which data/signals are transmitted from one component to another.

Bus	Function
Address bus	Carries memory addresses from the CPU to other components, like RAM or input/output devices.
Data bus	Transmits the actual data or instructions between the CPU and other components.
Control bus	Sends control signals and timing information between the CPU and other components.

The address bus is unidirectional, meaning data only flows from the CPU to other components. The data bus and control bus are bidirectional, allowing data to flow both to and from the CPU.

Fetch-Decode-Execute cycle

The FDE cycle is the process the CPU continuously performs to run programs, by fetching instructions from memory, decoding them, and executing them.

Fetch

- The Program Counter (PC) holds the memory address of the next instruction to be executed.
- This address is copied into the Memory Address Register (MAR).
- The address bus carries this address from the MAR to RAM.
- The instruction stored at that memory address is fetched from RAM and sent to the Memory Data Register (MDR) via the data bus.
- The Program Counter (PC) is then incremented so it points to the next instruction in the sequence.

Decode

- The instruction in the MDR is copied to the CIR.
- The Control Unit (CU) reads the instruction from the CIR.
- It decodes the instruction to understand what action is required.
- The CU then sends control signals via the control bus to the correct parts of the CPU (such as the ALU, ACC, or memory).

Execute

- The appropriate component of the CPU carries out the instruction:
  - If it's a calculation or logic operation, the Arithmetic Logic Unit (ALU) performs it.
  - If it's a data movement, the data is transferred between registers or between the CPU and memory.
- The result of any operation is usually stored in the Accumulator (ACC) or written back to RAM.
- The cycle then repeats for the next instruction.

CPU performance factors

Factor	Description
Clock speed	The clock is a device that sends a regular electrical signal which switches between low and high voltage at a regular frequency. This signal is used to synchronise the computer system's components; it controls the number of instructions carried out each second. With every tick of the clock, the CPU fetches, decodes, and executes one instruction. The greater the clock speed, the faster the CPU can execute instructions, improving performance.
Cache size	Cache is a small, fast memory device located on the CPU that stores frequently used data and instructions. A larger cache increases the amount of frequently used data that can be stored. This reduces the need for the CPU to access slower main memory (RAM), improving performance.
Number of cores	Cores are the individual processing units within a CPU. A CPU with more cores can process more instructions at once allowing it to handle multiple tasks simultaneously, making it faster and improving performance. However, not all programs are designed to use multiple cores, so performance may not always improve.

Instruction sets

An instruction set is a complete list of all the machine code instructions that a particular CPU can understand and execute. These instructions tell the CPU what operations to perform, such as loading data, storing data, or carrying out arithmetic and logical operations. The instruction set is built into the CPU's hardware and can vary between different types of processors. A CPU can only execute instructions that are part of its own instruction set.

Embedded systems

An embedded system is a computer system that is designed to perform specific, dedicated functions within a larger mechanical or electronic system. It is "embedded" into a device to control particular operations of that device. This is different to a general purpose computer that is used to perform many different functions. For example, a washing machine or smart-fridge would be an embedded system, whereas a laptop or PC would be a general purpose computer.

Characteristics of embedded systems include:

- Designed for one specific task or set of related tasks
- Built into other devices and cannot easily be separated
- Have minimal or no user interface
- Optimised for efficiency and reliability
- Typically low power, small, and efficient

Examples

- Domestic appliances - embedded systems can control temperature, timers, spin speed and safety features in devices like washing machines, dishwashers and fridges
- Cars - embedded systems can manage engine control, braking systems, airbag deployment and infotainment
- Security systems - embedded systems can detect motion, control alarms, manage cameras and lock or unlock doors
- Lighting systems - embedded systems can automate brightness, timing, and respond to motion or ambient light sensors
- Vending machines - embedded systems can manage user input, dispense products, process payments and monitor stock levels

3.2 Input and output devices

Input devices

An input device allows data to be entered into a computer system so it can be processed. These devices are essential for interacting with digital systems, feeding in commands, text, images, sound, or other forms of data.

Input device	What it does	Why it does it	When it might be used
Barcode scanner	Reads a barcode and converts it into digital data	To identify products quickly using a unique code	At supermarket checkouts or in stock control systems
Digital camera	Captures photographs or videos as digital files	To input images into a computer	In photography, video calls, facial recognition, or media creation
Keyboard	Inputs text, numbers and commands using keys	To allow a user to type data or control the computer	Writing documents, entering passwords, coding
Microphone	Captures analogue sound and converts it to a digital signal	To input voice or audio	Voice recognition, audio recording, video calls
Optical mouse	Detects movement and clicks to control a pointer on the screen	To navigate and interact with software	Selecting icons, dragging files, gaming
QR code scanner	Reads QR codes and converts them into readable data (e.g. URLs or payment info)	To quickly access information or complete tasks like payments	Advertisements, contactless menus, ticketing
Touch screen (resistive)	Registers touch using pressure on two layers	Allows input through touch – cheaper and can be used with gloves	ATMs, older smartphones
Touch screen (capacitive)	Registers touch using electrical properties of the finger	More responsive and accurate than resistive touchscreens	Modern smartphones, tablets

Touch screen (infra-red)	Uses a grid of infra-red beams to detect where the screen is touched	Durable and can detect any input object (e.g. finger, pen, stylus)	Industrial applications, public kiosks
2D scanner	Captures flat documents as digital image files	To digitise physical documents	Scanning passports, ID cards, or photos
3D scanner	Captures the shape and appearance of 3D objects to create digital models	To recreate real-world objects digitally	In gaming, medical imaging, engineering, or 3D printing

Output devices

An output device is any hardware component that presents data from a computer to the user or another system - this could be in visual, audio, or physical form.

Output device	What it does	Why it does it	When it might be used
Actuator	Produces physical movement (e.g. turns a motor or opens a valve)	Converts digital signals into real-world physical actions	Automatic doors, robotic arms, smart thermostats
Digital Light Processing (DLP) projector	Projects images onto a surface using tiny mirrors and a light source	To display large, high-quality visuals from a computer	Presentations, home cinema, classroom teaching
Inkjet printer	Sprays tiny drops of ink onto paper to form text and images	To produce colour or black-and-white prints on paper	Home or office printing
Laser printer	Uses lasers and heat to fuse toner powder to the paper	Faster and more efficient than inkjet for high-volume printing	Business environments, schools
Light Emitting Diode (LED) screen	Displays images using light-emitting diodes	Brighter and more energy-efficient than LCD	TVs, monitors, advertising boards

Liquid Crystal Display (LCD) projector	Uses a light source and liquid crystal panels to project images	To present digital visuals to an audience	Offices, classrooms, cinemas
Liquid Crystal Display (LCD) screen	Displays images using liquid crystals and a backlight	For low-power visual output	Computer monitors, smartphones, tablets
Speaker	Converts digital audio signals into sound	To output sound such as music, voice, or alerts	Media players, alarms, communication apps
3D printer	Builds objects layer by layer using materials like plastic or resin	Turns digital models into physical 3D objects	Engineering, product design, medical prosthetics

Sensors

A sensor is a device that detects or measures a physical property and sends this data to a computer system for processing.

Sensor type	What it does	Type of data captured	When it might be used
Acoustic sensor	Detects sound or vibrations	Sound level	Environmental monitoring, sonar
Accelerometer	Measures acceleration, movement, or tilt	Motion / orientation	Smartphones (auto-rotate), fitness trackers, gaming controllers
Flow sensor	Measures the flow rate of liquids or gases	Flow rate	Water/gas meters, medical devices
Gas sensor	Detects presence or concentration of gases	Gas levels	Air quality monitors, carbon monoxide alarms
Humidity sensor	Measures the amount of moisture in the air	Humidity level	Weather stations, smart homes, industrial environments

Infra-red sensor	Detects infrared radiation, often used to detect heat, motion or distance	IR radiation / proximity	TV remotes, motion detectors, thermometers
Level sensor	Measures the level of liquids or solids in a container	Fill level	Fuel tanks, reservoirs, industrial tanks
Light sensor	Measures light intensity	Light level	Automatic brightness adjustment, street lights
Magnetic field sensor	Detects magnetic fields or changes in magnetism	Magnetic field strength	Security systems, metal detectors, smartphones (compass)
Moisture sensor	Detects moisture content in soil or materials	Moisture level	Smart irrigation, agriculture, flood detection
pH sensor	Measures acidity or alkalinity	pH value	Water quality testing, chemical labs
Pressure sensor	Detects force applied by gases or liquids	Pressure level	Tyre pressure monitors, weather forecasting, medical devices
Proximity sensor	Detects when an object is near, without physical contact	Distance / presence	Phones (screen off when near ear), automatic doors
Temperature sensor	Measures how hot or cold something is	Temperature	Thermostats, computers (cooling), fridges

3.3 Data storage

The Need for Primary Storage

Primary storage is the computer's workspace for actively running programs, and provides fast access to data and instructions currently in use by the CPU. Without it, computers would be significantly slower, as the CPU would need to constantly retrieve data from slower secondary storage like hard drives. Primary storage usually consists of RAM and ROM.

RAM and ROM

RAM stands for Random Access Memory, and it is a form of main memory. RAM holds the data and instructions that the computer is currently working with, such as the operating system, running applications, and open documents. RAM is volatile, meaning its contents are lost when the computer loses power (e.g., when turned off).

ROM stands for Read-Only Memory, and it is a form of main memory. It is typically used to store firmware that is essential for the computer to boot up and operate. As the name suggests, it is read-only; it cannot be written to or modified during normal operation. It is also non-volatile, meaning that it retains its contents even when the power is off.

The Need for Secondary Storage

Secondary storage is considered to be any non-volatile storage mechanism not directly accessible by the CPU. Secondary storage is needed so that data/files can be stored on a long-term basis, using non-volatile storage so that they are retained when the computer is switched off.

Types of Secondary Storage

Three types of secondary storage are solid-state, optical and magnetic.

Solid-state

Solid-state storage uses flash memory technology based on NAND or NOR transistors. These transistors have control gates and floating gates that store data by trapping electrons, allowing the storage of data even when power is off. Solid-state storage has no moving parts, making it faster and more durable than magnetic storage. It is widely used in portable devices such as smartphones and tablets.
Examples: Solid-State Drive (SSD), USB flash drive, SD card

Optical

Optical storage works by using lasers to create and read pits and lands on the surface of a disc. These pits and lands represent binary data and are arranged in a spiral track. Optical discs are typically used to distribute media like music, films, and software because they are inexpensive to produce. However, their storage capacity is relatively low compared to other storage types.
Examples: CD, DVD, Blu-ray

Magnetic

Magnetic storage uses spinning platters divided into tracks and sectors. Data is read and written using electromagnets that alter the magnetic polarity of tiny regions on the surface of the platters. The platters and read/write heads involve moving parts which are essential for operation but can make the device more fragile. Magnetic storage is commonly used for storing large amounts of data, such as backups or desktop computer storage.
Examples: Hard Disk Drive (HDD)

Virtual Memory

Virtual Memory is needed when a computer's RAM is full and there are still more programs or data that need to be loaded. It allows the system to use part of the secondary storage (such as a hard drive or SSD) as if it were extra RAM. When this happens, the operating system moves data that is not currently needed from RAM to virtual memory (on the hard drive), creating space in RAM for new data. When the data in virtual memory is needed again, it is swapped back into RAM, possibly replacing other data. This process is slower than using RAM alone but allows the system to run more programs than it could with just physical RAM.

Cloud storage

Cloud storage allows users to store their files in a remote location, where magnetic and/or solid state storage is used to store their files on their behalf. Several companies such as Dropbox and Google Drive offer cloud storage as a service.

Advantages compared with local storage

- Enables users to access their data from more places and devices
- Parts of cloud storage can be made publicly available to others, enabling users to share their data more easily
- The cost of computing devices can be made cheaper to users as there is no need for as much built-in secondary storage

Disadvantages compared with local storage

- Cloud storage could potentially cost more in the long-term, as costs are typically ongoing
- There are potential data privacy issues, as there is an increased chance of others accessing personal data
- Relies on access to high-bandwidth network connection

3.4 Network hardware

Network Interface Cards (NICs)

NICs are hardware components inside devices that enable them to connect to networks; a computer needs a NIC to access a network. They convert data that needs to be sent across a network into signals that can be transferred: in a wired network, these signals will be voltages or pulses, and in wireless networks they'll be radio waves. Each NIC is given a MAC address during manufacture.

Media Access Control (MAC) addresses

A Media Access Control (MAC) address is a unique identifier assigned to a Network Interface Card (NIC) when it is manufactured. It serves as a hardware address used to identify devices on a local network. MAC addresses are usually written in hexadecimal format (to reduce character length) and consist of two main parts: the manufacturer code, which identifies the device maker, and the serial code, which uniquely identifies the specific device. Because MAC addresses are fixed and unique, they provide a reliable way for devices to recognize each other on the same physical network.

IP Addresses

IP addressing is a system for uniquely identifying devices connected to a network. There are two main versions: IPv4 and IPv6. IPv4 addresses are 32-bit numbers, typically written as four decimal numbers separated by dots (e.g., 192.168.1.1). IPv6 addresses are 128-bit numbers, expressed as eight groups of four hexadecimal digits, separated by colons (e.g., 2001:0db8:85a3:0000:0000:8a2e:0370:7334).

The role of routers within networks

A router is a device that directs data packets between different networks by sending data to a specific destination on a network. It reads the destination IP address of each data packet and forwards it along the best path to reach that address. Routers can also assign IP addresses to devices on a local network using a system called DHCP (Dynamic Host Configuration Protocol). Additionally, routers connect local networks (such as those in homes and offices) to the wider internet, allowing devices on the network to communicate with external servers.