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Industry 4.0

Course Code: 23BTMEL406

B. Tech – VII Semester

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Teaching and Evaluation Scheme

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Course Title: **Industry 4.0**										
Semester	VII	Teaching Scheme				Evaluation Scheme				
						Theory			Practical	
Term	Odd	Th	Tu	Pr	Credits	TAE	CAE	ESE	INT	EXT
Course Category	PEC 4	4 Hrs	-	-	04	10	15	50	-	-
Course Code	23BTMEL406									
Teaching Mode	Offline	4 Hrs.			Total	75			-	
Duration of ESE	3 Hrs.					75				

Course Objectives and Outcomes

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Course Objectives	1. Understand IOT architecture and its building block.
	2. Applications in the business world.
	3. Introduction to different IOT platform.
	2. Understanding technology and skill required in building IOT product.
	3. Understand IOT application across various segment
Course Outcomes	Upon successful completion of this course, student shall be able to:
	CO1. Illustrate the opportunities, and challenges brought through Industry 4.0.
	CO2. Outline the theoretical nature and concepts of the fourth industrial revolution.
	CO3. Identify the smartness in Factories, cities, products and services in industry.
	CO4. Apply IOT, cyber-physical systems, cloud computing, big data, smart factories in Industry 4.0.
	CO5. Analyze decision support systems and decision making models for Industry.

Mapping of Course Outcomes with Program Outcomes and Program Specific Outcomes:

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Following mapping is only for reference

Course Outcomes	Program Outcomes and Program Specific Outcomes													
	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO 10	PO 11	PSO 1	PSO 2	PSO 3
CO1	3	2	1	-	2	3	1	-	-	-	3	3	2	2
CO2	1	-	1	-	1	2	2	-	-	-	2	3	2	2
CO3	2	2	1	-	2	2	1	-	-	-	2	3	2	2
CO4	1	1	1	-	-	2	-	-	-	-	3	3	2	2
CO5	1	1	1	-	1	1	-	-	-	-	2	3	2	2

Syllabus

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Unit	Contents
Unit 1	**Introduction to Industry 4.0:** Industry 4.0: Definition, revolution and future view, benefits and applications. Key principles and strategies. Comparison of Industry 4.0 factory & today's factory, Cybersecurity in Industry 4.0, Challenges and risk. Advancements in Industry 4.0. Difference between Industry 4.0 and Industry 5.0.
Unit 2	**Industrial Automation:** Introduction to Industrial Automation, Elements of automation. Types. Architecture of Industrial Automation Systems, Building blocks of Automation systems: LAN, Analog & Digital I/O Modules, SCADA System & RTU. Automation in Production System, Principles and Strategies of Automation, Basic Elements of an Automated System. Advanced Automation Functions. Levels of Automations. Robotics Automations and Collaborative robots. Difference between conventional automation and Industry 4.0.
Unit 3	**Industrial Process Control:** Introduction to process control. Types of control, PID Control, Controller Tuning. Implementation of PID Controllers. Introduction to Sequence Control, the Hardware environment PLCs, Control of Machine tools- CNC Machines, FMS/CIM etc.

Syllabus

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Unit	Contents
Unit 4	**Android, IOT and IIOT Application:** Fundamentals and working principles, Learning the Language, Android OS, Adriano applications. Introduction to IOT. Requirement of IOT. Applications and advantages. Introduction of Industrial IOT (IIOT) and its application. Artificial Intelligence (AI) and Machine Learning (ML): Introduction, Types, Applications. Basics of Big Data and Data Analytics.
Unit 5	**Cloud Computing, AWS, Data Management System:** Cloud Computing, Introduction to cloud architect–AWS, AWS basic concept and services, Application development, Performance optimization, Code level optimization and security. Cloud Manufacturing. Management planning and control, decision making models, data bases, networks, decision theory, flow charting, smart logistics, smart factory management, man-machine-computer interfacing.

Study Material

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Text Books	1.	Ustundag A., and Cevikcan E. Industry 4.0: managing the digital transformation. Springer; 2017.
	2.	Gilchrist A., Industry 4.0: the industrial internet of things. A press; 2016.
	3.	Raj P, and Raman A.C. The Internet of Things: Enabling technologies, platforms, and use cases. Auerbach Publications; 2017.
	4.	Schröder C., The challenges of industry 4.0 for small and medium-sized enterprises. Friedrich- Ebert-Stiftung: Bonn, Germany. 2016.
E-Books	1.	Popkova EG, Ragulina YV, Bogoviz AV, editors. Industry 4.0: Industrial revolution of the 21st century. Berlin/Heidelberg, Germany: Springer; 2019.
	2.	Schwab K. The fourth industrial revolution. Currency; 2017 Jan 3.
Reference Books	1.	Ogata K., Modern control engineering. Upper Saddle River, N J: Prentice hall; 2010.
	2.	Burd B. Android application development all-in-one for dummies. John Wiley & Sons; 2015.
	3.	Kuppusamy P, and Vyas U. AWS Development Essentials. Packt Publishing Ltd; 2014.
	4.	Kurniawan A., Learning AWS IoT: Effectively manage connected devices on the AWS cloud using services such as AWS Greengrass, AWS button, predictive analytics and machine learning. Packt Publishing Ltd; 2018.

Unit 1

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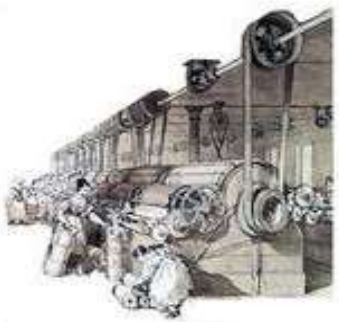
What is Industry 4.0?

Industry 4.0, which is synonymous with smart manufacturing, is the realization of the digital transformation of the field, delivering real-time decision making, enhanced productivity, flexibility and agility to revolutionize the way companies manufacture, improve and distribute their products.

Industry 4.0 (also called the **Fourth Industrial Revolution**) refers to the transformation of manufacturing and industry through **digital technologies, automation, and data exchange**. It connects machines, systems, and humans to create **"smart factories"** where processes are automated, optimized, and more efficient.

Industry 4.0 is a name given to the current trend of automation and data exchange in manufacturing technologies. It includes cyber-physical systems, the Internet of things, cloud computing and cognitive computing. Industry 4.0 is commonly referred to as the fourth industrial revolution

The Start of the Fourth Industrial Revolution



1st Industrial Revolution – water and steam powered mechanical manufacturing facilities

End of 18th century



2nd Industrial Revolution – manufacturing assembly line and infrastructure of electricity, gas, water, telegraph, roads

Start of 20th century



3rd Industrial Revolution – electronics, telephones, PLCs, NC machines, PCs, CAM, CIM, spreadsheets, Lean manufacturing

Late 20th century



4th Industrial Revolution - mobile, cloud, smart connected devices, cyber physical systems, smart factory, robots, mass customization, product as-service

Today

Productivity, Complexity



Revolution from Industry 1.0 to Industry 4.0

Industry 1.0

The first industrial revolution starts around 1780s through the introduction of mechanical production facilities with help of water and steam power. The First Industrial Revolution began in the late 18th century in the United Kingdom and marked the shift from manual labor to mechanized production. The invention of the Steam Engine enabled industries to use steam power, leading to the development of factories, especially in textile and iron sectors. This period significantly increased production but also caused urbanization, labor exploitation, and environmental issues.

Industry 2.0

The second industrial revolution took place 30 years later when the first electricity powered assembly line was built in 1870. The era of mass production has begun. The Second Industrial Revolution (late 19th–early 20th century) was driven by electricity and mass production. Countries like the United States and Germany led industrial growth. The assembly line system introduced by Henry Ford enabled large-scale, cost-effective manufacturing. This era improved productivity and living standards but introduced repetitive work and economic inequality.

Industry 3.0

The third industrial revolution started in the late 1960s when the first programmable logistic controller (PLC) Modicon 084 was built. It enabled production automation through the use of electronic and IT systems. The Third Industrial Revolution, starting around the 1950s, introduced automation through electronics and computers. Technologies such as microprocessors, PLCs, and industrial robots enabled precise and efficient production systems. This phase led to increased productivity, globalization, and reduced human intervention, but also raised concerns about job displacement and the need for skilled labor.

- Industry 4.0

The industrial revolution 4.0 is happening today through the use of cyber-physical systems. It means that physical systems such as machines and robotics will be controlled by automation systems equipped with machine learning algorithms. Minimal input from human operators will be needed. The Fourth Industrial Revolution, beginning in the 21st century, focuses on smart and connected systems. Technologies like IoT, AI, big data, and cloud computing enable real-time monitoring and autonomous decision-making in smart factories. While it enhances efficiency, flexibility, and customization, it also brings challenges such as cybersecurity risks, high costs, and skill gaps.

Examples:
Machines which can predict failures and trigger maintenance processes autonomously;

Self-organized logistics which react to unexpected changes in production;

Siemens' PLC manufacturing plant in Amberg, Germany automated the production of its automation systems. The result is a reported 99.99885 percent “perfect” production quality rate;

The progression from Industry 1.0 to Industry 4.0 illustrates a continuous evolution from mechanization to intelligent automation. Each revolution built upon the advancements of the previous one, transforming not only industrial processes but also economic structures and societal norms. From steam-powered machines to smart, interconnected systems, industrial revolutions have played a pivotal role in shaping the modern world, driving innovation, and redefining the relationship between humans and technology.

Cyber-Physical Systems (CPS)

A system of collaborating computational elements controlling physical entities.

Cyber-Physical Systems (CPS) are integrated systems that combine **physical processes with computation, networking, and control** to enable real-time interaction between the physical and digital world.

Cyber-Physical Systems are systems in which embedded computers and communication networks monitor and control physical processes, typically with feedback loops in which physical processes affect computations and vice versa.

CPS are physical and engineered systems whose operations are monitored, coordinated, controlled and integrated by a computing and communication core. They allow us to add capabilities to physical systems by merging computing and communication with physical processes.

- **How CPS Works**

- A CPS operates through three main components:
- **Sensing** → Sensors collect real-time data from the physical environment
- **Computation** → Embedded systems or software processes the data
- **Actuation** → Actuators perform actions based on processed data

This creates a **continuous feedback loop** between the physical and digital systems.

Cyber-Physical Systems (CPS) are advanced integrated systems that combine physical processes with computational and networking capabilities. In CPS, embedded computers and communication networks continuously monitor and control physical systems through real-time data exchange and feedback loops. These systems consist of sensors that collect data from the physical environment, controllers that process the data, and actuators that perform actions based on decisions. CPS plays a crucial role in modern industrial environments, particularly in smart factories under Industry 4.0, where machines communicate with each other and make decentralized decisions. Applications of CPS include autonomous vehicles, smart grids, healthcare monitoring systems, and intelligent manufacturing. The key advantage of CPS is its ability to enable real-time, adaptive, and intelligent control, although challenges such as cybersecurity and system complexity remain significant.

CPS Benefits

- Safer and more efficient systems
- Reduce the cost of building and operating the systems
- Build complex systems that provide new capabilities
- Reduced cost of computation, networking, and sensing
- Enables national or global scale CPS's
- A real-world example of such a system is the Distributed Robot Garden at MIT in which a team of robots tend a garden of tomato plants.
- This system combines distributed sensing (each plant is equipped with a sensor node monitoring its status, navigation, manipulation and wireless networking.

CPS in Manufacturing

- Comprise:
  - smart machines
  - storage systems and
  - production facilities
- Is capable of
  - autonomously exchanging information
  - triggering actions
  - controlling each other independently

Industry 4.0: Six design principles

- **Interoperability**: The ability of CPS (i.e. work piece carriers, assembly stations and products), humans and Smart Factories to connect and communicate with each other via the **Internet of Things** and the **Internet of Services.** Interoperability refers to the ability of machines, devices, sensors, and humans to **connect and communicate with each other** through technologies like IoT. In an Industry 4.0 environment, different systems can exchange data seamlessly, enabling coordinated and synchronized operations across the production system.
- **Virtualization**: a virtual copy of the Smart Factory which is created by linking sensor data (from monitoring physical processes) with virtual plant models and simulation models. Virtualization means creating a **digital representation (digital twin)** of the physical system using sensor data. This allows real-time monitoring and simulation of processes. By integrating data from various sources, industries can gain complete visibility and make informed decisions.
- **Decentralization**: the ability of CPS within Smart Factories to make decisions on their own. Decentralization allows systems to **make decisions independently** without relying on a central controller. Cyber-Physical Systems (CPS) enable machines to respond autonomously to changes, improving flexibility and reducing delays in decision-making.
- **Real-Time Capability**: the capability to collect and analyze data and provide the insights immediately. Industry 4.0 systems can **collect, process, and analyze data instantly**. Real-time capability ensures quick responses to changes, such as detecting faults, adjusting production, or optimizing performance without delays.
- **Service Orientation**: offering of services (of CPS, humans and Smart Factories) via the **Internet of Services.** This principle focuses on delivering functionalities as **services over the internet**, often referred to as "Everything as a Service (XaaS)." Using cloud computing, businesses can offer and access services like software, platforms, and infrastructure on demand.
- **Modularity**: flexible adaptation of Smart Factories for changing requirements of individual modules. Modularity refers to designing systems in **flexible and independent modules** that can be easily added, removed, or modified. This allows industries to quickly adapt to changing production requirements, such as customization or varying demand.
- These six principles—**interoperability, virtualization, decentralization, real-time capability, service orientation, and modularity**—form the foundation of Industry 4.0, enabling smart factories that are **flexible, efficient, and intelligent**.

Differences between a typical factory today and an Industry 4.0 factory

Current industry environment

- Key to success is providing high-end quality service or product with the least cost
- Achieve as much performance as possible to increase profit.
- Data sources are used to provide worthwhile information about different aspects of the factory.
- The utilization of data for understanding the current condition and detecting faults and failures is an important topic to research.

Industry 4.0 Factory

- In addition to condition monitoring and fault diagnosis, components and systems are able to gain self-awareness and self-prediction
- These will provide management with more insight on the status of the factory
- Furthermore, peer-to-peer comparison and fusion of health information from various components provides a precise health prediction in component and system levels.
- Force factory management to trigger required maintenance at the best possible time to reach just-in time maintenance and gain near zero downtime
- Modern information and communication technologies like CPS, Big Data and Cloud Computing help predict the possibility to increase productivity, quality and flexibility.

Comparison of today's factory and an Industry 4.0 factory

		Today's factory		Factory of the future	
	data source	main characteristics	main technologies	main characteristics	main technologies
component	sensor	precision	smart sensors and failure detection	knowledge of own operations, predictive ability	monitoring of all features, life expectancy forecasts
machine	controller	manufacturability and performance	state-based system monitoring and diagnostics	knowledge of own operation, predictive ability, comparability ability	real-time preventive status indicators
manufac-turing system	networked	performance and total asset efficiency	Lean operations: work and waste reduction	self-configuration, self-maintenance, self-organizing ability	risk exemption, performance

Industry 4.0: Challenges

Economic

- High economic costs
- Business model adaptation
- Unclear economic benefits/ excessive investment

Political

- Lack of regulation, standards and forms of certifications
- Unclear legal issues and data security

Social

- Privacy concerns
- Surveillance and distrust
- General reluctance to change by stakeholders
- Threat of redundancy of the corporate IT department
- Loss of many jobs to automatic processes and IT-controlled processes, especially for blue collar workers

- **Organizational/ Internal**
- The security problems of information technology (IT) are greatly aggravated by the reuse of previously completed projects.
- The need for reliability and stability for critical machine-to-machine communication (M2M)
- including very short and stable waiting times.
- The integrity of production processes must be maintained.
- Avoid any unforeseen obstacle to information technology that can cause expensive production downtime.
- Industrial know-how must be protected.
- There is a lack of appropriate expertise that would speed up the progress towards the fourth industrial revolution.
- Redundancy in information technology (IT).
- It is difficult for affected parties to change.
- Automated and IT-driven processes result in the loss of jobs, especially in the lower-tier social strata

Key Challenges of Industry 4.0

- **Industry 4.0**, while highly transformative, faces several **technical, economic, and organizational challenges** that affect its implementation and sustainability.

1. High Initial Investment

- Implementing Industry 4.0 technologies such as IoT, AI, robotics, and smart infrastructure requires **significant capital investment**. Small and medium enterprises (SMEs) often find it difficult to adopt due to cost constraints.

2. Cybersecurity Risks

- With increased connectivity and data exchange, systems become more vulnerable to **cyberattacks, data breaches, and hacking**. Ensuring secure communication and data protection is a major challenge.

3. Lack of Skilled Workforce

- Industry 4.0 demands professionals skilled in **data analytics, AI, automation, and digital technologies**. There is a growing gap between industry requirements and available expertise.

4. Integration with Legacy Systems

- Many industries still operate with **old (legacy) systems**. Integrating these with modern digital technologies is complex, time-consuming, and costly.

5. Data Management Issues

- Industry 4.0 generates massive amounts of data (Big Data). Managing, storing, and analyzing this data effectively while maintaining accuracy and reliability is challenging.

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6. Standardization and Interoperability Issues

- Lack of universal standards makes it difficult for different machines and systems to **communicate and work together seamlessly**.

7. Privacy Concerns

- The extensive use of data raises concerns about **data privacy and ownership**, especially when sensitive industrial or customer data is involved.

8. Resistance to Change

- Organizations and employees may resist adopting new technologies due to **fear of job loss, lack of awareness, or reluctance to change existing practices**.

9. Reliability and System Complexity

- Highly interconnected systems increase **complexity**, making them harder to manage, maintain, and troubleshoot.

10. Legal and Regulatory Issues

- There is a lack of clear **policies, regulations, and legal frameworks** governing digital manufacturing, data usage, and cybersecurity.

Although Industry 4.0 offers significant advantages, its successful implementation requires overcoming challenges related to **cost, security, skills, integration, and data management**.

What is Industry 5.0?

- The term Industry 5.0 refers to people working alongside robots and smart machines. It's about robots helping humans work better and faster by leveraging advanced technologies like the Internet of Things (IoT) and big data. It adds a personal human touch to the Industry 4.0 pillars of automation and efficiency.
- **Industry 5.0** is the next stage of industrial evolution that goes beyond automation and digitalization (Industry 4.0) by emphasizing **human-centric, sustainable, and resilient manufacturing systems**. It focuses on collaboration between **humans and intelligent machines** rather than replacing human workers.
- Industry 5.0 integrates advanced technologies like AI, robotics, and IoT with **human creativity, ethical considerations, and environmental sustainability** to create a balanced and inclusive industrial ecosystem.
- In manufacturing environments, robots have historically performed dangerous, monotonous, or physically demanding work, such as welding and painting in car factories and loading and unloading heavy materials in warehouses. As machines in the workplace get smarter and more connected, Industry 5.0 is aimed at merging those cognitive computing capabilities with human intelligence and resourcefulness in collaborative operations.

Key Pillars of Industry 5.0

1. Human-Centric Approach

- Unlike Industry 4.0, which focuses on automation, Industry 5.0 prioritizes **human involvement**. Workers collaborate with smart machines (cobots), enhancing productivity while maintaining human control and creativity.

2. Sustainability

- Industry 5.0 emphasizes **eco-friendly production**, efficient resource utilization, and reduced environmental impact. It supports circular economy practices such as recycling and reuse.

3. Resilience

- Industries are designed to be **robust and adaptable** to disruptions such as pandemics, supply chain failures, or economic changes. Systems can quickly respond and recover from uncertainties.

Industrial Changes

- Human–machine collaboration instead of full automation
- Personalized and customized production
- Ethical and responsible use of technology
- Focus on worker well-being and safety

Benefits

- Improved innovation through human creativity
- Sustainable and environmentally responsible production
- Better work-life balance and job satisfaction
- Increased system adaptability and resilience

Key Technologies

- Artificial Intelligence (AI)
- Collaborative Robots (Cobots)
- Internet of Things (IoT)
- Big Data & Analytics
- Digital Twins
- Green and sustainable technologies

Challenges

- High implementation cost
- Need for skilled workforce
- Balancing automation with human roles
- Ethical and regulatory concerns

3 Essential Facts About Industry 5.0

- ***#1 Industry 5.0 is aimed at supporting – not superseding – humans.***
- "Industry 5.0 will make the factory a place where creative people can come and work, to create a more personalized and human experience for workers and their customers,"

- ***#2 Industry 5.0 is about finding the optimal balance of efficiency and productivity.***
- "Industry 5.0 recognizes that man and machine must be interconnected to meet the manufacturing complexity of the future in dealing with increasing customization through an optimized robotized manufacturing process,"

- ***#3 The progress of Industry 5.0 is unavoidable.***
- Once you've used technology to make a process more efficient, there's no point in reverting to the old way of doing things. It's why we use computers with word-processing software instead of typewriters. Similarly, Industry 5.0 is the manufacturing world's event horizon. Given the efficiencies that can be gained, we're well past the point of going back.

Industry 4.0 and 5.0 both address basic considerations

1. **Cyber-physical systems that connect the world**: Connecting man, machine, information and organization for integrated operation
2. **New technology-driven approach:** Adopting disruptive technologies to help adapt products to changing requirements
3. **Digital twins:** Simulation and testing before actual implementation to ensure product precision and faster execution without bottlenecks
4. **Asset performance management:** Used for real-time plant and equipment diagnosis to predict and plan convenient maintenance schedules and eliminate unplanned shutdowns
5. **Product life cycle management:** Used to integrate and simulate the compatibility of all components of a new product in real-time, and to plan for a successful launch
6. **IIoT-driven total automation:** Integrates plant, logistics, and supply chain management
7. **Man/machine collaboration:** Collaborative robots enable better precision, faster execution, personification of products, and minimization of wastes
8. **Digital transformation:** Enables a connected process between plant, supply chain, OEMs, customers, and all other stakeholders to ensure quality, availability of products, a proper feedback system, and customization of products, ensuring continuity and a sustainable process
9. **Cybersecurity:** Ensures a risk-free cyber-physical platform with continuously upgraded, strong security standards.

What's the Difference Between Industry 4.0 and Industry 5.0?

Aspect	Industry 4.0	Industry 5.0
Core Focus	Automation and digitalization	Human-centric and sustainability
Objective	Smart, efficient production	Balanced production with human well-being
Role of Humans	Minimal (automation-driven)	Central role (human–machine collaboration)
Technology Use	AI, IoT, Big Data, robotics	Same technologies + focus on human interaction (cobots)
Decision Making	Data-driven and automated	Human + AI collaborative decisions
Production Type	Mass customization	Personalized and value-driven production
Approach	Technology-oriented	Human + technology integration
Sustainability	Limited focus	Strong emphasis on eco-friendly systems
Resilience	Efficiency-focused	Adaptability and resilience to disruptions
Work Environment	Smart factories	Human-friendly, safe workplaces

- Industry 4.0 primarily emphasizes **automation, connectivity, and intelligent systems**, where machines and digital technologies play a dominant role in optimizing industrial processes. In contrast, Industry 5.0 extends this concept by reintroducing the **human element**, focusing on collaboration between humans and machines, along with sustainability and societal well-being. While Industry 4.0 aims at efficiency and productivity, Industry 5.0 aims to achieve **a balance between technological advancement, human creativity, and environmental responsibility**.
- Some examples to show the difference between Industry 4.0 and Society 5.0 are:

1. Industry 4.0 focuses on how to automate the job, while society 5.0 focuses on how to optimize work hours to finish the task.
2. Industry 4.0 focuses on the automatic machine's effectiveness while society 5.0 focuses on how to optimize human knowledge with the help of artificial intelligence.
3. Industry 4.0 focuses on computerized systems, whereas society 5.0 focuses on people focuses on how to finish the task faster with the help of machines for the sake of humans.

Unit 2

Automation

- Automation is the use of technology, software, and machinery to perform tasks with minimal human intervention. It streamlines repetitive, manual processes to increase efficiency, precision, and productivity while reducing costs. Common examples include assembly line robots, software bots, and smart home devices. **Automation** is the use of **machines, control systems, and technology to perform tasks with minimal or no human intervention**.
- Automation refers to the application of **control systems such as computers, PLCs, and robotics** to operate equipment and processes automatically, improving efficiency, accuracy, and consistency.
- Automation is the technology by which a process or procedure is accomplished without human assistance.

"Automation = Automatic Control"

Basic elements of an automated system

The **basic elements of an automated system** are the fundamental components required for a system to operate automatically with minimal human intervention. These elements work together to sense, process, and act. An automated system consists of **input (sensing), processing (control), output (actuation), power, and feedback elements** working together.

- **1. Input Devices (Sensors)**
- Input devices collect real-time data from the environment or process.
- Measure physical parameters like temperature, pressure, position, etc.
- Convert physical signals into electrical signals
- **Examples:** Temperature sensors, proximity sensors, pressure sensors
- **2. Control System (Controller)**
- The controller is the "brain" of the system that processes input data and makes decisions.
- Executes programmed instructions
- Compares input data with desired values
- Sends commands to output devices
- **Examples:** PLC (Programmable Logic Controller), microcontrollers, computer

- **3. Output Devices (Actuators)**
- Output devices carry out actions based on commands from the controller.
- Convert electrical signals into physical action
- Perform tasks like movement, switching, or operation
- **Examples:** Motors, valves, relays, hydraulic cylinders
- **4. Power Supply**
- Provides the necessary energy to operate all system components.
- Can be electrical, hydraulic, or pneumatic
- Ensures continuous system operation
- **5. Feedback System**
- Feedback allows the system to monitor its own performance and make corrections.
- Sends output information back to the controller
- Enables accuracy and stability
- **Example:** Speed sensor in a motor control system.

Sensors collect data → Controller processes it → Actuators perform action → Feedback ensures accuracy

Industrial Automation

- **Industrial Automation** refers to the use of **control systems, machines, and information technologies** to operate industrial processes with **minimal human intervention**, improving efficiency, productivity, and quality.
- Industrial automation is the application of **computers, programmable logic controllers (PLCs), robotics, and control systems** to manage and control industrial operations automatically.

➢ Automation solutions are required right from agricultural to space technology.

➢ Plant Automation is the necessity for the manufacturing industry to survive in today's globally competitive market.

- Automation is basically the delegation of human control
- Function of technical equipment for

  •Increasing Productivity

  • Increasing Quality

  • Reducing Cost

  • Increasing Safety in working conditions

History of Automation

The history of automation dates back to ancient times when humans first attempted to reduce manual effort using simple mechanical devices. Early examples include water clocks, windmills, and basic mechanical systems developed in ancient civilizations such as Ancient Greece and Ancient Egypt. These systems were not fully automated but demonstrated the initial idea of using mechanisms to perform tasks with minimal human effort.

The concept of automation advanced significantly during the First Industrial Revolution with the introduction of mechanization powered by steam engines. The development of the Steam Engine enabled machines to operate continuously, reducing dependence on human and animal labor. This period marked the beginning of automated production processes in industries such as textiles and mining.

During the Second Industrial Revolution, automation advanced further with the introduction of electricity and mass-production systems. The use of assembly lines, particularly popularized by Henry Ford, allowed industries to produce goods in large quantities with improved efficiency and consistency. Automation at this stage was still largely mechanical but more organized and systematic.

The Third Industrial Revolution, also known as the Digital Revolution, brought a major transformation in automation through the use of electronics, computers, and control systems. The introduction of programmable logic controllers (PLCs), microprocessors, and industrial robots enabled fully automated and precise manufacturing processes. This era marked the transition from mechanical automation to intelligent, computer-based control systems.

In the present era, automation has reached an advanced stage with the emergence of Industry 4.0. Modern automation integrates technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), and Cyber-Physical Systems, enabling smart factories and real-time decision-making. Automation systems are now capable of self-monitoring, learning, and optimizing processes with minimal human intervention.

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BRIEF HISTORY OF AUTOMATION



EARLY BEGINNINGS OF AUTOMATION

c. 270 BC–725 AD

Water Clocks and Automata

Water Clocks and Automata

Hero of Alexa-ndria (10–70 AD)

Chinese Innovations



AUTOMATION IN THE MIDDLE AGES AND RENAISSANCE

8th–16th centuries

Islamic Golden Age (8th–13th centuries)

Al-Jazari designed intricate mechanical devices

Mechanical Clocks and Mills

Leonardo da Vinci strategy putt too



THE INDUSTRIAL REVOLUTION

18th–13th centuries

Textile Industry

James Hargreaves spinning lonny (1764)

Edmund Cartwrig-pocreceneins

Steam Engines and Factories

James Watt's flyball govemor



20TH CENTURY: THE RISE OF INDUSTRIAL AUTOMATION

Assembly Line Production

Henry Ford's moving assembly line (1913)

Programmable Machines and Numerical Control

(1940s–1950s)



21ST CENTURY: SMART AUTOMATION AND ARTIFICIAL INTELLIGENCE

Robotics and AI

Internet of Things (IoT)

Automation in Everyday Life

Sustainable Automation

- Manual Control
- Pneumatic Control
- Hard wired logic Control
- Electronic Control using Logic Gates
- Programmable Logic Controller

Manual Control

- All the actions related to process control are taken by the operators

Drawbacks

- Likely human errors and consequently its effect on quality of final product
- The production, safety, energy consumption and usage of raw material are all subject to the correctness and accuracy of human action.

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Pneumatic Control

- Industrial automation, with its machine and process control, had its origin in the 1920s with the advent of *"Pneumatic Controllers"*.
- Actions were controlled by a simple manipulation of pneumatic valves, which in turn were controlled by relays and switches.

Drawbacks

- Bulky and Complex System
- Involves a lot of rework to implement control logic
- Longer project time

Hard wired logic control

- The contactor and Relays together with hardware timers and counters were used in achieving the desired level of automation
- ***Drawbacks***
  - Bulky panels
  - Complex wiring
  - Longer project time
  - Difficult maintenance and troubleshooting

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Electronic Control using Logic Gates

- In 1960s with the advent of electronics, the logic gates started replacing the relays and auxiliary contactors in the control circuits.
- The hardware timers & counters were replaced by electronic timers

Advantages

- Reduced space requirements
- Energy saving
- Less maintenance & greater reliability
- ***Drawbacks***
- Changes in control logic not possible
- More project time

Programmable Logic Controllers

In the 1970s, with the coming of microprocessors and associated peripheral chips, the whole process of control and automation underwent a radical change. Instead of achieving the desired control or automation through physical wiring of control devices, in a PLC, it is achieved through a program or software. The programmable controllers have, in recent years, experienced an unprecedented growth as a universal element in Industrial Automation. It can be effectively used in applications ranging from simple control, like replacing a small number of relays, to complex automation problems.

Advantages of PLCs

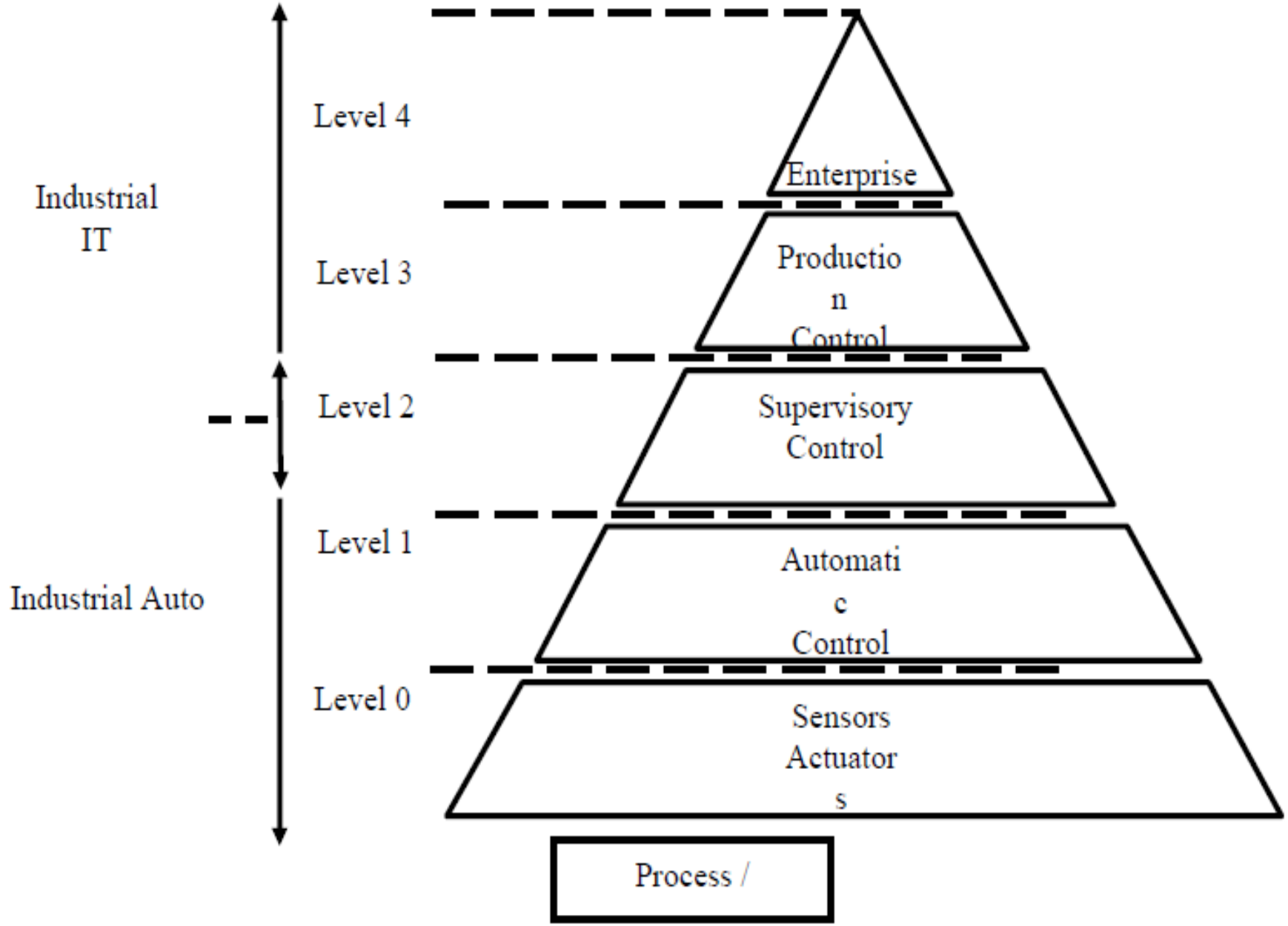
- Reduced space
- Energy saving
- Ease of maintenance
- Economical
- Greater life & reliability
- Tremendous flexibility
- Shorter project time
- Easier storage, archiving and documentation

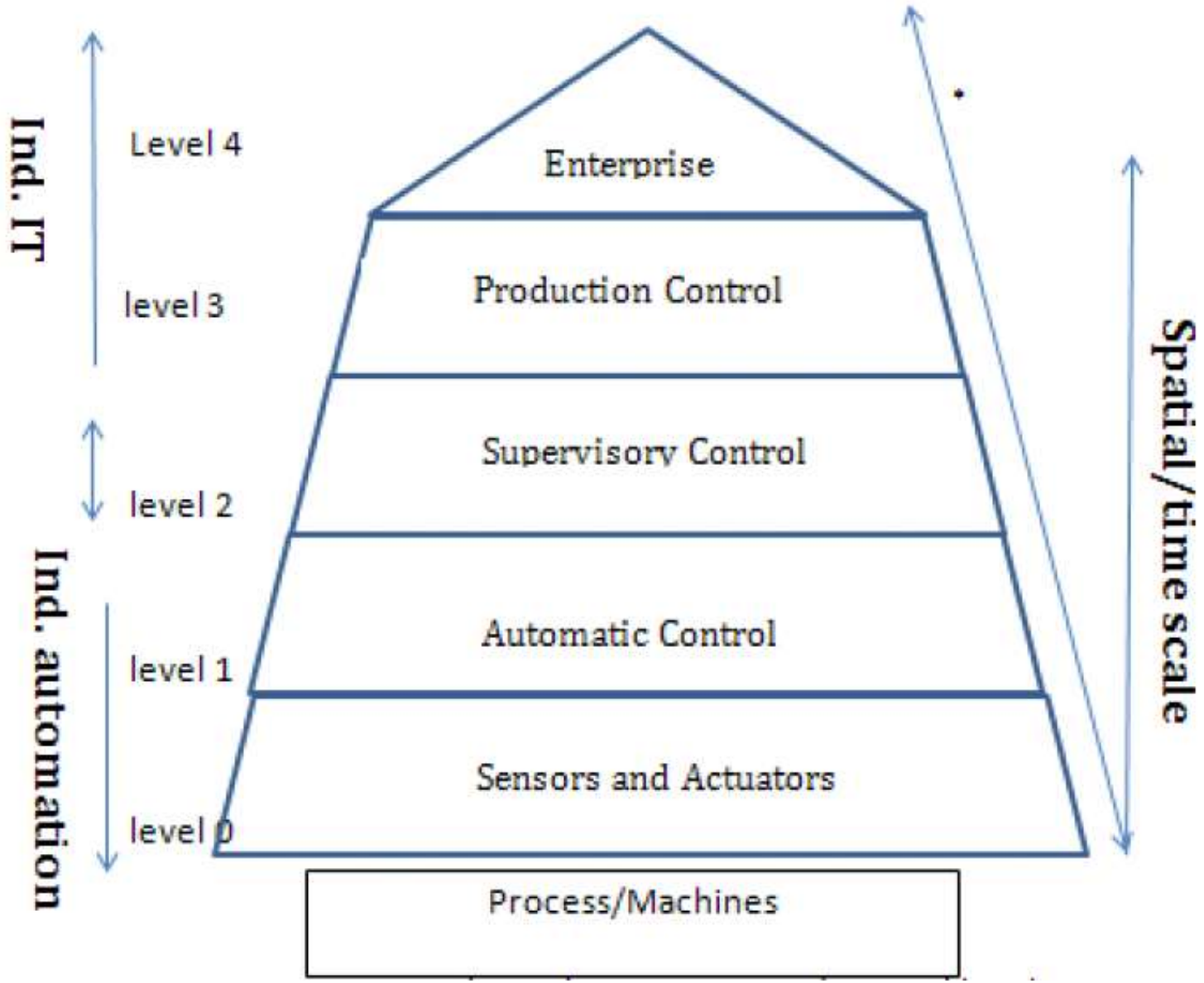
Simple mechanical aids → Steam-powered machines → Electrified mass production → Computer-based automation → Intelligent smart systems

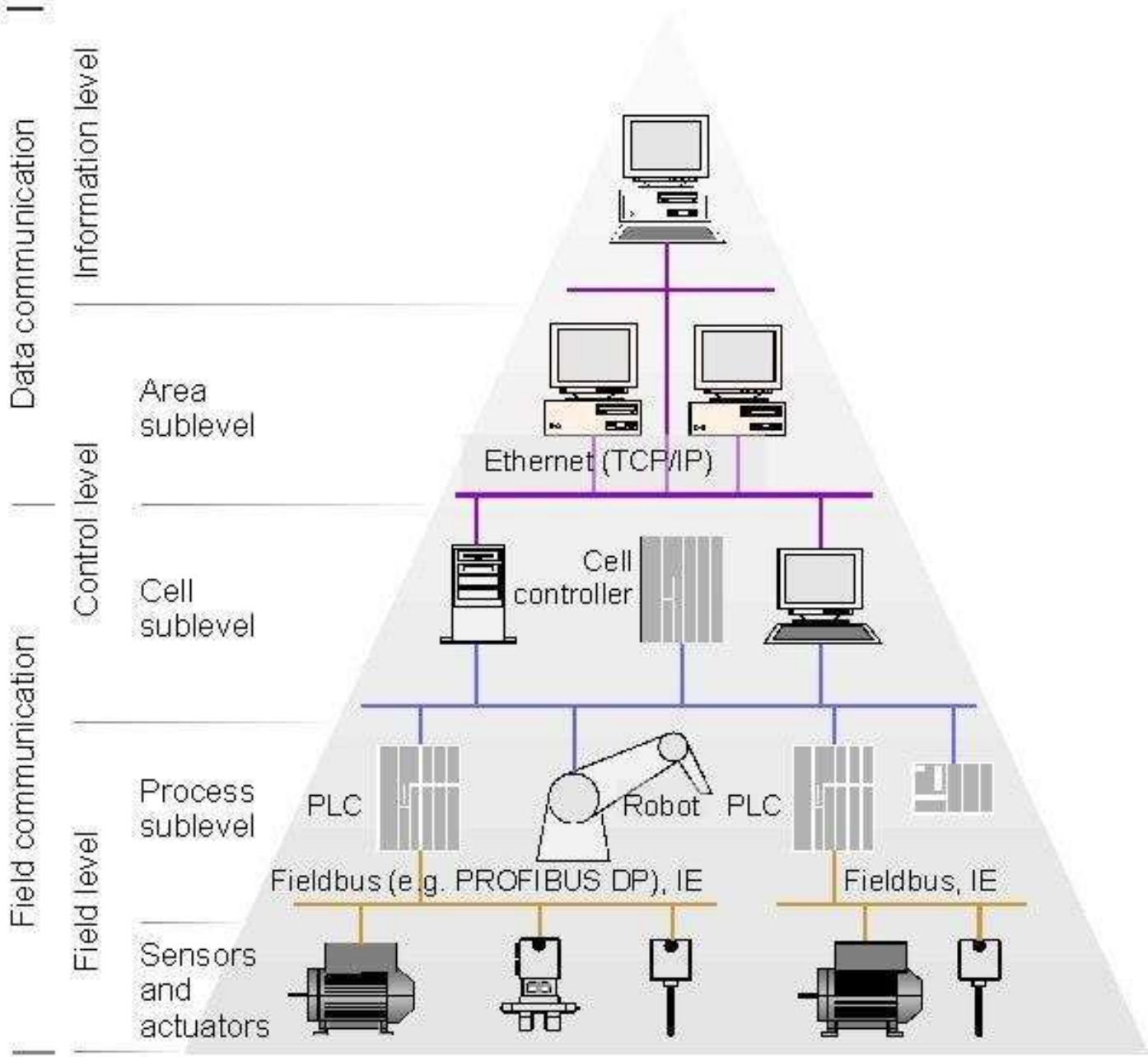
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Architecture of Industrial Automation Systems

- The **architecture of industrial automation systems** refers to the structured arrangement of hardware, software, and communication layers that work together to control and monitor industrial processes. It is typically organized in a **hierarchical (pyramid) structure**, where each level performs specific functions, from field operations to enterprise management.
- Industrial automation is defined as **a set of technologies that results in operations of industrial machines and systems without significant human intervention and achieve performance superior to manual operation**.
- An Industrial Automation System consists of numerous elements that perform a variety of functions related to Instrumentation, Control, Supervision and Operations Management related to the industrial process. These elements may also communicate with one another to exchange information necessary for overall coordination and optimized operation of the plant/factory/process.
- Industrial automation systems are very complex having large number of devices with confluence of technologies working in synchronization. In order to know the performance of the system we need to understand the various parts of the system. Industrial automation systems are organized hierarchially.


Industrial
IT
Industrial Auto
Level 4
Level 3
Level 2
Level 1
Level 0
Enterprise
Productio
n
Control
Supervisory
Control
Automati
c
Control
Sensors
Actuator
s
Process /


Ind. IT
Level 4
level 3
level 2
Ind. automation
level 1
level 0
Enterprise
Production Control
Supervisory Control
Automatic Control
Sensors and Actuators
Process/Machines
Spatial/time scale


Data communication
Information level
Control level
Area sublevel
Ethernet (TCP/IP)
Cell sublevel
Cell controller
Field communication
Field level
Process sublevel
PLC
Robot
PLC
Fieldbus (e.g. PROFIBUS DP), IE
Fieldbus, IE
Sensors and actuators

1. Field Level (Level 0) ***Sensors and Acuators Layer:*** This layer is closest to the proceses and machines, used to translate signals so that signals can be derived from processes for analysis and decisions and hence control signals can be applied to the processes. This forms the base layer of the pyramid also called 'level 0' layer.
This is the lowest level, directly interacting with the physical process.

- Includes **sensors and actuators**
- Responsible for **data acquisition and physical actions**
- Converts physical parameters into signals and vice versa

Examples: Temperature sensors, pressure sensors, motors, valves

2. Control Level (Level 1)/*Automatic Control Layer:* This layer consists of automatic control and monitoring systems, which drive the actuators using the process information given by sensors. This is called as 'level 1' layer.

This level controls the process based on inputs from the field level.

- Uses **controllers like PLCs and microcontrollers**
- Executes control logic and decision-making
- Sends commands to actuators

Examples: PLC, CNC controllers

3. Supervisory Level (Level 2)/*Supervisory Control Layer:* This layer drives the automatic control system by setting target/goal to the controller. Supervisory Control looks after the equipment, which may consis of several control loops. This is called as ‘level 2’ layer.

This level provides monitoring and supervisory control.
Uses systems like **SCADA (Supervisory Control and Data Acquisition)** and HMI
Enables **real-time visualization and control**
Collects and logs process data
Functions: Alarm handling, data acquisition, process monitoring

4. Production Planning Level (Level 3)/*Production Control Layer:* This solves the decision problems like production targets, resource allocation, task allocation to machines, maintenance management etc. This is called ‘level 3’ layer.

Also known as the **Manufacturing Execution System (MES) level**.
Manages and optimizes production operations
Tracks production, quality, and scheduling
Bridges shop floor and enterprise level
Functions: Production scheduling, quality control, performance analysis

5. Enterprise Level (Level 4)/*Enterprise control layer:* This deals less technical and more commercial activities like supply, demand, cash flow, product marketing etc. This is called as the 'level 4' layer.

The top level responsible for business-related decisions.

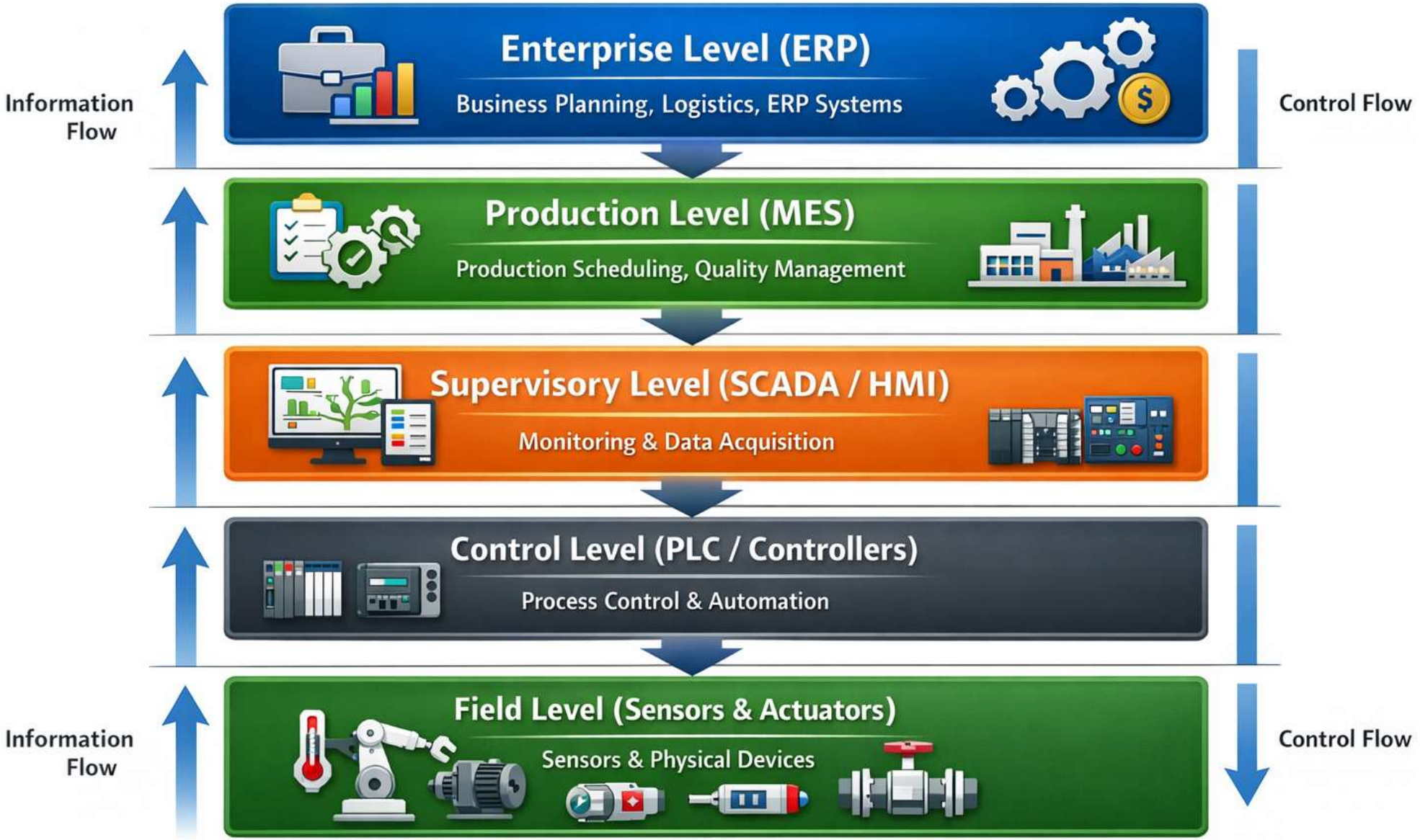
- Uses **ERP (Enterprise Resource Planning)** systems
- Handles planning, logistics, finance, and supply chain
- Integrates data from lower levels for decision-making

Examples: SAP, Oracle ERP

All the above layers are connected by various types of communication systems. For example the sensors and actuators may be connected to the automatic controllers using a point-to-point digital communication, while the automatic controllers themselves may be connected with the supervisory and production control systems using computer networks. Some of these networks may be proprietary. Over the last decade, with emergence of embedded electronics and computing, standards.

Industrial automation architecture is a **layered structure that connects field devices to enterprise systems for efficient monitoring, control, and management of industrial processes**.

Architecture of Industrial Automation Systems



What Is a LAN?

- A **LAN (Local Area Network)** is a network that connects computers and devices within a **limited geographic area**, such as a home, office, laboratory, or campus.
- A Local Area Network is a communication network that enables **data sharing and resource exchange** among devices located within a small area using wired or wireless connections.
- A local area network (LAN) is a collection of devices connected together in one physical location, such as a building, office, or home. A LAN can be small or large, ranging from a home network with one user to an enterprise network with thousands of users and devices in an office or school.
- Regardless of size, a LAN's single defining characteristic is that it connects devices that are in a single, limited area. In contrast, a wide area network (WAN) or metropolitan area network (MAN) covers larger geographic areas. Some WANs and MANs connect many LANs together.
- A LAN comprises cables, access points, switches, routers, and other components that enable devices to connect to internal servers, web servers, and other LANs via wide area networks.
- The rise of virtualization has also fueled the development of virtual LANs, which enable network administrators to logically group network nodes and partition their networks without a need for major infrastructure changes.
- For example, in an office with multiple departments, such as accounting, IT support, and administration, each department's computers could be logically connected to the same switch but segmented to behave as if they are separate.

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Analog & Digital I/O Modules

- Analog input modules **provide various sources of input, such as thermocouple, RTD, thermistor or general analog signals**. The two basic types of analog input modules are **voltage sensing and current sensing**.
- An I/O module is **a subsystem in an integrated circuit that performs the functionality specific to interfacing a CPU to the rest of the system**.
- **Analog I/O uses continuous signal and process it almost instantly when there is a change on the input. Digital I/O uses discrete signal and process time depending on clock speed or frequency**.
- Analog data is processed continuously. Every time the input changes, the output will also change. There is almost no delay between every change of the input.
- Digital data is processed in discrete time delay. The delay depends on the time delay listed on the device's datasheet.
- When it comes to advanced technology such as robotics, digital input, digital output, and digital processing is superior to analog.
- Since we have to program the robot, we need to use a computer. And as you have known, computers use digital data processing.
- Digital data has less electrical noise when transmitted.
- Digital data processing costs less than analog data processing and has a wide-variety of applications.

SCADA System

- Supervisory control and data acquisition (SCADA) is a system of software and hardware elements that allows industrial organizations to: Control industrial processes locally or at remote locations. Monitor, gather, and process real-time data.
- A SCADA system is **a combination of hardware and software that enables the automation of industrial processes by capturing Operational Technology (OT) data**. SCADA connects the sensors that monitor equipment like motors, pumps, and valves to an onsite or remote server.
- Supervisory control and data acquisition (SCADA) is a system of software and hardware elements that allows industrial organizations to:
  - Control industrial processes locally or at remote locations.
  - Monitor, gather, and process real-time data.
  - Directly interact with devices such as sensors, valves, pumps, motors, and more through human-machine interface (HMI) software.
  - Record events into a log file.
- SCADA systems are crucial for industrial organizations since they help to maintain efficiency, process data for smarter decisions, and communicate system issues to help mitigate downtime.
- The basic SCADA architecture begins with programmable logic controllers (PLCs) or remote terminal units (RTUs).
- SCADA (Supervisory Control and Data Acquisition) is a system that collects data from field devices, processes it, and provides **centralized monitoring and supervisory control** of industrial operations. A **SCADA system** is a computer-based control system used to **monitor, control, and manage industrial processes remotely in real time**.

Remote terminal units (RTUs)

- A remote terminal unit (RTU) is a microprocessor-based electronic device used in industrial control systems (ICS) to connect various hardware to distributed control systems (DCS) or supervisory control and data acquisition (SCADA). RTUs are also referred to as remote telemetry units or remote telecontrol units.
- RTUs pass sensor data from input streams in control loops to an output stream to be forwarded on to centralized control in an ICS. RTUs automatically negotiate connections to either local or remote controls.
- RTUs are part of the systems used in several processes, including:
  - Petrochemical (oil) and refineries.
  - Nuclear power plants.
  - Agriculture.
  - Quality control.
  - Chemical plants.
  - Sewage treatment plants.
  - Food processing.
  - Automobile manufacturing.
  - Pharmaceutical manufacturing.
  - Water treatment plants.
- RTUs monitor both analog and digital field data. An RTU gets the data from sensors monitoring target industrial process variables and then forwards that data onto centralized monitoring and control. The hardware of an RTU includes the setup software required to connect data output streams and communication protocols, as well as built-in troubleshooting.

Elements of automation

- The **elements of automation** are the fundamental components required for an automated system to function effectively. These elements work together to sense, process, and control industrial operations with minimal human intervention. An Industrial Automation System consists of numerous elements that perform a variety of functions in Instrumentation, Control, Supervision, and Operations Management for the industrial process.

- **These elements may also communicate with one another to exchange information necessary for overall coordination and optimized operation of the plant/factory/process.**

Typical Elements are

1) Field Instruments

2) Control Hardware

3) Control Software

1. Sensors (Input Elements)

- Sensors are used to **detect and measure physical parameters** such as temperature, pressure, position, and speed.
- Convert physical signals into electrical signals
- Provide real-time data to the system
- **Examples:** Temperature sensor, proximity sensor, pressure sensor.

2. Controller (Processing Unit)

- The controller acts as the **brain of the automation system**.
- Processes input data from sensors
- Executes control logic and decision-making
- Sends commands to output devices
- **Examples:** PLC (Programmable Logic Controller), microcontroller, computer

3. Actuators (Output Elements)

- Actuators perform the **physical action** based on controller signals.
- Convert electrical signals into mechanical movement
- Control operations like motion, flow, and position
- **Examples:** Motors, valves, relays, hydraulic cylinders

4. Power Supply

Provides the **necessary energy** to operate all automation components.
Electrical, pneumatic, or hydraulic power sources
Ensures continuous system operation

5. Feedback System

The feedback system ensures **accuracy and control** by monitoring output.
Sends information back to the controller
Enables error correction and stability
Example: Speed feedback in motor control

Sensors → Controller → Actuators → Feedback → Continuous control loop

Types of Industrial Automations

- Industrial automation can be classified into three main types based on **flexibility, production volume, and level of control**.

1. Fixed automation: Fixed automation is used for **high-volume, repetitive production** where the sequence of operations is fixed.

- **U**sed when the volume of production is very high, specialized equipment designed for efficiency.
- Sequence of processing operations is fixed by the equipment configuration.
- Sequence of simple operations.
- Integration and coordination of many operation in one equipment.

Typical features:

1. High initial cost.
2. Custom engineered equipment.
3. High production rates.
4. Inflexibility/Low flexibility
5. Dedicated equipment for a specific task

Examples:

1. Automobile assembly lines
2. Bottling plants

Advantages:

1. High efficiency and productivity
2. Low unit cost for large production

Limitations:

1. Not suitable for product variation
2. High initial investment

2.Programmable automation: Programmable automation is used for **batch production**, where machines can be reprogrammed for different products.

• Used when the volume of production is relatively low, and there is variety of products to be made, production equipment is designed to be adaptable to variations in product configuration.

• Production equipment is designed with capability to change sequence of operation to accommodate different product configurations.

• Operation sequence controlled by PROGRAM.

Typical features :

1. High investment in general purpose equipment.

2. Low production rate.

3. Flexibility to deal with product change.

4. High suitability for batch production.

Typical cycle for a product :

1. Set up and reprogramming. 2. Batch production of parts.

Examples :

1. NC Machine Tools. 2. Industrial Robots. 3. PLCs.

Advantages:

1. Flexibility to produce different products
2. Suitable for batch processing

Limitations:

1. Time required for reprogramming
2. Lower production rate than fixed automation

3. Flexible automation: Flexible automation allows **quick changes in production with minimal downtime**.

- Suitable for mid volume production range, typically consist of a series of workstations that are interconnected by material-handling and storage system, controlled by central computer extension of programmable automation.
- Produce variety of parts with virtually no time lost for changeovers from one part style to next.
- No production time lost in set up and reconfiguration.
- System can produce various mixes of parts.
- Example : FMS.

Typical Features :

- High Investment for custom engineered equipment.
- Continuous production of mix of products.
- Medium production rates.
- Flexible to deal with product design variations.

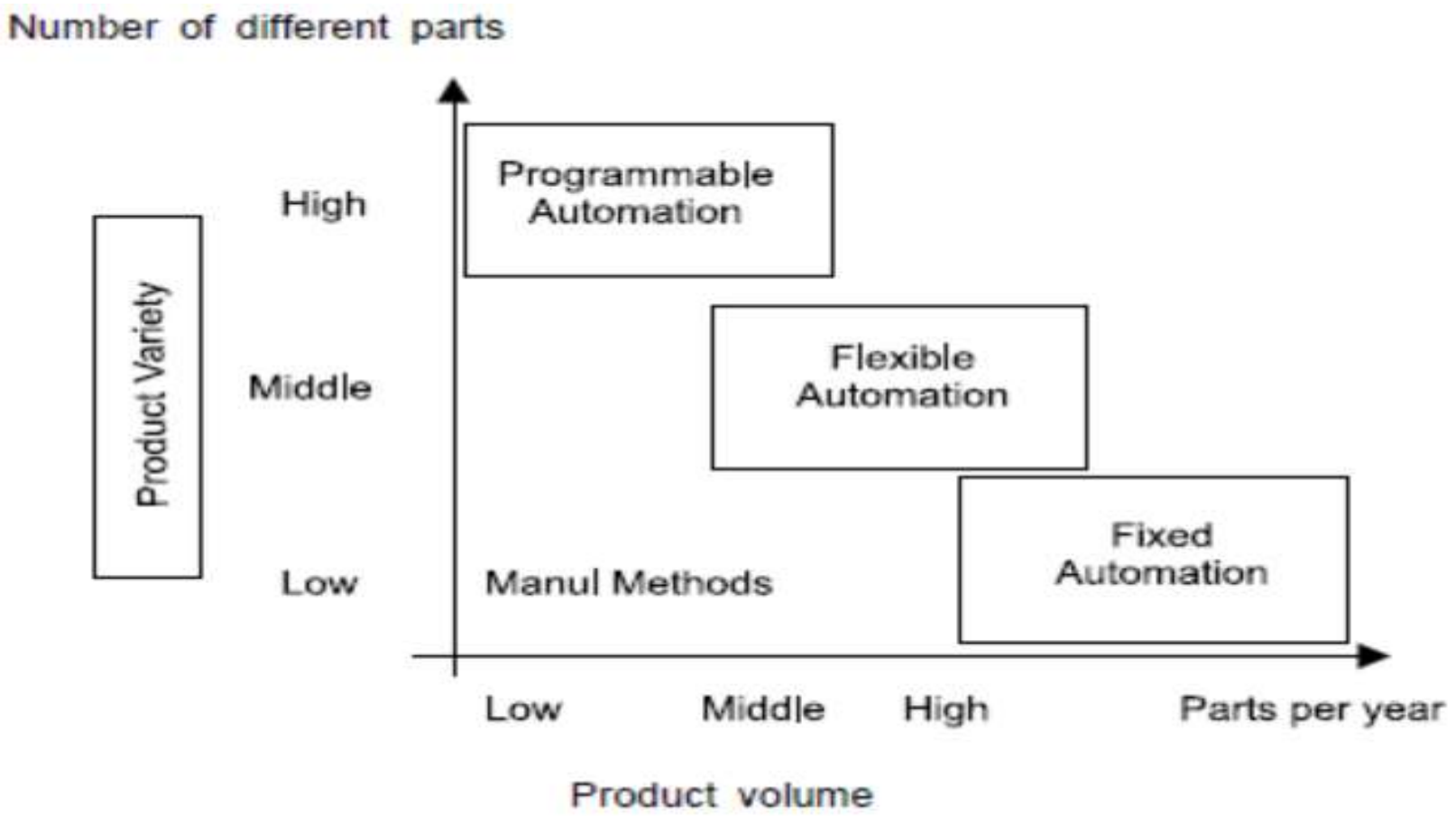
Advantages:

1. High product variety
2. Reduced setup time
3. Efficient for customized production

Limitations:

1. High cost and complexity
2. Requires skilled workforce

Type	Production Volume	Flexibility	Example
Fixed	High	Low	Assembly line
Programmable	Medium	Moderate	CNC machines
Flexible	Low to Medium	High	FMS



Building Blocks of Automation

- The **building blocks of automation** are the essential hardware and software components that form the foundation of any automated system. These blocks work together to sense, process, control, and execute operations efficiently.
- **1. Sensors (Input Devices)**
- Sensors are responsible for **detecting physical parameters** from the environment.
- Measure variables like temperature, pressure, position, flow, etc.
- Convert physical quantities into electrical signals
- **Examples:** Thermocouples, proximity sensors, photoelectric sensors
- **2. Signal Conditioning System**
- This block processes raw signals from sensors to make them suitable for the controller.
- Amplifies, filters, and converts signals
- Ensures accuracy and reliability
- **3. Controller (Control Unit)**
- The controller is the **decision-making unit** of the system.
- Processes input signals
- Executes control logic/program
- Sends commands to output devices
- **Examples:** PLC, microcontroller, industrial computer

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4. Actuators (Output Devices)

- Actuators convert control signals into **physical actions**.
- Perform operations like motion, switching, or flow control
- **Examples:** Electric motors, hydraulic cylinders, valves

5. Feedback System

- Provides information about the system output back to the controller.
- Enables closed-loop control
- Improves accuracy and stability

6. Human-Machine Interface (HMI)

- HMI allows interaction between the operator and the system.
- Displays system status and data
- Enables manual control and monitoring

7. Communication System

- Ensures data exchange between different components.
- Uses industrial networks and protocols
- Connects sensors, controllers, and higher-level systems

8. Power Supply

- Provides the necessary energy for all system components.
- Electrical, pneumatic, or hydraulic sources

Sensors → Signal Conditioning → Controller → Actuators → Feedback → HMI & Communication support

Principles and Strategies of Automation

USA Principle of Automation

It is a fundamental strategy used to implement automation effectively and economically. The **USA Principle** in automation stands for:

U → Understand the existing process
S → Simplify the process
A → Automate the process

- **1. Understand the Process (U)**
- Before automation, it is essential to **analyze and thoroughly understand** the current process.
- Study workflow, inputs, outputs, and sequence of operations
- Identify inefficiencies, delays, and bottlenecks
- Gather accurate data about the system
- Study current process in detail.

• Find answers :
1. What are inputs?
2. What are outputs?
3. What exactly happens between input & output?
4. What is function of process?
5. How does it add value to the product?
6. What are sequence of operations?

Automation without understanding may lead to **inefficiency and errors**.

- **2. Simplify the Process (S)**
- Once the process is understood, it should be **simplified and optimized**.
- Eliminate unnecessary steps
- Reduce complexity and redundancy
- Improve workflow and layout
- ☞ A simplified process is **easier and more cost-effective to automate**.

3. Automate the Process (A)

- After simplification, automation is applied using appropriate technologies.
- Use PLCs, robots, sensors, and control systems
- Implement automation only where beneficial
- Ensure reliability and flexibility

Automation improves **productivity, quality, and consistency**.

The USA principle emphasizes **analyze** → **improve** → **automate** for effective automation implementation.

Ten Strategies for Automation

- The **Ten Strategies for Automation** are guidelines used to improve manufacturing efficiency, reduce costs, and optimize production systems.

1. Specialization of Operations

- Divide complex work into **simple, specialized tasks** to improve efficiency and ease automation.

2. Combined Operations

- Perform multiple operations at a **single workstation** to reduce handling and setup time.

3. Simultaneous Operations

- Carry out **two or more operations at the same time** to reduce total production time.

4. Integration of Operations

- Link different processes into a **continuous, coordinated system** for smooth workflow.

5. Increased Flexibility

- Design systems to handle **product variations and changes** with minimal effort.

6. Improved Material Handling and Storage

- Use automated systems (conveyors, AGVs, robots) to ensure **efficient movement and storage** of materials.

7. Online Inspection

Perform **inspection during production** to detect defects early and reduce rework.

8. Process Control and Optimization

Use sensors and control systems to **monitor and optimize processes continuously**.

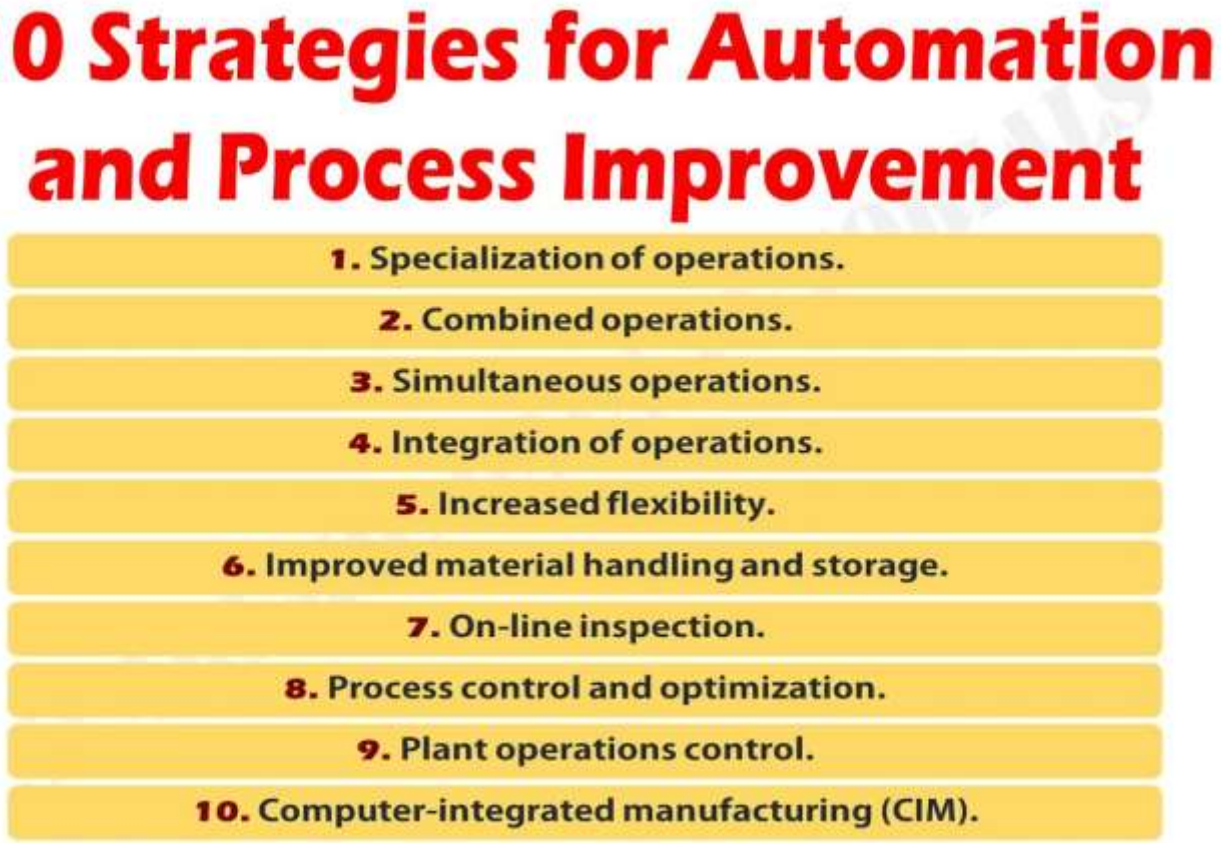
9. Plant Operations Control

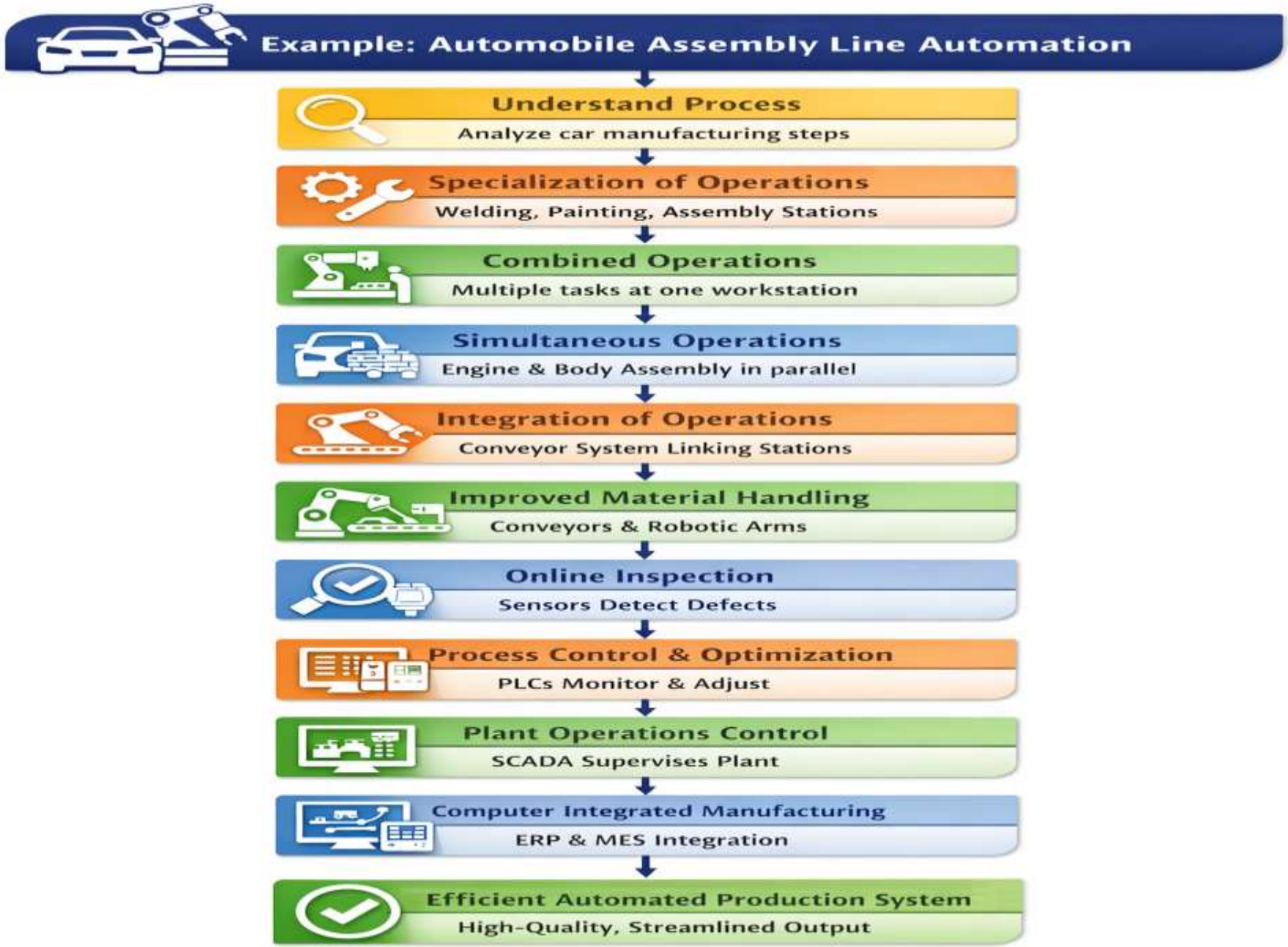
Implement centralized systems (e.g., SCADA) to **manage and coordinate entire plant operations**.

10. Computer-Integrated Manufacturing (CIM)

Integrate design, planning, and manufacturing using **computer-based systems**.

These strategies focus on **efficiency, integration, flexibility, and intelligent control** in automation. The ten strategies of automation aim to **simplify, integrate, and optimize production processes using advanced technologies**.




Example: Automobile Assembly Line Automation
Understand Process
Analyze car manufacturing steps
Specialization of Operations
Welding, Painting, Assembly Stations
Combined Operations
Multiple tasks at one workstation
Simultaneous Operations
Engine & Body Assembly in parallel
Integration of Operations
Conveyor System Linking Stations
Improved Material Handling
Conveyors & Robotic Arms
Online Inspection
Sensors Detect Defects
Process Control & Optimization
PLCs Monitor & Adjust
Plant Operations Control
SCADA Supervises Plant
Computer Integrated Manufacturing
ERP & MES Integration
Efficient Automated Production System
High-Quality, Streamlined Output

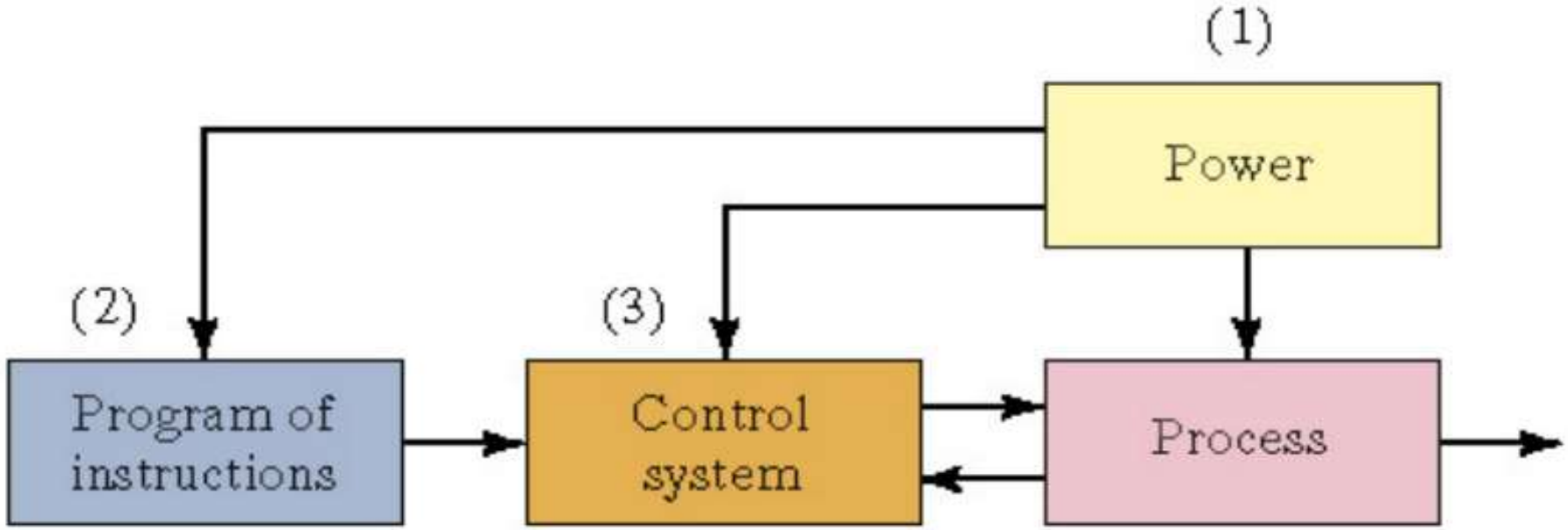
Basic Elements of an Automated System

- An automated system consists of essential components that work together to **sense, process, and control operations automatically** with minimal human intervention.

1. Power - to accomplish the process and operate the automated system

2. Program of instructions – to direct the process

3. Control system – to actuate the instructions



1- Electricity - The Principal Power Source

Widely available at moderate cost

- Can be readily converted to alternative forms, e.g., mechanical, thermal, light, etc.
- Low level power can be used for signal transmission, data processing, and communication
- Can be stored in long-life batteries

Power to Accomplish the Automated Process :

Power for the process:

- To drive the process itself
- To load and unload the work unit
- Transport between operations

Power for automation:

- Controller unit
- Power to actuate the control signals
- Data acquisition and information processing

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2- Program of Instructions

Set of commands that specify the sequence of steps in the work cycle and the details of each step

Example: CNC part program

During each step, there are one or more activities involving changes in one or more process parameters

Examples:

- Temperature setting of a furnace
- Axis position in a positioning system
- Motor on or off

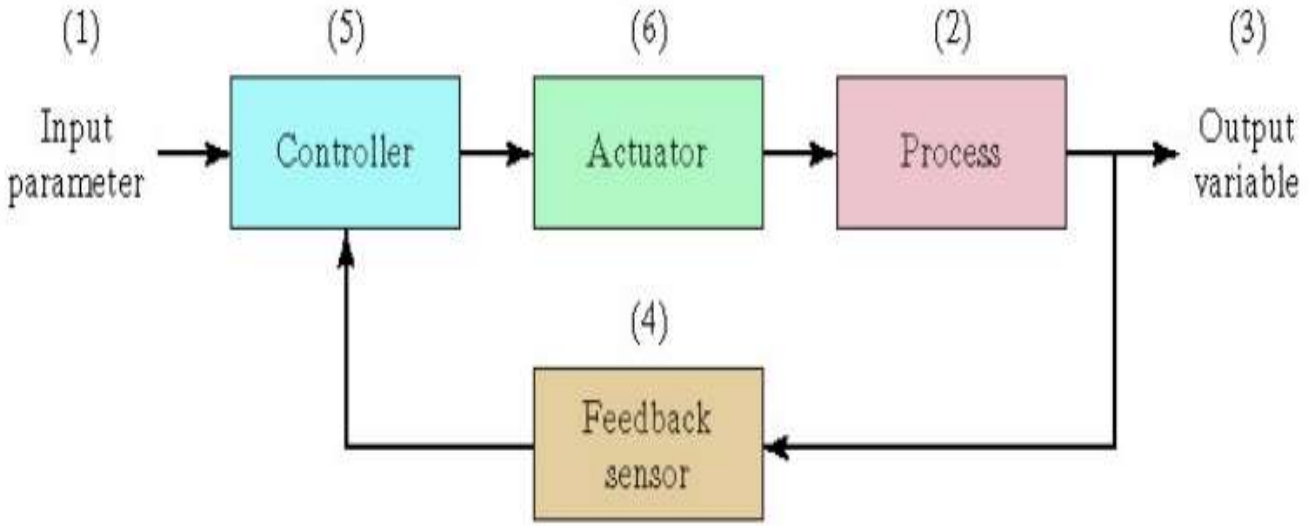
3- Control System – Two Types

1. Closed-loop (feedback) control system –

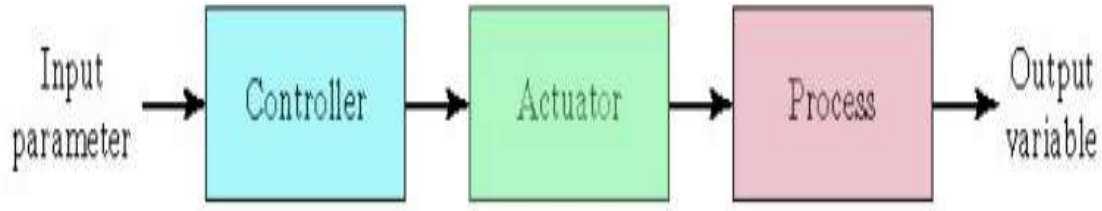
a system in which the output variable is compared with an input parameter, and any difference between the two is used to drive the output into agreement with the input

2. Open-loop control system –

- operates without the feedback loop
- Simpler and less expensive Risk that the actuator will not have the intended effect.



Feedback Control System



Open-Loop Control System

Advanced Automation Functions

In addition to executing work cycle programs, an automated system may be capable of executing advanced functions that are not specific to a particular work unit. In general these functions are concerned with enhancing the performance and safety of the equipment.

Advanced automation functions include the following:

- Safety monitoring
- Maintenance and repair diagnostics and
- Error detection and recovery

1) Safety Monitoring

Use of sensors to track the system's operation and identify conditions that are unsafe or potentially unsafe

Reasons for safety monitoring:

To protect workers and equipment

Possible responses to hazards:

Complete stoppage of the system

Sounding an alarm

Reducing operating speed of process

Taking corrective action to recover from the safety violation

2) Maintenance and Repair Diagnostics

Use of sensors to track the system's operation and identify conditions that are unsafe or potentially unsafe

Reasons for safety monitoring:

To protect workers and equipment

Possible responses to hazards:

Complete stoppage of the system

Sounding an alarm

Reducing the operating speed of the process

Taking corrective action to recover from the safety violation

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3) Error Detection and Recovery

Error detection – functions:

Use the system's available sensors to determine when a deviation or malfunction has occurred

Correctly interpret the sensor signal

Classify the error

Error recovery – possible strategies:

Make adjustments at the end of the work cycle

Make adjustments during the current work cycle

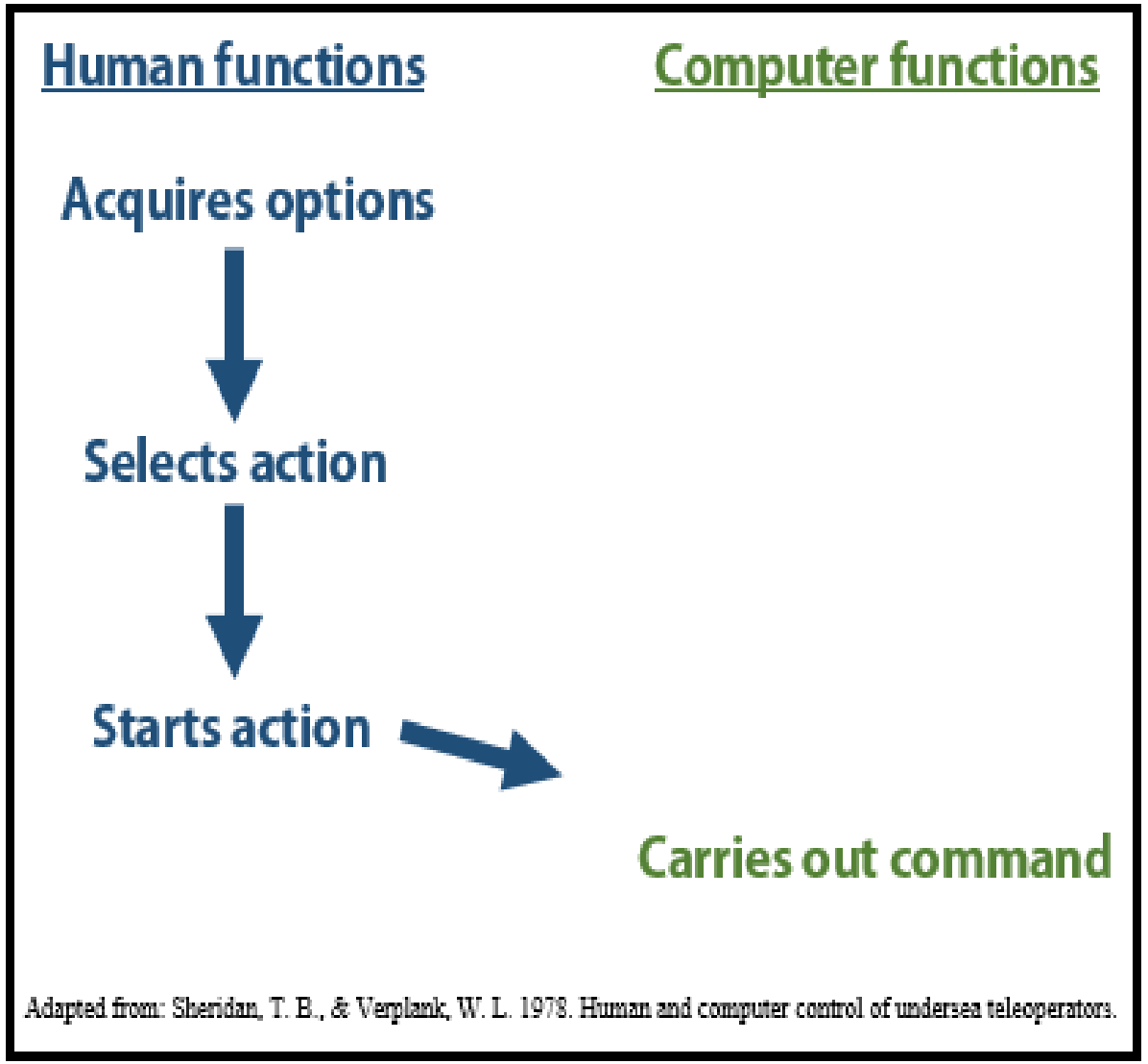
Stop the process to invoke corrective action

Stop the process and call for help

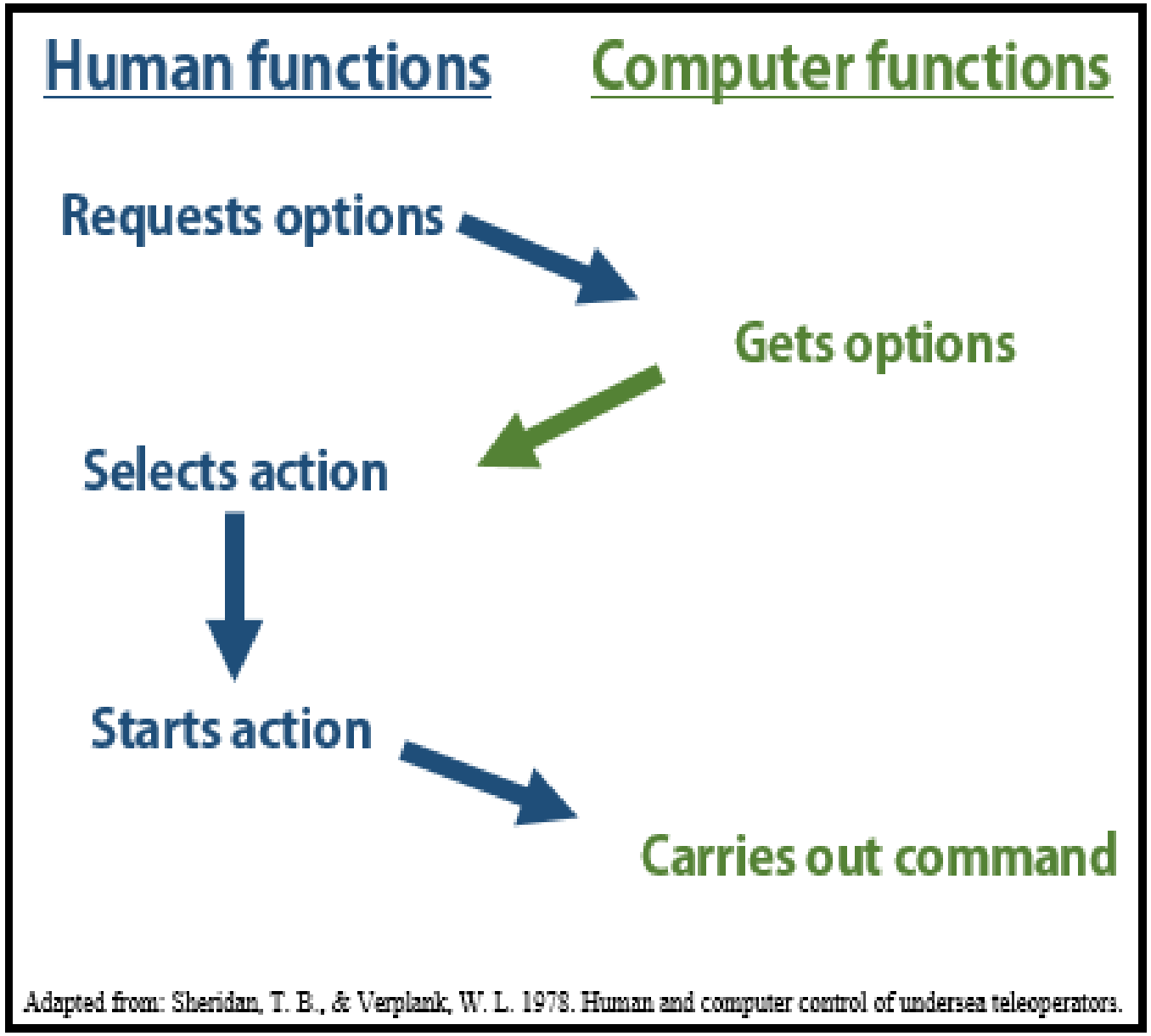
Levels of Automations

Automation levels:

Level 1 The human operator does the task and turns it over to the computer to implement.

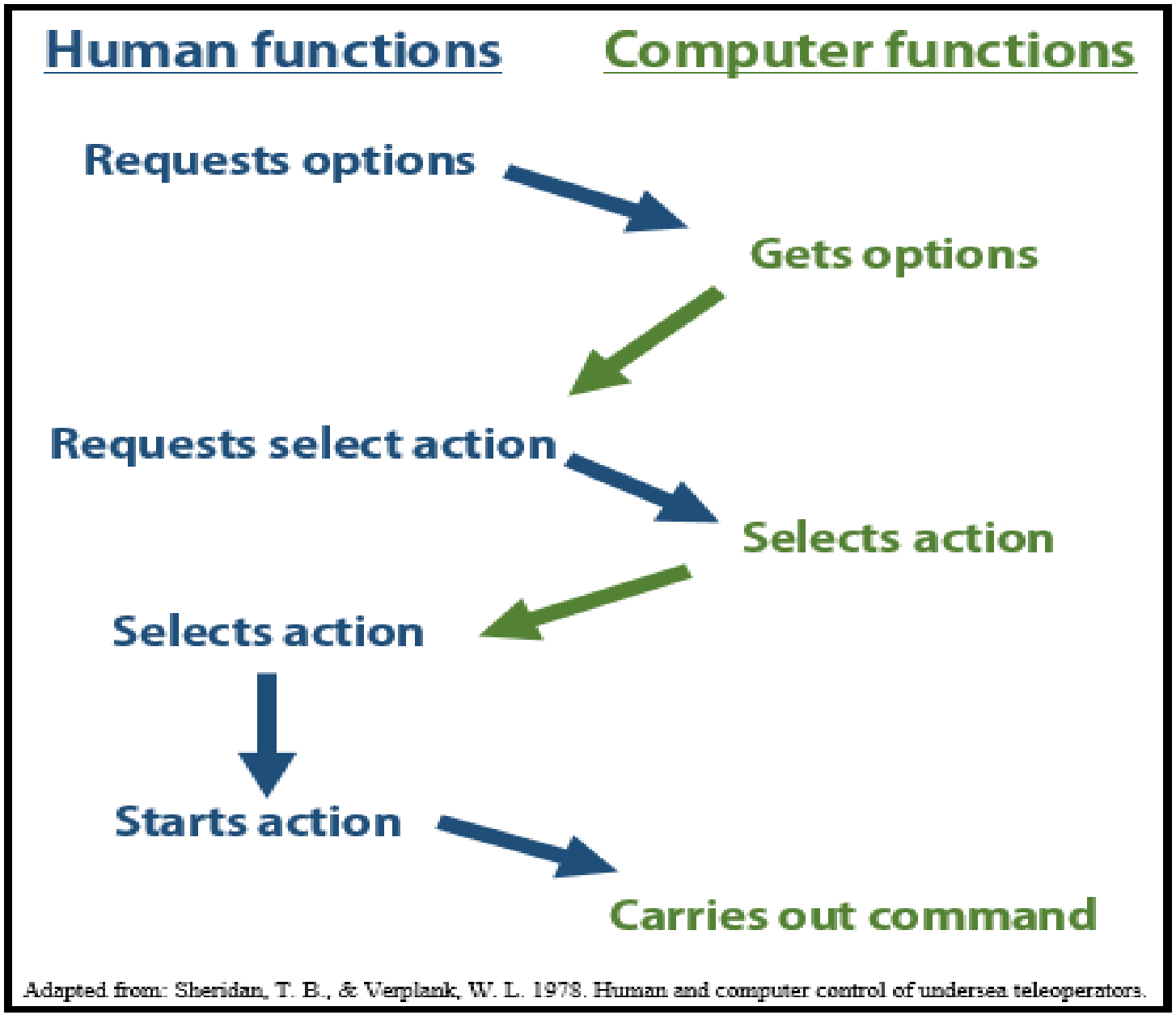


Level 2 The computer helps by determining the options.

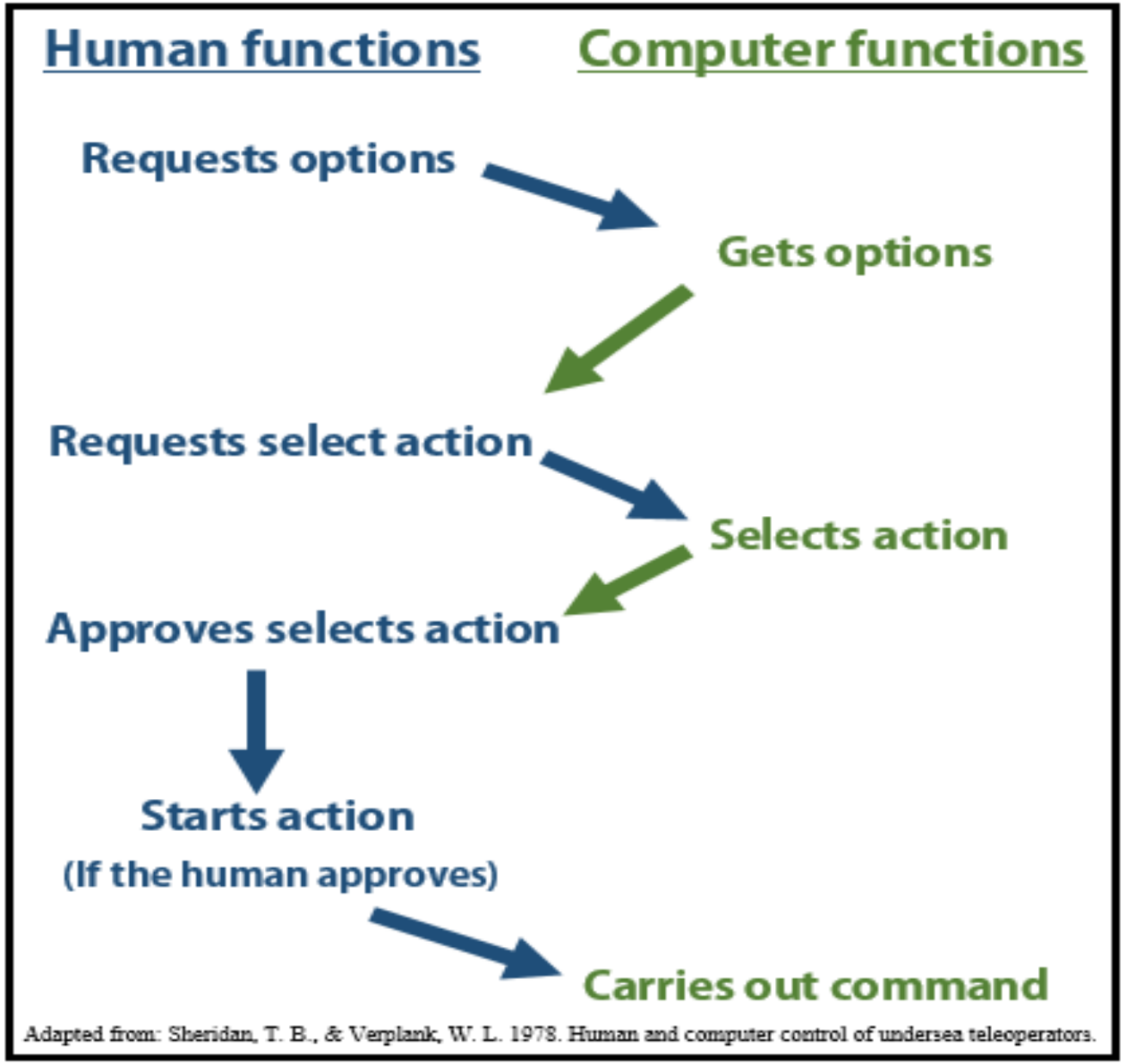


Adapted from: Sheridan, T. B., & Verplank, W. L. 1978. Human and computer control of undersea teleoperators.

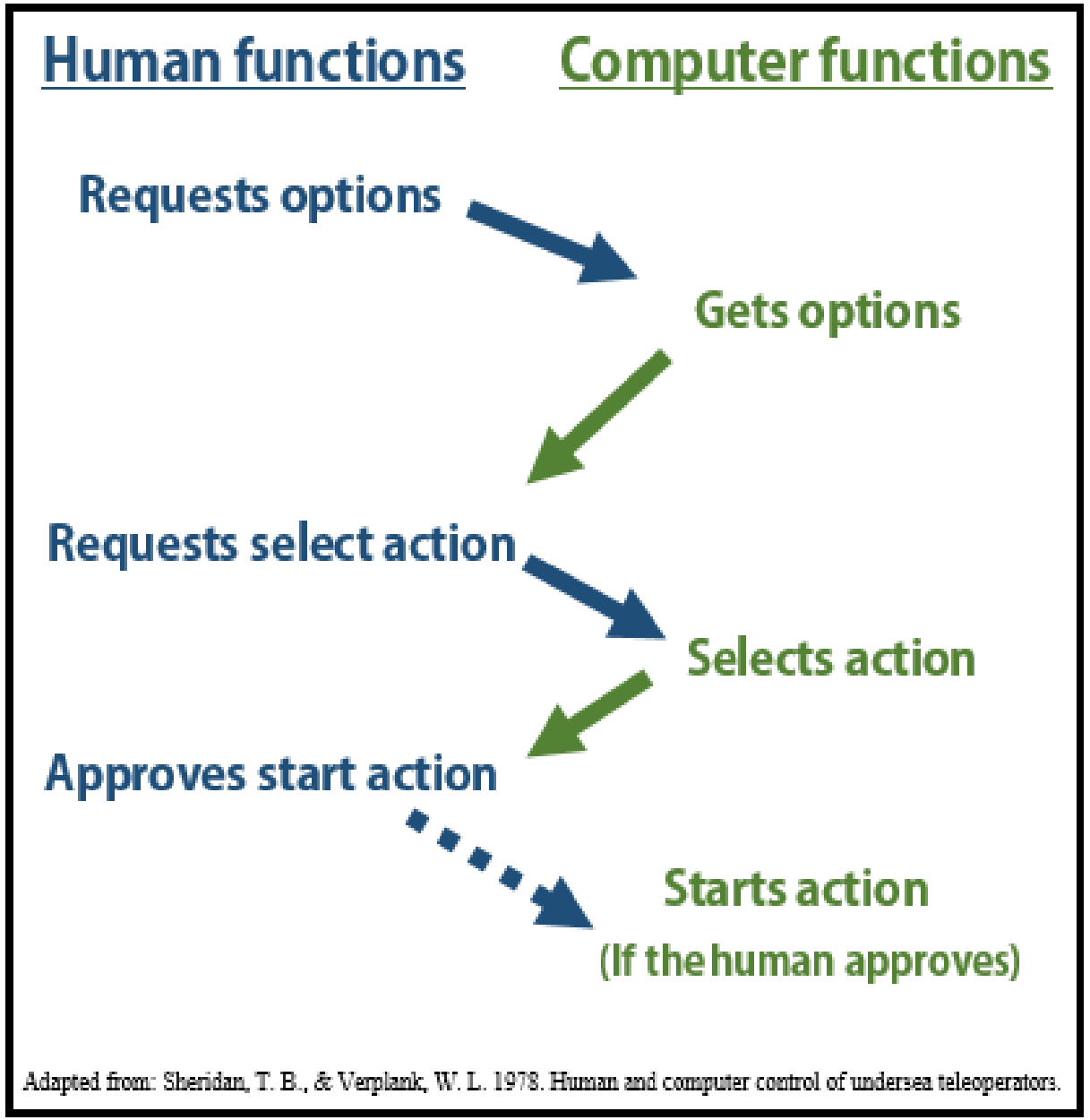
Level 3 The computer helps determine and suggests options. The human operator can choose to follow the recommendation.



Level 4 The computer selects the action and the human operator decides if it should or should not be done.

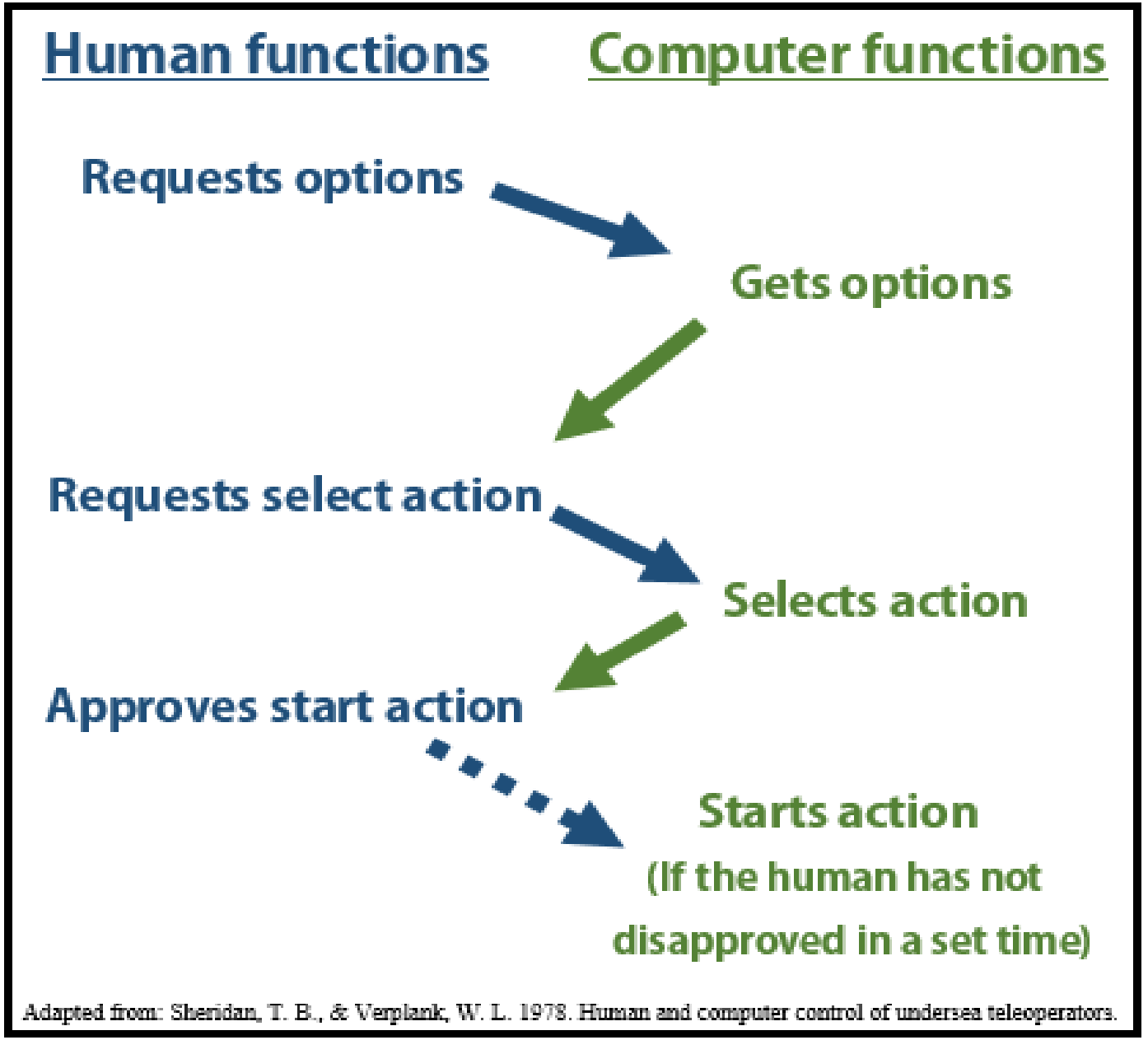


Level 5 The computer selects the action and implements it if the human operator approves the action.

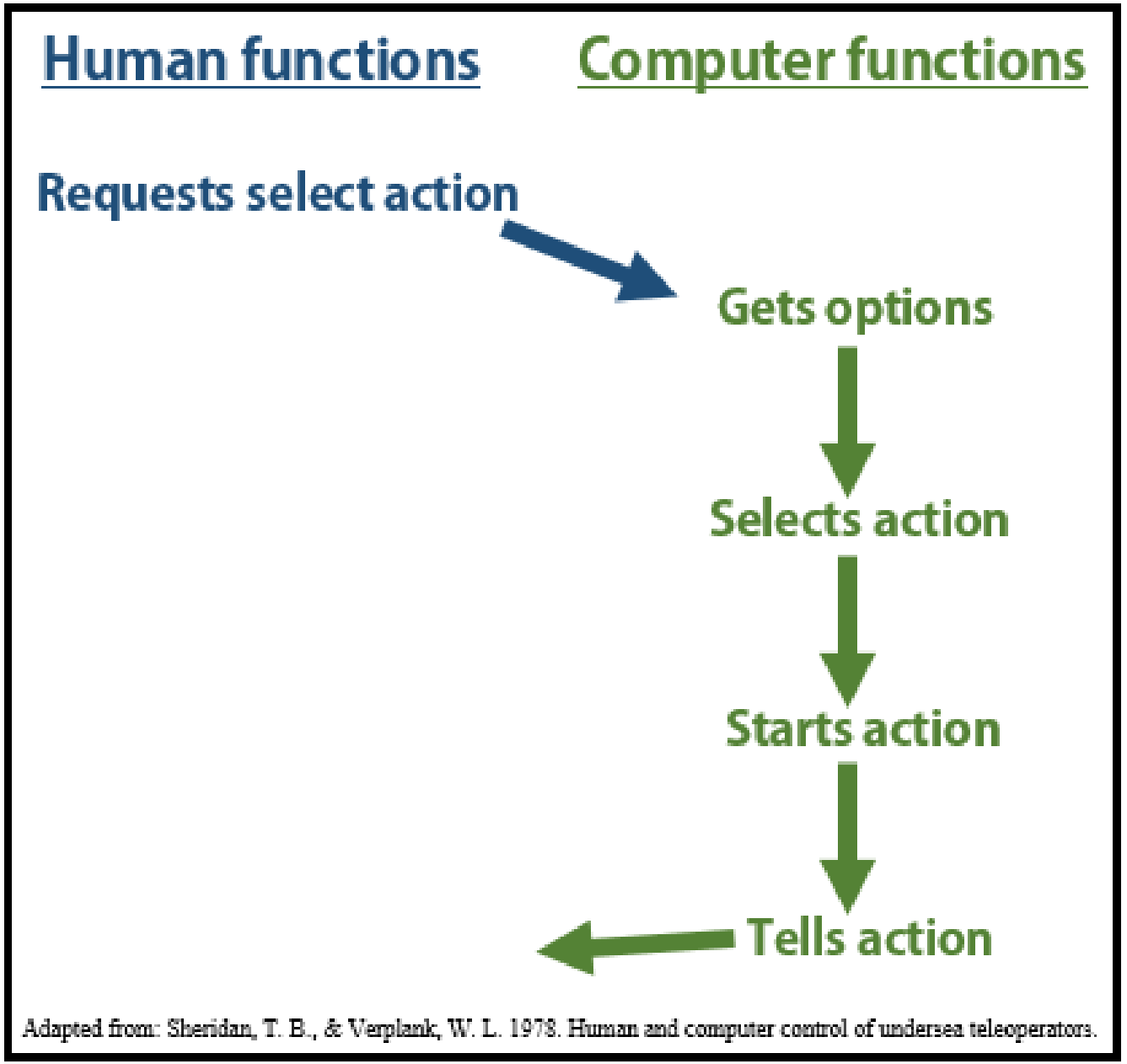


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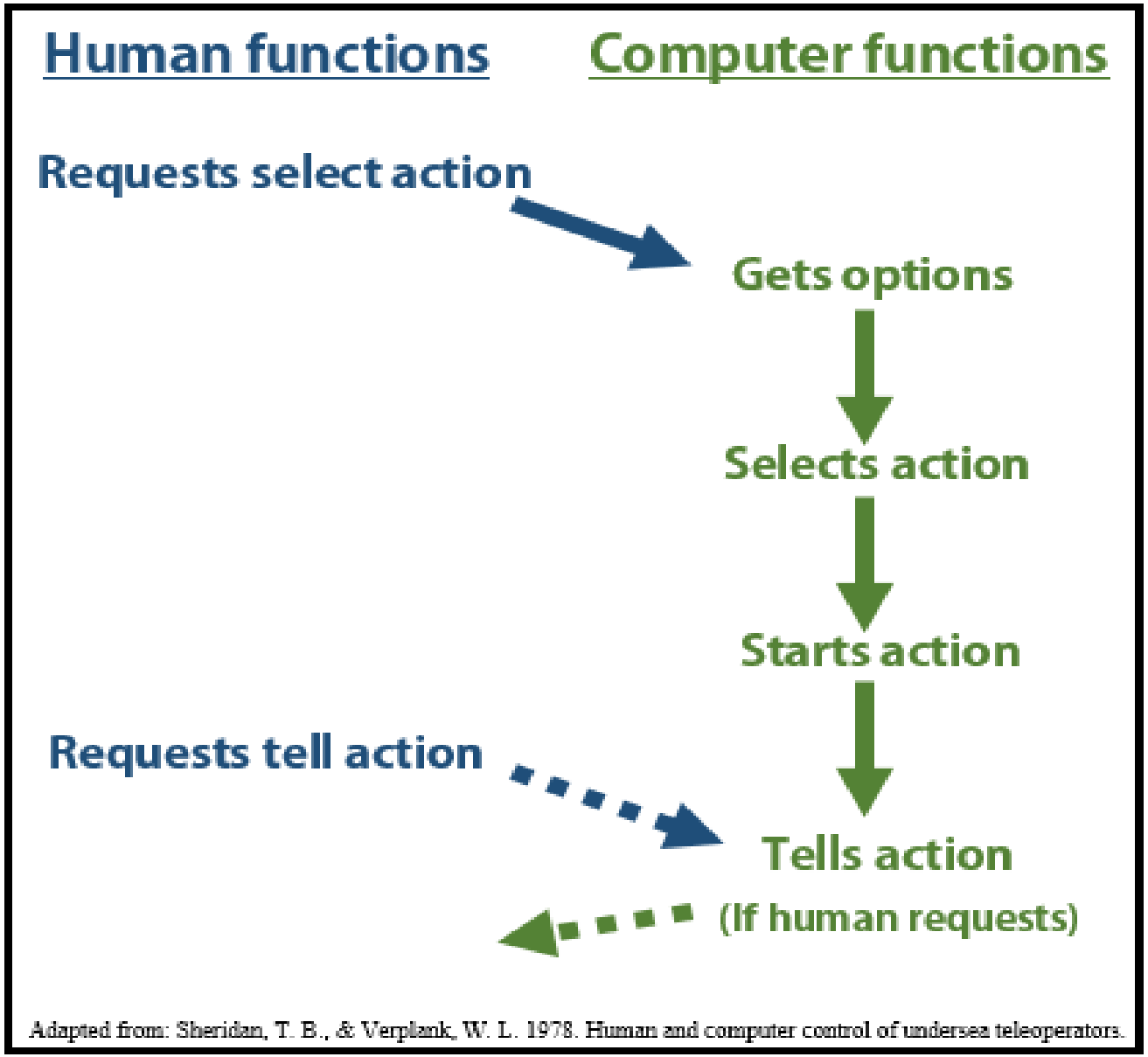
Level 6 The computer selects the action and informs the human operator in case the operator wants to cancel the action.



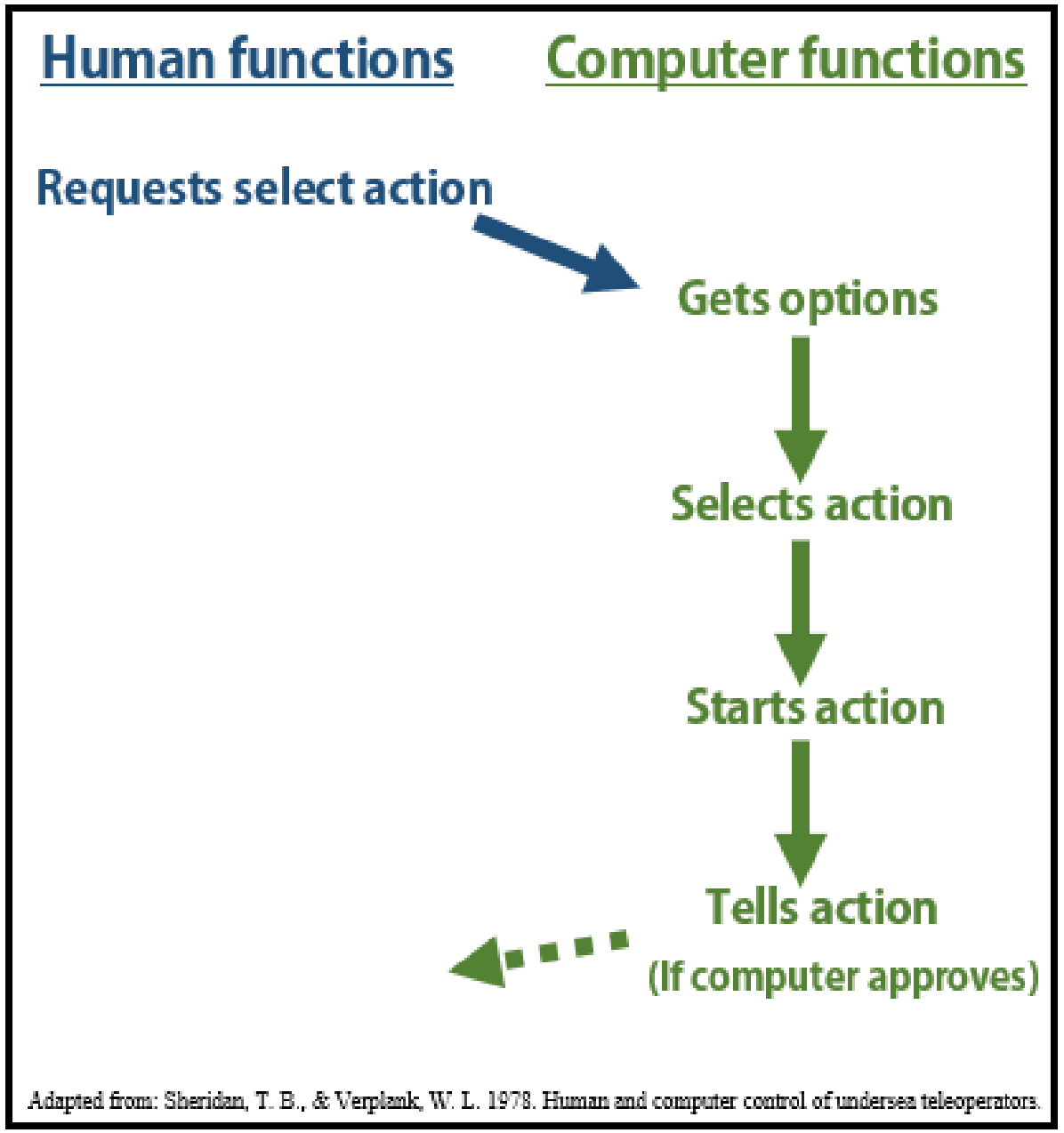
Level 7 The computer does the action and tells the human operator what is did.



Level 8 The computer does the action and tells the human only if the human operator asks.

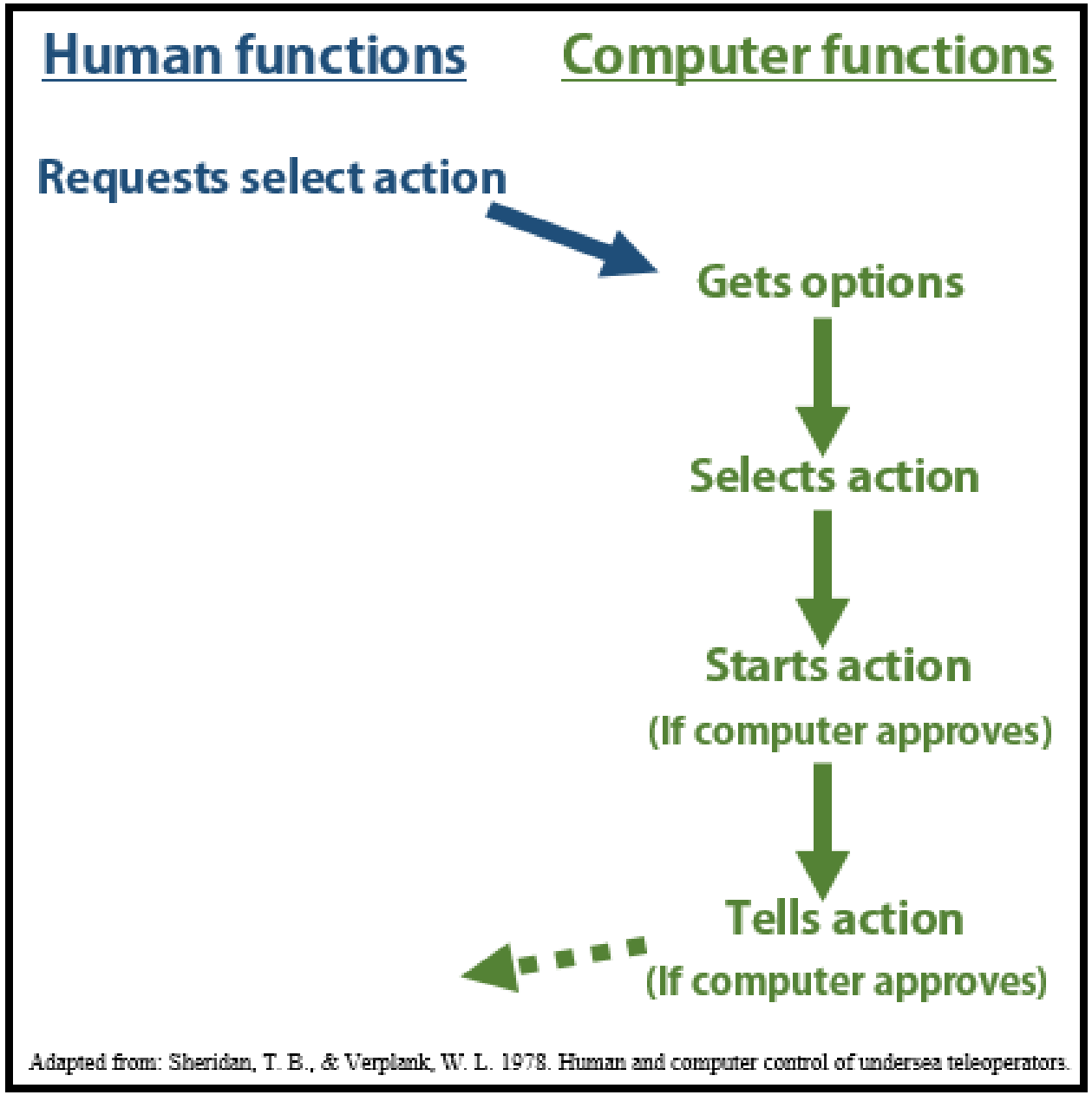


Level 9 The computer does the action when told and tells the human operator only if the computer decides the operator should be told.



Adapted from: Sheridan, T. B., & Verplank, W. L. 1978. Human and computer control of undersea teleoperators.

Level 10 The computer does the action if it decides it should be done. The computer tells the human operator only if it decides the operator should be told.



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Robotics Automations and Collaborative robots:

- Collaborative robots are a form of robotic automation built to work safely alongside human workers in a shared, collaborative workspace. In most applications, a collaborative robot is responsible for repetitive, menial tasks while a human worker completes more complex and thought-intensive tasks. The accuracy, uptime and repeatability of collaborative robots is designed to complement the intelligence and problem-solving skills of a human worker.
- Collaborative robot designs differ greatly from their industrial robot counterparts. Featuring rounded edges, force limitations, and light weights, collaborative robots are first and foremost designed for safety. Most collaborative robots are equipped with a series of sensors to avoid collisions with human workers, as well as safety protocols to shut down if any form of unplanned contact occurs.
- Remember that the key difference between industrial robots and collaborative robots is that **industrial robots can entirely automate a process without human interaction, while COBOTs work with humans**. COBOTs also cannot take on some of the heavy-duty manufacturing jobs that should be performed by an industrial robot.

- ***Collaborative robots*** are becoming increasingly popular in manufacturing. As more companies adopt automation, there are many tasks identified that require people to work in collaboration with a robot. Let's examine the four types of collaborative robot operation:
- **1. Power and Force Limiting cobots**
- Power and force limiting cobots are likely what most people think of when they hear the term collaborative robots. They are designed specifically to sense contact with people and cease operation, eliminating the need for safety barriers. They are best suited for smaller applications.
- For the three other types of collaborative operation -- any industrial robot can be integrated with safety devices to become "collaborative."
- **2. Safety Rated + Monitored Stop cobots**
- Safety rated + monitored stop cobots detect when a person has entered a designated area and stop operating until the person leaves that shared workspace, eliminating the need to have to restart a robot with the push of a button. Once the person leaves, the robot automatically continues its task. These are generally used when there's not as much interaction between a person and a robot.
- **3. Speed and Separation cobots (also called "fenceless")**
- Speed and separation cobots - more simply referred to as "fenceless" cobots - work well when there is not much interaction with a person, but a person needs easy access to the robot. Safety laser area scanners are commonly used to set up zones near the robot's workspace. When a person approaches the robot, its movements slow down, and then stop if that person gets within reach of the robot's workspace. As soon as the operator moves out of the robot's workspace, the robot automatically resumes normal speed.

- **4. Hand Guiding cobots**
- Finally, hand guiding cobots have a safety rated device attached to the end of the robot's arm to allow a person to manually guide or move the robot around. Hand guidance is often used to quickly and easily program new robot paths and positions by hand. It's ideal for mobile applications where the cobots move between stations and require re-training to accomplish different tasks, and when the cobot needs to be reprogrammed frequently for a new job.
- **The Benefits of Using Cobots**
- As manufacturing technologies advance, robots continue to help companies increase productivity and profitability. With more choices, payloads, reach, and speed options than any other brand, FANUC offers the widest range of cobots. For those considering cobots for future applications, it's important to weigh the benefits:
  - Save valuable floorspace - eliminating safety enclosures can streamline available workspace.
  - Increase flexibility with the ability to move a cobot from station to station.
  - Well suited for high-mix/low volume applications.
  - Quick and easy to install.
  - Easy to teach a cobot to perform new tasks and functions, allowing users to quickly move from one job or one part to another without having to invest too much time or effort into setting up for the next task.

Unit 3

What is Process ?

- A **process** is a sequence of **operations or activities** that transforms **inputs (materials, energy, or data)** into **desired outputs (products or results)**. In automation, a process refers to the **system or operation being monitored and controlled** using sensors, controllers, and actuators.
- A process in a collection of vessels, pipes, fittings, gauges etc., is built for the purpose of producing a product or group of products.

It Is defined as:

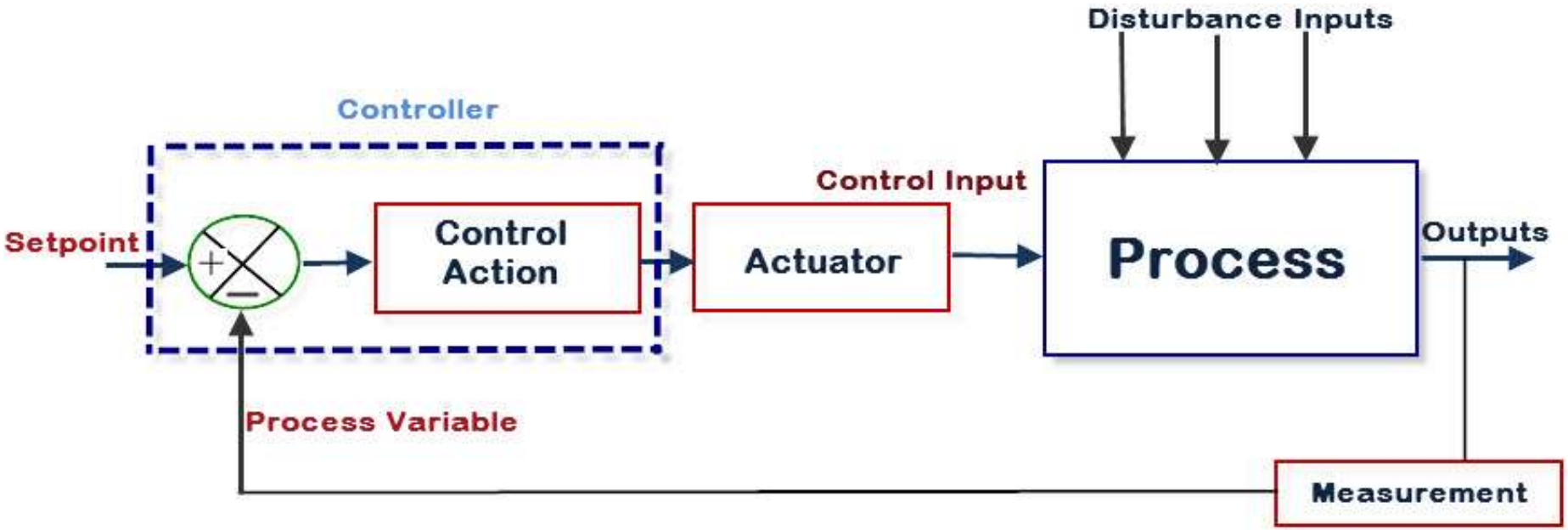
- Physical or chemical change of matter.
- Energy conversion

e.g., change in pressure, temperature, speed, electrical potential, etc.

- Every process involves:
- **Input** → Raw materials, energy, or information
- **Transformation** → Physical, chemical, or computational operations
- **Output** → Finished product or result
- **Examples**
- Manufacturing process (raw metal → finished component)
- Chemical process (reactants → products)
- Data processing (raw data → useful information)

Process Control

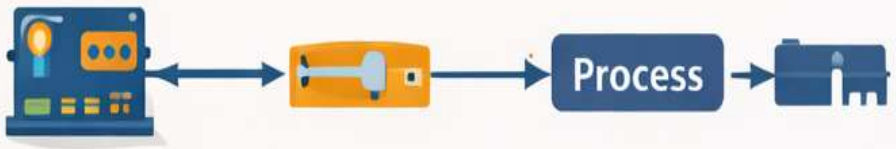
- **Process control** is the method of **monitoring and regulating process variables** (such as temperature, pressure, flow, and level) to ensure that a system operates at **desired conditions and performance**. Process control is the **continuous monitoring and adjustment of a system to maintain desired operating conditions**.
- The regulation or manipulation of variables influencing the conduct of a process in such a way as to obtain a product of desired quality and quantity in an efficient manner.
- In process control, the system continuously:
- Measures the current condition
- Compares it with the desired value (setpoint)
- Takes corrective action if there is any deviation



TYPES OF CONTROL

Open-Loop Control System

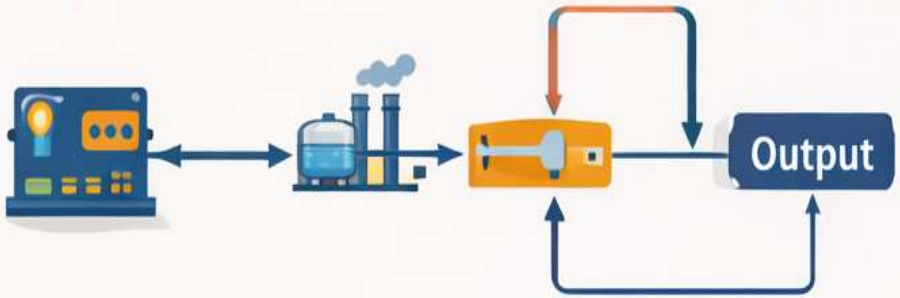
Input → Controller → Process → Output



- **No Feedback** Signal
- **No Correction** Mechanism
- Simple, Less Accurate

Closed-Loop Control System

Input → Controller → Process → Output



- Feedback Signal Present
- Automatically Corrects Errors
- Precise and Reliable

Different features of a Process Control

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- **Input to Process:** Mass or energy applied to the process.
- **Output of Process:** The product delivered by the process. This is a dynamic variable.
- **Supply:** Source of mass or energy input to process.
- **Control Valve:** Consists of the final actuator and final controlling elements. This is the forward controlling element which directly changes the value of the manipulated variable.
- **Load:** Anything that affects the value of the controlled variable under a constant supply input.
- **Open Loop:** Control without feedback. Open loop can not cope with load upsets. Example of open loop: automatic dishwasher, automatic water sprinkling system, a control loop with the controller in manual.
- **Primary Element:** The measuring element that quantitatively converts the measured variable energy into a form suitable for measurement.
- **Transmitter:** A transducer which responds to a measured variable by means of a sensing element, and converts it to a standardized transmission signal which is a function only of the measured variable.
- **Controlled Variable:** A variable the value of which is sensed to originate a feedback signal. (Also known as the process variable.)
- **Controller:** A device which operates automatically to regulate a controlled variable.
- **Controller Algorithm (PID):** A mathematical representation of the control action to be performed.
- **Set Point:** An input variable which sets the desired value of the controlled variable.

- **Error:** In process instrumentation, the algebraic difference between the real value and ideal value of the measured signal. It is the quantity which when algebraically subtracted from the indicated signal gives the ideal value.
- **Manipulated Variable:** A quantity or condition which is varied as a function of the algebraic error signal so as to cause a change to the value of the directly controlled variable.
- **Feedback Control:** Control action in which a measured variable is compared to its desired value to produce an actuating error signal which is acted upon in such a way as to reduce the magnitude of the error.
- **Cascade Control:** Control in which the output of one controller is introduced as the set point for another controller.
- **Feed forward Control:** Control action in which information concerning one or more conditions that can disturb the controlled variable is converted, outside of any feedback loop, into corrective action to minimize deviations of the controlled variable.

PROCESS CONTROL

Process control is the monitoring and regulating of a process to maintain desired operating conditions.

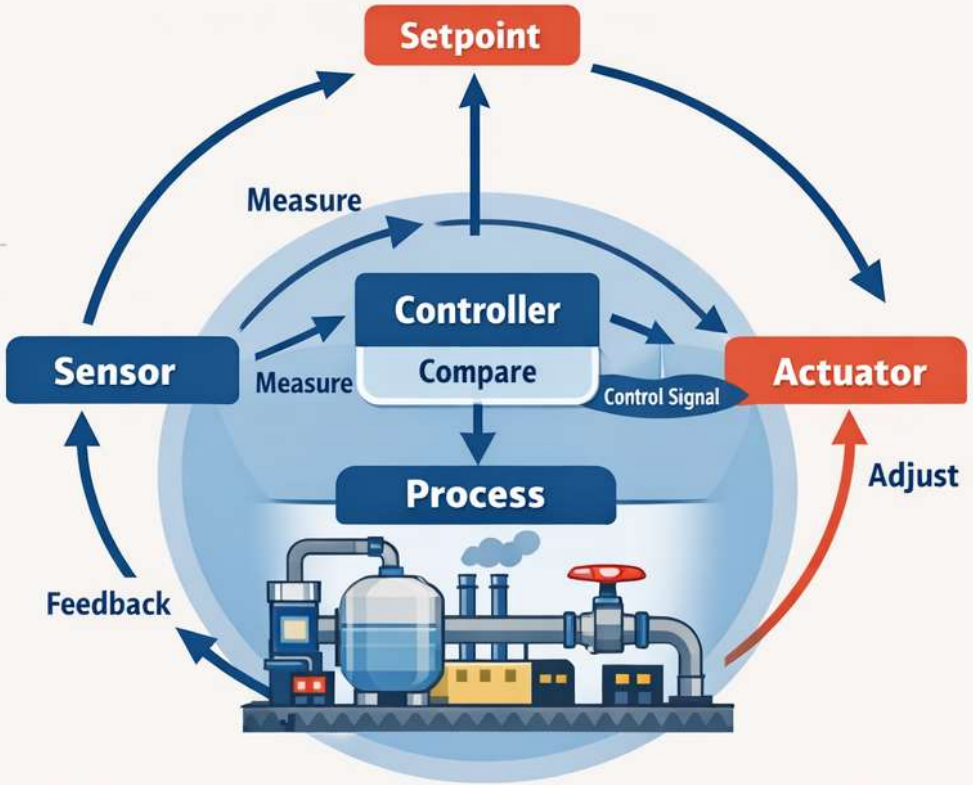
Key Elements

Process
System to be controlled

Sensor
Measures the Variable

Controller
Decides the Action

Actuator
Adjusts the Process



Control Types

Open Loop Control
No Feedback

Closed Loop Control
Feedback System

Examples

Temperature Control
Furnace

Level Control

Pressure Control
Pipeline

Measure → Compare → Correct → Adjust

Ensuring Stable and Efficient Operation

Types of control

1. Continuous Control

Continuous Control is used on continuous processes. A continuous process is one in which process material is continually flowing through the process equipment. Continuous control refers to systems where the **process operates continuously over time**, and variables are continuously monitored and controlled.

Characteristics

- Process runs without interruption
- Control variables change continuously
- Requires real-time monitoring and feedback

Examples

- Temperature control in a furnace
- Oil refining processes
- Power generation systems

Key Idea

- Output is continuously adjusted to maintain desired conditions.

Continuous = Uninterrupted process

2. Sequential Control

Sequential is often referred to as on/off control. It is a series of discrete control actions performed in a specific order or sequence. Sequential control involves operations carried out in a **specific sequence or order**, where each step follows the previous one.

Characteristics

- Step-by-step operation
- Each action triggered by time, event, or condition
- Logic-based control (often using PLCs)

Examples

- Automatic washing machine cycles
- Elevator control systems
- Assembly line operations

Key Idea

- Process follows a predefined sequence of steps.

Sequential = Step-by-step control

3. Batch Control

- **Batch** control is a combination of sequential and continuous control. A batch process is a process where the operation is time-dependent and repeatable. Batch control is used when production is carried out in **finite quantities (batches)**, with each batch processed separately.

Characteristics

- Start → Process → Stop cycle
- Same procedure repeated for each batch
- Suitable for limited quantity production

Examples

- Pharmaceutical production
- Food processing (e.g., baking)
- Chemical mixing processes

Type	Operation	Nature	Example
Continuous	Ongoing	Continuous	Oil refinery
Sequential	Step-wise	Discrete steps	Washing machine
Batch	Finite quantity	Cyclic	Pharmaceutical production

Key Idea

- A fixed quantity is processed in stages, then the cycle repeats.

Batch = Process in fixed quantities.

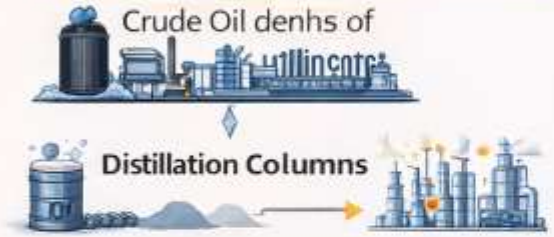
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Continuous Control

Case Study:

Oil Refinery

Process



Control System

- **Sensors** measure temperature, pressure, flow rate
- **Controllers** adjust valves, heaters in real time
- **SCADA/DCS system** maintains stable operation

Outcome:



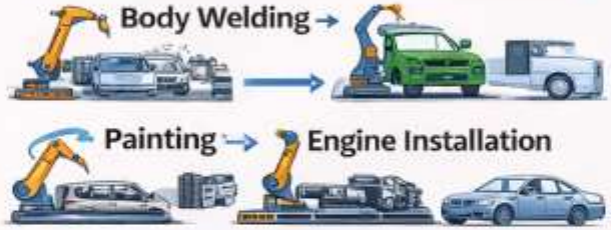
- **24/7 uninter-** operation
- High efficiency and consistent product quality

Sequential Control

Case Study:

Automobile (Ie.Ta Motors)

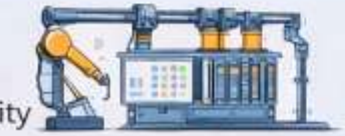
Process



Control System

- PLCs control step-by-step stages
- **Sensors** check positioning before next operation
- Each operation starts after the previous one is completed

Outcome:



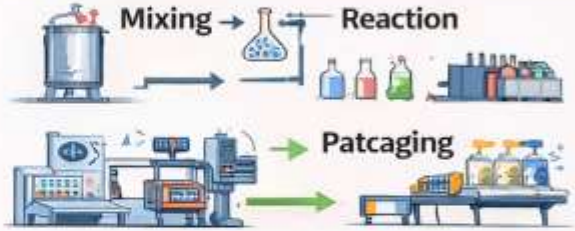
- High precision and repeatability
- Efficient mass production

Batch Control

Case Study:

Pharmaceutical

Process



Control System

- Parameters controlled by batch recipe
- **System stops** after each batch, restarts for the next
- Precise control of limited quantity production

Outcome:

- **High quality and consistency**
- Easy quality inspection and traceability

PID Control

- PID stands for **Proportional-Integral-Derivative. PID control** is a widely used **closed-loop control technique** that combines three control actions—**Proportional (P), Integral (I), and Derivative (D)**-to achieve **accurate, stable, and fast system response**. In modern industrial automation, maintaining process variables such as temperature, pressure, flow, and speed within desired limits is essential. **PID control** is one of the most widely used control strategies due to its **simplicity, robustness, and effectiveness**. It is a **closed-loop control system** that continuously calculates error and applies corrective action to minimize it.
- A **PID controller** is an instrument used in industrial control applications to regulate temperature, flow, pressure, speed and other process variables. PID (proportional integral derivative) controllers use a control loop feedback mechanism to control process variables and are the most accurate and stable controller. These three controllers are combined in such a way that it produces a control signal. PID controllers are found in a wide range of applications for industrial process control. Approximately 95% of the closed loop operations of industrial automation sector use PID controllers.
- As a feedback controller, it delivers the control output at desired levels.
- Before microprocessors were invented, PID control was implemented by the analog electronic components. But today all PID controllers are processed by the microprocessors.
- Programmable logic controllers also have the inbuilt PID controller instructions. Due to the flexibility and reliability of the PID controllers, these are traditionally used in process control applications.

All modern industrial controllers are of automatic type (or closed loop controllers), which are usually made to produce one or combination of control actions. These control actions include

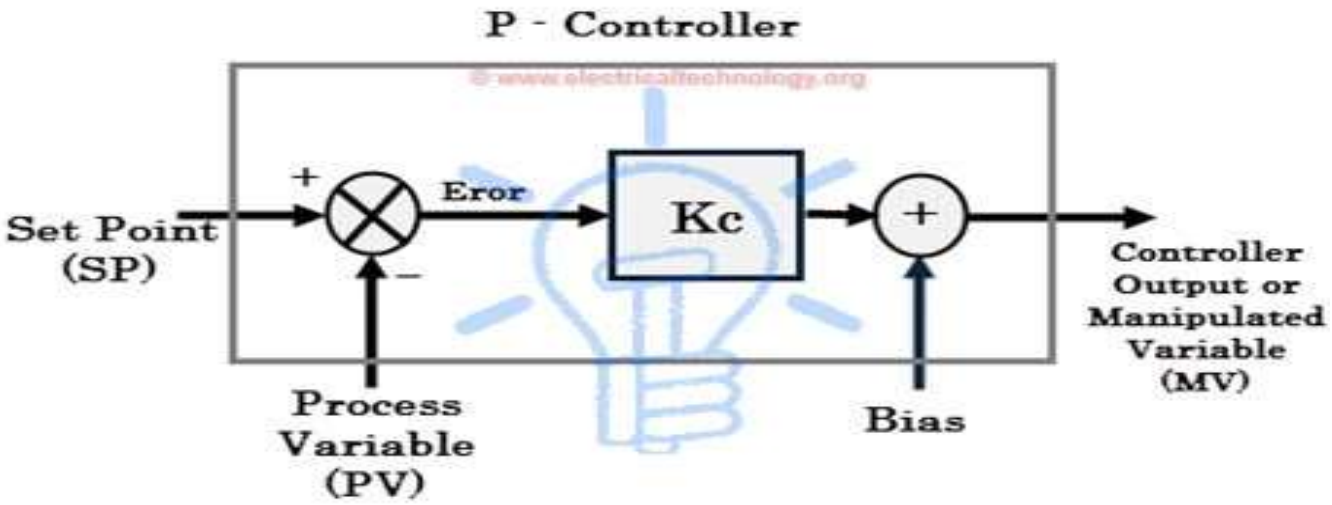
- **ON-OFF Controller**
- **Proportional Controller**
- **Proportional-Integral Controller**
- **Proportional-Derivative Controller**
- **Proportional-Integral-Derivative Controller**

- A **PID (Proportional-Integral-Derivative)** controller is the most common control algorithm used in industry to keep a system at a specific target. Whether it's maintaining a car's speed via cruise control or keeping a drone level, PID works by calculating the "error"—the difference between where the system is and where you want it to be—and applying a correction.
- The controller calculates three separate parameters and sums them to create an output:

Proportional (P): "The Present" The correction is proportional to the current error. If the error is large, the correction is large.

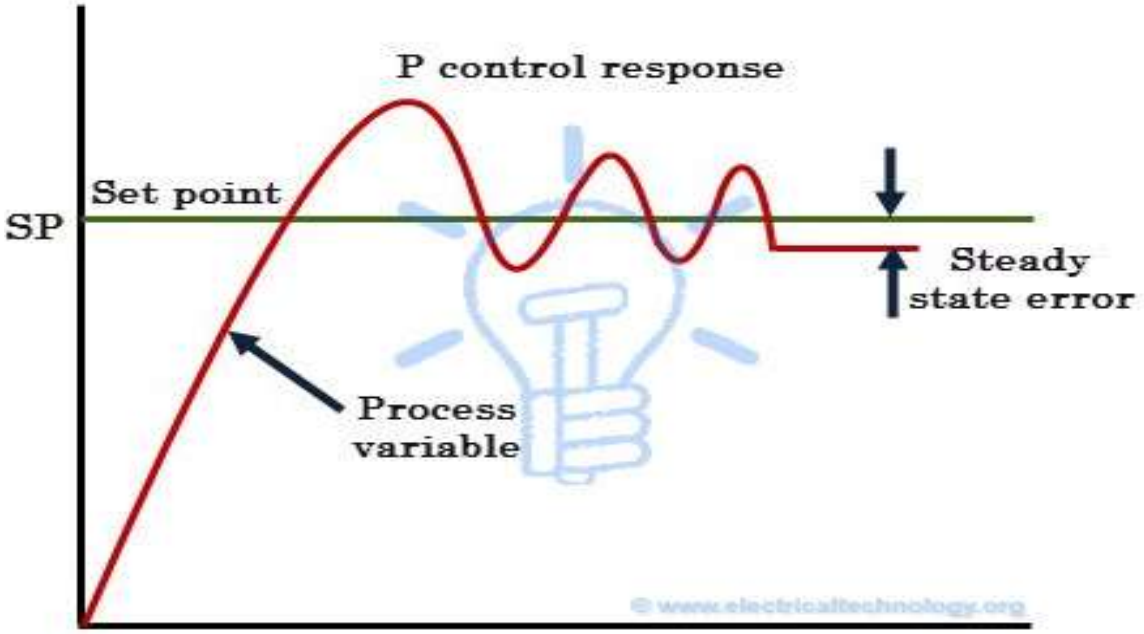
- You are steering a car and see you are drifting right. The further you drift, the harder you turn the wheel left.
- If used alone, it often results in "steady-state error" where the system gets close to the target but never quite reaches it.

- Gives output which is proportional to current error e (t).
- It compares desired or set point with actual value or feedback process value.
- The resulting error is multiplied with proportional constant to get the output.
- If the error value is zero, then this controller output is zero.



$$MV = Kc\ e + b$$

This controller requires biasing or manual reset when used alone. This is because it never reaches the steady state condition. It provides stable operation but always maintains the steady state error. Speed of the response is increased when the proportional constant Kc increases.



Proportional control produces an output that is **directly proportional to the error** (difference between setpoint and actual value).

- If error is large → strong corrective action
- If error is small → weak corrective action

- **Integral (I): "The Past"** This looks at the accumulation of past errors. If the system has been off-target for a long time, the Integral component grows to push it over the finish line. Integral control acts on the **accumulated error over time**. It keeps adjusting the output until the error becomes zero.
  - If you've been slightly off-center for a mile, you gradually increase your steering angle until you are exactly in the middle.
  - Too much "I" can cause the system to overshoot the target and oscillate.

- Due to limitation of p-controller where there always exists an offset between the process variable and set point, I-controller is needed, which provides necessary action **to eliminate the steady state error.** It integrates the error over a period of time until error value reaches to zero. It holds the value to final control device at which error becomes zero.
- The I controller accumulates the error over time. This ensures that even a small error, if persistent, will eventually result in a large enough control signal to eliminate it.
- Error e(t) enters an integrator block followed by a gain Ki.
- **Action:** It provides "memory" to the system, removing steady-state offsets that a P-only controller cannot fix.

$$u(t) = K_i \int_0^t e(\tau) d\tau$$

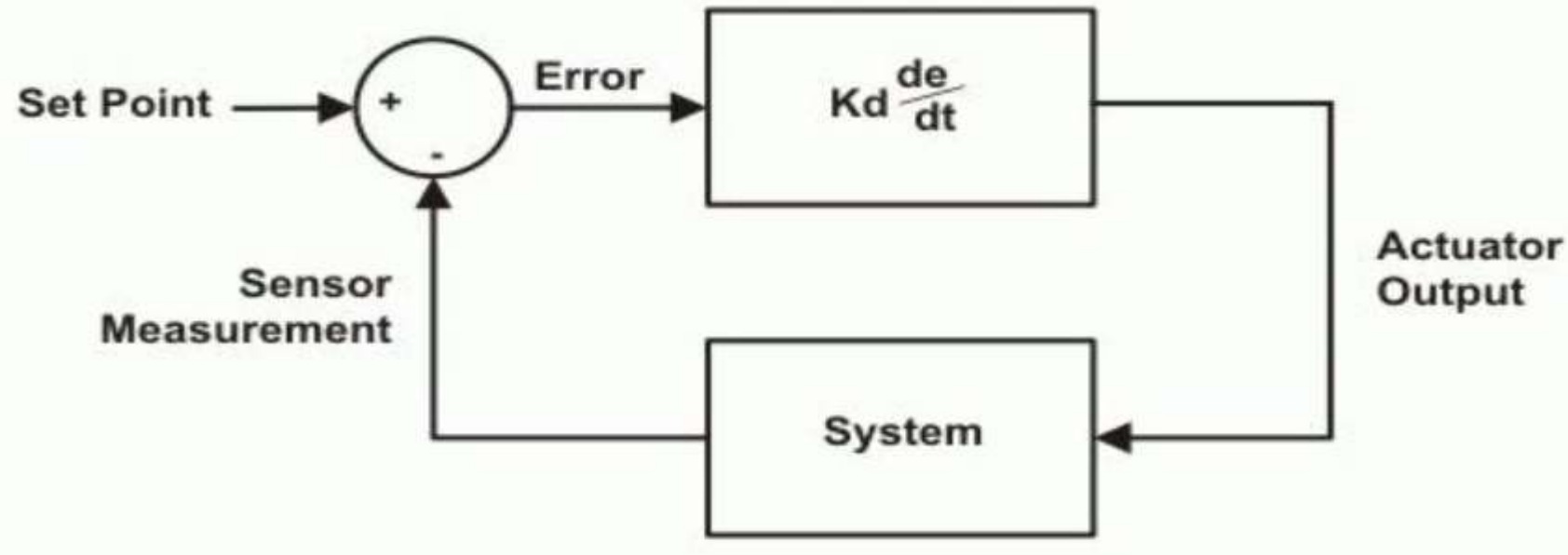
- **Derivative (D) Control**

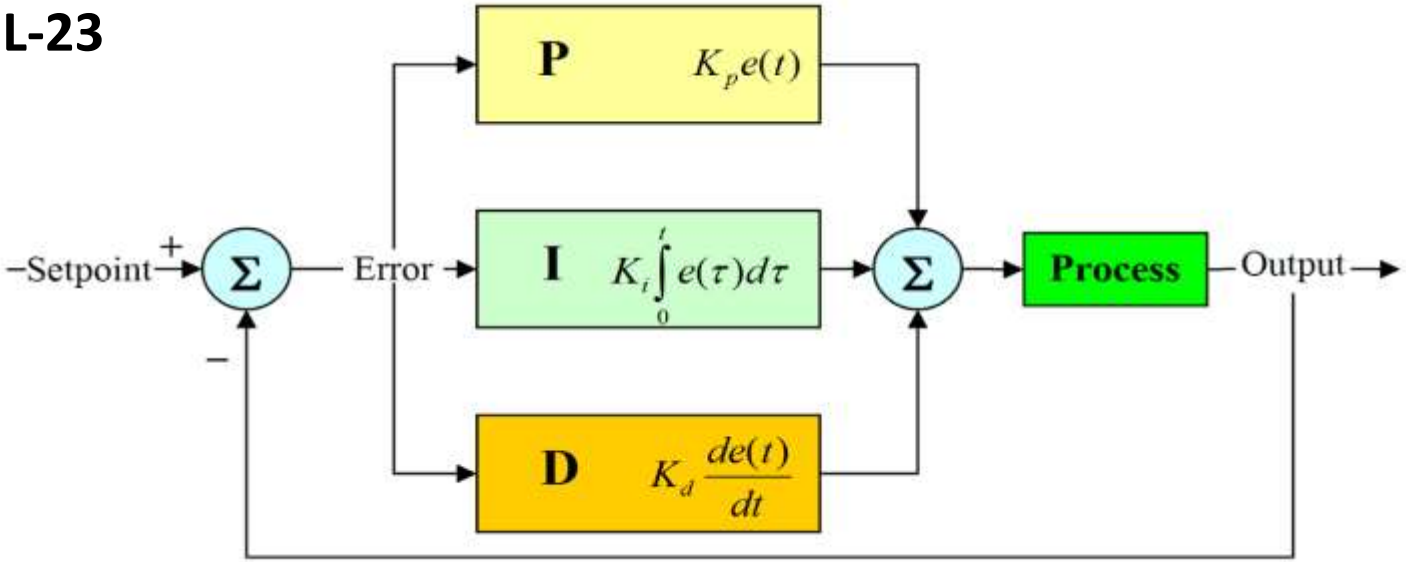
Derivative control reacts to the **rate of change of error**. It predicts future error and takes corrective action in advance. The D controller responds to the *rate of change* of the error. It predicts where the error is going.

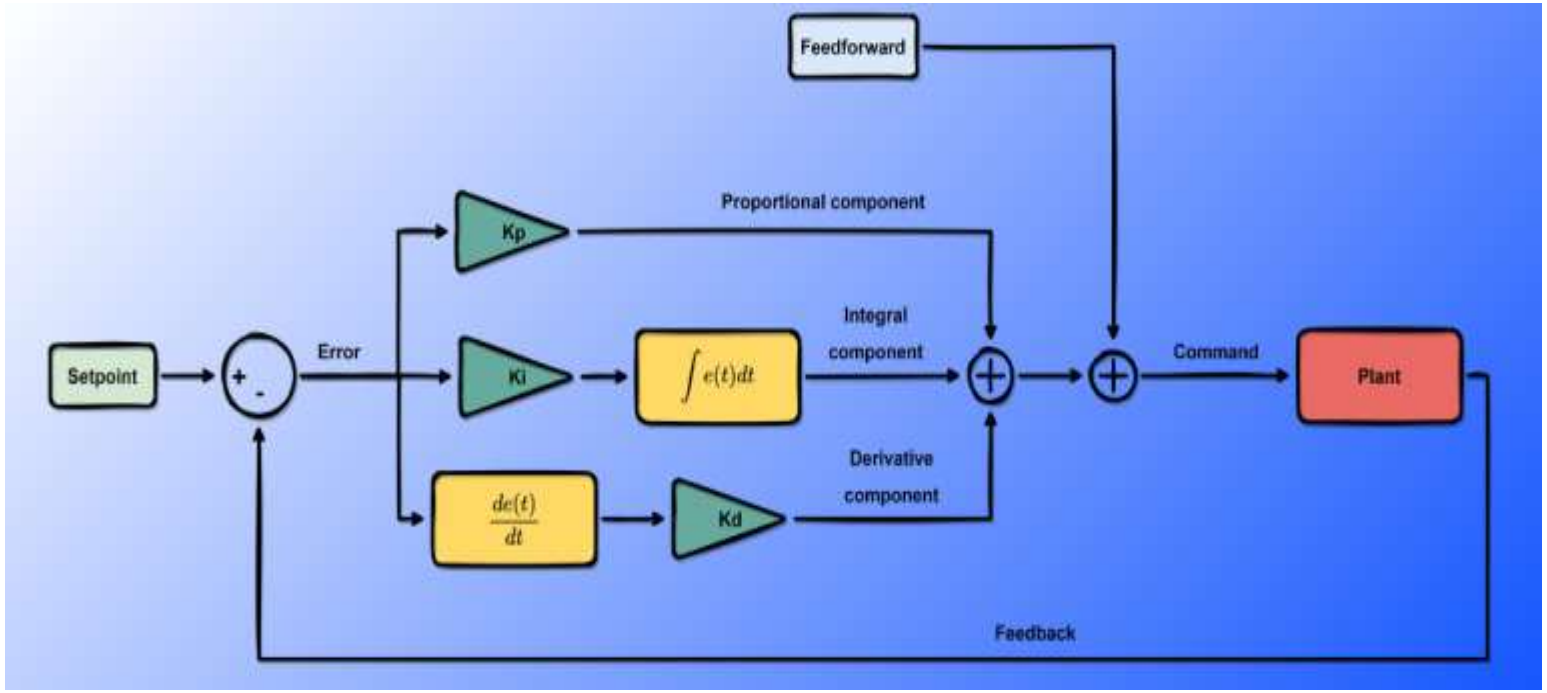
- Improves **system stability**
- Reduces overshoot
- Does not act alone (used with P or PI)

The Error e(t) enters a differentiator block) followed by a gain Kd.

It acts as a damper or brake. If the system is approaching the setpoint very fast, the D-term creates a counter-force to prevent overshoot and oscillations.




P
$K_p e(t)$
I
$K_i \int_0^t e(\tau)d\tau$
D
$K_d \frac{de(t)}{dt}$
Setpoint
+
−
Σ
Error
Σ
Process
Output


Feedforward
Proportional component
Kp
Setpoint
+ -
Error
Ki
$\int e(t)dt$
Integral component
Command
Plant
Derivative component
$\frac{de(t)}{dt}$
Kd
Feedback

Controller Tuning

Controller tuning is the process of determining the controller parameters which produce the desired output. Controller tuning allows for optimization of a process and minimizes the error between the variable of the process and its set point.

Types of controller tuning methods include the trial and error method, and process reaction curve methods. The most common classical controller tuning methods are the Ziegler-Nichols and Cohen-Coon methods. These methods are often used when the mathematical model of the system is not available. The Ziegler-Nichols method can be used for both closed and open loop systems, while Cohen-Coon is typically used for open loop systems. A closed-loop control system is a system which uses feedback control. In an open-loop system, the output is not compared to the input.

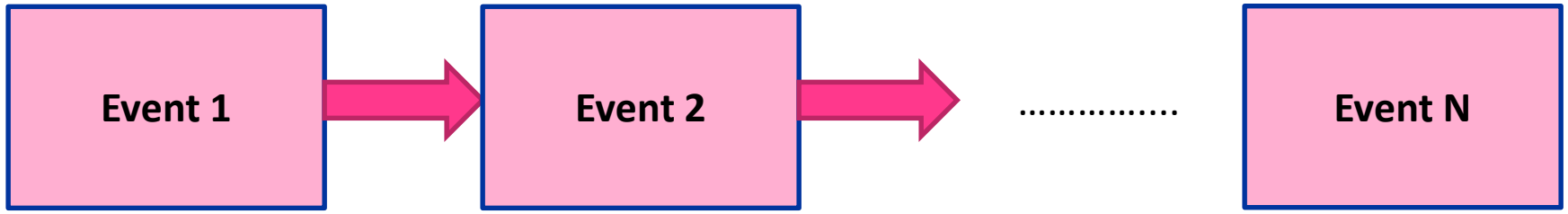
PID tuning is the **process of finding the values of proportional, integral, and derivative gains of a PID controller** to achieve desired performance and meet design requirements.

Tuning a controller—most commonly a **PID (Proportional-Integral-Derivative)** controller—is the process of adjusting the gain parameters to achieve the desired system response. The goal is to find a balance between speed, stability, and accuracy.

- **The PID Components**
- Before tuning, it’s helpful to understand what each "knob" does to the system:
- **Proportional (K_p):** The "Present." It applies correction based on the current error. High K_p makes the system faster but can cause overshoot and instability.
- **Integral (K_i):** The "Past." It eliminates steady-state error by accumulating past errors. Too much K_i leads to "ringing" or oscillation.
- **Derivative (K_d):** The "Future." It predicts future error by looking at the rate of change. It acts as a brake to flatten out overshoots but is sensitive to system noise.

Sequential Process Control

- The definition of "Sequence Control" is the controlled operation of a machine according to a predefined sequence. A process in which one event follows another until a job is completed.



Sequential Process Control refers to a type of control system in which operations are carried out in a **predefined sequence of steps**, one after another, based on logic conditions and events. Each step is executed only after the previous step is completed, ensuring a systematic and orderly operation of the process.

In this type of control, the system does not continuously regulate variables like temperature or pressure (as in continuous control systems), but instead focuses on **controlling the order of operations**. The sequence is typically defined using logic such as timers, counters, sensors, and conditional statements. Once a condition is satisfied (e.g., a signal from a sensor or completion of a task), the system moves to the next step in the sequence.

Sequential process control is commonly implemented using **Programmable Logic Controllers (PLCs)**, relay logic, or computer-based control systems. These controllers are programmed to follow a specific sequence of operations, often represented using flowcharts, ladder diagrams, or state diagrams.

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Working Principle

- The process starts with an initial command or trigger
- The first operation is executed
- A condition or feedback signal is checked
- If the condition is satisfied, the system proceeds to the next step
- This continues until all steps in the sequence are completed

Examples of Sequential Process Control

- Automatic washing machines (wash → rinse → spin)
- Traffic light control systems
- Assembly line operations
- Batch processing in chemical industries
- Elevator control systems

Key Features

- Step-by-step execution
- Logic-based control (ON/OFF decisions)
- Event-driven operation
- Easy to program and modify
- High reliability in repetitive tasks
- High efficiency and automation

Advantages

- Simple and structured control
- Suitable for repetitive processes
- Easy fault detection

Limitations

- Not suitable for continuous variable control
- Less flexible for highly dynamic processes
- Requires proper sequencing logic

Characteristics

1) Discrete loads
2) Product output is in units (cans boxes)
3) Different equipment modifies the product at each step
4) Steps are staged (do step 1 before 2)

Devices Used in Sequential Control

- Sequential control systems rely on various electrical, electronic, and mechanical devices to execute operations in a **predefined step-by-step sequence**. These devices help in sensing conditions, processing logic, and performing actions.

1. Sensors

- Sensors are input devices used to **detect physical conditions** such as position, temperature, pressure, or proximity. They provide signals to the control system to trigger the next step in the sequence.

Examples: Limit switches, proximity sensors, temperature sensors

2. Switches and Push Buttons

- These are manual input devices used to **start, stop, or control operations** in a sequence. They allow human operators to interact with the system.

Examples: Start/Stop buttons, selector switches

3. Relays

- Relays are electrically operated switches used to **control circuits based on logic conditions**. They are widely used in traditional sequential control systems.

Function: Enable ON/OFF control and interlocking operations

4. Timers

- Timers are used to introduce **time delays between operations** in a sequence. They ensure that certain steps occur only after a specified time interval.

Example: Delay before switching from one operation to another

5. Counters

- Counters keep track of the number of occurrences of an event and trigger actions after a **specific count is reached**.

Example: Counting products on a conveyor before packaging

6. Programmable Logic Controller (PLC)

- A PLC is the most important device in modern sequential control systems. It is a **digital computer used to automate industrial processes** by executing programmed logic.

Function: Controls sequence using ladder logic or other programming methods

7. Actuators

- Actuators are output devices that **perform physical actions** based on control signals.

Examples: Motors, solenoids, hydraulic and pneumatic cylinders

8. Contactors

- Contactors are heavy-duty relays used to **control high-power electrical loads**, such as motors.

9. Indicators and Alarms

- These devices provide **visual or audible feedback** about system status.

10. Control Panels

- Control panels house all control devices and provide a **centralized interface** for monitoring and operation.

Sequential control uses devices like **sensors, relays, timers, PLCs, and actuators to execute operations in a predefined sequence**.

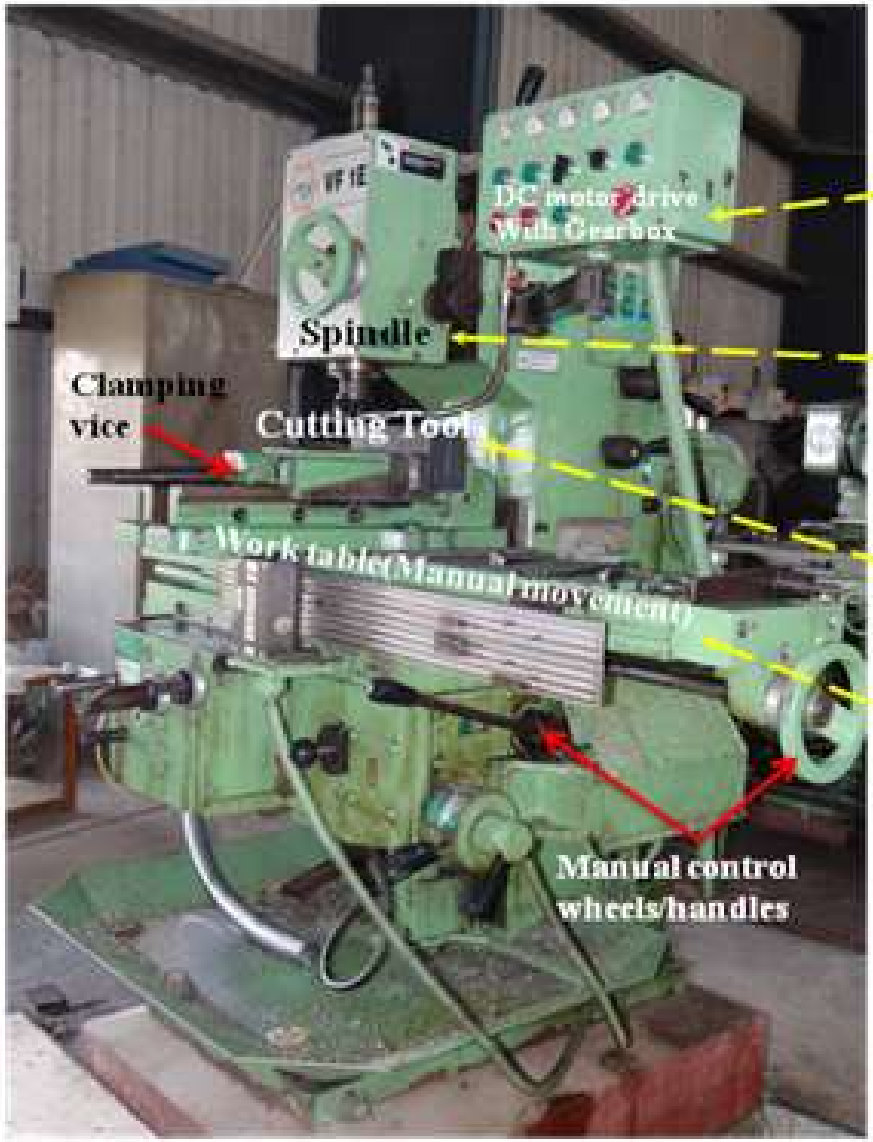
Control of Machine tools

Mechatronics has a variety of applications as products and systems in the area of ‘manufacturing automation'. Some of these applications are as follows:

- **Computer numerical control (CNC) machines**
- **Tool monitoring systems**
- **Advanced manufacturing systems**
  a. Flexible manufacturing system (FMS)
  b. Computer integrated manufacturing (CIM)
- **Industrial robots**
- **Automatic inspection systems: machine vision systems**
- **Automatic packaging systems**

Conventional Milling Machine

CNC Machine Tool





Computer numerical control (CNC) machines

Tool monitoring systems

Uninterrupted machining is one of the challenges facing manufacturers to meet production goals and customer satisfaction in terms of product quality. Tool wear is a critical factor that affects the productivity of a machining operation. Complete automation of a machining process realizes when there is a successful prediction of tool (wear) state during the course of machining operation. A **Tool Monitoring System (TMS)** is a system used in manufacturing to **monitor the condition, performance, and life of cutting tools** during machining operations. It helps in detecting tool wear, breakage, or failure in real time, ensuring smooth and efficient production.

In modern industries, especially in CNC machining and automated systems, continuous tool monitoring is essential to maintain product quality and avoid machine downtime. The system collects data from various sensors and analyzes it to determine the tool's condition. If any abnormality is detected, the system can alert the operator or automatically stop the machine to prevent damage.

Working Principle

- A tool monitoring system works by continuously measuring parameters related to tool performance, such as:
- Cutting force
- Vibration
- Temperature
- Acoustic signals

These signals are processed using algorithms or control systems to identify patterns indicating tool wear or failure. Based on the analysis, appropriate actions such as alarms, tool replacement, or process adjustment are taken.

- **Types of Tool Monitoring**
- **1. Direct Monitoring**
- Measures tool condition directly (e.g., visual inspection, tool geometry measurement)
- More accurate but difficult to implement in real-time
- **2. Indirect Monitoring**
- Uses indirect parameters like force, vibration, or soun
- More practical for real-time industrial applications

Direct methods	Indirect methods
Electrical resistance	Torque and power
Optical measurements	Temperature
Machining hours	Vibration & acoustic emission
Contact sensing	Cutting forces & strain measurements

1. Direct Tool Monitoring

Direct monitoring involves **measuring the actual physical condition of the cutting tool** during or after machining. It focuses on parameters like tool wear, tool geometry, or surface damage.

Methods Used

•**Optical/Visual Inspection** → Cameras or microscopes observe tool wear

•**Laser-based Measurement** → Measures tool dimensions and wear precisely

•**Contact Probes** → Physically touch and measure tool geometry

Working

The system directly examines the tool and compares its current condition with the standard or original shape. Any deviation indicates wear or damage.

Advantages

- High accuracy and reliability
- Direct measurement of tool condition
- Suitable for precision applications

Limitations

- Difficult to implement in real-time during machining
- May require stopping the machine
- Expensive and complex setup

Applications

- High-precision machining
- Tool inspection in quality control labs

2. Indirect Tool Monitoring

Indirect monitoring evaluates tool condition by measuring **process-related signals** instead of the tool itself. It is widely used for **real-time monitoring** in industries.

Common Parameters Used

a) Cutting Force Monitoring

- Measures forces acting on the tool during machining
- Increase in force indicates tool wear

b) Vibration Monitoring

- Detects changes in vibration patterns
- Abnormal vibration indicates tool damage or instability

c) Acoustic Emission (AE) Monitoring

- Captures high-frequency sound signals generated during cutting
- Useful for detecting tool breakage

d) Temperature Monitoring

- Measures heat generated during machining
- Higher temperature may indicate tool wear

e) Power Consumption Monitoring

- Monitors machine power usage
- Increased power indicates increased cutting resistance

Sensors collect signals during machining, which are analyzed using algorithms or AI techniques. The system identifies patterns and detects tool wear or failure.

Advantages

- Real-time monitoring
- No need to stop the machine
- Suitable for automated systems
- Cost-effective compared to direct methods

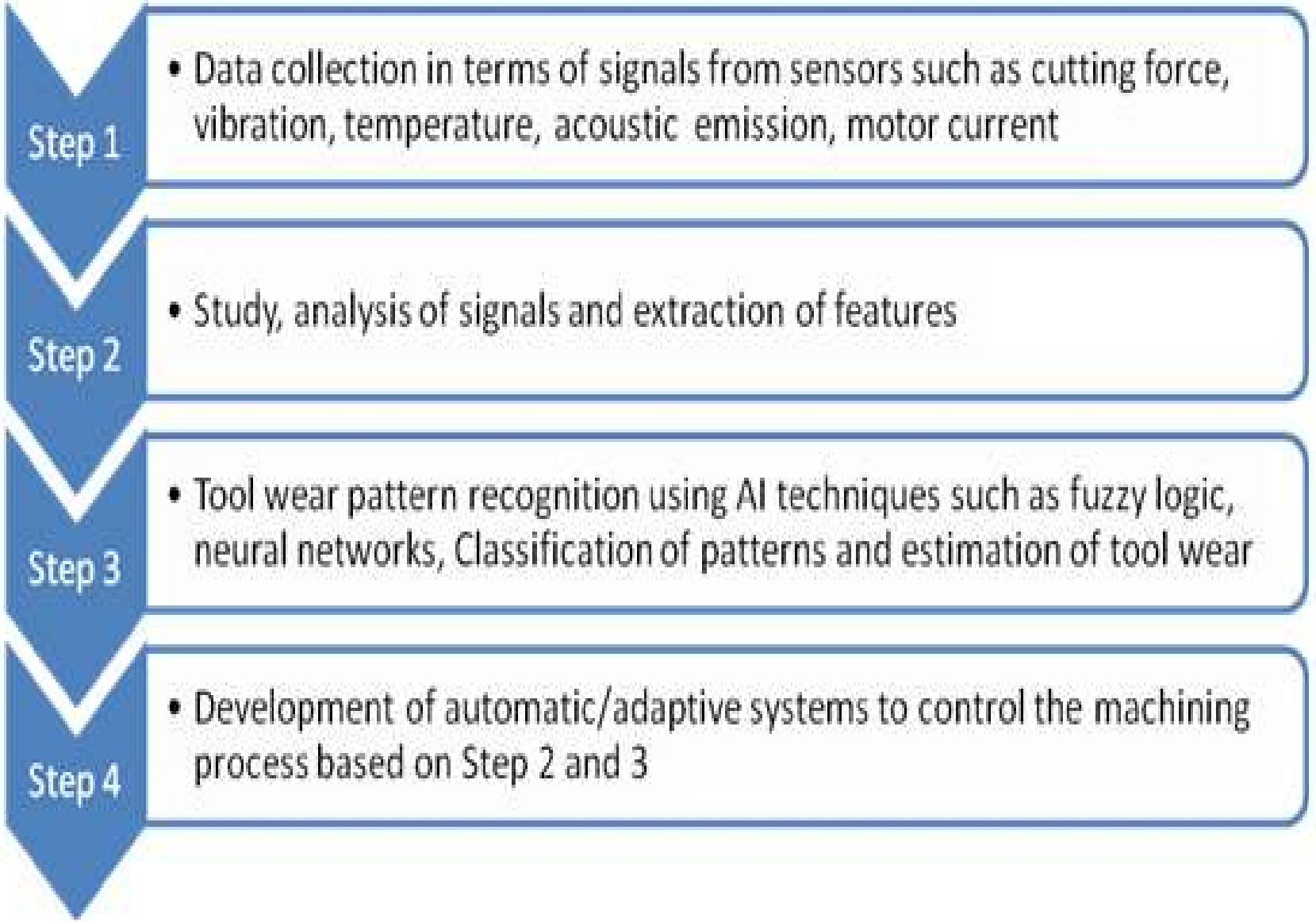
Limitations

- Indirect measurement (less accurate than direct methods)
- Requires calibration and signal processing
- Affected by noise and external factors

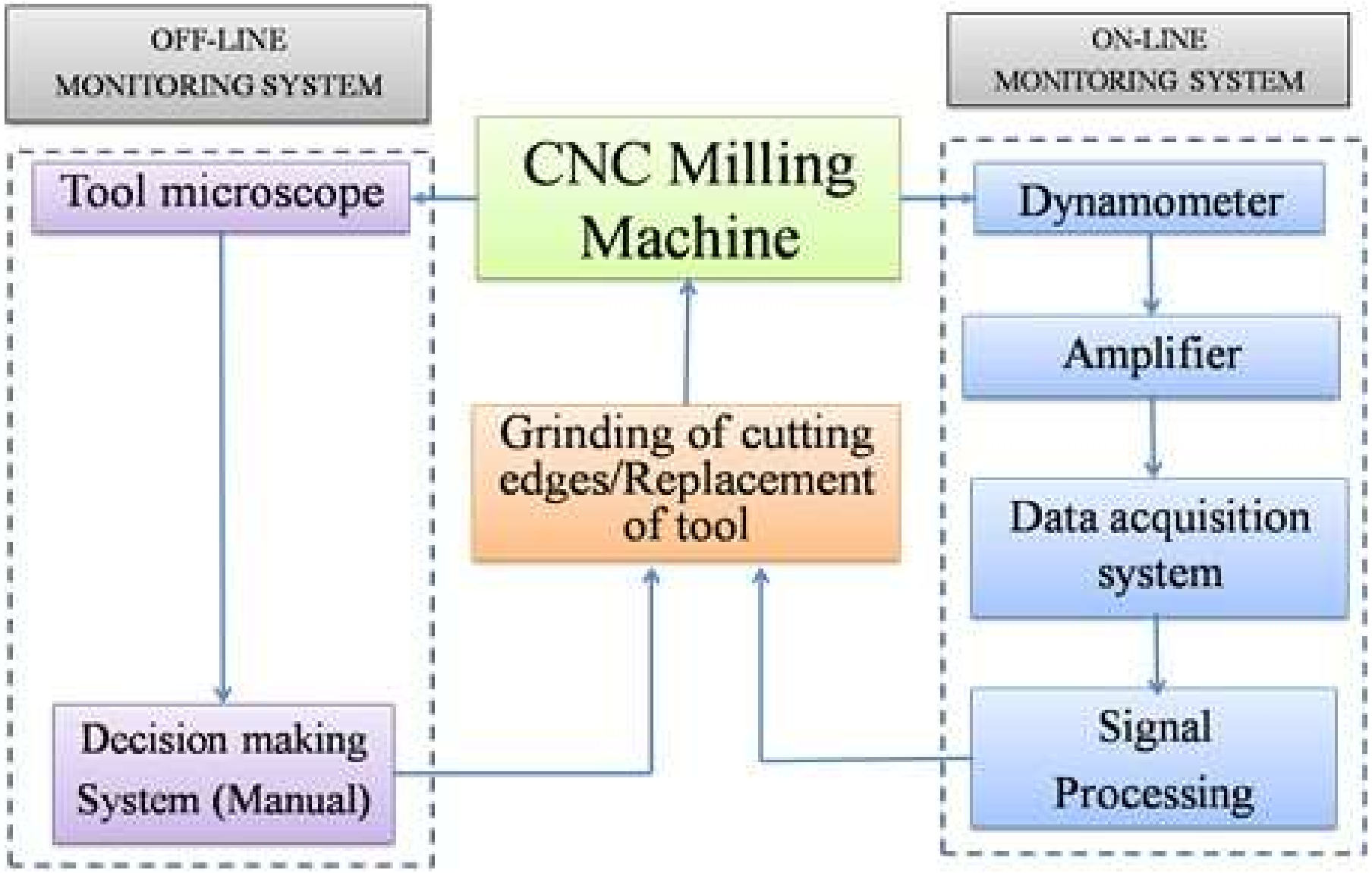
Applications

- CNC machining
- Automated production lines
- Smart manufacturing (Industry 4.0)

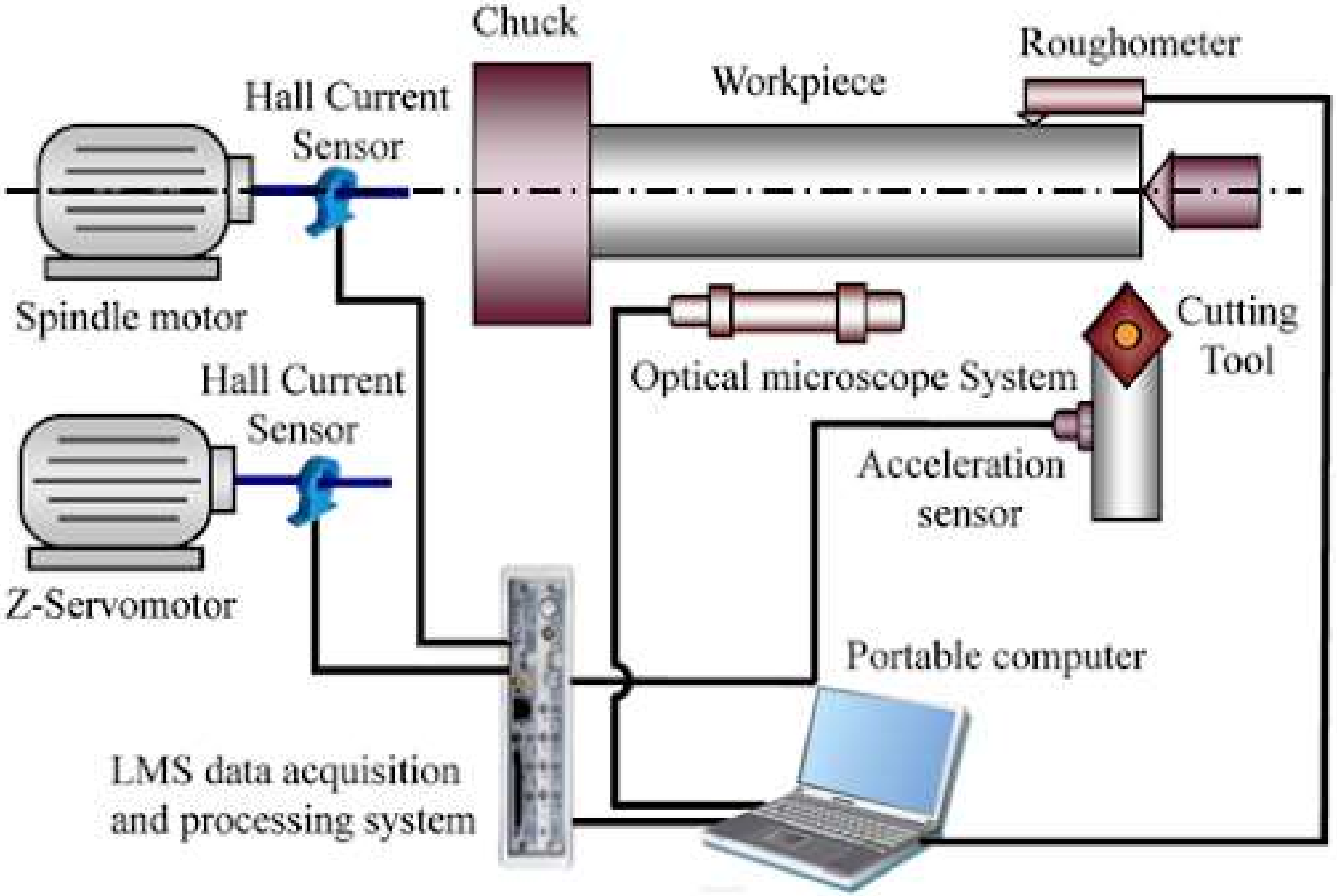
Aspect	Direct Monitoring	Indirect Monitoring
Measurement	Actual tool condition	Process signals
Accuracy	High	Moderate
Real-time capability	Limited	High
Cost	High	Moderate
Industrial use	Limited	Widely used

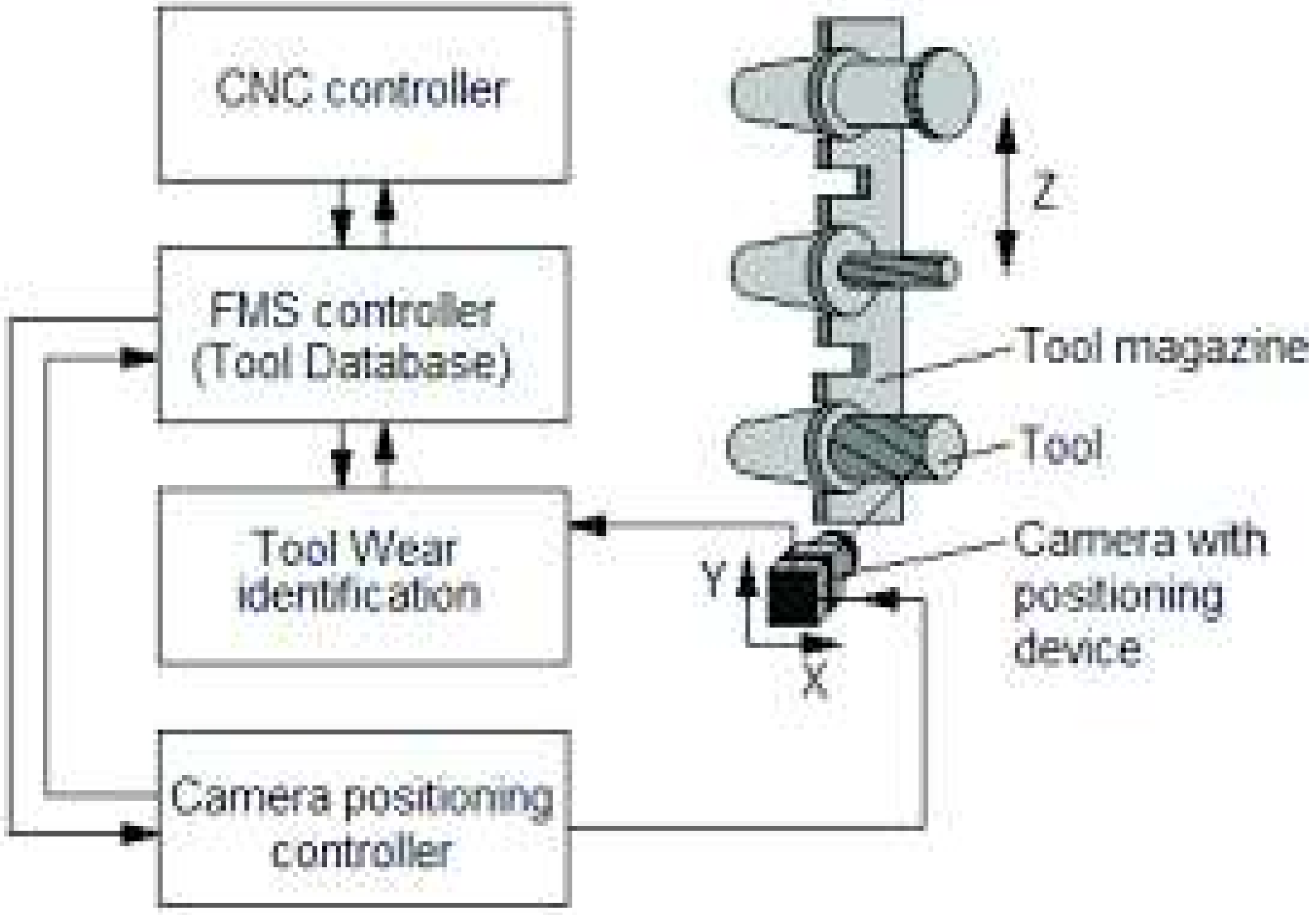


Steps followed in an indirect tool monitoring system



Off-line and on-line tool monitoring system for CNC Milling Machine


Chuck
Roughometer
Workpiece
Hall Current Sensor
Spindle motor
Optical microscope System
Cutting Tool
Hall Current Sensor
Acceleration sensor
Z-Servomotor
Portable computer
LMS data acquisition and processing system



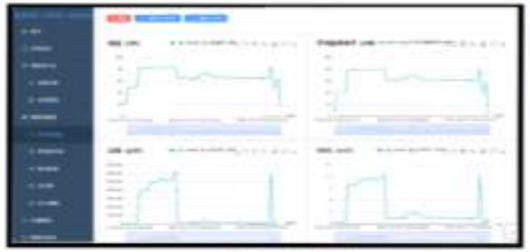
Tool-wear monitoring system



Rating results



Remote Configuration



Data Display



Remote notification of abnormal operation

TCP/IP, MQTT
Protobuf

4G/ LoRa/ RS485

Alibaba Cloud QingCheng Cloud Private Server

Different machining conditions have different acoustic emissions



Not smooth enough



Grinding wheel damage



Not enough grinding

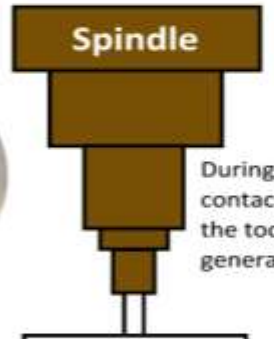
Sensor
Receive signals





RAEM2

- The sensor built in receives the acoustic signal.
- Analyze and process signals Extract for parameters



During machining, the contact surface between the tool and the workpiece generates an AE signal.

Output grinding status
Not enough finish/ wheel damage



Machine Tool System
The machine tool system takes measures (changing tools, stopping the machine, reducing the amount of feed, etc.) to avoid accidents and extend the service life of the tool.

Output to machine
Send STOP signal within 1ms

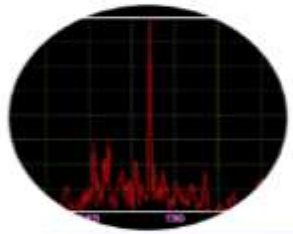
Ethernet/RS485
WiFi/4G



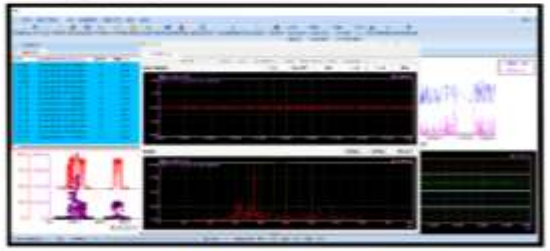
RAEM1

- Analyze and process the AE signal to determine the grinding state

Data Analyze



FFT / Wavelet Analysis
AI self-learning
User Interfaces



SWAE Analysis Software
In-depth study of the characteristics of grinding wheel damage signals



RAEM1-6

- Analyze and process AE signals extract characteristic parameters

Advanced Manufacturing Systems

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a) Flexible Manufacturing System

- FMS is a manufacturing cell or system consisting of one or more CNC machines, connected by an automated material handling system, pick-and-place robots, and all operated under the control of a central computer.
- It also has auxiliary sub-systems like component load/unload station, automatic tool handling system, tool pre-setter, component measuring station, wash station etc.

❑ A system that consists of numerous programmable machine tools connected by an automated material handling system.

A. Workstations
- CNC machine tools
- Assembly equipment
- Measuring Equipment
- Washing stations

B. Material handing Equipment
- Load unload stations (Palletizing)
- Robotics
- Automated Guided Vehicles (AGVs)
- Automated Storage and retrieval Systems (AS/RS)

C. Tool systems
- Tool setting stations
- Tool transport systems

D. Control system
- Monitoring equipments
- Networks

The characteristic features of an FMS system are as follows:

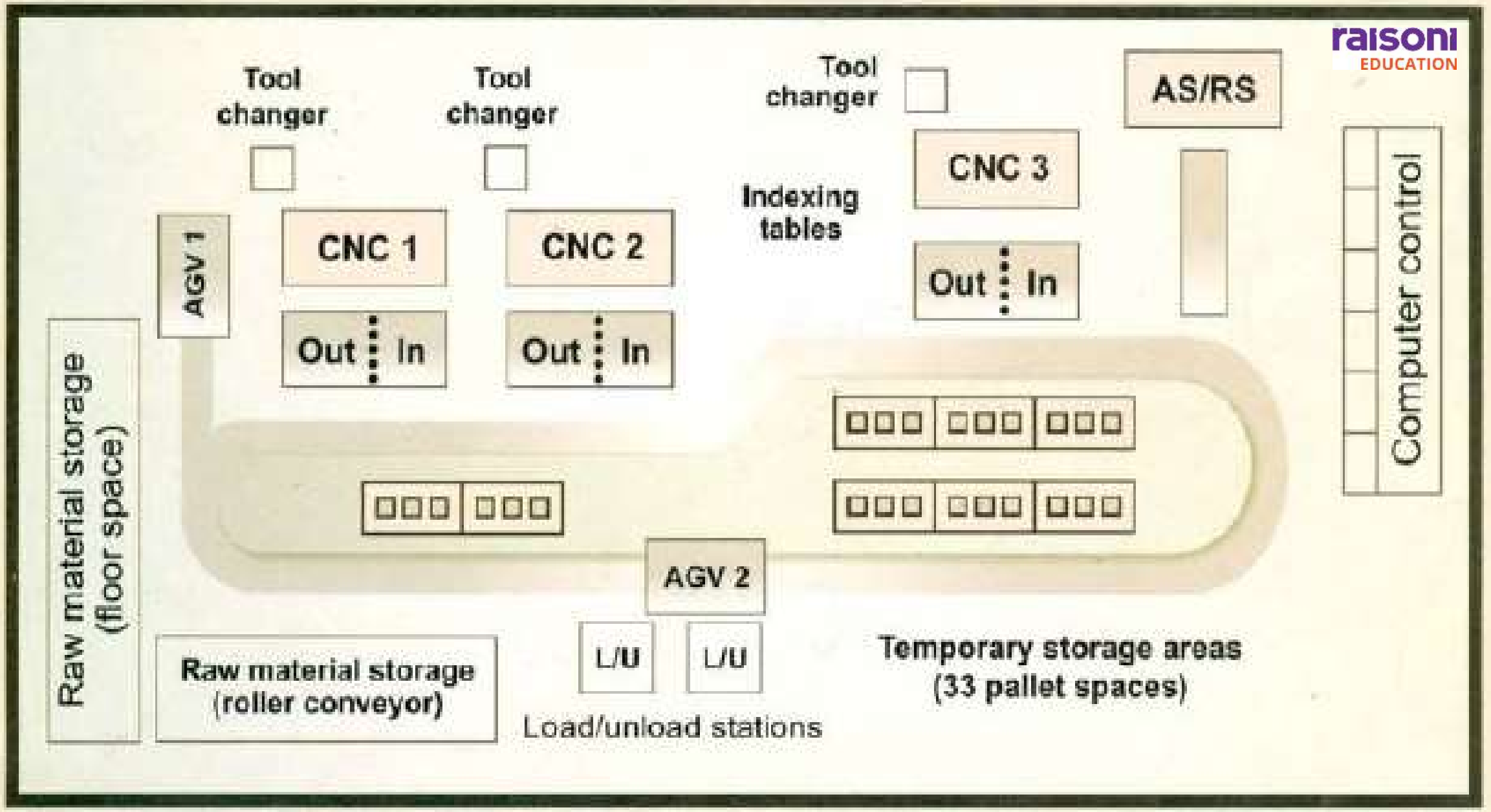
- FMS solves the mid-variety and mid-volume production problems for which neither the high production rate transfer lines nor the highly flexible stand-alone CNC machines are suitable.
- Several types of a defined mix can be processed simultaneously.
- Tool change-over time is negligible.
- Part handling from machine to machine is easier and faster due to employment of computer controlled material handling system.

Benefits of an FMS

- Flexibility to change part variety
- Higher productivity
- Higher machine utilization
- Less rejections
- High product quality
- Reduced work-in-process and inventory
- Better control over production
- Just-in-time manufacturing
- Minimally manned operation
- Easier to expand



Typical arrangement of FMS system and its constituents


Tool changer
Tool changer
Tool changer
AS/RS
CNC 3
Indexing tables
AGV 1
CNC 1
CNC 2
Out
In
Out
In
Out
In
Computer control
Raw material storage (floor space)
AGV 2
Raw material storage (roller conveyor)
L/U
L/U
Load/unload stations
Temporary storage areas (33 pallet spaces)

Industrial robots

Robots are widely employed in the following applications in manufacturing .

A. Parts handling: it involves various activities such as:

- Recognizing, sorting/separating the parts
- Picking and placing parts at desired locations
- Palletizing and de-palletizing
- Loading and unloading of the parts on required machines

B. Parts processing: this may involves many manufacturing operations such as:

- Routing, Drilling, Riveting, Arc welding, Grinding, Flame cutting, Deburring, Spray painting, , Coating, Sand blasting, Dip coating, Gluing, Polishing, Heat treatment

C. Product building:

This involves development and building of various products such as:

- Electrical motors
- Car bodies
- Solenoids
- Circuit boards and operations like
    - Bolting, Riveting, welding, Seam welding, Inserting, Nailing, Fitting, Adhesive bonding, Inspection.

Automatic quality control and inspection systems

A number of sensors and systems have been developed that can monitor quality continuously with or without the assistance of the operator. These technologies include various sensors and data acquisition systems, machine vision systems, metrology instruments such as co-ordinate measuring machine (CMM), optical profilometers, digital calipers and screw gauges etc. Now days the quality control activities are being carried out right from the design stage of product development. Various physics based simulation software is used to predict the performance of the product or the system to be developed. In the manufacture of products such as spacecrafts or airplanes, all the components are being critically monitored by using the digital imaging systems throughout their development.

Automatic Quality Control and Inspection Systems refer to the use of **advanced technologies and automated equipment** to monitor, measure, and ensure the quality of products during or after manufacturing without significant human intervention. These systems are an essential part of modern manufacturing and Industry 4.0, helping industries maintain high standards of accuracy, consistency, and reliability.

- **Working Principle**
- **Data Acquisition** → Sensors or cameras capture data (dimensions, shape, surface quality)
- **Signal Processing** → Data is processed using software or algorithms
- **Comparison** → Results are compared with standard specifications
- **Decision Making** → System decides accept/reject
- **Action** → Defective products are removed or process is adjusted

Types of Inspection Systems

1. Contact Inspection

- Uses physical contact to measure dimensions

Example: Coordinate Measuring Machine (CMM)

2. Non-Contact Inspection

- Uses optical, laser, or vision systems

Example: Machine vision systems for surface inspection

3. In-Process Inspection

- Inspection during manufacturing
- Detects defects early and reduces waste

4. Post-Process Inspection

- Inspection after production is completed

Automatic inspection systems are integrated with **Computer Integrated Manufacturing (CIM)** and smart factories, enabling **real-time quality monitoring, feedback control, and continuous improvement**. Automatic quality control systems use **sensors, vision systems, and computers to inspect products and ensure quality without human intervention**.

Technologies Used

- Machine Vision Systems (cameras and image processing)
- Sensors (laser, ultrasonic, infrared)
- Artificial Intelligence (AI) for defect detection
- Robotics for automated inspection
- Computer systems for data analysis

Applications

- Automotive parts inspection
- Electronics manufacturing (PCB inspection)
- Pharmaceutical quality control
- Food and packaging industries
- Aerospace component inspection

Advantages

- High accuracy and consistency
- Faster inspection process
- Reduced human error
- Real-time quality control
- Improved product reliability

Limitations

- High initial cost
- Complex system setup
- Requires skilled operation and maintenance

Computer Integrated Manufacturing (CIM)

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The Society of Manufacturing Engineers (SME) defined CIM as "CIM is the integration of the total manufacturing enterprise through the use of integrated systems and data communications coupled with new managerial philosophies that improve organizational and personal efficiency".

Computer Integrated Manufacturing (CIM) is a manufacturing approach in which **all production processes are integrated and controlled using computer systems**. It combines various technologies such as design, planning, production, and management into a **single, coordinated system** to improve efficiency, accuracy, and productivity.

CIM enables seamless communication between different stages of manufacturing, from product design to final production and delivery. By integrating computers into all aspects of manufacturing, CIM eliminates manual intervention, reduces errors, and ensures smooth data flow across departments.

In CIM, all manufacturing activities—such as **Computer-Aided Design (CAD)**, **Computer-Aided Manufacturing (CAM)**, production planning, inventory control, and quality management—are interconnected through a central computer system. This integration allows real-time data sharing and coordinated decision-

- **Components of CIM**
- **CAD (Computer-Aided Design)** → Designing products digitally
- **CAM (Computer-Aided Manufacturing)** → Controlling machine operations
- **CNC Machines** → Automated machining tools
- **Robotics** → Automated handling and processing
- **Flexible Manufacturing Systems (FMS)** → Adaptable production systems
- **Database Management Systems** → Central data storage and management
- **Enterprise Resource Planning (ERP)** → Planning and resource management making.

Components of Computer Integrated Manufacturing (CIM)

Computer Integrated Manufacturing (CIM) consists of several interconnected components that work together to **automate, integrate, and optimize the entire manufacturing process**. Each component plays a specific role, from product design to production planning and execution.

1. CAD (Computer-Aided Design)

- CAD is used for **designing products digitally** using computer software. Engineers create 2D drawings and 3D models of components, which help in visualization, analysis, and modification before actual production.

Role in CIM:

- Provides accurate product design
- Reduces design errors
- Enables easy modification and simulation

2. CAM (Computer-Aided Manufacturing)

- CAM uses the design data from CAD to **control and automate manufacturing processes**. It generates instructions (G-code) for machines to produce the designed part.

Role in CIM:

- Converts design into manufacturing instructions
- Improves precision and efficiency
- Reduces manual intervention

3. CNC Machines (Computer Numerical Control)

- CNC machines are **automated machine tools** controlled by computer programs. They perform operations like cutting, drilling, milling, and turning with high precision.

Role in CIM:

- Executes manufacturing tasks automatically
- Ensures consistency and accuracy
- Enables mass production

4. Robotics

- Industrial robots are used for **material handling, assembly, welding, painting, and inspection**. They perform repetitive and hazardous tasks efficiently.

Role in CIM:

- Increases productivity
- Enhances safety
- Reduces human effort

5. Flexible Manufacturing Systems (FMS)

- FMS is a production system that can **adapt to changes in product type and production volume** with minimal setup time.

Role in CIM:

- Provides flexibility in manufacturing
- Supports batch and customized production
- Reduces downtime during changeovers

6. Database Management Systems (DBMS)

- DBMS is used to **store, manage, and retrieve data** related to design, production, inventory, and quality.

Role in CIM:

- Ensures smooth data flow between systems
- Maintains centralized information
- Supports decision-making

7. Enterprise Resource Planning (ERP)

- ERP systems are used for **planning and managing resources** such as materials, manpower, finance, and production schedules.

Role in CIM:

- Integrates all business processes
- Improves coordination between departments
- Helps in efficient planning and decision-making

All these components are interconnected.

CAD → CAM → CNC/Robots → FMS → DBMS → ERP

This integration ensures **seamless data flow and coordinated manufacturing operations**.

Working Principle

- Product is designed using CAD
- Design data is transferred to CAM systems
- Machines (CNC/robots) execute manufacturing operations
- Production data is monitored and controlled in real time
- Feedback is used for quality control and process improvement

Features

- Complete integration of manufacturing processes
- Real-time data exchange
- High automation and precision
- Improved coordination between departments
- Reduced human intervention

Applications

- Automotive industry
- Aerospace manufacturing
- Electronics production
- Mass production industries

Advantages

- Increased productivity and efficiency
- Improved product quality
- Reduced lead time
- Better resource utilization
- Flexibility in production

Limitations

- High initial investment
- Complex system integration
- Requires skilled workforce
- Maintenance challenges

Relation with Industry 4.0

CIM is considered a **foundation for Industry 4.0**, as it integrates manufacturing processes digitally. Industry 4.0 further enhances CIM with technologies like **IoT, AI, Big Data, and Cloud Computing**.

Computer Integrated Manufacturing (CIM) is the **integration of all manufacturing processes using computers for efficient, automated, and coordinated production**.

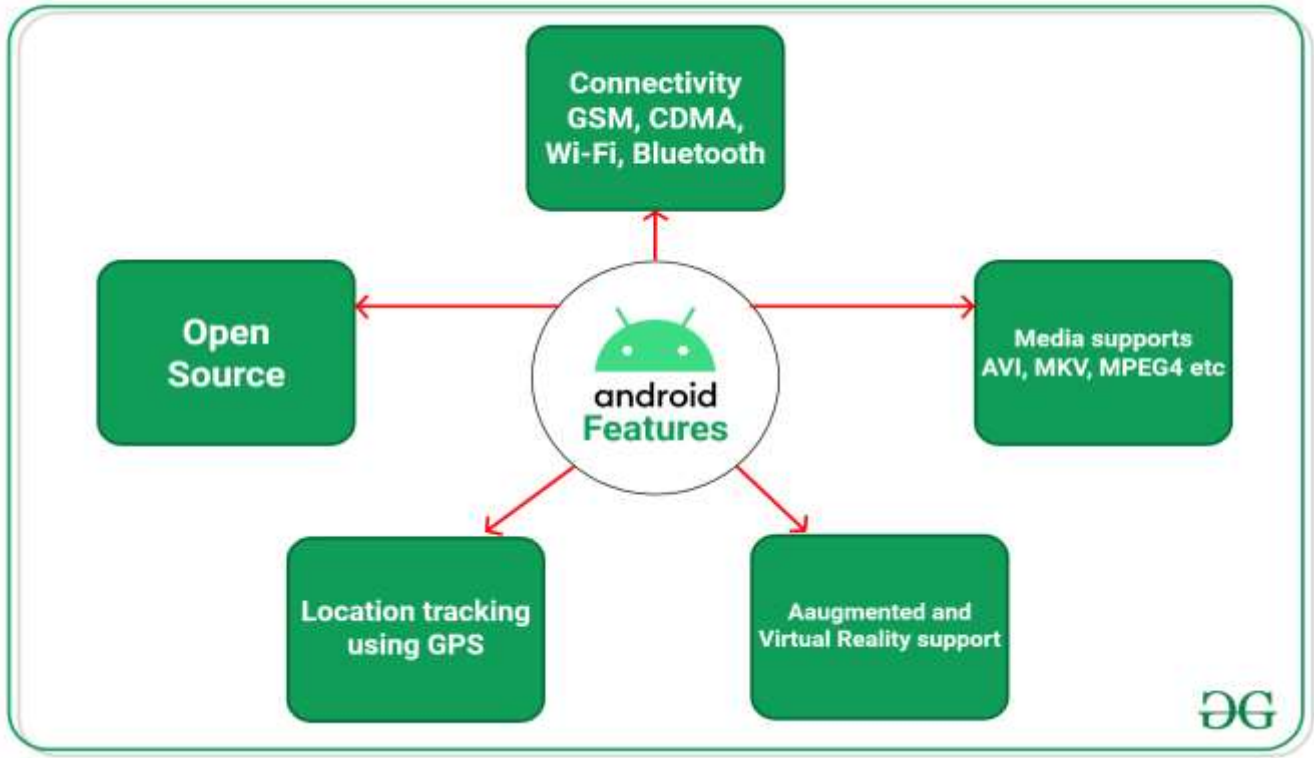
Unit 4

Android

- Android is an open-source, Linux-based operating system designed for touchscreen mobile devices, structured in layers (kernel, libraries, runtime, framework, apps). It uses a "least privilege" security model where each app runs in its own isolated Linux process and virtual machine (ART), ensuring high security and system stability.
- **Android** is an open-source **mobile operating system** developed by Google, designed primarily for smartphones, tablets, and embedded devices. It is based on the **Linux kernel** and supports a wide range of applications.

Android is a **powerful, flexible, and widely used operating system** that operates on a layered architecture, efficiently managing hardware and software to deliver a seamless user experience.

Android works by **connecting user applications to hardware through a layered architecture and runtime environment**.



Key Aspects of Android OS

•**Open Source & Customization:** Based on the Android Open Source Project (AOSP), it allows manufacturers to customize the software.

•**Core Components:** Uses a modified Linux kernel for security, memory management, and process management.

•**Ecosystem & Apps:**

Features the Google Play Store for apps, along with pre-installed services like Google Maps, YouTube, and Chrome.

•**Updates:** Security updates are generally provided directly through Google Play for devices running Android 10 or higher.

•**Version History:** As of late 2024, the latest major version is Android 15, following a history of dessert-themed releases, according to Simple English Wikipedia and YouTube.

Android is designed for flexibility, allowing it to run on diverse hardware, including smart TVs, cars, and wearable technology, beyond just smartphones and tablets.

Android (operating system)

Android is a mobile operating system based on a modified version of the Linux kernel and other open-source software, designed primarily for touchscreen mobile devices such as smartphones and tablets. Android is developed by a consortium of developers known as the Open Handset Alliance, though its most widely used version is primarily developed by Google. It was unveiled in November 2007, with the first commercial Android device, the HTC Dream, being launched in September 2008.

At its core, the operating system is known as Android Open Source Project (AOSP) and is free and open-source software (FOSS) primarily licensed under the Apache License. However most devices run on the proprietary Android version developed by Google, which ship with additional proprietary closed-source software pre-installed, most notably Google Mobile Services (GMS) which includes core apps such as Google Chrome, the digital distribution platform Google Play, and the associated Google Play Services development platform. While AOSP is free, the "Android" name and logo are trademarks of Google, which imposes standards to restrict the use of Android branding by "uncertified" devices outside their ecosystem.



Android Applications

- Android applications are **software programs developed to run on the Android operating system**, enabling users to perform specific tasks on mobile and smart devices. Android applications are **software programs designed to perform specific tasks on Android devices using its platform and services**.

Applications (Uses of Android Apps)

- **Communication** → Calls, messaging, email
- **Entertainment** → Games, video streaming
- **Education** → E-learning apps
- **Business** → Banking, e-commerce
- **Healthcare** → Fitness tracking, telemedicine
- **Navigation** → GPS and maps

Advantages

- Easy to use
- Wide availability of apps
- Customizable and flexible
- Open-source platform

Limitations

- Security risks (malware)
- Device fragmentation
- Performance varies with hardware

WHAT IS THE INTERNET OF THINGS?

- **Internet connects all people a "Internet of People"**
- **IoT connects all things a "Internet of Things"**

Wikipedia says

"The Internet of Things (IoT) is the interconnection of uniquely identifiable embedded computing devices within the existing Internet infrastructure."

Actual Definition

The Internet of Things (IoT) is the network of physical objects or "things" embedded with electronics, software, sensors, and network connectivity, which enables these objects to collect and exchange data.

In 1999 IoT gets the Name; **Kevin Ashton** coins the term "Internet of Things" and establishes MIT's Auto-ID Center, a global research network of academic laboratories focused on RFID and the IoT



- The **Internet of Things (IoT)** is a modern technological concept that refers to the **interconnection of physical devices through the internet**, enabling them to **collect, share, and process data automatically without continuous human involvement**. These devices, often called "smart devices," are embedded with **sensors, software, and communication technologies**, which allow them to interact with both their environment and other connected systems.
- In an IoT system, everyday objects such as home appliances, industrial machines, vehicles, and wearable devices are equipped with sensors that continuously monitor conditions like temperature, motion, pressure, or location. This data is transmitted through communication networks such as Wi-Fi, Bluetooth, or cellular networks to centralized systems, often cloud-based platforms, where it is processed and analyzed. Based on this analysis, the system can either provide useful information to users or automatically trigger actions, such as adjusting temperature, sending alerts, or controlling devices.
- The working principle of IoT involves a continuous cycle of **data collection, communication, processing, and action**. For example, in a smart home, a temperature sensor detects room temperature and sends data to a cloud server. If the temperature exceeds a set limit, the system automatically activates an air conditioner or sends a notification to the user. This seamless interaction between physical devices and digital systems is what makes IoT powerful and efficient.
- IoT has a wide range of applications across various sectors. In homes, it enables automation through smart lighting, security systems, and appliances. In industries, it plays a crucial role in **Industrial IoT (IIoT)** by enabling predictive maintenance, real-time monitoring, and smart manufacturing. In healthcare, IoT devices like wearable fitness trackers and remote monitoring systems help in continuous patient care. Similarly, in agriculture, IoT supports smart irrigation and crop monitoring, while in transportation, it enables connected vehicles and traffic management systems.
- Despite its numerous advantages, including improved efficiency, real-time decision-making, and cost savings, IoT also presents challenges such as **data security, privacy concerns, and system complexity**. As the number of connected devices continues to grow, ensuring secure communication and efficient data management becomes increasingly important.
- In conclusion, IoT represents a significant advancement in technology by bridging the gap between the **physical and digital worlds**, allowing devices to communicate intelligently and operate autonomously. It is a key enabler of smart environments and plays a vital role in shaping the future of industries and daily life.

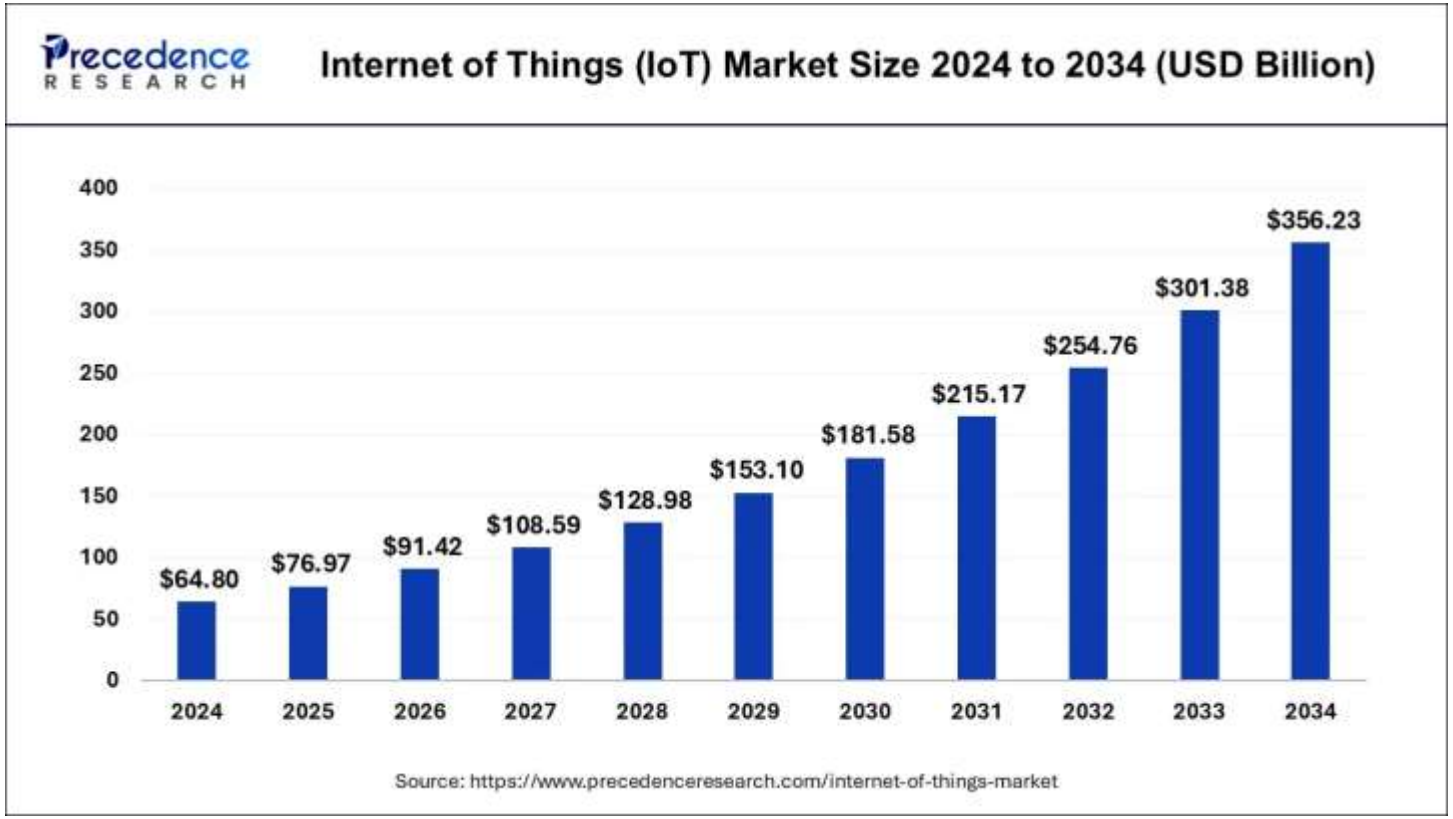
- The Internet of Things is simply "A network of **Internet** connected objects able to collect and exchange data. It is commonly abbreviated as IoT.
- The word "Internet of Things" has two main parts; **Internet** being the backbone of connectivity, and **Things** meaning objects / devices .

➢ Connect

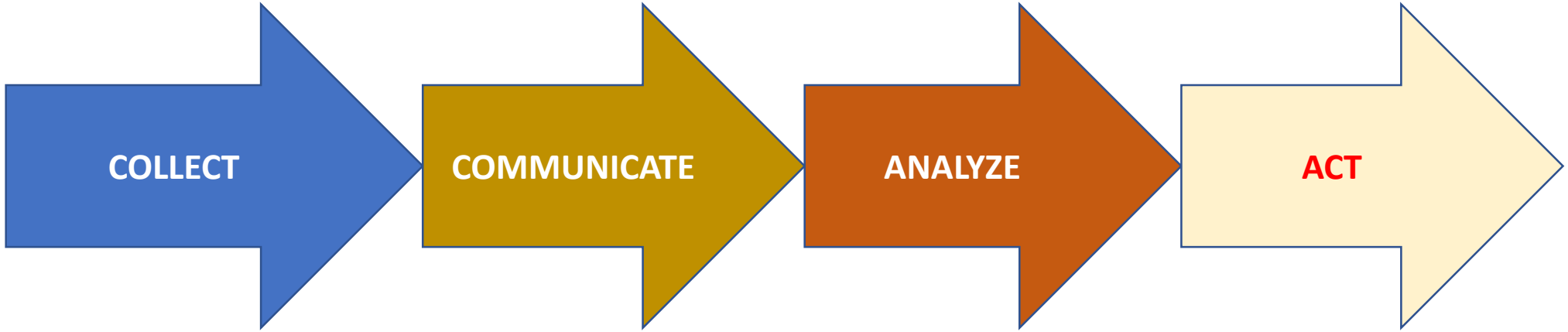
➢ Communicate

➢ Compute

The **Internet of things** (**IoT**) is a system of interrelated computing devices, mechanical and digital machines, objects, animals or people that are provided with unique identifiers (UIDs) and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction.



IOT Lifecycle

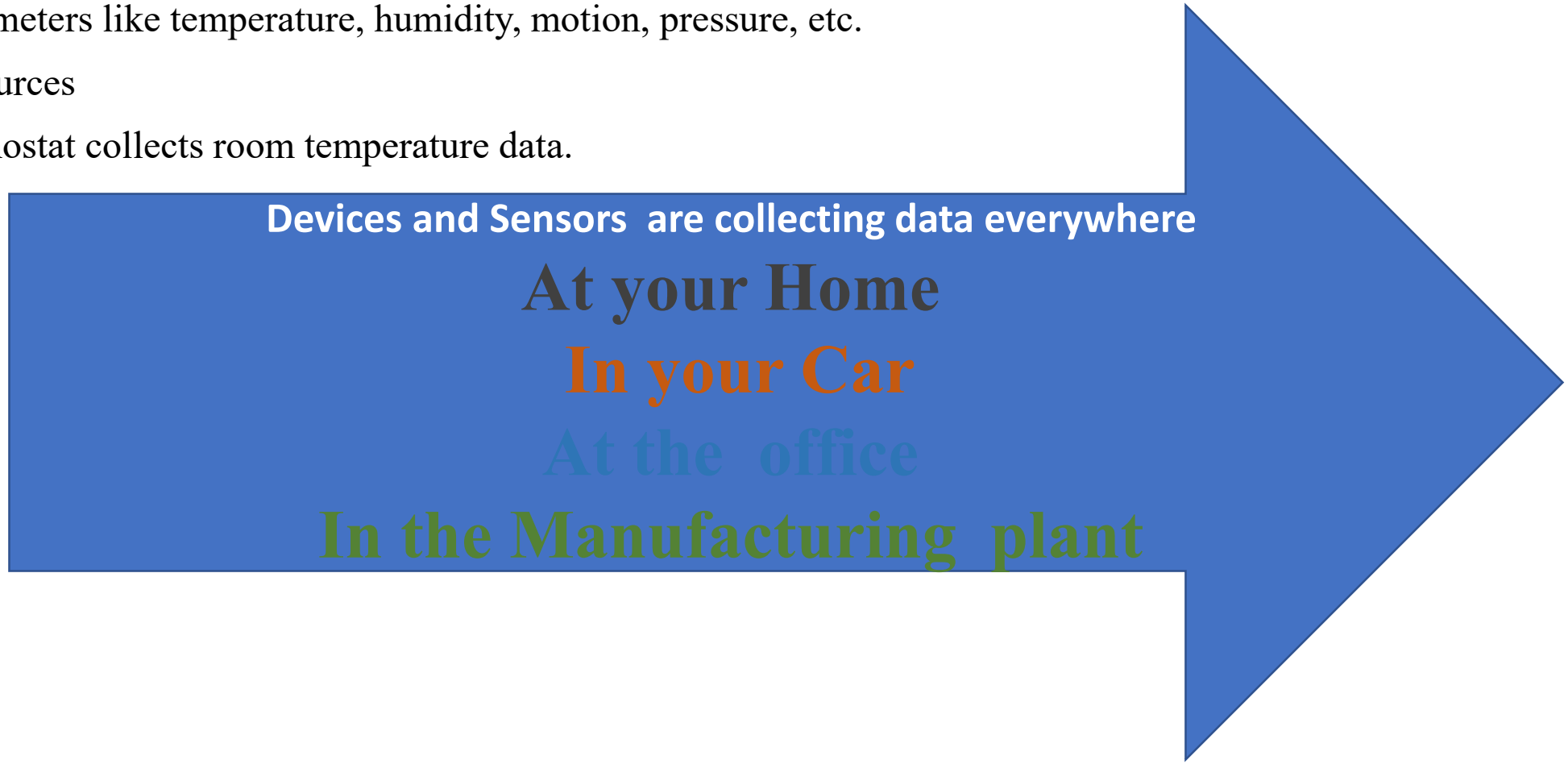


- The IoT life cycle can be simplified into four key stages: **Collect, Communicate, Analyze, and Act**. These stages describe how data flows in an IoT system to enable intelligent decision-making.

1. Collect (Data Acquisition)

- This is the first stage where **data is gathered from the physical environment** using sensors and devices.
- Sensors measure parameters like temperature, humidity, motion, pressure, etc.
- Devices act as data sources

Example: A smart thermostat collects room temperature data.

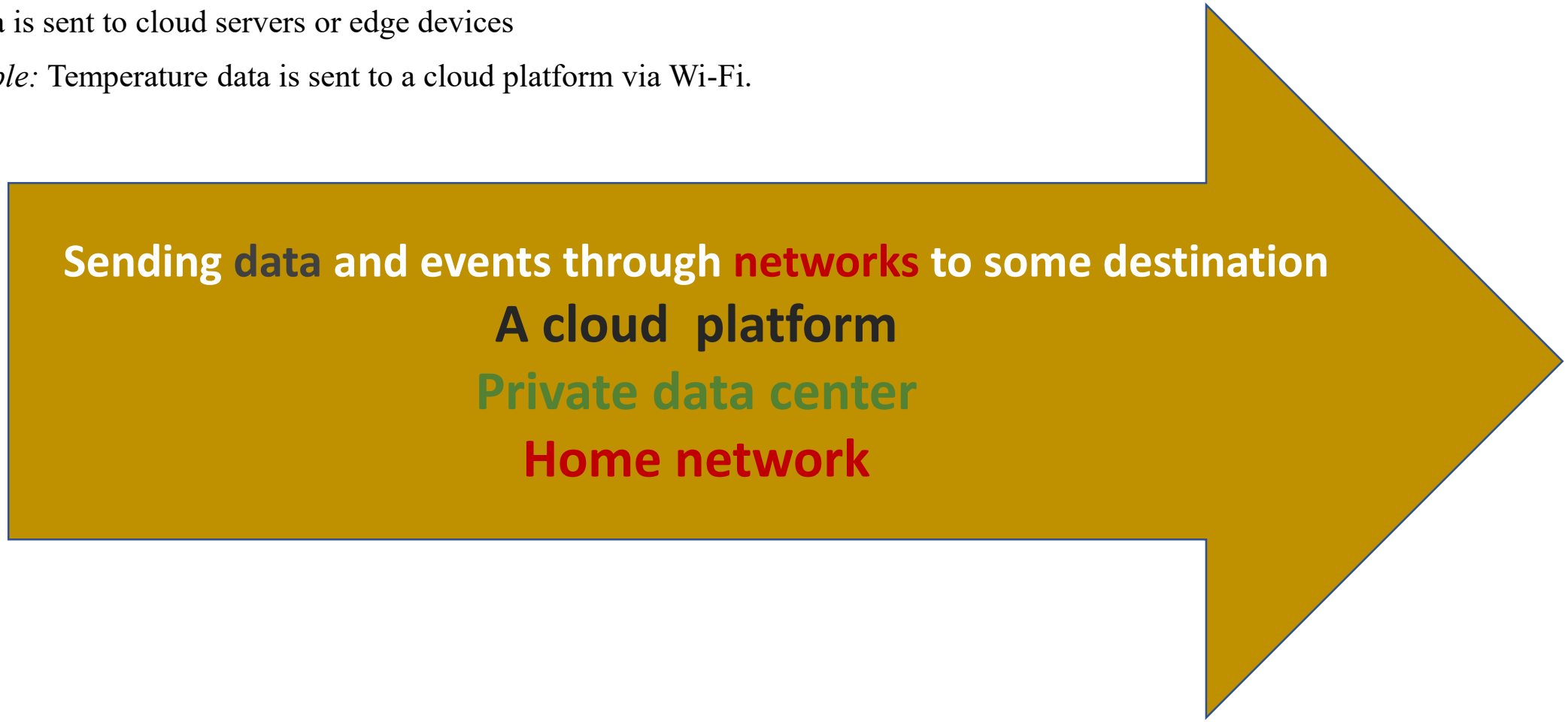


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2. Communicate (Data Transmission)

- The collected data is then **transmitted to other systems** for processing.
- Uses communication technologies like Wi-Fi, Bluetooth, Zigbee, or cellular networks
- Data is sent to cloud servers or edge devices

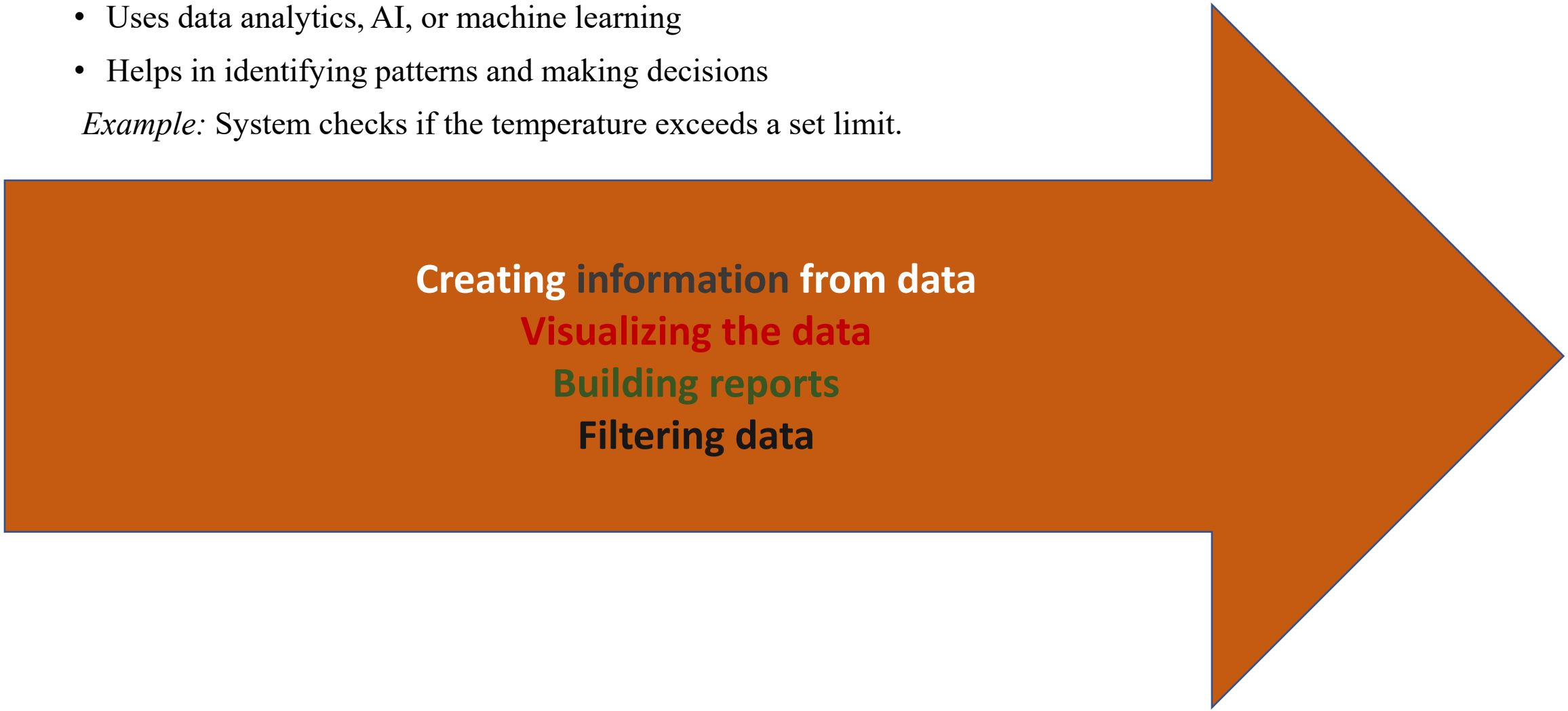
Example: Temperature data is sent to a cloud platform via Wi-Fi.



3. Analyze (Data Processing & Interpretation)

- In this stage, the data is **processed and analyzed** to extract useful information.
- Uses data analytics, AI, or machine learning
- Helps in identifying patterns and making decisions

Example: System checks if the temperature exceeds a set limit.



- **4. Act (Decision & Action)**
- Based on analysis, the system **takes appropriate action** automatically or notifies the user.
- Actuators perform physical actions
- Alerts or recommendations are generated
- ☞ *Example:* Air conditioner turns ON automatically when the temperature rises.

Taking action based on the information and data

Communication with another machine (M2M)

Send a notification (sms, email, text)

Talk to another system

4 Layers Model of IoT

Integrated Application

Information Processing

Network Construction

Sensing and Identification



Application of IOT

- The **Internet of Things (IoT)** has transformed multiple sectors by enabling **real-time monitoring, automation, and intelligent decision-making**. Below are key application areas explained in detail with proper examples.

1. Smart Home

Description

- IoT enables automation of household devices, allowing users to **control appliances remotely** and improve comfort, security, and energy efficiency.

Applications

- Smart lighting systems
- Smart thermostats
- Smart security cameras and door locks

Example

A smart home system uses sensors to detect room occupancy and automatically turns lights ON/OFF. A smart thermostat adjusts temperature based on user preferences, reducing energy consumption

2. Industrial IoT (IIoT)

Description

- In industries, IoT is used for **monitoring machines, optimizing production, and predictive maintenance**.

Applications

- Machine condition monitoring
- Predictive maintenance
- Smart manufacturing (Industry 4.0)

Example

Sensors installed on machines monitor vibration and temperature. If abnormal conditions are detected, the system predicts failure and schedules maintenance, preventing costly downtime.

3. Healthcare (Smart Healthcare)

Description

- IoT improves healthcare by enabling **remote monitoring and real-time patient data tracking**.

Applications

- Wearable health devices
- Remote patient monitoring
- Smart medical equipment

Example

A wearable fitness band tracks heart rate and sends data to doctors. In case of abnormal readings, alerts are generated for immediate medical attention.

4. Smart Agriculture

Description

- IoT helps farmers monitor environmental conditions and **optimize crop production**.

Applications

- Soil moisture monitoring
- Automated irrigation systems
- Weather tracking

Example

Soil sensors detect moisture levels and automatically activate irrigation systems only when needed, conserving water and improving crop yield

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5. Smart Transportation

Description

- IoT enables **connected vehicles and intelligent traffic management systems**.

Applications

- Vehicle tracking
- Traffic monitoring
- Smart parking systems

Example

A GPS-enabled system tracks vehicle location in real time and suggests optimal routes, reducing travel time and fuel consumption.

- **6. Smart Cities**

Description

- IoT is used to manage urban infrastructure efficiently and improve quality of life.

Applications

- Smart street lighting
- Waste management systems
- Air quality monitoring

Example

Smart bins equipped with sensors notify authorities when they are full, enabling efficient waste collection.

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7. Energy Management (Smart Grid)

Description

- IoT helps in efficient generation, distribution, and consumption of energy.

Applications

- Smart meters
- Load monitoring
- Energy optimization

Example

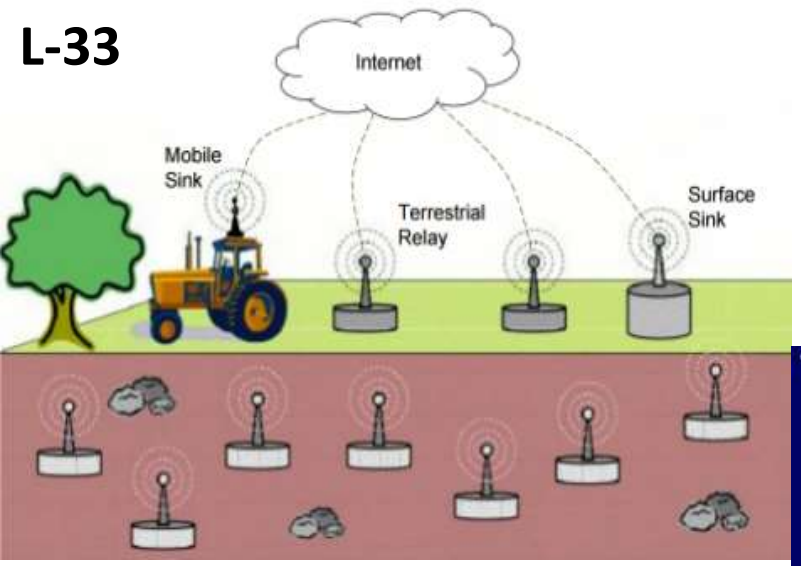
Smart meters track electricity usage in real time and help consumers reduce power consumption by analyzing usage patterns.

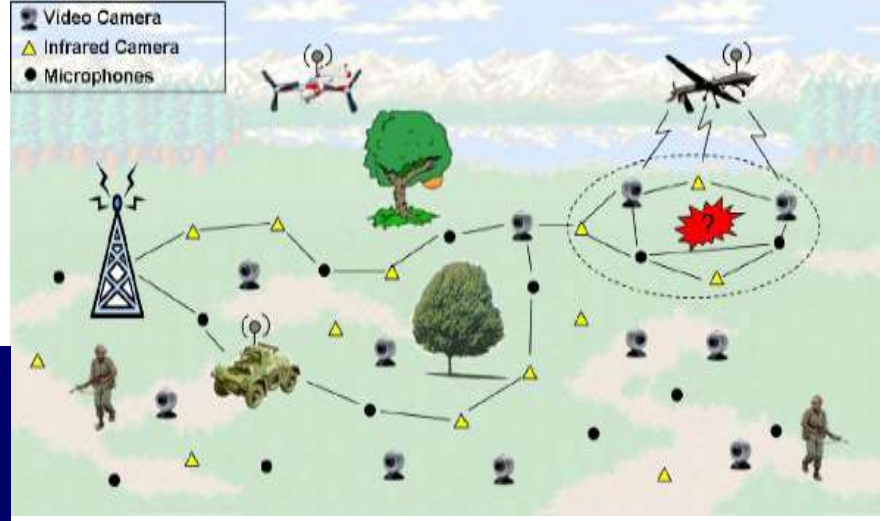
- **8. Retail and Supply Chain**
- **Description**
- IoT improves inventory management and enhances customer experience.
- **Applications**
- Smart shelves
- Inventory tracking
- Automated billing

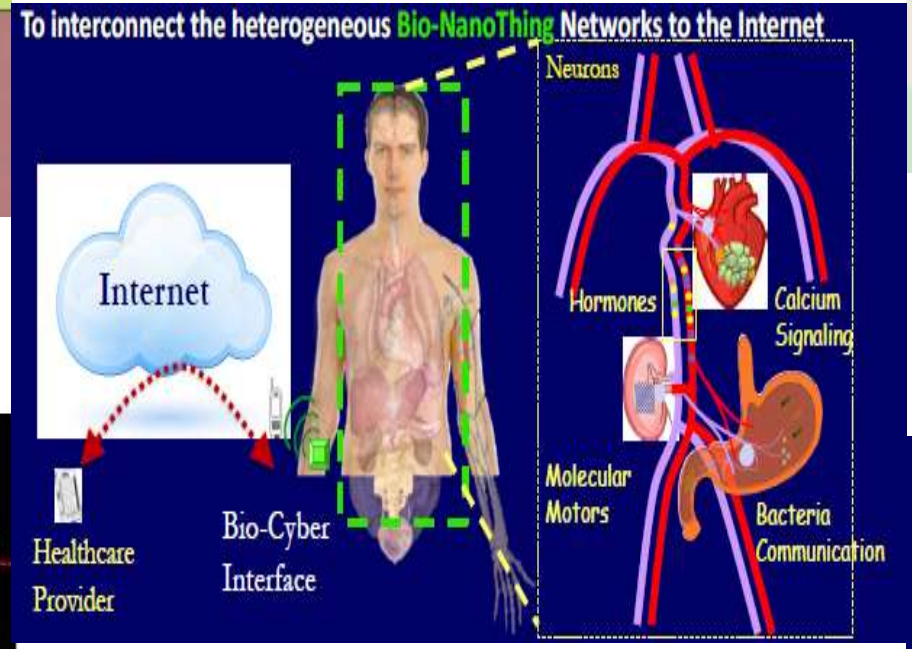
Example

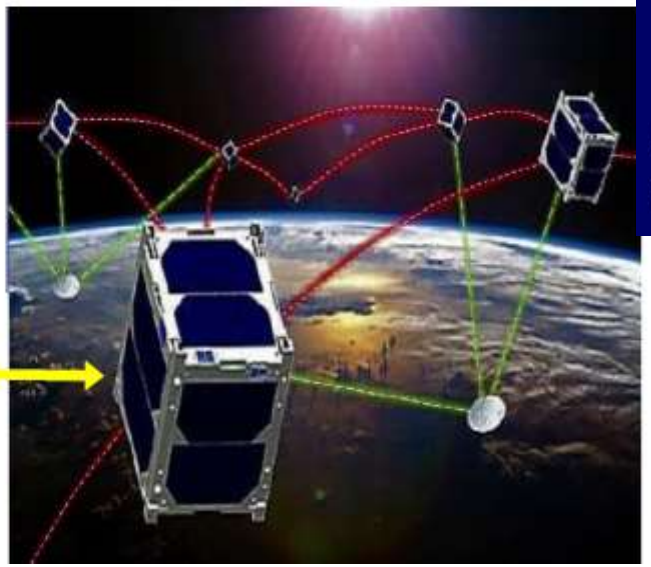
RFID-based systems track product movement in warehouses, ensuring efficient inventory control and reducing losses.

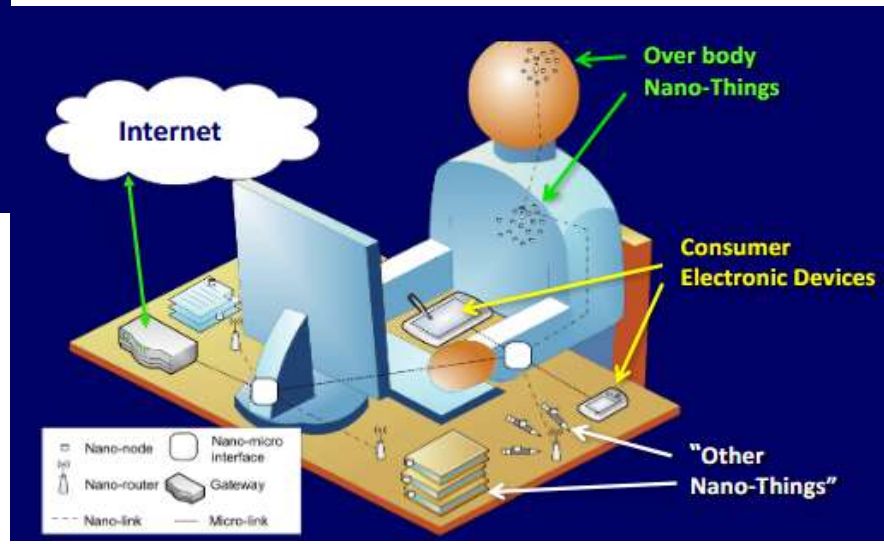
IoT applications span across **homes, industries, healthcare, agriculture, transportation, and cities**, making systems smarter, more efficient, and highly responsive. By enabling **data-driven decisions and automation**, IoT plays a crucial role in modern technological advancement.


Internet
Mobile Sink
Terrestrial Relay
Surface Sink


Video Camera
Infrared Camera
Microphones


To interconnect the heterogeneous Bio-NanoThing Networks to the Internet
Internet
Healthcare Provider
Bio-Cyber Interface
Neurons
Hormones
Calcium Signaling
Molecular Motors
Bacteria Communication


Coffee mug size Satellites


Internet
Over body Nano-Things
Consumer Electronic Devices
"Other Nano-Things"
Nano-node
Nano-micro interface
Nano-router
Gateway
Nano-link
Micro-link

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INTERNET OF THINGS
APPLICATIONS

Smart Home

Home Automation

Healthcare


Remote Monitoring

Smart Agriculture

Precision Farming

Retail & Supply Chain

Inventory Tracking

Smart City


Urban Management

Industrial IoT

Predictive Maintenance

Energy Management


Smart Transportation

Smart Grid

Where is IoT used?

IoT devices can be **used** to monitor and control the mechanical, electrical and electronic systems **used** in various types of buildings (e.g., public and private, industrial, institutions, or residential) in home automation and building automation systems.

Is Alexa an IoT device?

The term "Internet of Things" applies to any nonstandard computing **device** that connects to wi-fi and can transmit data. Well-known examples of **IoT devices** include smart speakers like Amazon **Alexa** or Google Home, smart watches like the Apple Watch, internet-connected baby monitors, video doorbells, and even toys.

What is IoT programming?

Programming for **IoT** is usually a polyglot (multiple languages) effort since the Internet-of-Things (**IoT**) is a system of inter-related computing devices that are provided with unique identifiers and the ability to transfer data over a network.

What language does IoT use?

C
C++
Java
JavaScript
Python and
PHP

What devices are IoT?

IoT devices include wireless sensors, software, actuators, and computer **devices**. They are attached to a particular object that operates through the internet, enabling the transfer of data among objects or people automatically without human intervention.


TOP INDUSTRIES KEY FOR
IOT APPLICATIONS & REVENUE GENERATION
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SMART MANUFACTURING
HEALTHCARE
SMART CITIES
CONNECTED VEHICLES
RETAIL & SUPPLY CHAIN
AGRICULTURE

Industrial Internet of Things (IIoT)

- The **Industrial Internet of Things (IIoT)** is an advanced application of the **Internet of Things (IoT)** in industrial environments. It involves the integration of **machines, sensors, control systems, and data analytics** to improve industrial processes through **automation, monitoring, and intelligent decision-making**.
- IIoT is a core component of **smart manufacturing** and plays a vital role in the evolution of **Industry 4.0**. **IIoT** refers to the use of **connected sensors, devices, and systems in industries** to collect, exchange, and analyze data for improving **efficiency, productivity, safety, and reliability**.
- IIoT connects industrial equipment such as machines, robots, and production systems to the internet, enabling them to:
- Communicate with each other (Machine-to-Machine, M2M)
- Monitor performance in real time
- Predict failures and optimize operations

Key Components of IIoT

1. Sensors and Devices

- Collect data such as temperature, pressure, vibration, and speed

2. Connectivity

- Communication via industrial networks (Ethernet, Wi-Fi, 5G, etc.)

3. Data Processing

- Uses edge computing or cloud platforms to process data.

4. Data Analytics

- Advanced analytics, AI, and machine learning for insights

5. Control Systems

- PLC, SCADA, and DCS systems for monitoring and control

6. User Interface

- Dashboards and HMIs for visualization and decision-making

Applications of IIoT

1. Predictive Maintenance

- Detects machine faults before failure
- Reduces downtime

2. Smart Manufacturing

- Automated production systems
- Real-time monitoring and optimization

3. Energy Management

- Tracks and optimizes energy consumption

❑ **Working Principle of IIoT**

Sensors collect data from machines
Data is transmitted via network
Data is processed (edge/cloud)
Analytics generate insights
System takes action or alerts operators
Continuous feedback improves performance

❑ **IIoT Architecture**

IIoT typically follows a layered architecture:
Device Layer → Sensors, actuators
Edge Layer → Local data processing
Communication Layer → Network connectivity
Cloud Layer → Data storage and analytics
Application Layer → User interaction and control

4. Supply Chain Optimization

Real-time tracking of goods and inventory

5. Quality Control

Automated inspection systems
Reduces defects

Advantages of IIoT

- Increased productivity
- Reduced downtime
- Improved safety
- Better decision-making
- Cost savings
- Enhanced product quality

Challenges of IIoT

Cybersecurity risks
High initial investment
Integration complexity
Data management issues
Skilled workforce requirement

Future of IIoT

Integration with AI and machine learning
5G-enabled industrial communication
Digital twins and smart factories
Fully autonomous industrial systems

Smart Factory Example:

In a manufacturing plant, sensors monitor machine vibration and temperature. If abnormal behavior is detected, the system predicts failure and schedules maintenance automatically, avoiding unexpected breakdowns.

IIoT is revolutionizing industries by enabling **intelligent, connected, and automated systems**. It enhances operational efficiency, reduces costs, and supports the transition toward **smart and sustainable manufacturing**. IIoT connects industrial machines and systems to enable **real-time monitoring, intelligent decision-making, and optimized industrial operations**.

Industrial Internet

The **Industrial Internet** is the integration and linking of big data, analytical tools and wireless networks with physical and **industrial** equipment, or otherwise applying meta-level networking functions, to distributed systems. The term was coined by General Electric (GE), a U.S. corporation.

What is IIoT platform?

An **IIoT platform** is a set of hardware and software facilities that assist and support applications for industrial companies using the internet to connect devices and equipment. This use of the internet is now commonly called the Industrial Internet of Things (**IIoT**)

How IIoT works?

IIoT is a network of intelligent devices connected to form systems that monitor, collect, exchange and analyze data. Each industrial IoT echosystem consists of:
Intelligent assets that can sense, communicate and store information about themselves;
Public and/or private data communications infrastructure
Analytics and applications that generate business information from raw data; and
People.

Benefits of IIoT

The **Industrial Internet of Things (IIoT)** provides numerous advantages by enabling **real-time monitoring, automation, and intelligent decision-making** in industrial environments.

- **1. Increased Productivity**
- Continuous monitoring of machines improves efficiency
- Reduces idle time and enhances output

2. Reduced Downtime (Predictive Maintenance)

- Detects faults before they occur
- Schedules maintenance proactively

3. Cost Reduction

- Minimizes maintenance and operational costs
- Reduces energy consumption and waste
- ☞ Improves overall profitability

4. Real-Time Monitoring and Control

- Provides live data from machines and processes
- Enables quick decision-making

5. Improved Product Quality

- Continuous inspection and monitoring
- Reduces defects and variations

6. Enhanced Safety

- Monitors hazardous conditions
- Generates alerts for unsafe situations

7. Energy Efficiency

Tracks energy usage in real time

Optimizes power consumption

8. Better Decision-Making

- Uses data analytics and AI
- Provides actionable insights

9. Supply Chain Optimization

- Real-time tracking of materials and products
- Improves inventory management

10. Automation and Smart Operations

- Enables autonomous systems
- Reduces human intervention

IIoT versus IoT

Aspect	Internet of Things (IoT)	Industrial Internet of Things (IIoT)
Definition	Network of connected devices for general use	Application of IoT in industrial environments
Focus Area	Consumer applications and daily life	Industrial processes and manufacturing
Primary Goal	Convenience, comfort, and automation	Efficiency, productivity, and reliability
Applications	Smart homes, wearables, smart cities	Smart factories, predictive maintenance, energy systems
Examples	Smart thermostat, fitness tracker	Machine monitoring, automated production lines
Data Importance	Moderate importance	Critical and high-value data
System Complexity	Relatively simple	Highly complex and integrated systems
Reliability Requirement	Moderate	Very high (critical operations)
Security Requirement	Important	Extremely critical (industrial safety risks)
Real-Time Operation	Not always required	Essential for continuous operations
Scale	Smaller-scale systems	Large-scale industrial networks
Technology Used	Basic sensors, mobile apps	Advanced sensors, PLC, SCADA, AI, cloud
Cost	Lower implementation cost	High initial investment
Risk Level	Low to moderate	High (failure can cause major losses)

IoT vs IIoT
COMPARATIVE DIAGRAM

IoT INTERNET OF THINGS For Consumer & Everyday Use	ASPECT	IIoT INDUSTRIAL INTERNET OF THINGS For Industrial & Manufacturing Use
Network of connected devices for general use	DEFINITION	Application of IoT in industrial environments
Consumer applications & daily life	FOCUS AREA	Industrial processes & manufacturing
Convenience, comfort & automation	PRIMARY GOAL	Efficiency, productivity & reliability
Smart Homes, Wearables, Smart Cities	APPLICATIONS	Smart Factories, Predictive Maintenance, Energy Management
Smart Thermostat, Fitness Tracker	EXAMPLES	Machine Monitoring, Automated Production Line
Moderate	DATA IMPORTANCE	Critical & High-Value
Relatively Simple	SYSTEM COMPLEXITY	Highly Complex & Integrated
Moderate	RELIABILITY NEED	Very High (Mission-Critical)
Important	SECURITY REQUIREMENT	Extremely Critical
Not Always Required	REAL-TIME OPERATION	Essential & Continuous
Small to Medium Scale	SCALE	Large-Scale Industrial Networks
Basic Sensors, Mobile Apps	TECHNOLOGY USED	Advanced Sensors, PLC, SCADA, AI, Cloud
Lower Implementation Cost	COST	High Initial Investment
Low to Moderate	RISK LEVEL	High (Failure Can Cause Major Losses)

KEY INSIGHT: IoT is for smart everyday applications, while IIoT is for intelligent and mission-critical industrial operations.

IoT vs IIoT
COMPARATIVE DIAGRAM

INTERNET OF THINGS (IoT)
FOR CONSUMER & GENERAL USE

FOCUS

Convenience, Comfort & Automation
Improving daily life
and personal experiences

APPLICATIONS

- Smart Homes
- Wearables
- Smart Cities

EXAMPLES

- Smart Thermostat (24°C)
- Fitness Tracker

KEY FEATURES

- Relatively Simple Systems
- Moderate Data & Security Needs
- Lower Cost & Easy Deployment
- Non-Critical Operations

INDUSTRIAL INTERNET OF THINGS (IIoT)
FOR INDUSTRIAL & MANUFACTURING USE

FOCUS

Efficiency, Productivity & Reliability
Optimizing industrial operations
and performance

APPLICATIONS

- Smart Factories
- Predictive Maintenance
- Energy Management

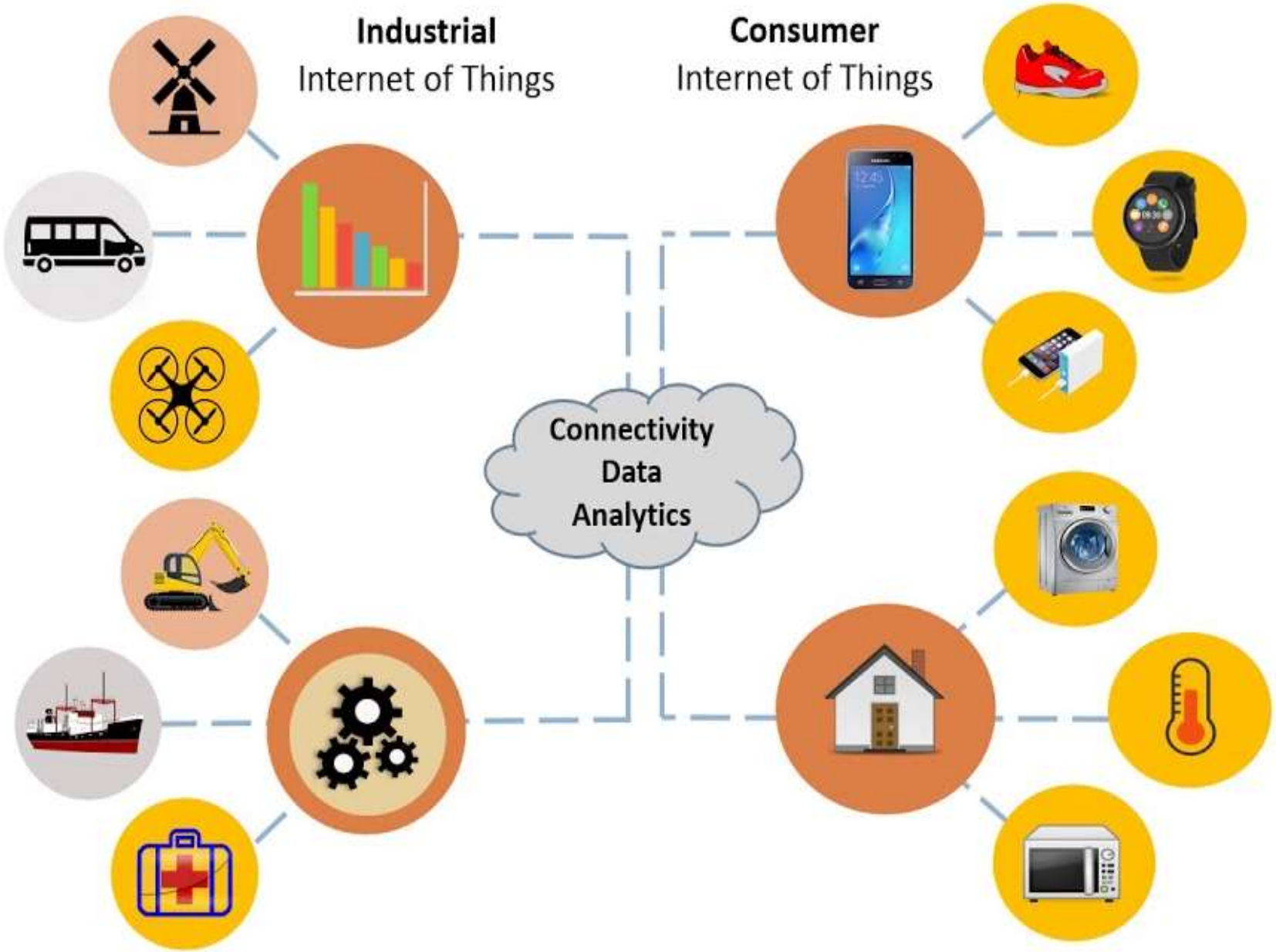
EXAMPLES

- Machine Condition Monitoring
- Automated Production Line

KEY FEATURES

- Highly Complex & Integrated Systems
- Critical Data with High Security
- High Investment & Specialized Infrastructure
- Mission-Critical & Real-Time Operations

IoT IS FOR SMART LIVING | **IIoT IS FOR SMART INDUSTRY**


Industrial
Internet of Things
Consumer
Internet of Things
Connectivity
Data
Analytics

IIoT APPLICATIONS



Artificial intelligence (AI)

- Artificial Intelligence (AI) refers to the branch of computer science that focuses on creating machines and systems capable of performing tasks that typically require human intelligence. These tasks include learning from experience, reasoning, problem-solving, understanding language, recognizing patterns, and making decisions. AI systems are designed to simulate human cognitive functions by using algorithms, data, and computational power to improve their performance over time.
- AI operates by processing large amounts of data and identifying patterns within it. Through techniques such as machine learning and deep learning, AI systems can learn from past data without being explicitly programmed for every scenario. For example, in industrial applications, AI can analyze machine performance data to predict failures before they occur, enabling predictive maintenance. In everyday life, AI is used in applications such as virtual assistants, recommendation systems, speech recognition, and image processing.
- One of the key components of AI is **machine learning**, where systems learn from data and improve automatically. Another important area is **deep learning**, which uses artificial neural networks inspired by the human brain to process complex data such as images and speech. AI also includes **natural language processing (NLP)**, which allows machines to understand and interact using human language.
- The applications of AI are vast and span multiple domains, including manufacturing, healthcare, finance, transportation, and education. In Industry 4.0, AI plays a crucial role in enabling smart factories, where machines can make intelligent decisions, optimize processes, and adapt to changing conditions in real time. AI-driven automation enhances productivity, reduces errors, and improves overall system efficiency.
- Despite its numerous advantages, AI also presents certain challenges. These include concerns related to data privacy, ethical issues, high implementation costs, and the potential displacement of jobs due to automation. Additionally, AI systems require large amounts of high-quality data and significant computational resources to function effectively.
- In conclusion, Artificial Intelligence is a transformative technology that enables machines to think, learn, and act intelligently. It is a key driver of modern technological advancements and plays a central role in shaping the future of industries and society.

Core Components of AI

Artificial intelligence (AI) refers to the development of computer systems capable of performing tasks that traditionally require human intelligence. Rather than following a rigid, pre-programmed set of instructions, AI systems use algorithms and data to "learn" how to solve problems, recognize patterns, and make decisions.

At its core, AI is about mimicking cognitive functions—such as learning, reasoning, and self-correction—to achieve specific goals efficiently.

To understand how AI works, it is helpful to look at the primary subfields that drive its capabilities:

1. Machine Learning (ML)

- This is the "engine" of modern AI. Machine learning allows systems to improve their performance on a task over time by analyzing large datasets. Instead of being told exactly what to do, the system identifies statistical regularities in the data.

2. Deep Learning & Neural Networks

- Inspired by the human brain, deep learning uses layers of "artificial neurons" to process information. This is particularly effective for complex tasks like facial recognition, language translation, and autonomous driving.

3. Natural Language Processing (NLP)

- NLP enables machines to understand, interpret, and generate human language. This technology powers virtual assistants, real-time translation tools, and sentiment analysis.

Types of Artificial Intelligence (AI)

Artificial Intelligence can be classified in two main ways: **based on capability** and **based on functionality**.

1. Based on Capability

◆ **Narrow AI (Weak AI)**

- Narrow AI is designed to perform a **specific task** and operates within a limited scope. It cannot function beyond its programmed capabilities. Most AI systems used today fall under this category, such as virtual assistants, recommendation systems, and image recognition software. These systems are efficient but lack true understanding or consciousness.

◆ **General AI (Strong AI)**

- General AI refers to a system with the ability to perform **any intellectual task that a human can do**. It would have reasoning, problem-solving, and learning capabilities similar to humans. This type of AI is still **theoretical** and has not yet been achieved.

◆ **Super AI**

- Super AI is a hypothetical concept where machines surpass **human intelligence in all aspects**, including creativity, decision-making, and emotional intelligence. This level of AI does not exist yet and is mainly discussed in research and future predictions.

How AI Processes Information

- The lifecycle of an AI "thought" process generally follows these steps:
- **Data Input:** Collecting vast amounts of information (text, images, sensor data).
- **Processing:** Algorithms sort and weight the data, looking for features or "labels" that define the information.
- **Pattern Recognition:** The system finds correlations (e.g., "When pixels are arranged like this, it is usually a bridge").
- **Inference/Action:** The system makes a prediction or executes a command based on the recognized patterns.
- **Note:** AI does not "understand" concepts the way humans do; it calculates probabilities. For example, a generative AI model doesn't "know" what a sunset is, but it knows which pixels are statistically likely to be adjacent to each other to create the image of one.

Real-World Applications

•**Predictive Analytics:** Forecasting trends in manufacturing, weather, or economics.

•**Computer Vision:** Identifying structural defects in engineering materials or navigating drones.

•**Automation:** Streamlining repetitive administrative tasks or optimizing logistics.

2. Based on Functionality

◆ Reactive Machines

- These are the most basic types of AI systems. They do not store past experiences or learn from them. They only respond to current inputs. For example, simple game-playing AI systems operate based on predefined rules.

◆ Limited Memory

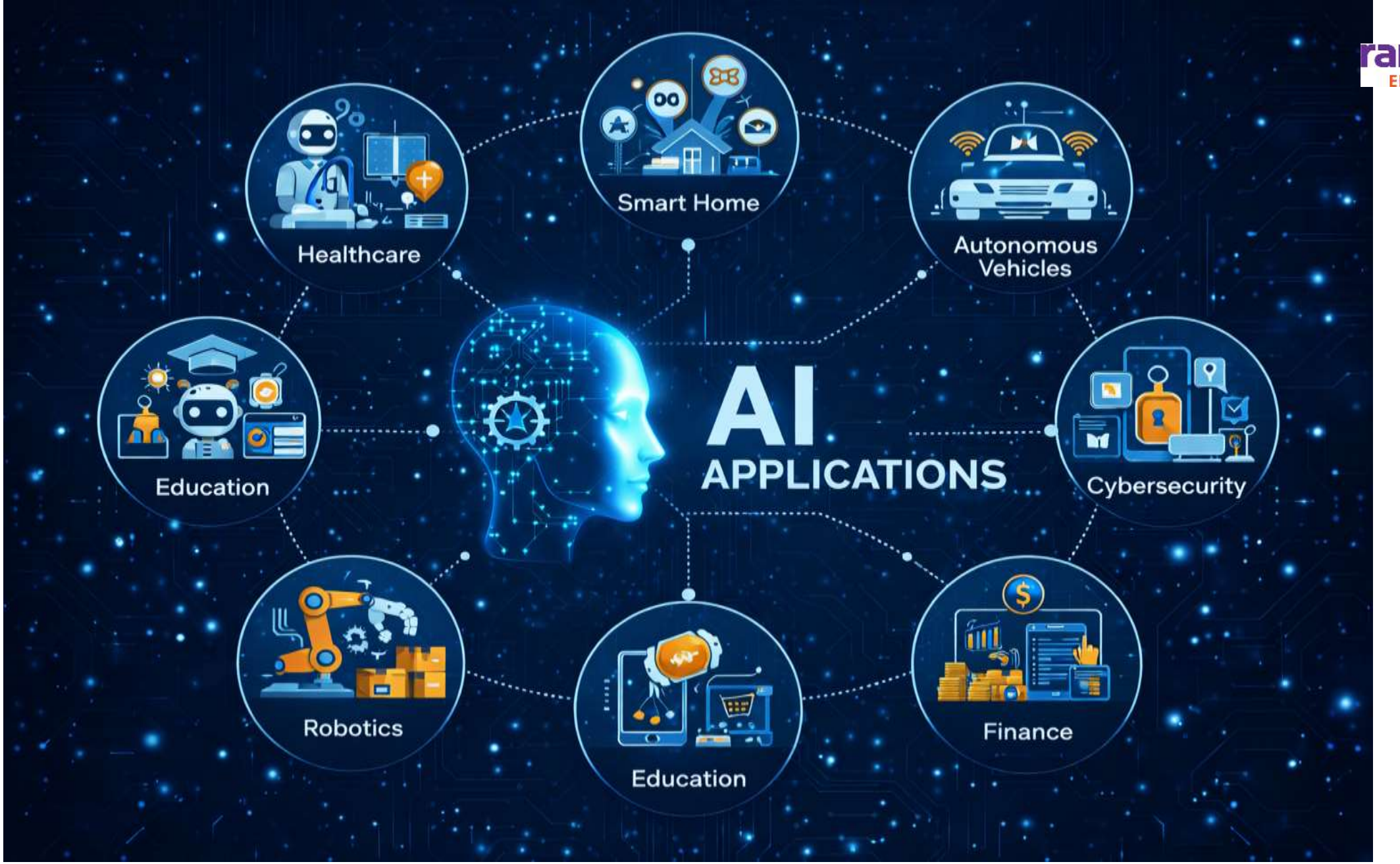
- These AI systems can use **past data and experiences** to make decisions. Most modern AI applications, such as self-driving cars and industrial robots, fall under this category.

◆ Theory of Mind

- This type of AI would be able to **understand human emotions, beliefs, and intentions**, enabling more natural interactions. It is still under development and not yet fully realized.

◆ Self-Aware AI

- Self-aware AI represents the most advanced stage, where machines would possess **consciousness and self-awareness**. This remains purely hypothetical and is a subject of future research.


AI
APPLICATIONS
Healthcare
Smart Home
Autonomous Vehicles
Education
Cybersecurity
Robotics
Education
Finance

Machine learning (ML)

- Machine Learning (ML) is a subset of Artificial Intelligence that focuses on developing algorithms and models that enable computers to learn from data and improve their performance without being explicitly programmed. Instead of relying on fixed instructions, ML systems identify patterns in data and use these patterns to make predictions, decisions, or classifications. This ability to learn from experience makes machine learning a powerful tool for solving complex, real-world problems.
- At its core, machine learning works by feeding large amounts of data into algorithms that analyze and extract meaningful relationships. These algorithms then build models that can generalize from the data and apply learned knowledge to new, unseen inputs. The learning process typically involves training (learning from data), validation (tuning the model), and testing (evaluating performance). The accuracy and effectiveness of a machine learning model depend heavily on the quality and quantity of data used.

The Machine Learning Workflow

The process of "learning" typically follows a structured pipeline:

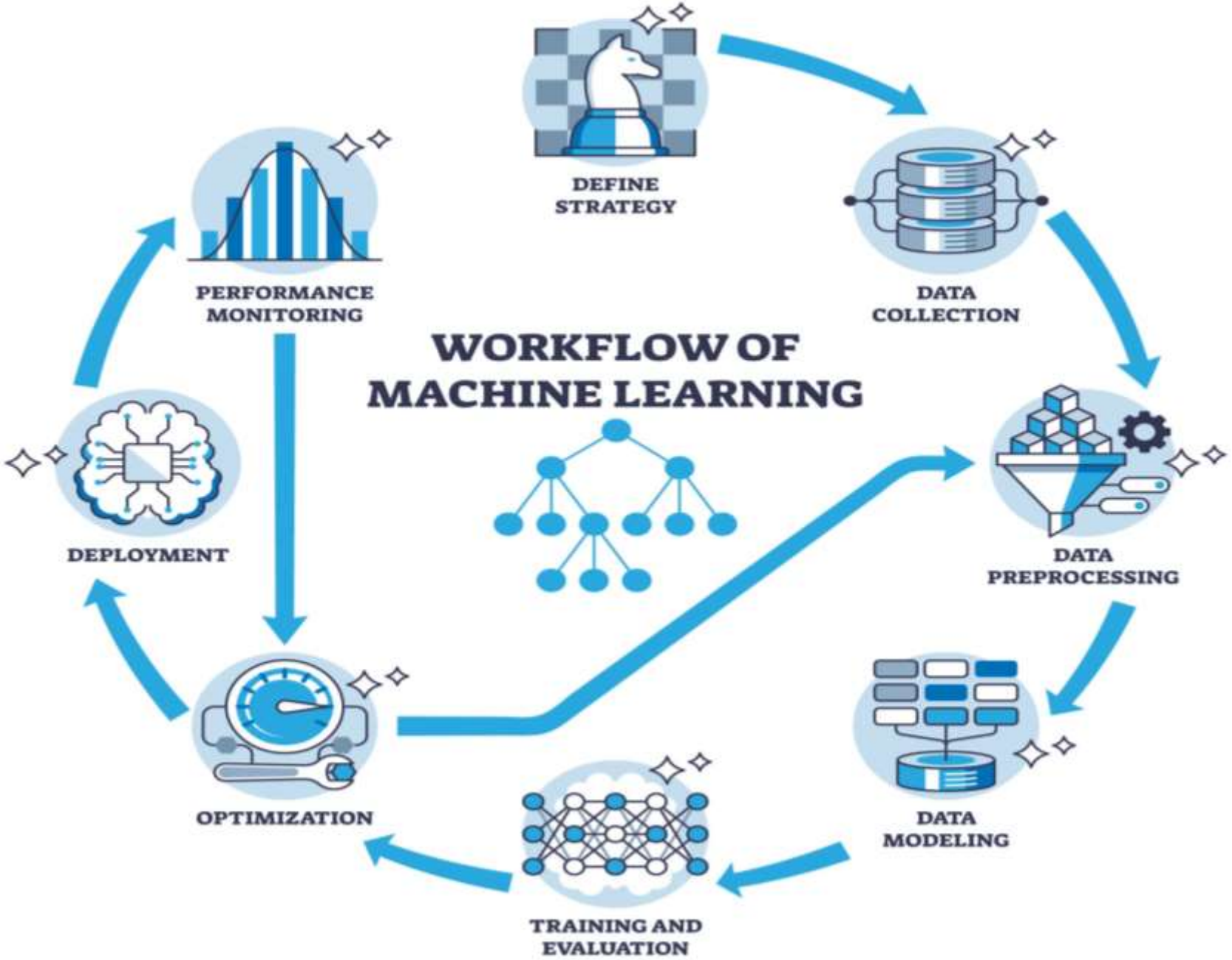
Data Collection: Gathering raw information (numbers, text, images, or sensor readings).

Data Preparation: Cleaning the data to remove errors and selecting relevant "features" (variables) that influence the outcome.

Model Training: Feeding the data into an algorithm. The algorithm adjusts its internal parameters to minimize the difference between its predictions and the actual results.

Evaluation: Testing the model on a "hidden" dataset it hasn't seen before to ensure it can generalize to new situations.

Deployment & Tuning: Putting the model to work and refining it as more data becomes available.


WORKFLOW OF
MACHINE LEARNING
DEFINE
STRATEGY
DATA
COLLECTION
DATA
PREPROCESSING
DATA
MODELING
TRAINING AND
EVALUATION
OPTIMIZATION
DEPLOYMENT
PERFORMANCE
MONITORING

Types of Machine Learning

Machine Learning is mainly classified into **three primary types** based on how the model learns from data.

1. Supervised Learning

Supervised learning is a type of machine learning in which the model is trained using **labeled data**, meaning the input data is paired with the correct output. The algorithm learns the relationship between inputs and outputs and uses this knowledge to make predictions on new data. It is commonly used for problems where the outcome is known, such as classification and regression tasks.

Examples:

- Email spam detection (spam or not spam)
- Predicting house prices
- Image classification

2. Unsupervised Learning

Unsupervised learning deals with **unlabeled data**, where the model tries to identify hidden patterns or structures within the data without any predefined outputs. The goal is to explore the data and find meaningful groupings or relationships.

Examples:

- Customer segmentation
- Clustering of similar products
- Pattern recognition in large datasets

3. Reinforcement Learning

Reinforcement learning is based on a **trial-and-error approach**, where an agent learns by interacting with an environment. The system receives **rewards or penalties** based on its actions and gradually learns the best strategy to maximize rewards.

Examples:

- Self-driving cars
- Game-playing AI (like chess or video games)
- Robotics control systems

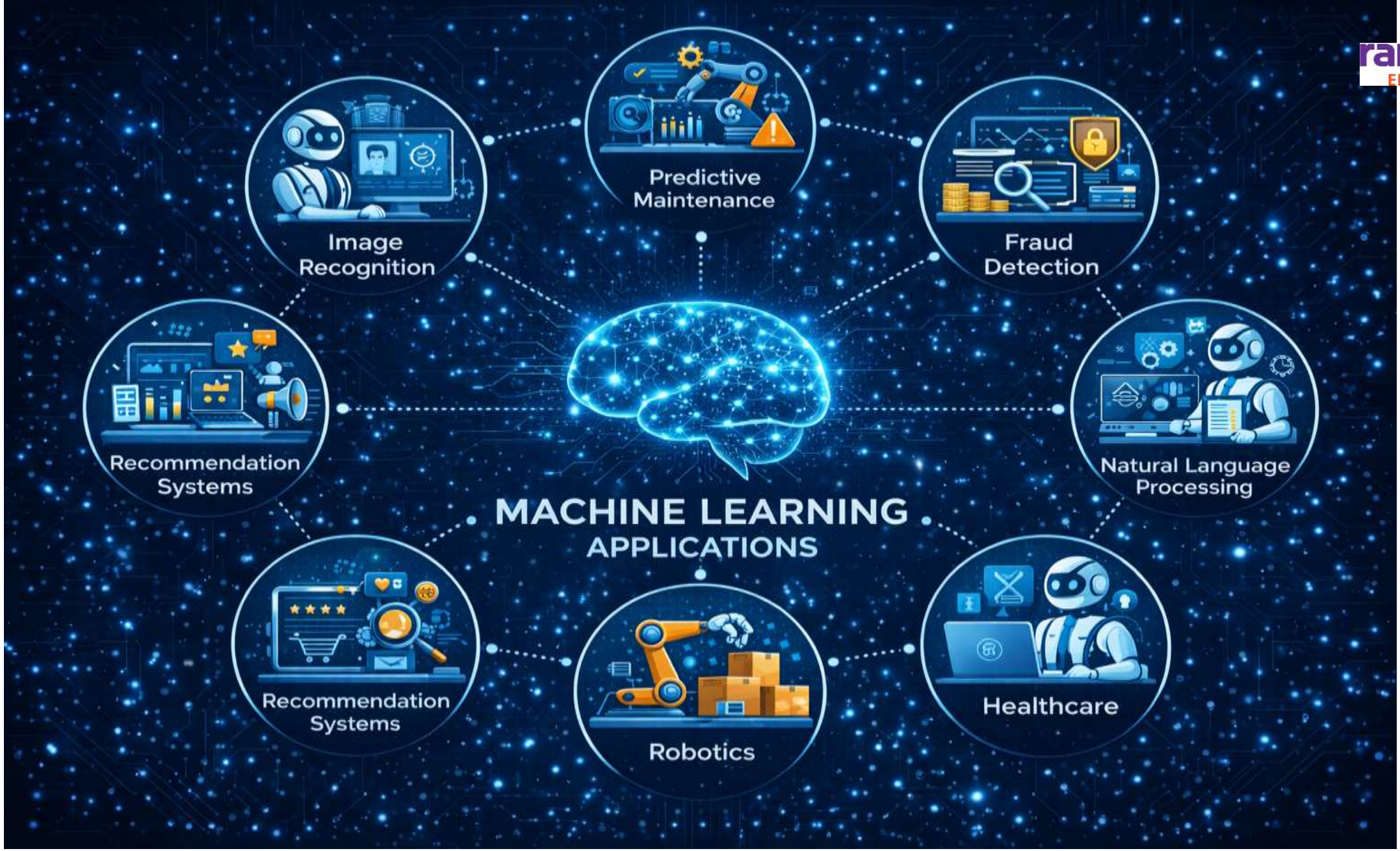
Other Types (Advanced/Hybrid)

Semi-Supervised Learning

- Combines both labeled and unlabeled data to improve learning accuracy.

Deep Learning

- A specialized type of machine learning that uses **neural networks** to process complex data such as images, speech, and text.


Predictive Maintenance
Image Recognition
Fraud Detection
Recommendation Systems
Natural Language Processing
MACHINE LEARNING
APPLICATIONS
Recommendation Systems
Robotics
Healthcare

Big Data

Big data primarily refers to data sets that are too large or complex to be dealt with by traditional data-processing application software. Data with many entries (rows) offer greater statistical power, while data with higher complexity (more attributes or columns) may lead to a higher false discovery rate. Though used sometimes loosely partly due to a lack of formal definition, the best interpretation is that it is a large body of information that cannot be comprehended when used in small amounts only.

Big data analysis challenges include capturing data, data storage, data analysis, search, sharing, transfer, visualization, querying, updating, information privacy, and data sources. Big data was originally associated with three key concepts: *volume*, *variety*, and *velocity*. The analysis of big data presents challenges in sampling, and thus previously allowing for only observations and sampling. Thus a fourth concept, *veracity,* refers to the quality or insightfulness of the data. Without sufficient investment in expertise for big data veracity, the volume and variety of data can produce costs and risks that exceed an organization's capacity to create and capture *value* from big data.



The definition of big data is data that contains greater variety, arriving in increasing volumes and with more velocity. This is also known as the three Vs.

- Put simply, big data is larger, more complex data sets, especially from new data sources. These data sets are so voluminous that traditional data processing software just can't manage them. But these massive volumes of data can be used to address business problems you wouldn't have been able to tackle before.

Volume	The amount of data matters. With big data, you'll have to process high volumes of low-density, unstructured data. This can be data of unknown value, such as Twitter data feeds, clickstreams on a web page or a mobile app, or sensor-enabled equipment. For some organizations, this might be tens of terabytes of data. For others, it may be hundreds of petabytes.
Velocity	Velocity is the fast rate at which data is received and (perhaps) acted on. Normally, the highest velocity of data streams directly into memory versus being written to disk. Some internet-enabled smart products operate in real time or near real time and will require real-time evaluation and action.
Variety	Variety refers to the many types of data that are available. Traditional data types were structured and fit neatly in a relational database. With the rise of big data, data comes in new unstructured data types. Unstructured and semistructured data types, such as text, audio, and video, require additional preprocessing to derive meaning and support metadata.

The value—and truth—of big data

Two more Vs have emerged over the past few years: **value** and **veracity**. Data has intrinsic value. But it's of no use until that value is discovered. Equally important: How truthful is your data—and how much can you rely on it?

Today, big data has become capital. Think of some of the world's biggest tech companies. A large part of the value they offer comes from their data, which they're constantly analyzing to produce more efficiency and develop new products.

Recent technological breakthroughs have exponentially reduced the cost of data storage and compute, making it easier and less expensive to store more data than ever before. With an increased volume of big data now cheaper and more accessible, you can make more accurate and precise business decisions.

Finding value in big data isn't only about analyzing it (which is a whole other benefit). It's an entire discovery process that requires insightful analysts, business users, and executives who ask the right questions, recognize patterns, make informed assumptions, and predict behavior.

Big Data refers to extremely large and complex datasets that cannot be efficiently processed, stored, or analyzed using traditional data processing tools. It involves handling vast amounts of structured, semi-structured, and unstructured data to extract meaningful insights for decision-making.

Big Data is characterized as **high-volume, high-velocity, and high-variety data** that requires advanced technologies such as distributed computing, analytics, and machine learning for processing and analysis.

Big data use cases

Big data can help to address a range of business activities, from customer experience to analytics. Here are just a few.

Product development	Companies like Netflix and Procter & Gamble use big data to anticipate customer demand. They build predictive models for new products and services by classifying key attributes of past and current products or services and modeling the relationship between those attributes and the commercial success of the offerings. In addition, P&G uses data and analytics from focus groups, social media, test markets, and early store rollouts to plan, produce, and launch new products.
Predictive maintenance	Factors that can predict mechanical failures may be deeply buried in structured data, such as the year, make, and model of equipment, as well as in unstructured data that covers millions of log entries, sensor data, error messages, and engine temperature. By analyzing these indications of potential issues before the problems happen, organizations can deploy maintenance more cost effectively and maximize parts and equipment uptime.
Customer experience	The race for customers is on. A clearer view of customer experience is more possible now than ever before. Big data enables you to gather data from social media, web visits, call logs, and other sources to improve the interaction experience and maximize the value delivered. Start delivering personalized offers, reduce customer churn, and handle issues proactively.

Fraud and compliance	When it comes to security, it's not just a few rogue hackers—you're up against entire expert teams. Security landscapes and compliance requirements are constantly evolving. Big data helps you identify patterns in data that indicate fraud and aggregate large volumes of information to make regulatory reporting much faster.
Machine learning	Machine learning is a hot topic right now. And data—specifically big data—is one of the reasons why. We are now able to teach machines instead of program them. The availability of big data to train machine learning models makes that possible.
Operational efficiency	Operational efficiency may not always make the news, but it's an area in which big data is having the most impact. With big data, you can analyze and assess production, customer feedback and returns, and other factors to reduce outages and anticipate future demands. Big data can also be used to improve decision-making in line with current market demand.
Drive innovation	Big data can help you innovate by studying interdependencies among humans, institutions, entities, and process and then determining new ways to use those insights. Use data insights to improve decisions about financial and planning considerations. Examine trends and what customers want to deliver new products and services. Implement dynamic pricing. There are endless possibilities.

Data analytics

- Data analytics is the collection, transformation, and organization of data in order to draw conclusions, make predictions, and drive informed decision making.
- Data analytics is often confused with data analysis. While these are related terms, they aren't exactly the same. In fact, data analysis is a subcategory of data analytics that deals specifically with extracting meaning from data. Data analytics, as a whole, includes processes beyond analysis, including data science (using data to theorize and forecast) and data engineering (building data systems).
- Data analytics is a multidisciplinary field that employs a wide range of analysis techniques, including math, statistics, and computer science, to draw insights from data sets. Data analytics is a broad term that includes everything from simply analyzing data to theorizing ways of collecting data and creating the frameworks needed to store it.
- Data analytics is important across many industries, as many business leaders use data to make informed decisions. A sneaker manufacturer might look at sales data to determine which designs to continue and which to retire, or a health care administrator may look at inventory data to determine the medical supplies they should order.

Data analytics: Key concepts

There are four key types of data analytics: descriptive, diagnostic, predictive, and prescriptive. Together, these four types of data analytics can help an organization make data-driven decisions. At a glance, each of them tells us the following:
Descriptive analytics: Tell us what happened.
Diagnostic analytics: Tell us why something happened.
Predictive analytics: Tell us what will likely happen in the future.
Prescriptive analytics: Tell us how to act.

People who work with data analytics will typically explore each of these four areas using the data analysis process, which includes **identifying** the question, **collecting** raw data, **cleaning** data, **analyzing** data, and **interpreting** the results.

Big data analytics uses and examples

Here are some examples of how big data analytics can be used to help organizations: **Customer acquisition and retention.** Consumer data can help the marketing efforts of companies, which can act on trends to increase customer satisfaction. For example, personalization engines for Amazon, Netflix and Spotify can provide improved customer experiences and create customer loyalty.

Targeted ads. Personalization data from sources such as past purchases, interaction patterns and product page viewing histories can help generate compelling targeted ad campaigns for users on the individual level and on a larger scale. **Product development.** Big data analytics can provide insights to inform about product viability, development decisions, progress measurement and steer improvements in the direction of what fits a business' customers. **Price optimization.** Retailers may opt for pricing models that use and model data from a variety of data sources to maximize revenues.

Supply chain and channel analytics. Predictive analytical models can help with preemptive replenishment, B2B supplier networks, inventory management, route optimizations and the notification of potential delays to deliveries. **Risk management.** Big data analytics can identify new risks from data patterns for effective risk management strategies. **Improved decision-making.** Insights business users extract from relevant data can help organizations make quicker and better decisions.

Big data analytics benefits

The benefits of using big data analytics include:

- Quickly analyzing large amounts of data from different sources, in many different formats and types. Rapidly making better-informed decisions for effective strategizing, which can benefit and improve the supply chain, operations and other areas of strategic decision-making.
- Cost savings, which can result from new business process efficiencies and optimizations. A better understanding of customer needs, behavior and sentiment, which can lead to better marketing insights, as well as provide information for product development.
- Improved, better informed risk management strategies that draw from large sample sizes of data.

Big data analytics challenges

Despite the wide-reaching benefits that come with using big data analytics, its use also comes with challenges:

Accessibility of data: With larger amounts of data, storage and processing become more complicated. Big data should be stored and maintained properly to ensure it can be used by less experienced data scientists and analysts.

Data quality maintenance: With high volumes of data coming in from a variety of sources and in different formats, data quality management for big data requires significant time, effort and resources to properly maintain it.

Data security: The complexity of big data systems presents unique security challenges. Properly addressing security concerns within such a complicated big data ecosystem can be a complex undertaking.

Choosing the right tools: Selecting from the vast array of big data analytics tools and platforms available on the market can be confusing, so organizations must know how to pick the best tool that aligns with users' needs and infrastructure. With a potential lack of internal analytics skills and the high cost of hiring experienced data scientists and engineers, some organizations are finding it hard to fill the gaps.

Unit 5

What is Cloud Computing?

Cloud Computing refers to the delivery of computing services such as servers, storage, databases, networking, software, and analytics over the internet ("the cloud") instead of using local computers or physical infrastructure. It allows users and organizations to access and store data, run applications, and perform computing tasks remotely through online platforms, eliminating the need for on-site hardware and maintenance.

Cloud computing is the on-demand delivery of compute power, database, storage, applications, and other IT resources via the internet with pay-as-you-go pricing.

In cloud computing, data and applications are hosted on remote servers managed by service providers. Users can access these resources anytime and from anywhere using internet-enabled devices. This model provides flexibility and scalability, as resources can be increased or decreased based on demand. For example, businesses can store large volumes of data or run complex applications without investing in expensive infrastructure.

Cloud computing operates on different service models. **Infrastructure as a Service (IaaS)** provides basic computing resources like virtual machines and storage. **Platform as a Service (PaaS)** offers a platform for developing and deploying applications without worrying about underlying hardware. **Software as a Service (SaaS)** delivers software applications over the internet on a subscription basis, such as email services and online office tools.

It also includes deployment models such as **public cloud**, where services are provided over the internet to multiple users; **private cloud**, dedicated to a single organization; and **hybrid cloud**, which combines both public and private environments for greater flexibility.

Cloud computing is widely used in industries for data storage, backup, application hosting, big data analytics, and disaster recovery. In the context of Industry 4.0, it enables real-time data access, supports IoT systems, and facilitates intelligent decision-making by integrating with technologies like Artificial Intelligence and Big Data.

Despite its advantages such as cost efficiency, scalability, and accessibility, cloud computing also presents challenges including data security concerns, dependency on internet connectivity, and potential privacy risks.

Cloud architect

A **Cloud Architect** is a professional responsible for designing, developing, and managing cloud computing systems and infrastructure. They play a crucial role in helping organizations adopt cloud technologies by creating efficient, scalable, and secure cloud environments tailored to business needs.

A cloud architect works by analyzing an organization's requirements and then selecting appropriate cloud services, deployment models, and architectures. They design solutions that ensure high performance, reliability, and cost-effectiveness. This includes deciding how data is stored, how applications are deployed, and how different cloud components interact with each other. Cloud architects also ensure that systems are secure and comply with industry standards and regulations.

The role involves working with various cloud service models such as Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS). Additionally, cloud architects must understand deployment models like public, private, and hybrid clouds to choose the best approach for a given application or organization.

A key responsibility of a cloud architect is to design scalable systems that can handle increasing workloads efficiently. They also focus on fault tolerance and disaster recovery to ensure that services remain available even in case of failures. Cost optimization is another important aspect, as cloud resources are typically billed based on usage.

To perform their role effectively, cloud architects require knowledge of networking, virtualization, databases, security, and programming. They often work with major cloud platforms such as Amazon Web Services (AWS), Microsoft Azure, and Google Cloud Platform (GCP). Strong problem-solving skills and an understanding of business processes are also essential.

Cloud architects are vital in modern organizations, especially in the era of digital transformation and Industry 4.0. They enable businesses to leverage cloud computing for improved flexibility, faster innovation, and efficient resource utilization.

Amazon Web Services (AWS)

- Amazon Web Services (AWS) is a comprehensive and widely used **cloud computing platform** provided by Amazon. It offers a broad range of on-demand computing services such as storage, processing power, databases, networking, analytics, and artificial intelligence over the internet. AWS enables individuals, businesses, and governments to access powerful IT resources without investing in physical infrastructure.
- AWS operates on a **pay-as-you-go model**, meaning users only pay for the resources they use. This makes it highly cost-effective and scalable, allowing organizations to easily increase or decrease resources based on their requirements. AWS data centers are distributed globally, ensuring high availability, reliability, and low latency for applications and services.
- The platform provides a wide variety of services. For computing, AWS offers services like virtual servers (EC2), while for storage, it provides scalable solutions such as object storage (S3). It also supports databases (RDS, DynamoDB), networking (VPC), and advanced services like machine learning, big data analytics, and Internet of Things (IoT). These services help organizations build, deploy, and manage applications efficiently in the cloud.
- AWS supports different cloud deployment models, including public, private, and hybrid cloud environments. It also provides strong security features such as encryption, identity and access management, and compliance certifications, making it suitable for sensitive and large-scale applications.
- AWS is widely used across industries for application hosting, data backup, disaster recovery, web development, and enterprise solutions. In the context of Industry 4.0, AWS plays a significant role by enabling real-time data processing, integration with IoT devices, and support for Artificial Intelligence and Big Data applications.
- Despite its advantages such as scalability, flexibility, and global reach, AWS also has some challenges, including complexity for beginners, dependency on internet connectivity, and potential cost management issues if not monitored properly.


Compute
EC2
Networking
VPC
Storage
S3
Analytics &
Big Data
aws
Database
RDS / DynamoDB
IoT &
Robotics
Amazon Web Services
Machine Learning
AI/ML
Security &
Compliance
On-Demand Pricing
Scalable & Flexible
Global Reach
Secure & Reliable
Global Infrastructure
Regions
Availability Zones
Edge Locations

What is AWS architect?

AWS Certified Solutions Architect - Associate is a category of technical certifications offered by Amazon Web Services (AWS) for beginners and professionals who run enterprise architecture programs, as well as solutions architects. It covers deployment of AWS systems, AWS best practices, and many other topics.

What is the role of cloud architect?

Cloud Architects are Information Technology (IT) experts responsible for the supervision of a company's cloud computing system. This involves working on cloud application designs, cloud approval plans, and systems required to manage cloud storage.

Cloud Computing Architecture is an AWS Academy curriculum designed to help students develop technical expertise in cloud computing and prepare them for the AWS Certified Solutions Architect– Associate certification exam.

The curriculum is delivered through instructor-led classes, hands-on labs, and project work. Students have access to course manuals, online knowledge assessments, hands-on labs, a free practice certification exam, and a discount voucher for the certification exam.

Amazon Web Services (AWS) – Basic Concepts and Services

- Amazon Web Services (AWS) is a leading cloud computing platform provided by Amazon that delivers a wide range of IT resources over the internet. It allows users to build, deploy, and manage applications without owning physical infrastructure.
- Amazon Web Services (AWS) is a comprehensive cloud computing platform that provides over 200 fully featured services from data centers globally. Instead of buying, owning, and maintaining physical data centers and servers, you access technology services, such as computing power, storage, and databases, on an as-needed basis.

1. Cloud Computing Model

- AWS follows an **on-demand, pay-as-you-go model**, where users only pay for the resources they consume. This eliminates the need for large upfront investments in hardware.

2. Global Infrastructure

- AWS operates worldwide through:
- **Regions** → Geographical areas (e.g., Asia, Europe)
- **Availability Zones (AZs)** → Isolated data centers within a region
- **Edge Locations** → Used for content delivery (low latency)
- ☞ This ensures **high availability, fault tolerance, and reliability**.

3. Service Models

- AWS provides three main cloud service models:
- **IaaS (Infrastructure as a Service)** → Virtual servers, storage, networking
- **PaaS (Platform as a Service)** → Development platforms
- **SaaS (Software as a Service)** → Ready-to-use applications

4. Security and Access Control

- AWS provides strong security using:
- Identity and Access Management (IAM)
- Data encryption
- Secure network configurations

5. Scalability and Elasticity

Resources can be scaled **up or down automatically** based on demand, ensuring efficient utilization and cost savings.

Major AWS Services

1. Compute Services

- **EC2 (Elastic Compute Cloud)** → Virtual machines
- **Lambda** → Serverless computing (run code without servers)

2. Storage Services

- **S3 (Simple Storage Service)** → Object storage for files
- **EBS (Elastic Block Store)** → Storage for EC2 instances
- **DynamoDB** → NoSQL database

4. Networking Services

- **VPC (Virtual Private Cloud)** → Private network in AWS
- **CloudFront** → Content delivery network (CDN)

3. Database Services

RDS (Relational Database Service) → Managed databases (MySQL, etc.)

5. Analytics & Big Data

Data processing and analysis tools for large datasets

6. AI & Machine Learning

Tools for building intelligent applications

7. Security Services

IAM (Identity management)

Encryption and monitoring tools

8. IoT Services

Connect and manage smart devices

- **Amazon Machine Image:**

An Amazon Machine Image (AMI) provides the information that is required to launch an instance in the cloud.

- **Elastic Block Storage:**

Elastic Block Storage (EBS) provides persistent block storage volumes for use with Amazon Elastic Compute Cloud (EC2) instances in the AWS cloud.

- **Elastic Compute Cloud:**

Elastic Compute Cloud (EC2) is a web service that provides resizable compute capacity in the cloud.

- **EC2 security group:**

EC2 security groups act as a virtual firewall that control the traffic for one or more instances. An AWS account automatically has a default security group for each Virtual Private Cloud (VPC). You can use this default security group or create your own security group with customized rules.

- **Identity and Access Management:**

Identity and Access Management (IAM) is a web service that helps you securely control access to AWS resources for users.

- **IAM access key:**

IAM access keys are required for authentication when hosts are provisioned from AWS. These access keys are used to sign programmatic requests to AWS.

- **Virtual Private Cloud:**

Virtual Private Cloud (VPC) launches AWS resources in a defined virtual network.

- **VPC subnet:**

VPC subnets are a range of IP addresses in your VPC. You can launch AWS resources into a selected subnet.

Amazon Web Services



Compute

EC2
Virtual Servers in the Cloud



Lambda PREVIEW
Run Code in Response to Events

Storage & Content Delivery



S3
Scalable Storage in the Cloud



Storage Gateway
Integrates On-Premises IT Environments with Cloud Storage



Glacier
Archive Storage in the Cloud



CloudFront
Global Content Delivery Network

Database



RDS
MySQL, Postgres, Oracle, SQL Server, and Amazon Aurora



DynamoDB
Predictable and Scalable NoSQL Data Store



ElastiCache
In-Memory Cache



Redshift
Managed Petabyte-Scale Data Warehouse Service

Networking



VPC
Isolated Cloud Resources



Direct Connect
Dedicated Network Connection to AWS



Route 53
Scalable DNS and Domain Name Registration

Administration & Security



Directory Service
Managed Directories in the Cloud



Identity & Access Management
Access Control and Key Management



Trusted Advisor
AWS Cloud Optimization Expert



CloudTrail
User Activity and Change Tracking



Config PREVIEW
Resource Configurations and Inventory



CloudWatch
Resource and Application Monitoring

Deployment & Management



Elastic Beanstalk
AWS Application Container



OpsWorks
DevOps Application Management Service



CloudFormation
Templated AWS Resource Creation



CodeDeploy
Automated Deployments

Analytics



EMR
Managed Hadoop Framework



Kinesis
Real-time Processing of Streaming Big Data



Data Pipeline
Orchestration for Data-Driven Workflows

Application Services



SQS
Message Queue Service



SWF
Workflow Service for Coordinating Application Components



AppStream
Low Latency Application Streaming



Elastic Transcoder
Easy-to-use Scalable Media Transcoding



SES
Email Sending Service



CloudSearch
Managed Search Service

Mobile Services



Cognito
User Identity and App Data Synchronization



Mobile Analytics
Understand App Usage Data at Scale



SNS
Push Notification Service

Enterprise Applications



WorkSpaces
Desktops in the Cloud



Zocalo
Secure Enterprise Storage and Sharing Service

Benefits of modern application development

1) Faster to market:

By speeding up the release cycle and offloading operational overhead, developers can quickly build new features. Automated test and release processes reduce error rates, so products are market-ready faster.

2) Increased innovation:

With a modular architecture, changes to any individual application component can be made quickly, and with a lower risk to the whole application, so teams can experiment with new ideas more often.

3) Improved reliability:

By automating test procedures, and monitoring at every stage of the development lifecycle, modern applications are reliable at deployment. Any issues can be evaluated and addressed in real time.

4) Reduced costs:

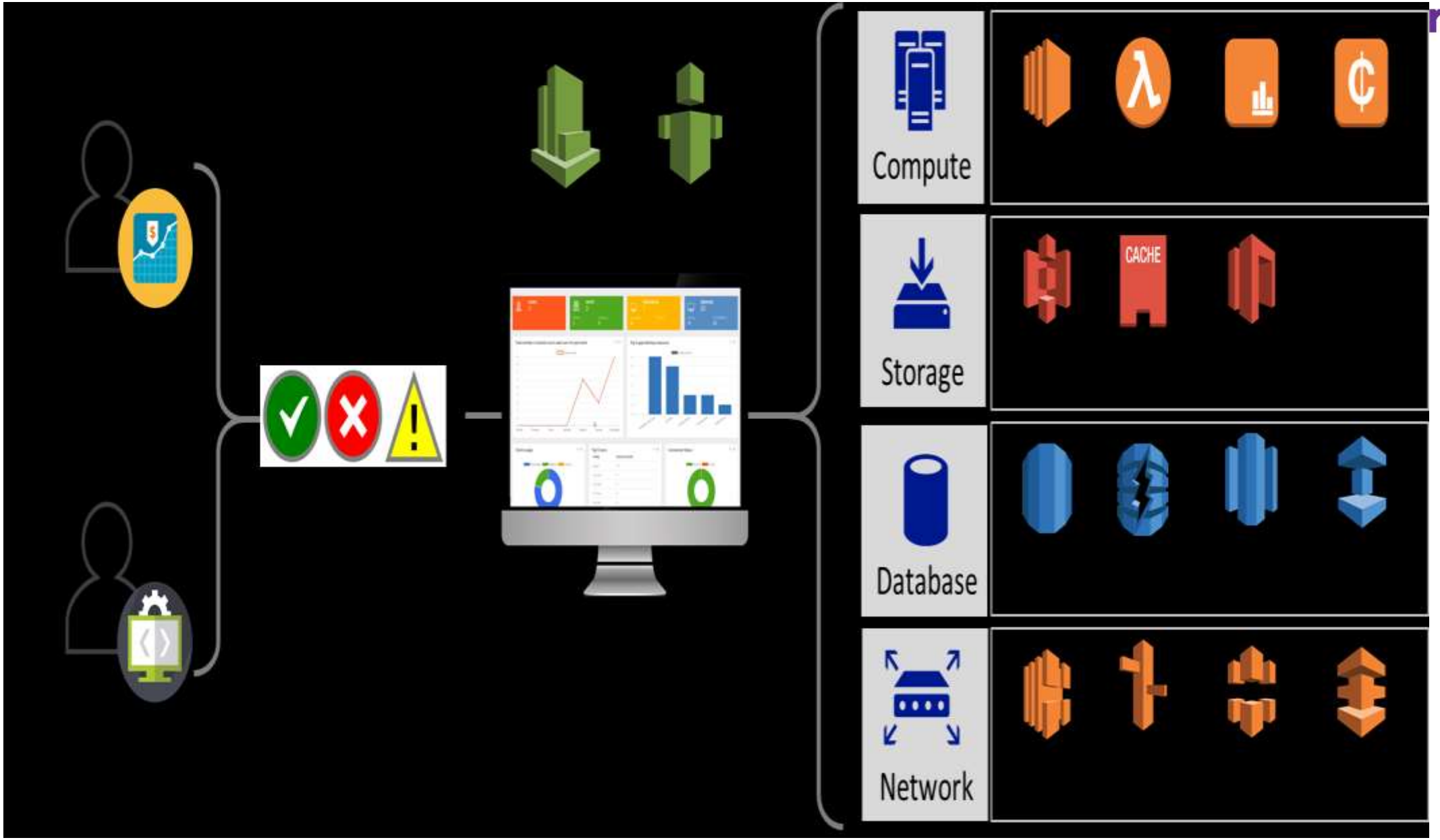
With a pay-for-value pricing model, modern applications reduce the cost of over-provisioning or paying for idle resources. By offloading infrastructure management, maintenance costs are also lower.

Performance optimization

- Amazon Web Services (AWS) offers various resources and services to help you build SaaS and PaaS solutions, however, the challenge is to achieve and maintain performance efficiency that has its own important share in delivering business value.
- This topic highlights some of the best practices for designing and operating reliable, secure, efficient, and cost-effective cloud applications that offers Performance efficiency.

There are two primary areas to focus on:

- **Select and Configure Cloud Resources for Higher performance**
- **Review and Monitor Performance**


Compute
Storage
CACHE
Database
Network

Code level optimization and security

What is optimization?

In computing, optimization is the process of **modifying a system to make some aspect of it work more efficiently or use fewer resources.**

For instance, a computer program may be optimized so that it executes more rapidly, or is capable of operating with less memory storage or other resources, or draw less power. The system may be a single computer program, a collection of computers or even an entire network such as the internet.

What does it mean to optimize code?

Code optimization is any method of **code modification to improve code quality and efficiency.**

A program may be **optimized** so that it becomes a smaller size, consumes less memory, executes more rapidly, or performs fewer input/output operations.

Levels' of code optimization

Optimization can occur at a number of 'levels':

1) Design level:

At the highest level, the design may be optimized to make best use of the available resources. **The implementation of this design will benefit from the use of suitable efficient algorithms and the implementation of these algorithms will benefit from writing good quality code**. The architectural design of a system overwhelmingly affects its performance. The choice of algorithm affects efficiency more than any other item of the design.

2) Compile level:

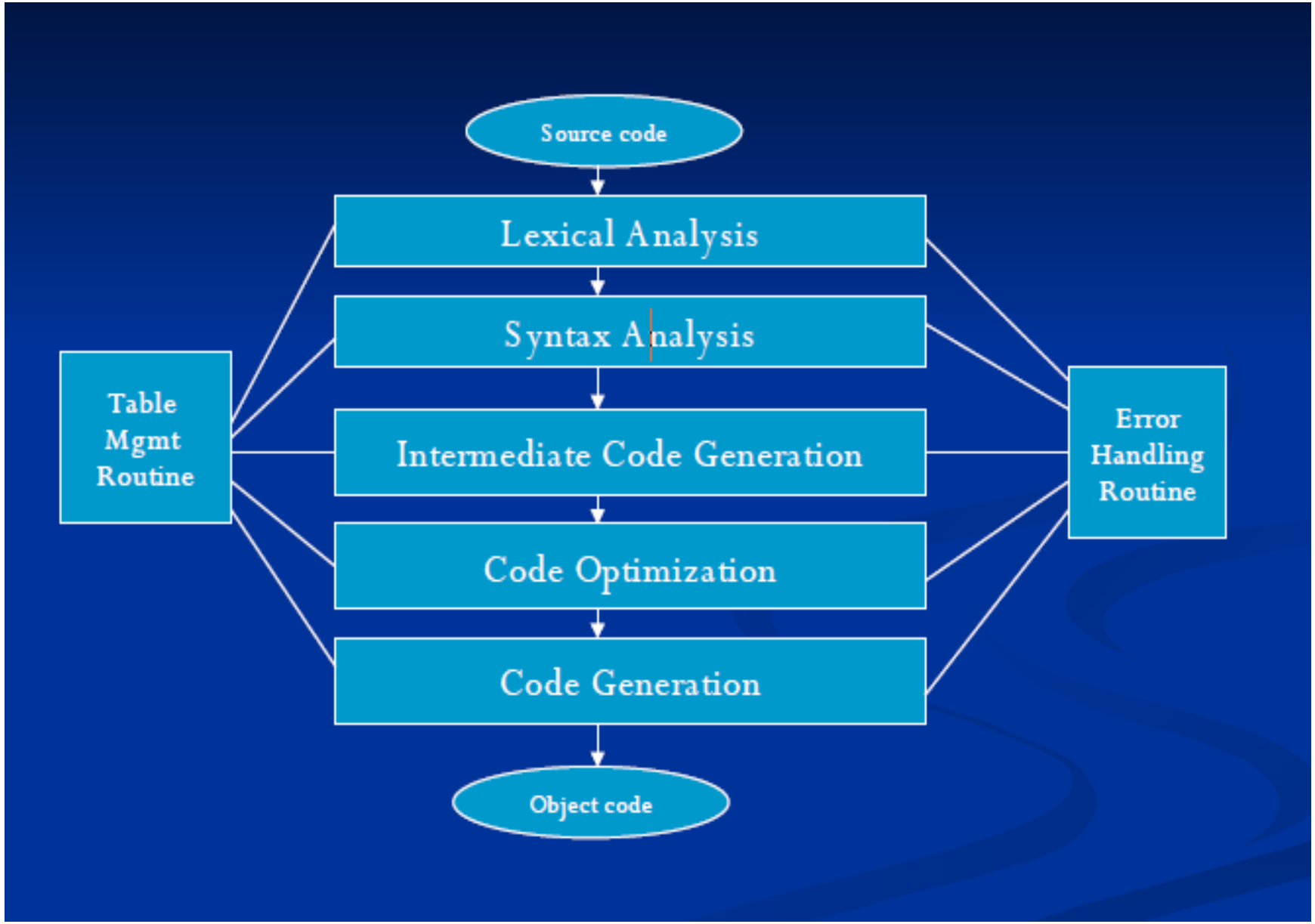
Use of an optimizing compiler tends to ensure that the executable program is optimized at least as much as the compiler can predict.

3) Assembly level:

At the lowest level, writing code using an Assembly language designed for a particular hardware platform will normally produce the most efficient code since the programmer can take advantage of the full repertoire of machine instructions. The operating systems of most machines has been traditionally written in Assembler code for this reason.

4) Runtime:

Just In Time Compiler and assembler programmers are able to perform runtime optimization.



Design of Compiler

When to optimize ?

Optimization is often performed at the end of the development stage since it

- reduces readability
- adds code that is used to improve the performance.

Criteria For optimization

- **An optimization must preserve the meaning of a program :**

  -Cannot change the output produced for any input

  -Can not introduce an error

- **optimization should, on average, speed up programs**
- **Transformation should be worth the effort**

Types of Code optimization

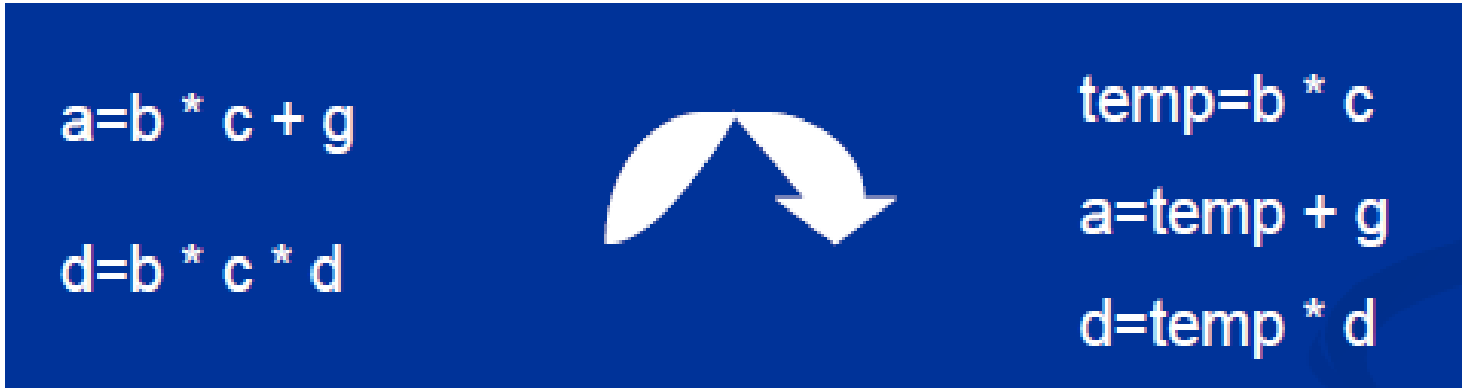
1) Common Sub-expression Removal

2) Dead Code Optimization

3) Loop Optimization

1) Common Sub expression elimination:

Common Sub expression elimination is a optimization that searches for instances of identical expressions (i. e they all evaluate the same value), and analyses whether it is worthwhile replacing with a single variable holding the computed value.



2) Dead code Optimization:

Dead Code elimination is a compiler optimization that removes code that does not affect a program. Removing such code has two benefits It shrinks program size, an important consideration in some contexts. It lets the running program avoid executing irrelevant operations, which reduces its running time.

Dead Code elimination is of two types

a) Unreachable Code

b) Redundant statement

a) Unreachable Code:

In Computer Programming, Unreachable Code or dead code is code that exists in the source code of a program but can never be executed.

b) Redundant Code:

Redundant Code is code that is executed but has no effect on the output from a program.

3) Loop optimization

- Loop optimization plays an important role in improving the performance of the source code by reducing overheads associated with executing loops.
- Loop Optimization can be done by removing:
  - Loop invariant
  - Induction variables

Code optimization is the process of improving a program to make it **run faster, use less memory, and utilize resources efficiently** without changing its output. It can be broadly classified into different types based on how and where optimization is applied.
Code optimization involves **improving program performance by reducing execution time and memory usage using various techniques at compile-time, run-time, and machine levels**.

Benefits of AWS Security

1) Keep your data safe:

The AWS infrastructure puts strong safeguards in place to help protect customer privacy. All data is stored in highly secure AWS data centers.

2) Meet Compliance Requirements:

AWS manages dozens of compliance programs in its infrastructure. This means that segments of your compliance have already been completed.

3) Save Money:

Cut costs by using AWS data centers. Maintain the highest standard of security without having to manage your own facility.

4) Scale Quickly:

Security scales with your AWS cloud usage. No matter the size of your business the AWS infrastructure is designed to keep data safe.

Cloud Manufacturing.

- **Cloud Manufacturing (CMfg)** is an advanced manufacturing paradigm that integrates **cloud computing, manufacturing resources, and digital technologies** to provide manufacturing services over the internet. It enables users to access manufacturing capabilities such as design, production, simulation, and testing as **on-demand services**, similar to how cloud computing provides IT resources.
- Cloud Manufacturing transforms traditional manufacturing systems into **service-oriented, networked, and intelligent environments**, where resources such as machines, software, and expertise are shared through a centralized cloud platform.
- In Cloud Manufacturing, physical manufacturing resources (machines, tools, production lines) and virtual resources (software, data, knowledge) are connected through the cloud. These resources are then **virtualized and offered as services**, allowing users to utilize them remotely without owning the actual infrastructure.
- **Key Components**
- **Cloud Platform** → Central system that manages and delivers services
- **Manufacturing Resources** → Machines, robots, tools, and production systems
- **Service Providers** → Organizations offering manufacturing services
- **Users/Clients** → Customers who access services on demand
- **Network & Communication Systems** → Enable connectivity and data exchange

Working Principle

- Manufacturing resources are digitized and connected to the cloud
- Resources are virtualized into services (e.g., machining-as-a-service)
- Users request services through the cloud platform
- The system allocates resources and executes tasks
- Results are delivered to users remotely

Features

- On-demand manufacturing services
- Resource sharing and collaboration
- Scalability and flexibility
- Real-time monitoring and control
- Integration with IoT, AI, and Big Data

Applications

- Product design and simulation
- Remote manufacturing and prototyping
- Supply chain management
- Smart factories (Industry 4.0)
- Mass customization

Advantages

- Reduced cost (no need for infrastructure ownership)
- Efficient resource utilization
- Faster product development
- Global accessibility
- Improved collaboration

Challenges

- Data security and privacy concerns
- High dependency on internet connectivity
- Integration complexity
- Standardization issues

Relation with Industry 4.0

Cloud Manufacturing is a key enabler of **smart manufacturing**, combining:

- Cloud Computing
- Cyber-Physical Systems (CPS)
- Internet of Things (IoT)
- Artificial Intelligence (AI)

Cloud Manufacturing is the **delivery of manufacturing resources and services over the cloud, enabling on-demand, flexible, and intelligent production systems**.

Management planning and control

Management Planning and Control are two fundamental functions of management that ensure organizational activities are **systematic, goal-oriented, and efficient**. They work together to guide an organization from setting objectives to achieving them effectively.

Management Planning

Planning is the process of **deciding in advance what to do, how to do it, when to do it, and who will do it**. It involves setting objectives and determining the best course of action to achieve those objectives. Planning provides direction and reduces uncertainty by preparing for future situations.

It includes activities such as forecasting, setting goals, developing strategies, and allocating resources. Effective planning helps organizations anticipate challenges, utilize resources efficiently, and coordinate efforts across different departments. Planning can be classified into different levels, such as strategic planning (long-term), tactical planning (medium-term), and operational planning (short-term).

Management Control

Control is the process of **ensuring that actual performance matches the planned objectives**. It involves monitoring activities, measuring performance, and taking corrective actions if deviations occur.

The control process typically includes:

- Setting performance standards
- Measuring actual performance
- Comparing performance with standards
- Taking corrective actions

Control ensures that organizational activities remain on track and helps in improving efficiency and effectiveness.

Relationship Between Planning and Control

Planning and control are two closely related and interdependent functions of management that work together to ensure the achievement of organizational goals. While planning determines **what is to be done and how it should be done**, control ensures that activities are carried out **according to the plan**.

Planning serves as the foundation for control. It establishes objectives, standards, and performance criteria against which actual results can be measured. Without planning, there would be no benchmarks for evaluation, making control ineffective. On the other hand, control provides feedback to planning by identifying deviations and suggesting corrective actions. This feedback helps in improving future plans and making them more realistic and effective.

The relationship between planning and control is often described as a **continuous cycle**. Planning sets the direction, and control monitors progress and ensures alignment with that direction. If any deviation occurs, control mechanisms take corrective actions, which may lead to adjustments in the original plan. Thus, control not only ensures the implementation of plans but also contributes to their refinement.

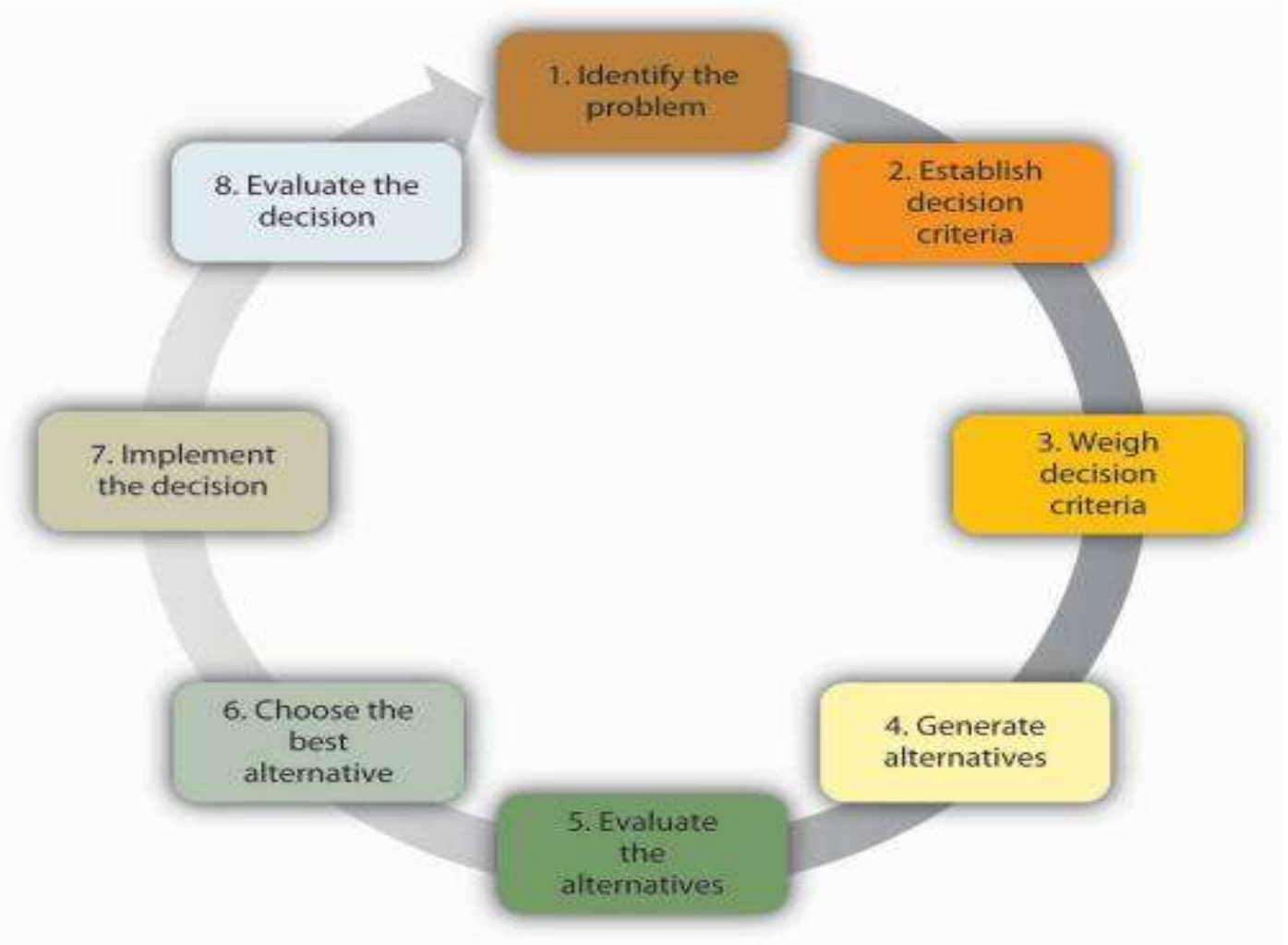
Both functions are essential for organizational efficiency. Planning without control may lead to poor execution, while control without planning lacks purpose and direction. Together, they ensure proper utilization of resources, minimize risks, and enhance overall performance.

Decision making models

- Decision-making models are systematic approaches or frameworks used to **analyze problems, evaluate alternatives, and select the best course of action**. These models help individuals and organizations make rational, efficient, and informed decisions, especially in complex situations.

Steps involved:

- Identify the problem
- Gather relevant information
- Generate alternatives
- Evaluate alternatives
- Select the best option
- Implement and review



Steps Involved in Decision Making Model

1. Identify the Problem

The first step in the decision-making process is to clearly recognize and define the problem. It involves understanding the gap between the current situation and the desired outcome. A well-defined problem ensures that efforts are directed toward solving the right issue rather than addressing symptoms.

2. Gather Relevant Information

Once the problem is identified, relevant data and information are collected from various sources. This may include internal data, external research, expert opinions, and past experiences. Accurate and sufficient information helps in making informed and rational decisions.

3. Generate Alternatives

In this step, possible solutions or courses of action are developed. Multiple alternatives are generated to ensure flexibility and creativity in problem-solving. Brainstorming and analytical techniques are often used to explore different options.

4. Evaluate Alternatives

Each alternative is carefully analyzed based on criteria such as feasibility, cost, benefits, risks, and impact. This step helps in comparing different options and understanding their advantages and limitations before making a choice.

5. Select the Best Option

After evaluation, the most suitable alternative is selected. The chosen option should provide the best possible solution to the problem while aligning with organizational goals and available resources.

6. Implement and Review

The selected decision is put into action, and its performance is monitored. Feedback is collected to assess whether the decision has effectively solved the problem. If necessary, corrective measures are taken to improve outcomes.

Smart factory Management and smart logistics

Smart Factory Management

Smart Factory Management refers to the use of advanced digital technologies to **monitor, control, and optimize manufacturing processes in real time**. It is a core concept of Industry 4.0, where factories become intelligent, connected, and highly automated systems.

In a smart factory, machines, sensors, and systems are interconnected through technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), and Cyber-Physical Systems (CPS). These technologies enable continuous data collection from machines and processes, which is then analyzed to improve efficiency, quality, and productivity. Smart factories can automatically detect faults, predict maintenance needs, and adjust production processes without human intervention.

Smart factory management focuses on **real-time decision-making**, flexible production, and resource optimization. It allows manufacturers to produce customized products efficiently, respond quickly to market demands, and reduce downtime and waste. However, it requires significant investment, advanced infrastructure, and skilled personnel.

Smart Logistics

Smart Logistics involves the application of digital technologies to **optimize the planning, implementation, and control of the flow of goods, information, and resources** across the supply chain. It ensures efficient movement of raw materials, products, and information from suppliers to manufacturers and finally to customers.

Technologies such as IoT, GPS tracking, Big Data analytics, and cloud computing are widely used in smart logistics. These technologies provide real-time visibility of shipments, improve inventory management, and enable better route planning and demand forecasting. Automation tools like autonomous vehicles, drones, and robotic warehouses further enhance efficiency and reduce human effort.

Smart logistics improves delivery speed, reduces operational costs, minimizes errors, and enhances customer satisfaction. It also enables better coordination between different stakeholders in the supply chain. However, challenges such as data security, system integration, and high implementation costs need to be addressed.

Man machine-computer interfacing

Man–Machine–Computer Interfacing (MMCI) refers to the interaction and communication between **humans (man), machines, and computer systems** to perform tasks efficiently and effectively. It is an essential concept in modern automation and Industry 4.0, where human operators work alongside machines and intelligent computer systems in a coordinated manner.

MMCI focuses on designing systems that allow humans to **control, monitor, and interact with machines through computer-based interfaces**. These interfaces act as a bridge, enabling smooth communication between the user and the system. The goal is to ensure that machines operate according to human instructions while also providing feedback to the user in an understandable form.

The system typically consists of three main components. The **human (operator)** provides input, makes decisions, and supervises operations. The **machine** performs physical tasks such as manufacturing, processing, or movement. The **computer system** processes data, controls machine operations, and facilitates communication between the human and the machine. Input devices such as keyboards, touchscreens, sensors, and control panels are used to send commands, while output devices like displays, alarms, and visual indicators provide feedback to the user.

In industrial applications, MMCI is commonly implemented through systems like Human-Machine Interface (HMI) and Supervisory Control and Data Acquisition (SCADA). These systems allow operators to monitor real-time data, control processes, and respond to system changes efficiently. For example, in a smart factory, an operator can monitor machine performance on a computer screen and adjust parameters remotely.

The importance of MMCI lies in its ability to improve **efficiency, safety, and decision-making**. It reduces human effort, minimizes errors, and enhances productivity by enabling better control over automated systems. However, designing effective interfaces is challenging, as it requires consideration of human factors such as usability, ergonomics, and cognitive load.

In conclusion, Man–Machine–Computer Interfacing is a critical aspect of modern industrial systems, enabling seamless interaction between humans, machines, and digital technologies for efficient and intelligent operations.

Content Beyond Syllabus

Digital Twins

- A **Digital Twin** is a virtual (digital) representation of a **physical object, system, or process** that is continuously updated using real-time data. It acts as a mirror of the real-world entity, allowing monitoring, simulation, analysis, and optimization without directly interacting with the physical system.

- In a digital twin system, sensors installed on physical equipment collect data such as temperature, pressure, speed, and performance. This data is transmitted to a digital model (twin), which replicates the behavior of the real system. The digital twin can then be used to **analyze performance, predict failures, and optimize operations**.

Key Components

- **Physical System** → Actual machine, product, or process
- **Sensors & IoT Devices** → Collect real-time data
- **Digital Model** → Virtual representation of the system
- **Data Processing & Analytics** → Analyze data using AI/ML
- **Communication Network** → Connects physical and digital systems

Working Principle

- Sensors collect real-time data from the physical system
- Data is transmitted to the digital model
- The digital twin simulates system behavior
- Analysis and predictions are performed
- Insights are used to optimize the real system

Challenges

- High implementation cost
- Data security and privacy concerns
- Complex data integration
- Requires advanced technologies and expertise

Applications

- Smart manufacturing (monitoring machines)
- Predictive maintenance in industries
- Aerospace and automotive design
- Smart cities and infrastructure
- Healthcare (patient monitoring models)

Advantages

- Real-time monitoring and control
- Predictive maintenance (reduces downtime)
- Improved design and performance
- Cost and time savings
- Risk-free testing and simulation

Relation with Industry 4.0

Digital Twins are a key technology in Industry 4.0, integrating:

- IoT (data collection)
- Big Data (data analysis)
- AI/ML (prediction and optimization)
- Cloud Computing (data storage and processing)

Blockchain in Industry 4.0

Blockchain is a decentralized digital ledger technology used to **securely record, store, and share data across multiple systems without the need for a central authority**. In the context of Industry 4.0, blockchain plays a vital role in ensuring **data security, transparency, traceability, and trust** among interconnected systems such as IoT devices, smart factories, and supply chains.

Industry 4.0 involves highly connected systems where machines, sensors, and software continuously exchange data. However, this connectivity introduces challenges such as **data tampering, cyber threats, and lack of trust between stakeholders**. Blockchain addresses these issues by providing a **distributed and immutable record of transactions**, where each piece of data is securely stored in blocks and linked in a chain.

Each transaction in a blockchain is:

- **Verified by multiple participants (nodes)**
- **Encrypted for security**
- **Immutable (cannot be altered once recorded)**
- This ensures that industrial data remains **accurate, secure, and transparent**.

Working Principle

- Data (transaction/event) is generated (e.g., sensor data, production data)
- The data is grouped into a “block”
- The block is verified by network participants using consensus algorithms
- Once verified, the block is added to the blockchain
- The data becomes permanent and accessible to authorized users

Applications in Industry 4.0

1. Supply Chain Management

- Tracks movement of materials and products from supplier to customer
- Ensures **transparency and traceability**
  Example: Tracking origin of raw materials in manufacturing

2. Smart Contracts

- Self-executing contracts with predefined conditions
- Automatically execute actions when conditions are met
  Example: Automatic payment after delivery confirmation

3. Industrial IoT (IIoT) Security

- Secures communication between connected devices
- Prevents unauthorized access and data tampering

4. Quality Control and Certification

- Stores product quality records permanently
- Ensures authenticity and compliance

5. Asset and Data Management

Maintains secure records of machines, tools, and maintenance history

Key Features

- **Decentralization** → No single controlling authority
- **Transparency** → All transactions are visible to authorized users
- **Immutability** → Data cannot be changed once recorded
- **Security** → Uses cryptographic techniques
- **Traceability** → Easy tracking of data history

Advantages

- Enhanced data security and trust
- Reduced fraud and data manipulation
- Improved supply chain transparency
- Automated processes through smart contracts
- Better collaboration between stakeholders

Challenges

- High implementation cost
- Scalability issues (handling large data volumes)
- Integration with existing systems
- Energy consumption (in some blockchain types)
- Lack of standardization