Process automation
Introduction

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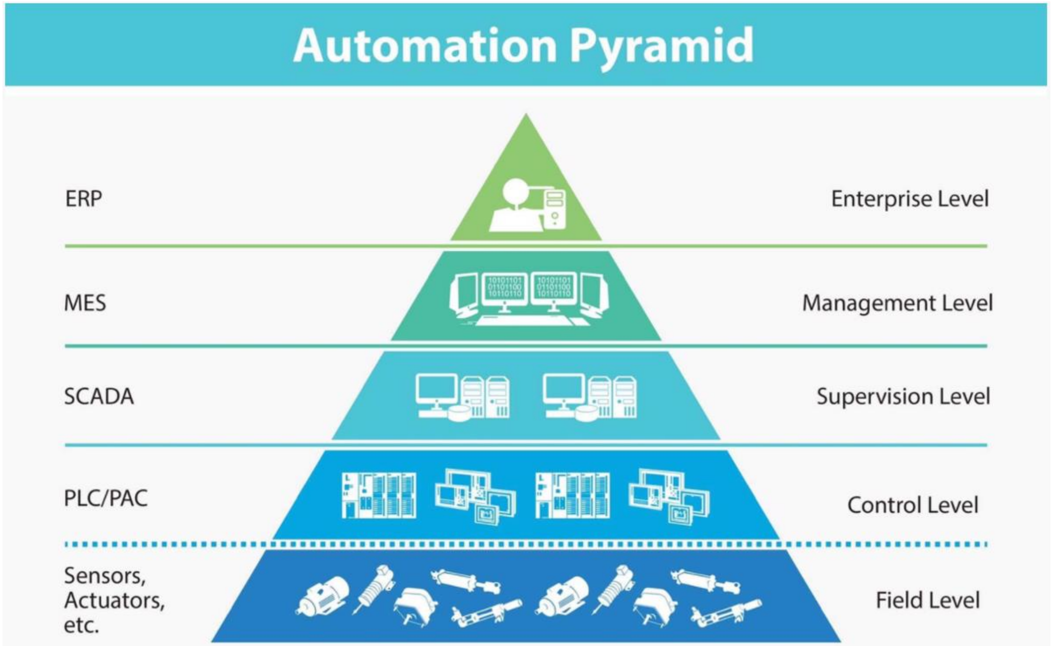
Outline

- Introduction to process automation
- Process control
- Systems and processes
- Elements of control systems
- Historical overview of automation
- Hierarchy of control systems
- The role of computer systems in control

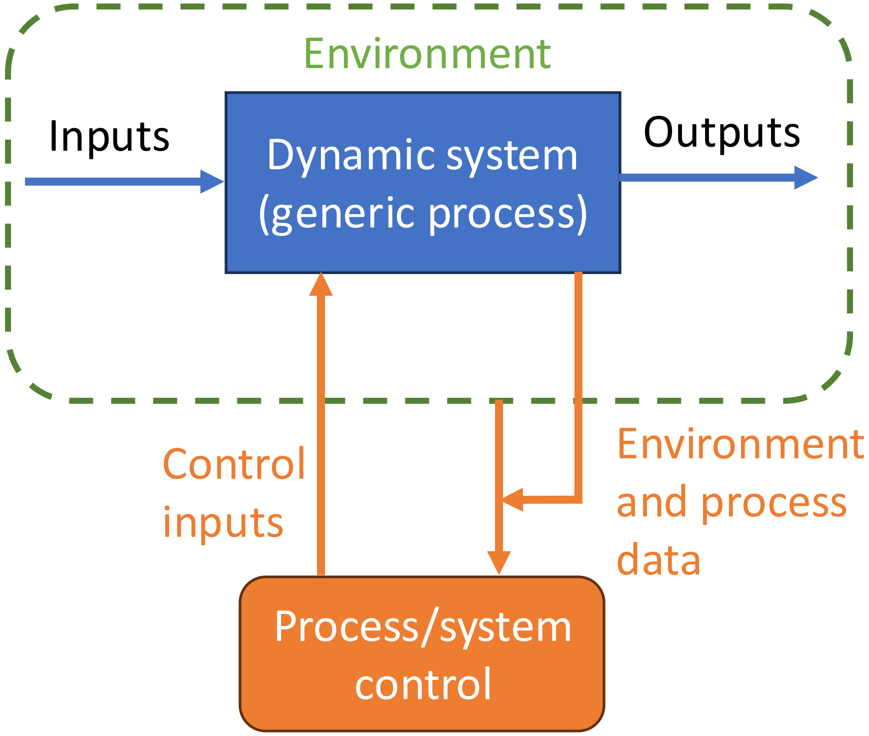
Process automation - subject content

- Introduction
  - System, process, management, hierarchy of management systems
- Management systems
  - Programmable Logic Controllers: Architecture and Programming
  - Man-machine communication interfaces, SCADA/HMI systems
  - Sensor and actuator systems
  - Industrial communication networks
  - Software application interfaces: OPC
  - Higher management systems: MES + ERP
- Selected chapters
  - Visit to the factory/warehouse, invited lectures
  - Introduction to electrical wiring diagrams
  - Management systems in companies and systems engineering
  - Errors in management systems and corrective actions
  - System accessibility and security
  - Smart factory



Process control

- Control is the process by which we influence the operation of a system with the aim of achieving a set goal.
- **System**
  - A system is a collection of interconnected, functioning elements that interact with each other and with the environment.
  - Connection implies the exchange of matter, energy, or information.
- **Process**
  - A process is the sequence, procedure, or occurrence that causes a change in the state of the system.
  - An important component is time, which affects the change in the state of the system.
  - A technical process is a collection of interdependent sequences within a system that cause the transformation/movement/storage of matter/energy/information.
- **Control**
  - Control system (process = control algorithm)
  - Manual control, automatic control, computer-based control



Advantages of Automatic Control

- **Productivity**
  - Rapid response to market demands
  - Support in decision-making
- **Quality**
  - Product tracking
  - Compliance with regulations (e.g., in pharmaceuticals)
- **Energy Consumption**
  - Smart scheduling of product manufacturing
  - Combustion efficiency
- **Ecological Improvements**
- **Efficient use of raw materials**
  - Less waste
  - Machinery: thinner profiles, etc.
- **Sociological Improvements**
  - Better working conditions
  - Less monotonous work

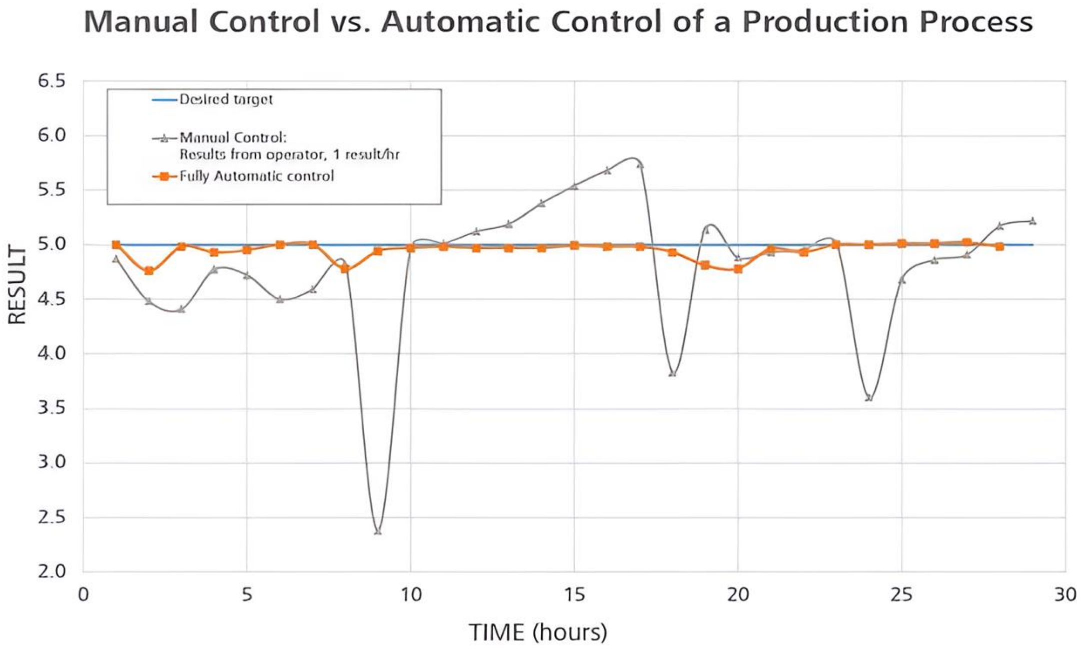


Image source: https://www.metrohm.com/fr_fr/decouvrir/blog/20-21/to-automate-or-not-to-automate--advantages-of-pat---part-1.html

Systems and processes: classification

Natural Systems	**Artificial Systems**
Result of natural processes	Result of human creation
Examples: human, galaxy	*Examples: car, school*
Physical Systems	**Conceptual Systems**
Arrangement of matter, energy, and space	Organization of ideas
Examples: animal, house	*Examples: circuit design, electoral system*
Static Systems	**Dynamic Systems**
Structure without activities	Structure with activities
Examples: bridge, chair	*Examples: generator, economy*
Open Systems	**Closed Systems**
High interaction with the environment	Low interaction with the environment
Examples: plant, company	*Examples: ship, mountain hut/shelter*
Simple Systems	**Complex Systems**
Small number of components, simple connections	Large number of components, complex connections
Examples: atom, molecule	*Examples: human, society*

Systems and Processes: Classification of Processes

1. Classification Based on the Transformed Element

- **Material Processes**
  - Transformation of matter
- **Energy Processes**
  - Generation and conversion of energy
- **Information Processes**
  - Processing, transmission, and storage of data

2. Classification Based on the Method of Material Processing

- **Transformative Processes**
  - Physical and chemical transformation of matter
- **Manufacturing Processes**
  - Bending, cutting, assembling

3. Classification Based on the Change of State

- **Production Processes**
  - Creation of a substance or product
- **Distribution Processes**
  - Transfer of matter, energy, or information from one place to another
- **Storage Processes**
  - Storage of matter, energy, or information

Systems and Processes

- Classification Based on the Type of Process Variables

  - Discrete, Stepwise

  - Continuous

  - Batch, Lot-based

https://fortress-safety.com/industry-expertise/automotive-manufacturing/body-in-white-assembly-line-safety/
https://www.flaticon.com/free-icon/oil-factory_5729626
https://slcontrols.com/continuous-manufacturing-vs-batch-manufacturing-in-the-pharmaceutical-industry/

Systems and Processes

Classification Based on the Type of Process Variables

- **Discrete Processes**
  - Involve individual objects that are transformed, assembled, transported, or stored while retaining their identity.
  - Examples include manufacturing from components, packaging, and warehousing.
  - The process can be described by:
    - Well-defined states
    - Clear transitions between them, triggered by various events
  - Discrete processes are usually reversible but not monotonic:
    - The system can return to a previous state, but not always by simply reversing the trigger.
    - Reversal may only be possible through several other states.
    - Example: An elevator can return to the ground floor, but not just by releasing the button that called it.
  - Discrete processes can be represented as finite automata.
  - **Main task: control (commanding)**.

Systems and Processes

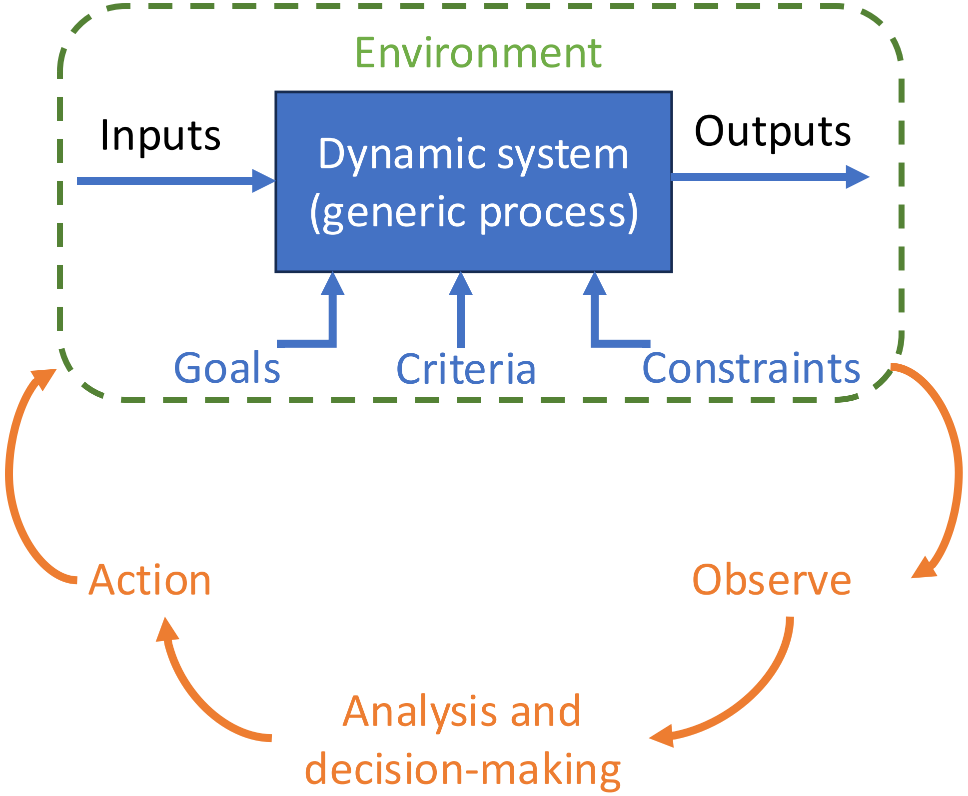
Classification Based on the Type of Process Variables

- **Continuous Processes**
  - Matter, energy, or information flows continuously through the process.
  - The process operates continuously, except for phases of startup, shutdown, or changes in mode.
  - Examples: cement production, paper manufacturing, rubber profiling.
  - **Main task: regulation.**
- **Batch Processes**
  - A combination of continuous and discrete procedures that are highly intertwined.
  - Typically a sequence of several continuous processes.
  - Processing occurs in a finite quantity of material known as a batch or lot.
  - Examples: chemical industry, pharmaceuticals, food industry, rubber industry.
    - Example tasks: filling a mixer, mixing, emptying the mixer.
  - **Main task: control (commanding).**

Elements of control

- **Goals**
  - The task of the system that we aim to control
- **Criteria - Quality of Control**
  - Speed, safety, cost, enjoyment
- **Constraints**
  - External (regulations, requirements)
  - Internal (system capacity)

Observation: Acquiring information
Thinking and Decision-Making: Choosing actions
Action: Methods and means



Elements of control

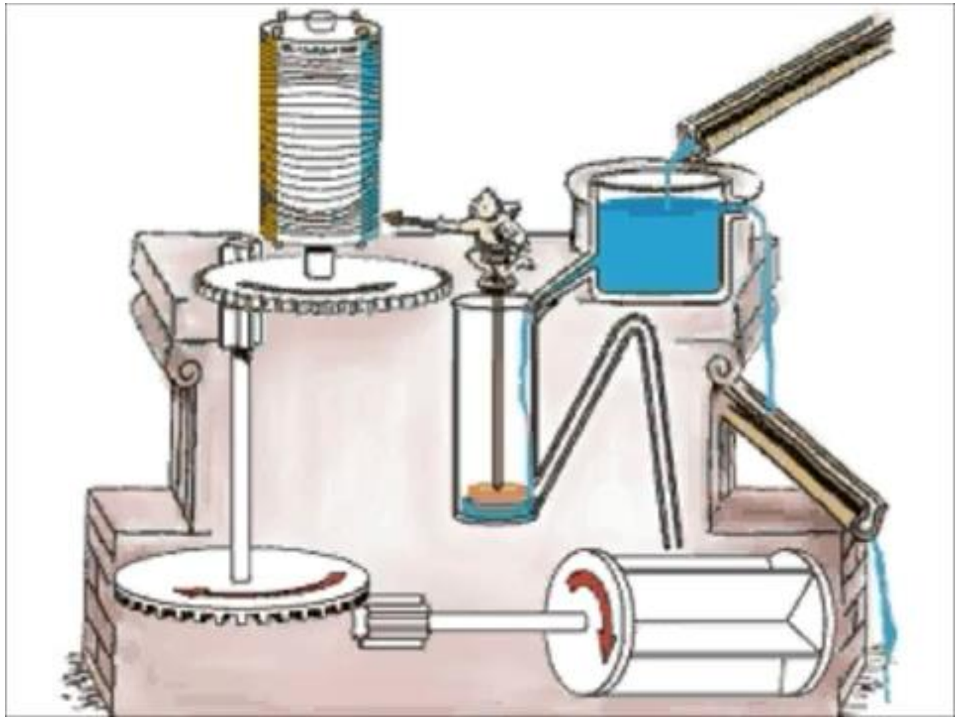
Observation
- Measurement system
- Sensor + measurement transducer
- Standardized signals, buses, protocols

Thinking and Decision-Making
- Control algorithms
- Examples:
    - Microcontroller, embedded systems
    - Programmable logic controller (PLC)
    - Industrial regulator
        - Today, the line between controllers and regulators is blurred
    - Process computers

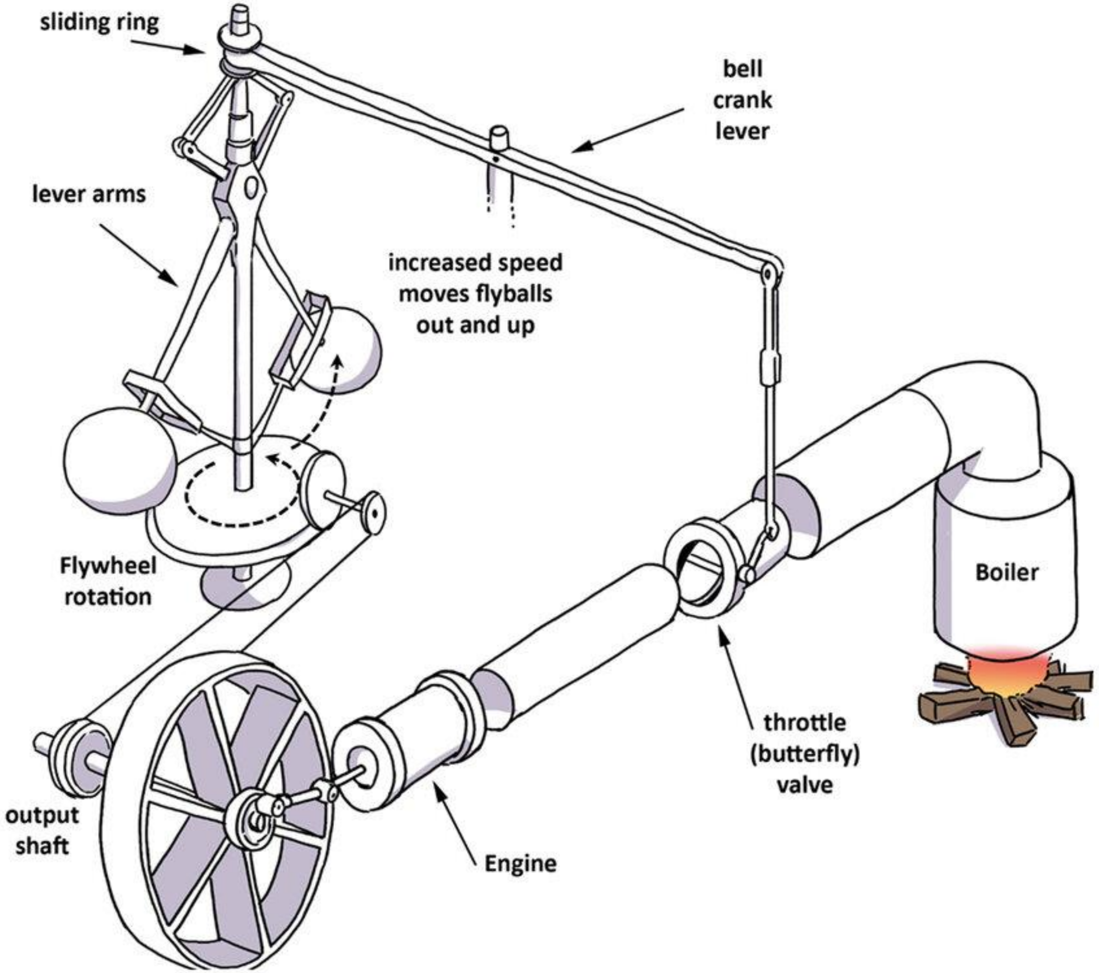
Action
- Execution system
- Actuator + final control element
- Standardized signals, buses, protocols
- Motors, valves, pneumatic cylinders

Historical overview

- Control is as old as dynamic technical systems:
- **Prehistoric Era**: Control was performed by humans.
- **Antiquity**: Automatic regulation of water flow (Ctesibius's water clock "clepsydra").
- **Modern beginnings**:
  - Automatic regulation of temperature in egg incubators (1620).
  - Watt's centrifugal governor (1788).



Watt's centrifugal governor (1788)



The Centrifugal Governor was invented by James Watt. He had recently developed his new steam engine and required a way

Historical overview

1800: The concept of interchangeable (standardized) parts

- First application: in gun production
- The beginning of mass production

1868: Intuition and Inventions

- Maxwell's mathematical description of the centrifugal governor
- Vyshnegradski: Theory of regulators

1913: Automatic assembly line for cars, Ford

Before World War II

- USA: Development of the telephone system and electronic amplifiers, description in the frequency domain
- Feedback amplifiers (Bode), system stability (Nyquist)
- Russia: Description in the time domain

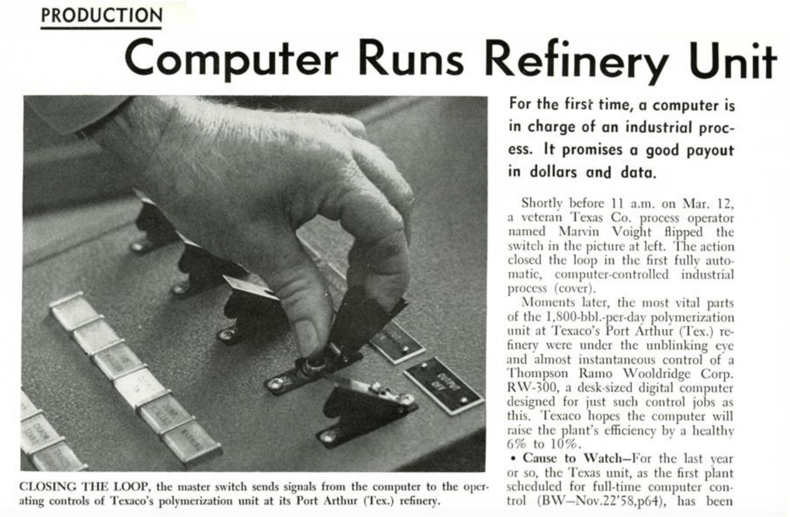
World War II

- Automatic pilots, ballistic systems, radar antennas
- Control becomes its own discipline

Historical overview

1960 – 1980

- First process computer, Texaco, Port Arthur, USA, 1959
- Emergence of the first programmable robots
- Flourishing of control theory, differential equations



PRODUCTION

Computer Runs Refinery Unit

For the first time, a computer is in charge of an industrial process. It promises a good payout in dollars and data.

Shortly before 11 a.m. on Mar. 12, a veteran Texas Co. process operator named Marvin Voight flipped the switch in the picture at left. The action closed the loop in the first fully automatic, computer-controlled industrial process (cover).

Moments later, the most vital parts of the 1,800-bbl.-per-day polymerization unit at Texaco's Port Arthur (Tex.) refinery were under the unblinking eye and almost instantaneous control of a Thompson Ramo Wooldridge Corp. RW-300, a desk-sized digital computer designed for just such control jobs as this. Texaco hopes the computer will raise the plant's efficiency by a healthy 6% to 10%.

• **Cause to Watch**–For the last year or so, the Texas unit, as the first plant scheduled for full-time computer control (BW–Nov.22'58,p64), has been

CLOSING THE LOOP, the master switch sends signals from the computer to the operating controls of Texaco's polymerization unit at its Port Arthur (Tex.) refinery.

1980 – Present

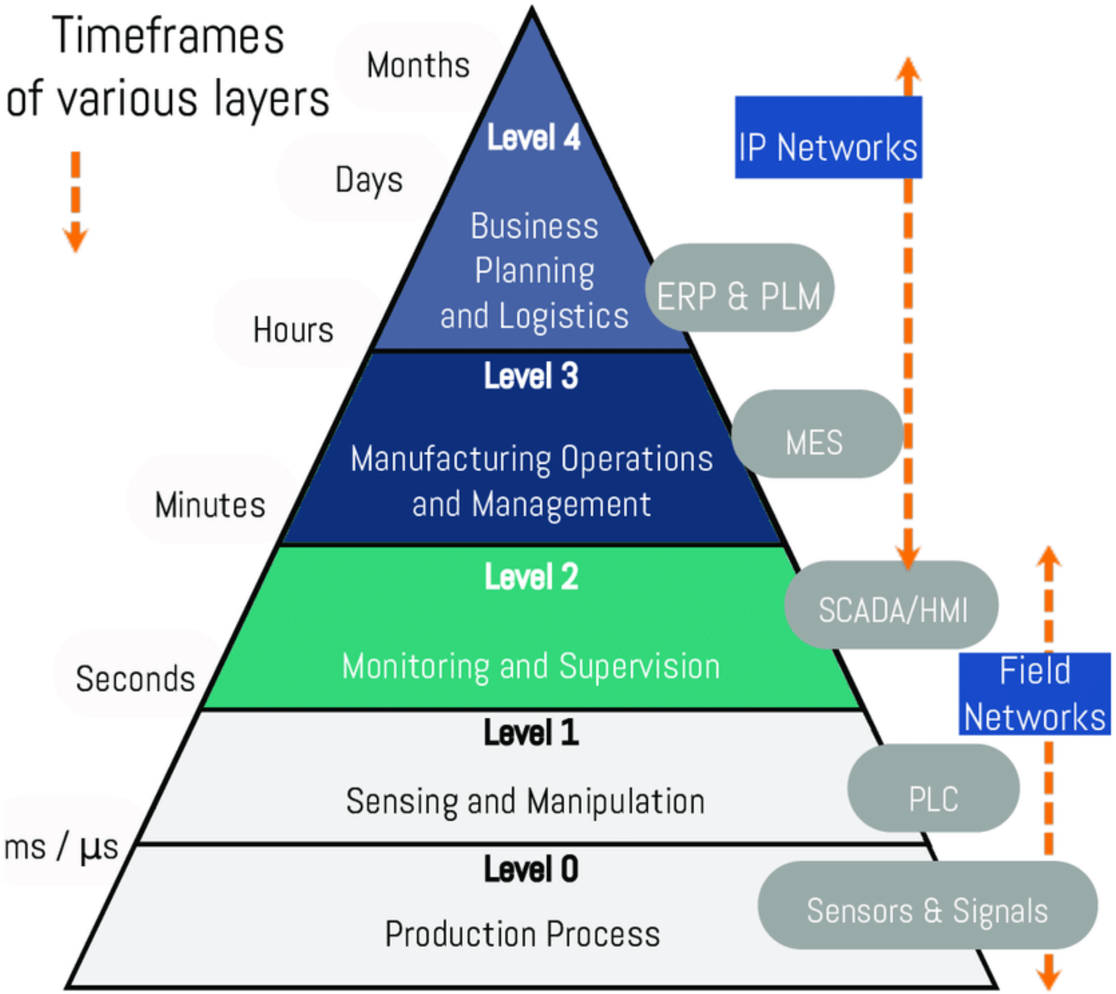
- Study of robust control systems
- Focus on automation (cost reduction)
  - Microprocessors, microcomputers, replacement of analog systems with digital ones
- Feedback control in automobiles (1995)
- Development of electronics and computer technology
- Exploration of Mars with autonomous vehicles

Hierarchy of control systems

- In the architecture of control systems, there are very few differences even though applications vary significantly among themselves.
- The reasons why, for example, the control system of a hydroelectric power plant is not used for the automation of a brewery are mainly due to:
  - Existing relationships between customers and clients
  - Specific requirements (e.g., explosion-proof areas)
  - Regulations (e.g., FDA - Federal Drug Administration)
  - Tradition

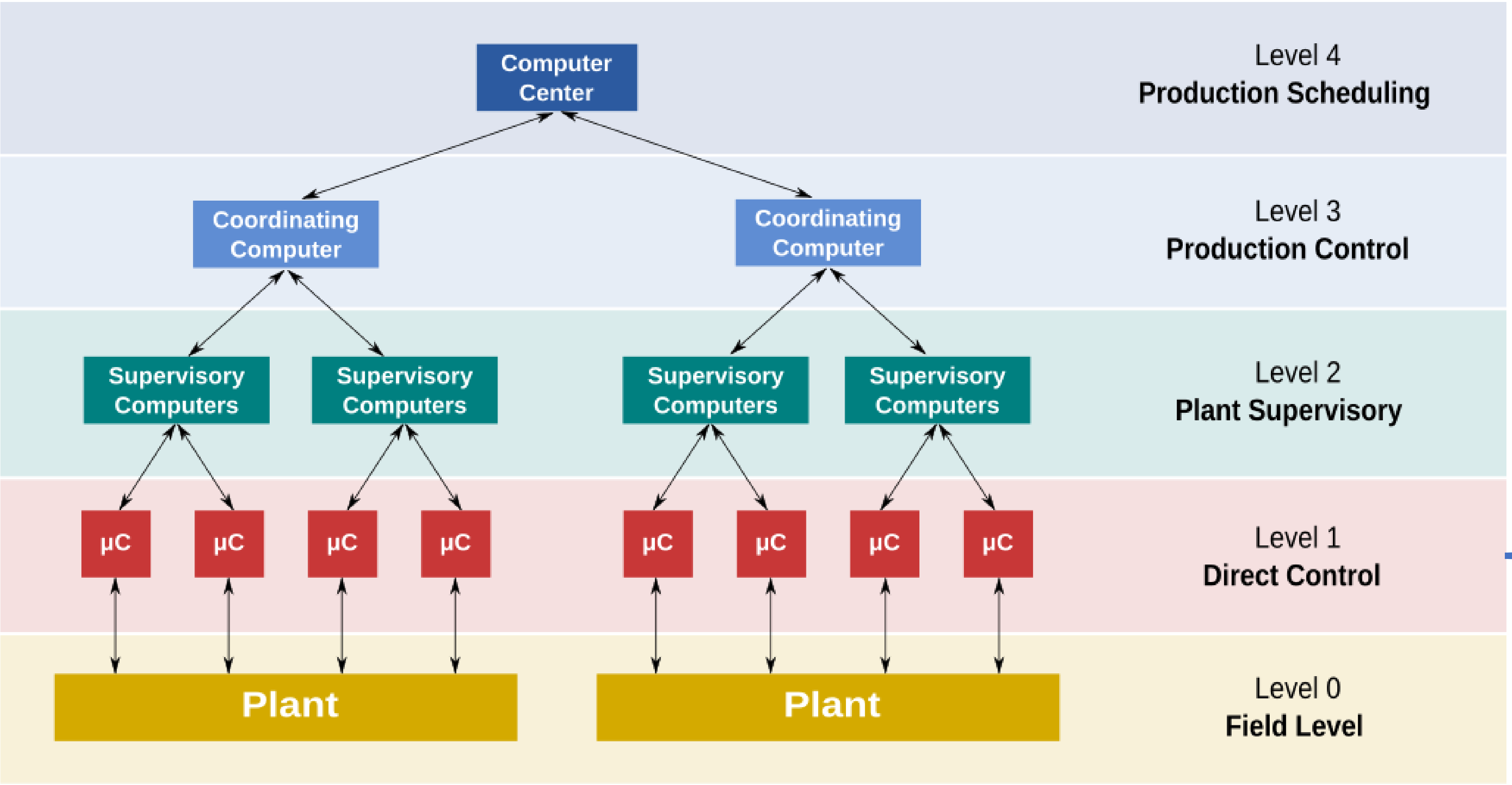
Hierarchy of control systems: ANSI/ISA 95 Standard

- **Integration of Business Information Systems and Control Systems**
- The standard provides terminology and best practices for interface development.
  - Unified communication between customers and clients.
- Suitable for all systems.
- Consistently lists control models and the functionalities of individual applications.



Source: https://learn.umh.app/lesson/introduction-into-it-ot-automation-pyramid/

Hierarchy of control systems: ANSI/ISA 95 Standard



- Business-level decisions
- Operational process management
- High-level supervision and control
- Plant control
- Unit control
- Field-level devices
- Sensors and actuators
- Basic technology

Hierarchy of control systems

Sensing and Control (Layer 1)

- **Sensors and Actuators**
  - Installed on basic technology
- **Field**
  - Data acquisition from measuring elements
  - Digitization, data transmission
  - Activation of executive elements
- **Control Units**
  - **Measurement**
    - Sampling, conversion, processing, adjustment
  - **Control**
    - Control and regulation
    - Adjusting reference values and parameters
  - **Requirements**
    - Sequence compliance
    - Protection and interlocking (mutual dependencies)
- **Plant Control**
  - Control of an independent part of the system
  - Coordination of individual units
  - Setting reference values and parameters
  - Control of multiple units as a whole

Monitoring and Supervision (Layer 2)

- Managing and monitoring processes
- Data acquisition, logging
- Process database
- Optimization, real-time operations
- Control room

Production: Operations and Management (Layer 3)

- Resource management (labor, raw materials, products)
- Production management (task scheduling, process oversight)
- Coordination of activities across different locations
- Quality control
- Maintenance (preventive, corrective, predictive)
- Warehousing

Business Management and Logistics (Layer 4)

- Strategic decision-making
- Procurement, sales
- Planning, analysis, finance
- Personnel, legal services, documentation

Hierarchy of control systems: data processing

- **Lower Layers (0 and 1)**
- A large number of simple data
- Processing is trivial
    - Previously done with hardware,
    - Now computer-controlled, except for safety systems during maintenance and startup
- Time requirements are paramount: quick response—typical times range from 0.1 ms to 1 s

Monitoring and Supervision (Layer 2)

- Presentation of complex data to the operator
- Decision support (expert systems) and maintenance
- Knowledge of the system's knowledge base
- Response times: 100 ms to minutes

Higher Layers (3 and 4)

- As we move up the control hierarchy, we have fewer but more complex data (summary reports)
- Processing and decision-making are complex (use of models)
- Increasingly relaxed time requirements (minutes, hours, days, months)

The role of computer systems in control

- Mutual Integration
- Ensuring up-to-date and accurate information at layers, between layers, and in communication with the environment
- Ability to modify the system
- Ensuring reliable operation
- Emergency operation capability
- Data management (protection, archiving)

Sensing and Control (Layer 1)

- Data acquisition
- Preprocessing
- Control and regulation
- Data transmission between operators and the system
- Displaying the process state
- Event logging
- Protection and interlocking—preventing hazardous operations

The role of computer systems in control

Example of a Work Process:

- **Business Management**
  - Order acceptance
  - Raw material ordering
  - Product sales

Production

- **Raw Material Reception**
  - Entry into the database and isolation
  - Sampling
  - Release and storage
- **Production**
  - Transfer from storage
  - Allocation to machines
  - Machine setup
  - **Production line control**
  - Packaging
  - Storage (isolation)
- **Shipping**
  - Sampling and release
  - Transfer from storage
  - Dispatch

Process automation
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