Topic 6: Automated and Emerging Technologies

IGCSE Computer Science 0478 | SenpaiCorner | Mr. Wei

Learning Objectives

6.1 Automated Systems: Describe the roles of sensors, microprocessors, and actuators; explain the need for ADC/DAC conversion; trace the continuous feedback loop.

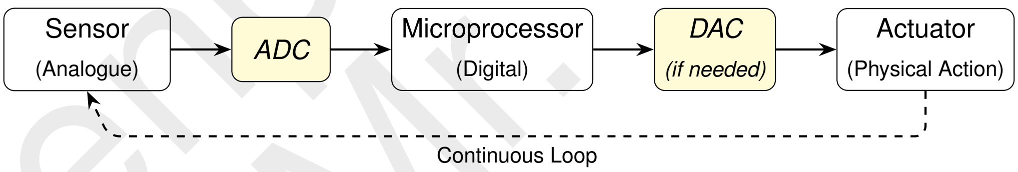
6.2 Robotics: State the three defining characteristics of a robot; identify roles of robots across different sectors.

6.3 Artificial Intelligence: Distinguish expert systems from machine learning; describe the components of an expert system; evaluate advantages and limitations of each approach.

6.1 Automated Systems

An **automated system** operates without human intervention by combining three core components: **sensors**, **microprocessors**, and **actuators**. The whole pipeline runs in a **continuous loop**, constantly reading, processing, and acting on the environment.

Data Flow Pipeline



Sensors

Sensors measure physical properties from the environment and output **analogue** signals. Because computers only process digital data, this signal must first pass through an **Analogue-to-Digital Converter (ADC)**.

Sensor Type	Common Applications
Temperature sensors	Greenhouses, chemical laboratories.
Pressure sensors	Burglar alarms under carpets, car tyres.
Infrared / Motion sensors	Security systems, automatic doors.
Light sensors (LDRs)	Street-lighting control.
Acoustic / Sound sensors	Voice command systems, burglar alarms.

ADC — The Essential Bridge

Always state that sensor output is **analogue** and must be converted to **digital** via an ADC before the microprocessor can use it. Omitting this detail typically costs a mark.

Microprocessors

The microprocessor is the "brain" of the system:

1. Receives **digital** data from the ADC.
2. Compares incoming data against **pre-set or stored values**.
3. Makes a decision based on logic (e.g. *IF temperature* $> 25°C$).
4. Sends output signals to actuators.
5. Returns to step 1 — the **loop is continuous**.

Actuators

Actuators carry out physical actions in response to microprocessor instructions. If the actuator is an analogue device (e.g. a variable-speed motor), a **Digital-to-Analogue Converter (DAC)** is required.

- **Motors** — rotate wheels, open doors, move robotic arms.
- **Valves** — control water or gas flow.
- **Heaters** / **Coolers** — regulate temperature.
- **LEDs** / **Alarms** / **Buzzers** — visual or audio feedback.

Application Examples

Automated Irrigation

Sensors: Soil moisture sensors detect dryness and output an analogue signal.
ADC: Converts the signal to digital.
Microprocessor: Compares moisture level to a stored threshold; decides whether watering is needed.
Actuators: Opens water valves or switches on pumps.
Benefit: Reduces water wastage; ensures consistent crop growth.

Sector	Sensor	Microprocessor action	Actuator
Industry	Camera/position sensor	Detect component position; check quality	Robotic arm (weld/place)
Transport	Speed sensor	Compare to target speed set by driver	Throttle/fuel injection
Weather	Temp/humidity/wind	Record and transmit data to database	Wind vane, rain gauge reset
Gaming	Accelerometer/gyroscope	Translate movement to game command	Haptic vibration motor
Lighting	Light sensor (LDR)	Check brightness vs. threshold	Light switch
Science	pH/temp/chemical sensor	Analyse result; decide what to adjust	Pump, heater, pipette

Advantages and Disadvantages of Automated Systems

Advantages	Disadvantages
Increased efficiency: operates 24/7 without fatigue.	High initial cost: hardware and software are expensive to install.
Reduced human error: high precision and consistent output.	Maintenance: requires expensive, highly skilled technicians.
Safety: can operate in hazardous environments (e.g. nuclear plants).	Job displacement: replaces manual labour, causing unemployment.
Long-term savings: reduces wage and training costs over time.	Inflexible: cannot easily adapt to changes outside their programming.

6.2 Robotics

Robotics is a branch of computer science concerned with the design, construction, and operation of robots.

Defining Characteristics of a Robot

A system qualifies as a **robot** only if it has *all three* of:

1. A **mechanical structure or framework** (physical body and parts).
2. **Electrical components** (sensors, microprocessors, and actuators).
3. **Programmable control systems** (code that dictates its behaviour).

Robots vs. Automated Systems

An automated system (e.g. a greenhouse irrigation controller) is **not** a robot unless it also has a physical mechanical structure. The programmable requirement also distinguishes a robot from a simple mechanical machine.

Roles of Robots by Sector

- **Industry:** Assembly-line work, heavy lifting, welding, painting.
- **Transport:** Autonomous delivery vehicles, drones for aerial surveys.
- **Agriculture:** Automated harvesters, robotic weeders.
- **Medicine:** High-precision surgical robots, automated pharmacy dispensers.
- **Domestic:** Robotic vacuum cleaners, smart lawnmowers.
- **Entertainment:** Animatronics in theme parks, robotic toys.

Advantages and disadvantages of robotics closely mirror those of automated systems: high efficiency and safety gains versus high upfront costs and potential job losses.

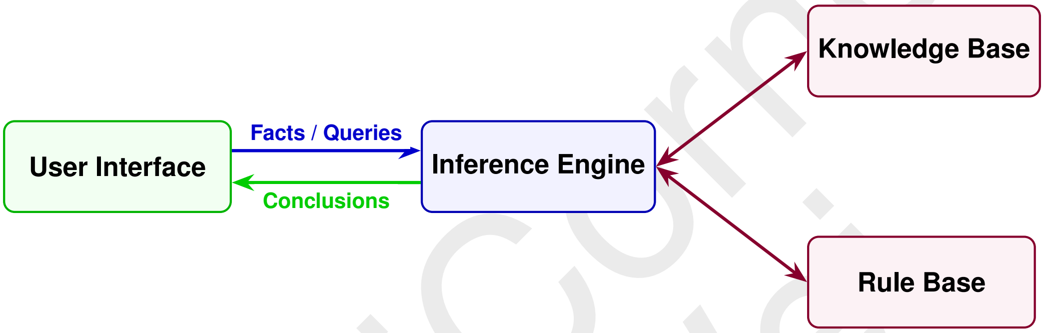
6.3 Artificial Intelligence

Artificial Intelligence (AI) is a branch of computer science that focuses on simulating intelligent behaviour in computers — the ability to use data, apply rules or logic, reason about situations, and (in some systems) learn and adapt from experience.

Expert Systems

An **expert system** is a computer program that mimics the decision-making of a human expert within a specific domain (e.g. medical diagnosis, technical support, agriculture pest diagnosis, financial eligibility checks).

Components:



Knowledge Base A store of facts and domain knowledge (e.g. "fever is $> 38°$C"; "rash $+$ fever may indicate X"). Created from interviews with experts, manuals, and validated sources.

Rule Base A collection of IF–THEN rules applying logic to facts. Example: *IF (fever = high) AND (rash = present) THEN (suggest disease X)*.

Inference Engine The "reasoning" component. Applies the Rule Base to the Knowledge Base to reach conclusions.

- **Forward chaining** (data-driven): known facts $\rightarrow$ apply rules $\rightarrow$ derive new facts $\rightarrow$ conclusion.
- **Backward chaining** (goal-driven): hypothesis $\rightarrow$ check which rules support it $\rightarrow$ query user to confirm/deny $\rightarrow$ conclude.

User Interface Where users input symptoms or facts and receive recommendations. Often includes explanation facilities ("Why this conclusion?").

Operation flow:

1. User inputs facts via the interface.
2. Inference engine matches facts against rules in the rule base.
3. New conclusions are added as facts; process repeats until a solution is found.
4. Output (diagnosis / recommendation) is returned, optionally with a reasoning trace.

Medical Symptom Checker

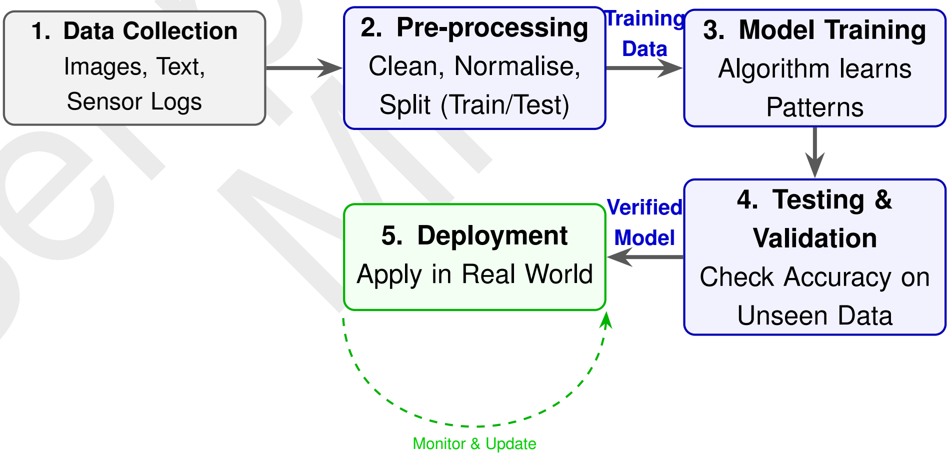
A patient reports high fever and a rash. The inference engine checks the rule base:
IF fever = high AND rash = present THEN suspect condition X.
It queries the knowledge base for supporting evidence, then returns a ranked list of possible conditions alongside an explanation of the reasoning path.

Advantages — Expert Systems	**Disadvantages — Expert Systems**
Consistency: applies the same rules every time.	Knowledge acquisition bottleneck: slow and costly to encode expertise.
Availability: accessible 24/7 and scalable to many users.	Static rules: cannot adapt without a human updating them.
Knowledge preservation: captures expertise for reuse and sharing.	No true understanding: fails on cases outside the knowledge base.
Explainability: can show the reasoning path taken.	Maintenance: rules and facts must be kept current.

Machine Learning

Machine Learning (ML) is when a program *automatically adapts its own processes and data* by learning patterns from examples, rather than being explicitly programmed with every rule.

Basic ML Pipeline:



Types of Machine Learning:

Types of Machine Learning

Supervised Learning

Core Mechanism:
Learns from *labelled* examples.
(Input → Known Output)

Examples:
- ***Classification:*** *Predict labels (e.g. email spam)*
- ***Regression:*** *Predict numbers (e.g. house prices)*

Unsupervised Learning

Core Mechanism:
No labels provided.
Finds patterns or clusters automatically.

Example:
- ***Clustering:*** *Grouping customers by purchasing behaviour.*

Reinforcement Learning

Core Mechanism:
Learns by trial and error to maximise a reward signal.

Examples:
- *Robot learning to walk.*
- *Game-playing AI.*

(IGCSE: Awareness Level Only)

ML in Agriculture

Leaf images labelled "healthy" or "diseased" train a supervised classification model. Once deployed, the model analyses images from field cameras in real time and alerts farmers to outbreaks before they spread.

Advantages	**Disadvantages**
Learns and adapts as more data is collected.	Data dependence: requires large, high-quality datasets.
Handles complex patterns too complicated for fixed rules.	Overfitting: model memorises training data and fails on new inputs.
Scalable automation: fast predictions at large scale once trained.	Bias: biased training data produces unfair or inaccurate outputs.
	Explainability: some models are "black boxes" — hard to justify.
	Maintenance: models drift as the real world changes and need updates.

Expert Systems vs. Machine Learning — Summary Comparison

Feature	Expert Systems	Machine Learning
How it "learns"	Fixed IF–THEN rules written by human experts.	Learns patterns automatically from data.
Adaptability	Static: a human must manually update rules.	Dynamic: can retrain with new data.
Explainability	High — rules and reasoning trace are visible.	Lower — depends on model type; some are black boxes.
Best for	Stable domains with clear logical rules (e.g. troubleshooting, eligibility checks).	Pattern recognition and prediction where rules are hard to define (e.g. image or voice recognition).

Keyword Triggers for AI Questions

- **Knowledge base** / **rule base** / **inference engine** / **interface** ⇒ answer is about **Expert Systems**.
- **Learns from data** / **adapts** / **patterns** / **experience** / **improves over time** ⇒ answer is about **Machine Learning**.
- Always link any AI definition to **reasoning** and — where appropriate — **learning/adaptation**.
- Use sector examples (industry, transport, agriculture, medicine, domestic, entertainment) to earn application marks.

Expert Systems Do Not Learn Automatically

A common error is writing that an expert system "learns" or "adapts." Expert systems apply **fixed rules** — they do **not** retrain or self-update. Only Machine Learning systems adapt without explicit reprogramming by a human.

Sensor Data Is Always Analogue First

Do not write that a sensor sends digital data directly to the microprocessor. Sensors produce **analogue** output. The microprocessor is digital. An **ADC** bridges the two. Missing this step in a describe/explain question loses marks.