3. Hardware

3.1 Computes and their components

Primary Storage

- the part of computer memory that <mark>can be accessed **directly** from the CPU</mark>; it **temporarily** holds data and instructions that are <u>currently being processed by the CPU</u>
    - including **Random Access Memory** and **Read-Only Memory**
- **Characteristics**: Fast access speed, Volatile (loses data when the power is off), Limited in size compared to secondary storage

RAM v.s. ROM

- **Random Access Memory**: a <mark>volatile</mark> memory used for temporary storage while a computer is running; stores **data and programs that are currently in use**
    - **Characteristics:** Data can be read from and written to RAM
    - RAM is broken down into **SRAM** and **DRAM**
- **Read-Only Memory**: a <mark>non-volatile</mark> memory that stores **critical startup instructions and system firmware**
    - **Characteristics:** Data is pre-written; can only be read, not easily written to or modified
    - ROM is broken down into **PROM**, **EPROM**, and **EEPROM**

Types of RAM: DRAM and SRAM

DRAM	SRAM
uses a <mark>single transistor and capacitor</mark>	uses <mark>more than one transistor</mark> to form a memory cell
need to be <mark>constantly refreshed</mark>	**does not** need to be constantly refreshed
has a **higher** memory density	has **faster** data access
main memory uses DRAM	**processor memory cache** uses SRAM
consumes **more power** under <mark>a reasonable level of access</mark>, as it needs to be constantly refreshed	if accessed at a <mark>high frequency</mark>, power usage can be **higher**
less expensive to manufacture	**more expensive** to manufacture
stores each bit as a <mark>**charge**</mark>	stores each bit as a <mark>**flip-flop**</mark>

Types of ROM: PROM, EPROM, and EEPROM

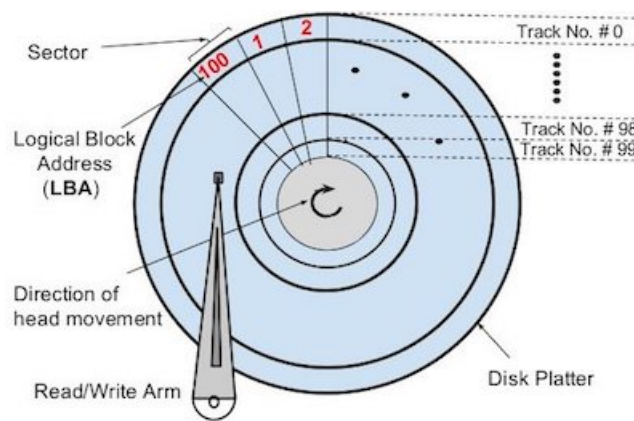| ROM Type	Characteristics
Programmable ROM (PROM)	- Programmable Read-Only Memory - Read-only memory that can be modified/programmed only once - Used in mobile phones and RFID tags
Erasable Programmable ROM (EPROM)	- Erasable Programmable Read-Only Memory - Programmable ROM that can be erased and reused, reprogramming using UV light - Used in applications under development such as the development of new game consoles
Electrically Erasable Programmable ROM (EEPROM)	- Electrically Erasable Programmable Read-Only Memory - A user-modifiable ROM that can be erased and reprogrammed repeatedly through a normal electrical voltage - Used in some microcontrollers and embedded systems

Buffers

- **Buffers** are **temporary** storage areas in a computer's memory (RAM) to hold data <mark>while it is being transferred from one place to another</mark>
    - they manage the flow of data between
- **Purpose**: they help to handle speed differences between the producer (source) and consumer (destination) of the data
- **Example**: consider a computer with a *higher* processing speed and a printer with a *lower* speed
    1. When a computer sends a document to a printer, it first places the data in a buffer
    2. This buffer temporarily holds the document, allowing the computer to continue other tasks
    3. The printer then slowly retrieves and prints the document from the buffer
    - **Efficiency**: the computer doesn't have to wait for the printer to finish printing; it can proceed with other tasks
    - **Continuous printing**: the printer has a consistent stream of data to print, even though it works slower than the computer

Secondary Storage

- Storage devices <mark>that are not directly accessible by the CPU</mark>; they are used to **permanently** store
    - including **magnetic**, **electronic**, and **optical**
- **Characteristics**: Slower data access time, Larger storage, Non-volatile (Permanent storage)
- **Benefits**
    - Large capacity to store videos with large file sizes
    - Reasonably fast access speed
    - Inexpensive per unit of storage
    - Does not need to be moved
    - Slower degradation of data
- **Need**
    - Additional secondary file storage
    - Backup of files
    - Archiving of files
    - Transfer files to second computer

Hard Disk Drives (HDD) → Magnetic

- **Platter**: the rotating disk where data is magnetically recorded and read
    - most HDDs have multiple platters stacked on a central spindle
- **Track**: the storage ring; **Sector**: a smaller division within a track
    - a sector typically holds a fixed amount of data (like 512 bytes)
- **Read/Write Arm**: positions the **read/write heads** to the correct track and sector for data reading

- **Principal Operation**
  - The hard disk has (one or more) platter/plate/disk
  - Each surface of the platter/disk is (ferrous oxide which is) capable of being magnetised
  - The platters/disks are mounted on a (central) spindle
  - The entire mechanism is contained inside a sealed (aluminium) box.
  - The disks are rotated (at high-speed)
  - (Each surface of the disk) has a read/write head mounted on an arm (positioned just above the surface)
  - Electronic circuits control the movement of the arm (and hence the heads)
  - The surface of the platter/disk is divided into concentric tracks / circles
  - The surface of the platter/disk is divided into sectors
  - One track in one sector is the basic unit of storage called a block
  - The data is encoded as a magnetic pattern for each block
  - When writing to disk, a variation in the current in the head produces a variation in magnetic field on the disk
  - When reading from disk, a variation in magnetic field produces a variation in current through the head
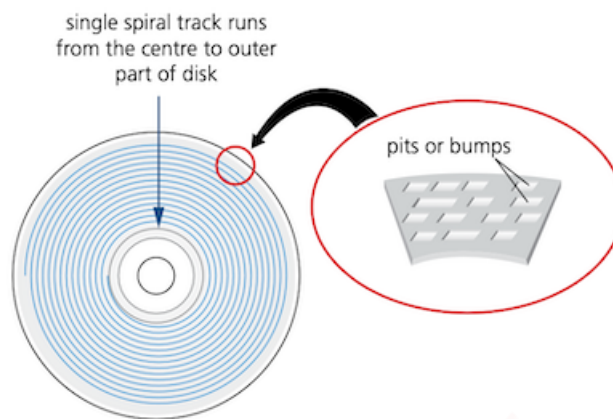
Solid-State Drives (SSD) → Electronic

- **Flash Memory**: uses NAND-based non-volatile memory for data storage
  - absence of moving parts (i.e., read/write heads) reduces mechanical failures
- **Memory Cells**: data is stored in tiny cells grouped into pages, and pages into blocks
- **Principal Operation**:
  - SSD uses semiconductor technology to store data
  - It utilizes NAND flash memory chips, which are a type of semiconductor memory
  - These flash memory chips contain floating gate transistors that can hold electrical charges, representing bits of data
  - When writing data, the electrical charges are manipulated to store information
  - Reading data involves detecting the presence or absence of charges in specific memory cells
  - The memory cell can have one or more transistors, usually multiple transistors

Optical Disks (CDs, DVDs, Blu-rays) → Optical

- **Reflective Layer**: Data is stored on a reflective layer within the disk
  - the layer is usually made of aluminum or head coating
- **Pits & Lands**: Data is encoded as tiny **pits** and **lands** (flat areas). The **variation** in reflection between pits and lands is translated into binary data

- When a laser beam in a CD or DVD player moves from a pit to a land or from a land to a pit, this change is interpreted as a binary '1'
- The absence of a transition (staying on a pit or land) is interpreted as a binary '0'

single spiral track runs from the centre to outer part of disk

pits or bumps

- **Principal Operation:**
  - Drive motor is used to spin the disc
  - Tracking mechanism moves the laser assembly
  - A lens focuses the laser onto the disc
  - Laser beam is shone onto disc to read / write
  - Surface of disc has a reflective metal layer / phase change metal alloy
  - Track(s) on the disc have sequence of pits and lands / amorphous and crystalline state
  - Reflected light in then encoded as a bit pattern

Comparisons

Feature	HDD (Hard Disk Drive)	SSD (Solid State Drive)	Optical Drive (CD/DVD/Blu-ray)
Speed	Moderate (limited by mechanical movement)	Fast (limited by electronic circuits)	Slow (limited by disc spinning and laser speed)
Durability	Moderate (sensitive to shock and vibration)	High (resistant to shock and vibration)	Moderate (susceptible to scratches, but no mechanical wear)
Storage Capacity	Very High (up to several TBs)	High (up to several TBs)	Low to moderate (up to 128 GB for Blu-ray)
Cost per GB	Low	Moderate to high	Low
Power Consumption	Moderate	Low	Moderate
Use Cases	Large data backup, computers & servers	mobile devices, high-performance computing	Media & software distribution

Input & Output Devices → Principal Operations Cr. Michael Zhang

Laser printers

- The revolving drum is initially given an electrical charge
- A laser beam (bounces off moving mirrors) scans back and forth across the drum
- ...discharging certain points (i.e. 'drawing' the letters and images to be printed as a pattern of electrical charges)
- The drum is coated with oppositely charged toner (which only sticks to charged areas)
- The drum rolls over electro-statically charged paper // Electro-statically charged paper is fed (towards the drum)
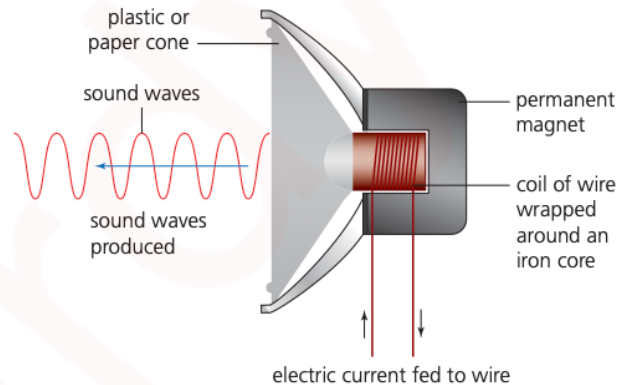- The 'pattern' on the drum is transferred to the paper

- The paper is passed through the fuser to seal the image
- The electrical charge is removed from the drum // the excess toner is collected

3D printers

- The object is designed using Computer Aided Design (CAD) software
- The software splits the object into slices
- The data about the slices is sent to the printer
- The solid plastic is melted and transferred to the nozzle
- A stepper motor moves the nozzle into position
- The nozzle extrudes the molten plastic
- The steps 5 to 6 are repeated until the layer is complete
- A fan cools the layer
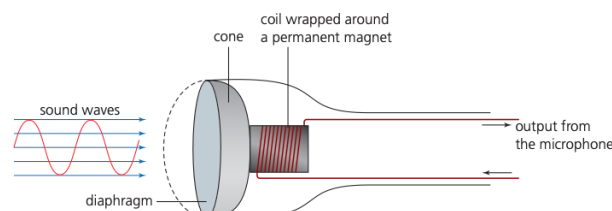- The steps 4 to 8 are repeated for each subsequent

Speakers

- An electric current is sent to the speaker
- The electric current passes through the coil
- The current in the coil creates an electromagnetic field
- Changes in the audio signal cause the direction of the electrical current to change. This determines the polarity of the electromagnet
- The electromagnet is repelled by, or attracted to the permanent magnet
- The movement of the coil causes the diaphragm to vibrate
- The vibration creates sound waves

Microphone

- The microphone has a diaphragm / ribbon (accept equivalent)
- The incoming sound waves cause vibrations (of the diaphragm)
- causing a coil to move past a magnet (dynamic microphone) // changing the capacitance (condenser microphone) // deforms the crystal (crystal microphone) etc.
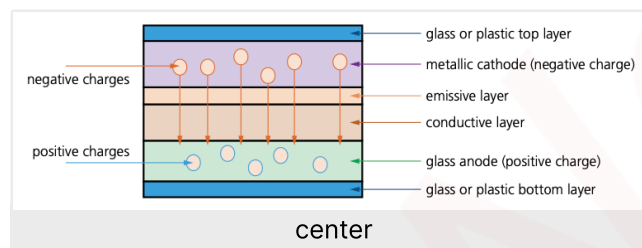- An electrical signal is produced

Touchscreens

- **Liquid Crystal Display (LCD)**
  - **Backlight Layer:** Provides light from behind the screen constantly
  - **Liquid Crystal Layer:** When an electric current passes through the liquid crystals, it changes their alignment, affecting the light's ability to pass through
  - **Color Filters:** each pixel contains filters for red, green, and blue (RGB)
- **Organic Light Emitting Diodes (OLED)**
  - **Organic materials:** organic materials that emit light when electricity is applied
    - different organic compounds are used to produce different colors of light
    - each pixel in an OLED display comprises small dots of organic materials that emit light in red, green, and blue

center

- **Capacitive Touchscreen**
  - The capacitive screen made from materials that store electric charge
  - When touched, charge transferred to the finger
  - There is a change in the electrostatic field
  - Sensors at the screen corners detect change
  - The coordinates of the point of contact can be calculated
  - These coordinates are used to calculate the position and send to the touchscreen driver
- **Resistive Touchscreen**
  - Consists of two charged plates
  - Pressure from a finger causes the plates to touch
  - Completing the circuit
  - Point of contact registered
  - Coordinates used to calculate the position

Virtual Reality Headsets

- Video sent from computer to headset (using HDMI/smartphone fitted into headset)
- Two feeds sent to LCD/OLED display (for left and right side)
- Lenses placed between eyes and screen allow for focusing/reshaping of the video for each eye, giving a 3D effect
- Most headsets use a 110° FOV, enough to give pseudo 360° surround video
- 60-120 FPS is used to give a realistic image
- As the user moves head, series of sensors (gyroscopic/accelerometers) and/or LEDs (working w/ mini cameras) measure movement
- Allows the video on the screen to react to head movements
- Use surround sound so that speaker output appears to come from different directions and distances
- Some use infrared sensors, monitors eye movement
- Allows for depth of field on the screen to be more realistic
- Ex. make objects in the foreground appear fuzzy when the user's eyes indicate they are looking into the distance, vice versa

Embedded Systems

- **Microprocessor** that <mark>performs one specific task</mark>

Pros and Cons

Pros	Cons
specialization and efficiency (very fast reaction to changing input)	limited functionality
low cost to make	difficulty in upgrading
consume very little power	dependency on hardware
high reliability and stability	difficulty in troubleshooting

Monitoring and Control Systems

- **Monitoring**: To <mark>observe and report</mark> on the status or conditions of various systems or environments
    1. it collects the data and sends back to the control room
    2. no changes are made to the environment by the system
- **Control:** To <mark>manage and regulate</mark> the operation of machinery, systems, or processes
    - collecting data and making changes

Controlling Workflow → Contexualization

1. the sensor **constantly** reads the data from the environment
2. the **analog data from the sensor** is sent to the **ADC**
3. the **digital data** is sent to the **microprocessor**
4. the microprocessor **compares** the incoming data with the stored or **pre-set value**
5. if the data is within the range or matches the stored value then, no action is taken, and the process continues
6. if the data is outside the range, then the microprocessor will send a signal to the **actuator** via a **DAC**
7. the whole process **continues** and **loops**
    - Feedback ensures that the environment meets the predefined-criteria

Feedbacks in Control Systems

- **Importance of feedback**
    - To ensure that the system operates within the given criteria
    - By enabling system output to affects subsequent system inputs
    - Thus enabling system to automatically adjust conditions
    - Example: temperature reading from the sensor