PLC e SCADA, Sect.1

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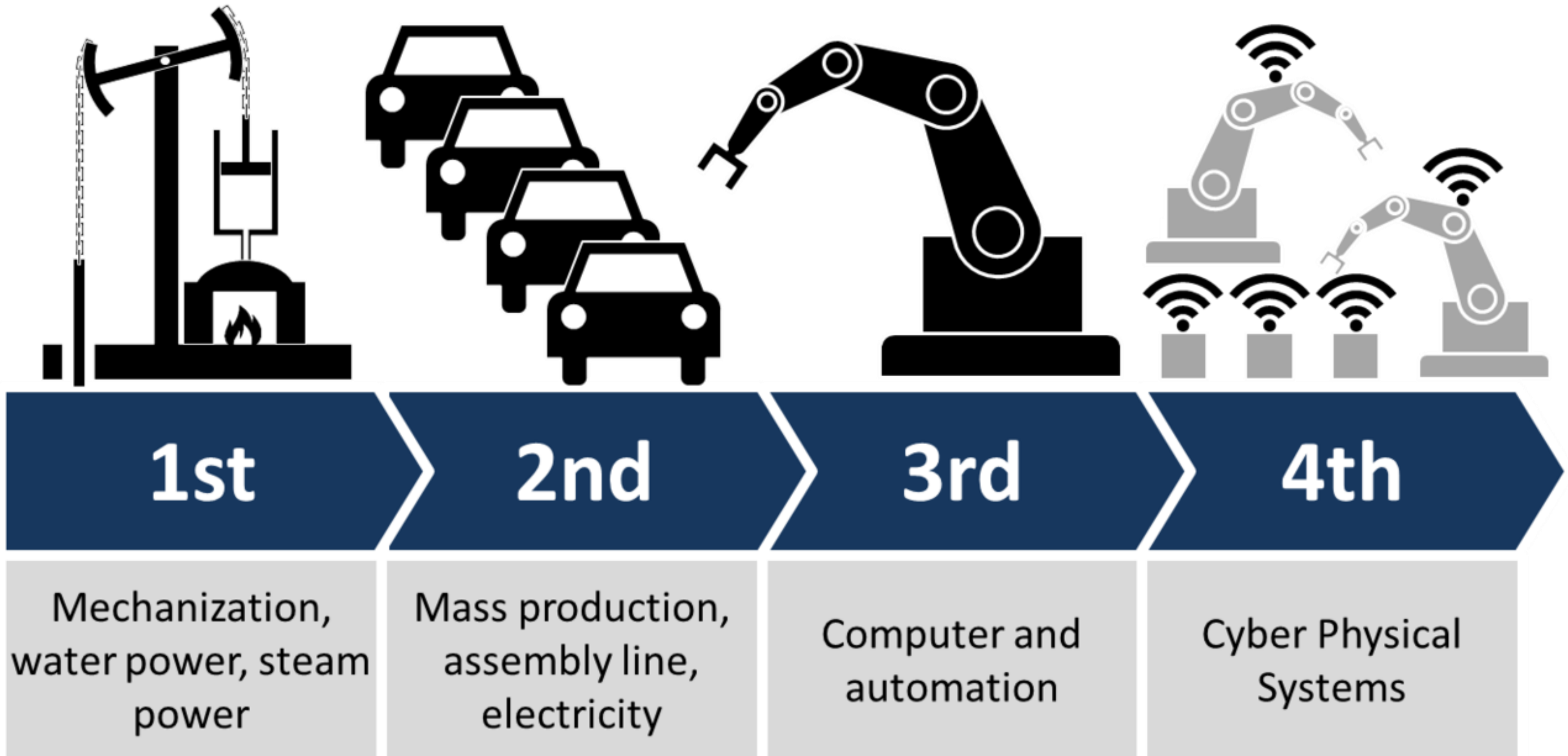
Factory automation and industrial process control

Industrial revolutions



- **Introduction of machines (steam powered) in chemical and iron processes, 1830**
- **Technological revolution, use of electricity, machine tool, production line, 1900**
- **Digital revolution, digital electronics, computer, ICT, 1980**
- **Total computerization of manufactoring, 2012 Germany**
  - **Industry 4.0 Workgroups) Smart factory, Real environment, economic environment, human beings and work, technology factor**

Automation goals

- **Process Optimisation**
  - **Energy, material and time savings**
  - **Quality improvement and stabilisation**
  - **Reduction of waste, pollution control**
  - **Compliance with regulations and laws, product tracking**
  - **Increase availability, safety**
  - **Fast response to market**
  - **Connection to management and accounting**

- **Asset Optimisation (management of production means)**
  - **Automation of engineering, commissioning and maintenance**
  - **Software configuration, back-up and versioning**
  - **Life-cycle control**
  - **Maintenance support**

- **Personal costs reduction**
  - **Less «heavy» human work**
  - **More technicians and engineers (machines to be managed)**
  - **More vendors (more product to be sold) and financial**

Digital revolution and data quantity in plants

- **Power Plant 30 years ago**
  - **100 measurement and action variables (called "points")**
  - **Analog controllers, analog instruments**
  - **One central "process controller" for data monitoring and protocol.**

- **Coal-fired power plant (Centrale a carbone) today**
  - **10'000 points, comprising**
    - **8'000 binary and analog measurement points**
    - **2'000 actuation point**
  - **1'000 micro-controllers and logic controllers**

- **Electricity distribution network**
  - **100’000 - 10’000’000 points**
  - **information flow to the personal: > 5 kbit/s**
  - **human processing capacity: about 25 bit/s**
  - **without computers, 200 engineers (today: 3)**

Data reduction and processing (e.g. Key Performance Indicators) is necessary to operate plants

Definitions

- **Automation (automazione)**
  - **Science and Technologies aiming the replacing of human work through machines**
  - **Automation goals**
    - ✓ **Reduction of personal costs**
    - ✓ **Enforcement of safety and availability**
    - ✓ **Processing of the information flow**
    - ✓ **Many sensors to save energy, materials, human work and to improve quality, accuracy and precision**

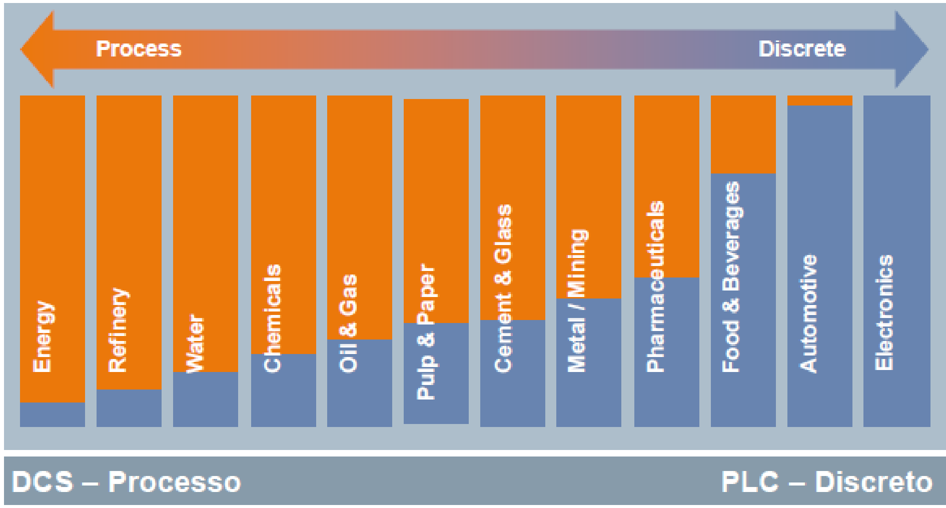
- **Automation* (automatizzazione)**
  - **Repetitive sequence to perform a job**
  - **Replacement of conscious activity by reflexes (more speed, open loop)**
  - **Automation* goals**
    - ✓ **Reduction of time (that is more product, that is less expensive product)**
    - ✓ **Simplification of processes**

- **Automation, Automation* and Henry Ford**
  - **Henry Ford founded «Ford Motor Company» in 1903 (Michigan) introducing methods for large-scale manufacturing (Tempi Moderni, Fordismo, mass-produced car Model-T, 1908)**

Definitions

- **Factory Automation (or factory automation infrastructure)**
  - **Repetitive sequence to perform a job used in the production of goods.**
  - **General engineering and manufacturing environment that is defined by its ability to manufacture and/or assemble goods mainly by <u>machines</u>, integrated assembly lines, and <u>robotic arms</u>.**
  - **Manufactoring speed, lean production and diagnostic are mandatory (more speed, more product in the same time, less expensive product)**

- **Industrial Processes (or process automation)**
  - **A systematic series of mechanical or electrical or physical or chemical operations that produce or manufacture or distribute something on a <u>very large scale</u>, often in <u>hazardous areas</u>.**
  - **Chemical processes, Heat processes and Electrolysis, Cutting (laser, water,..), Stamping, Forging, Casting, Moulding, Welding, Separation**
  - **Safety is mandatory, as well as «green behaviour»**
  - **Many sensors, closed control loop**



Automation Systems, world players

Company	Local	Major mergers
ABB	CH-SE	Brown Boveri, ASEA, CE, Alfa-Laval, Elsag-Bailey
Alstom-Schneider-Areva	FR	Alsthom, GEC, CEGELEC, Telemécanique,..
Bosch	DE	Rexroth
Emerson	US	Fisher Rosemount
General Electric	US	
Hitachi - Yokogawas	JP	
Honeywell	US	
Invensys	UK	Foxboro, Siebe, BTR, Triconex,…
OMRON	JP	
Pepperl&Fuchs	DE	
Rockwell Automation	US	Allen Bradley, Rockwell,..
Schneider Electric	DE	Modicon,..
Siemens	DE	Plessey, Landis & Gyr, Stäfa, Cerberus,..

€ 80 Mld / year business in the world (€ 20 Mld in Europe)
(depends on viewpoint),
growing 5 % annually

Courtesy of Prof. Kirmann, EPFL

Definitions

- **Industrial plant**
  - **The object of automation (motors, machines, pipes…), also known as "the field". Electromechanical, chemical, mechanical, hydraulics, …primary technologies or components of heavy industry**

- **General contractor (contraente) -> plant**
  - **organizes the suppliers of the different areas (parts and production or assembling lines) of the plant**

- **Supplier (fornitore di parti di impianto) -> area**
  - **organizes the EOM supplying machines, robots, and cells**

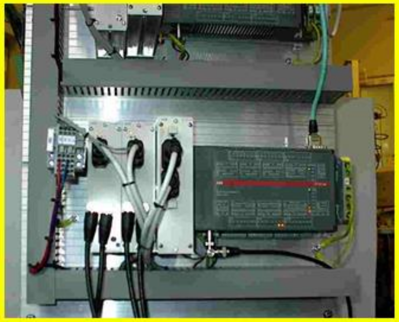
- **OEM (Original equipment manufactorer) -> cell**
  - **Buys components from third parts and assemblies**

- **Turkey plant ("impianto chiavi in mano")**
  - **The client just hires consultants to supervise the general contractor**

Definitions

Four distinct businesses

primary technology (mechanical, electrical)	automation equipment (control & command)	engineering & commissioning	maintenance & disposal



…seldom offered by the same company

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Life-phases of a plant (example: rail vehicle)

Manufacturers
Equipment Design
(développement, Entwicklung*)*

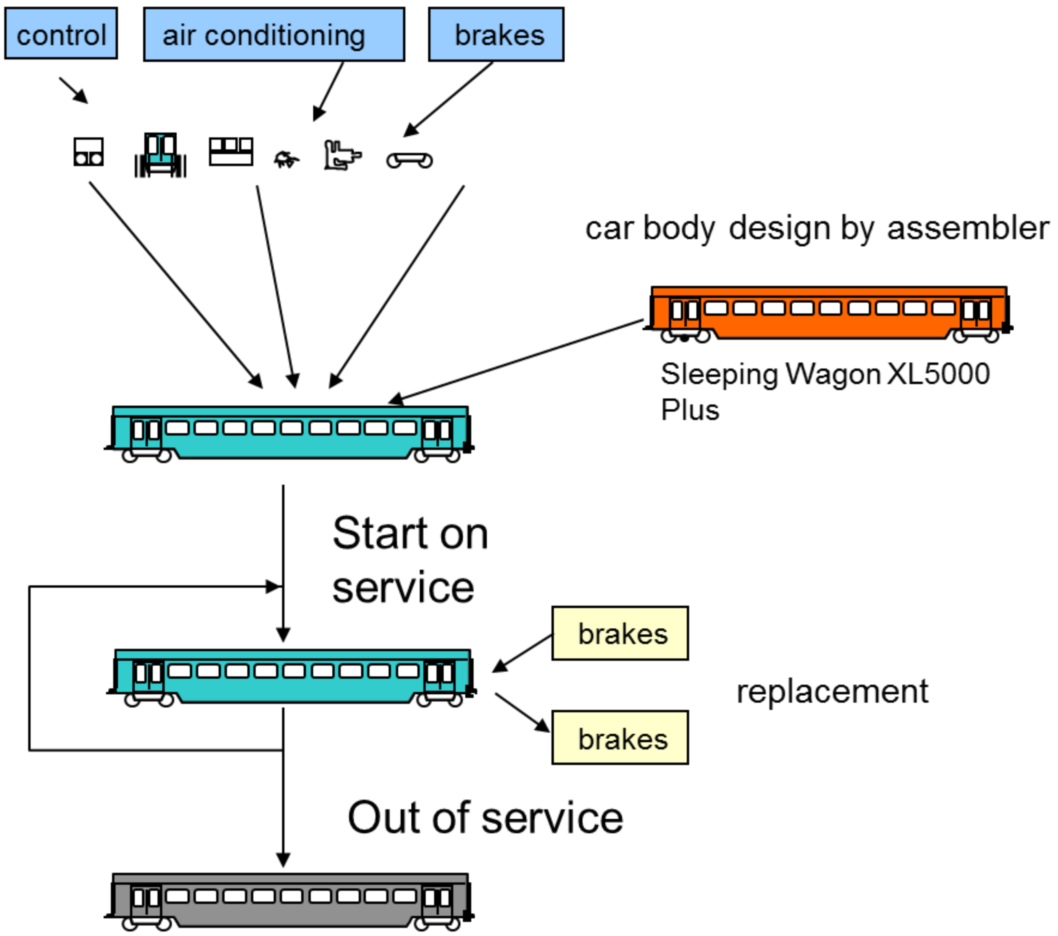
Equipment Production
(production, Herstellung*)*

Assembler (ensemblier)
Engineering
(bureau d'étude, Projektierung*)*

Commissioning
(mise en service, Inbetriebnahme*)*

Client, Service
Maintenance
(entretien, Unterhalt*)*

Recycling
(Recyclage, Wiederverwertung*)*



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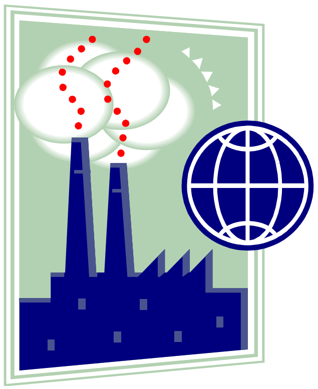
Automation

Automation =
the neural system



Society

Enterprise

Trends & History = Brain

Display and react = Cortex

Communication networks = neural, spine

controller = ganglions

Sensors & Actors = Sense cells & muscles

physical plant = skeleton

Courtesy of Prof. Kirmann, EPFL

Automation as a hierarchy of services

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5 Planning, Statistics, Finances

4 Production planning, orders, purchase

3 Workflow, order tracking, resources

2 Supervisory

SCADA = Supervisory Control And Data Acquisition

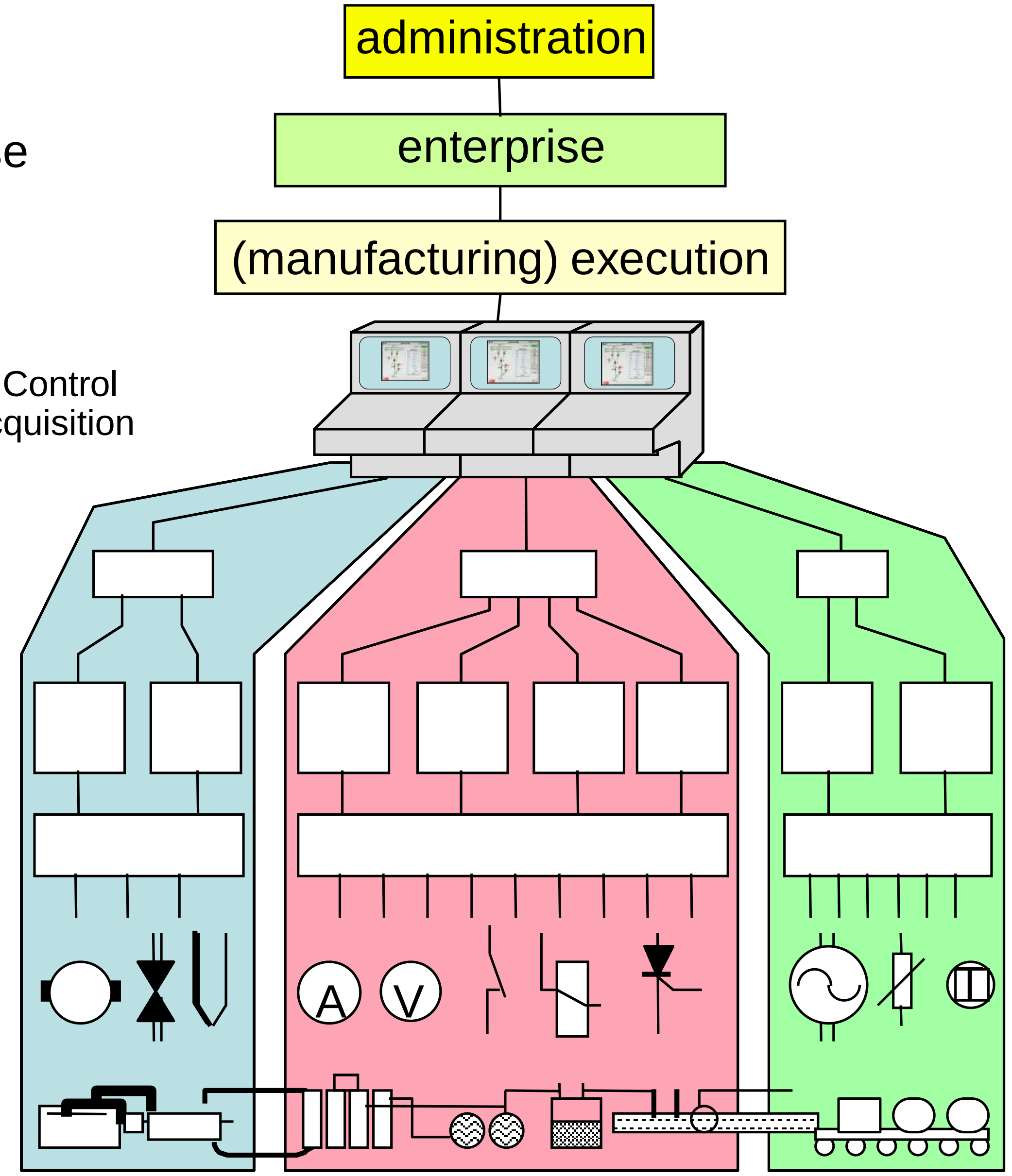
1 Group control (Area)

Unit control (Cella)

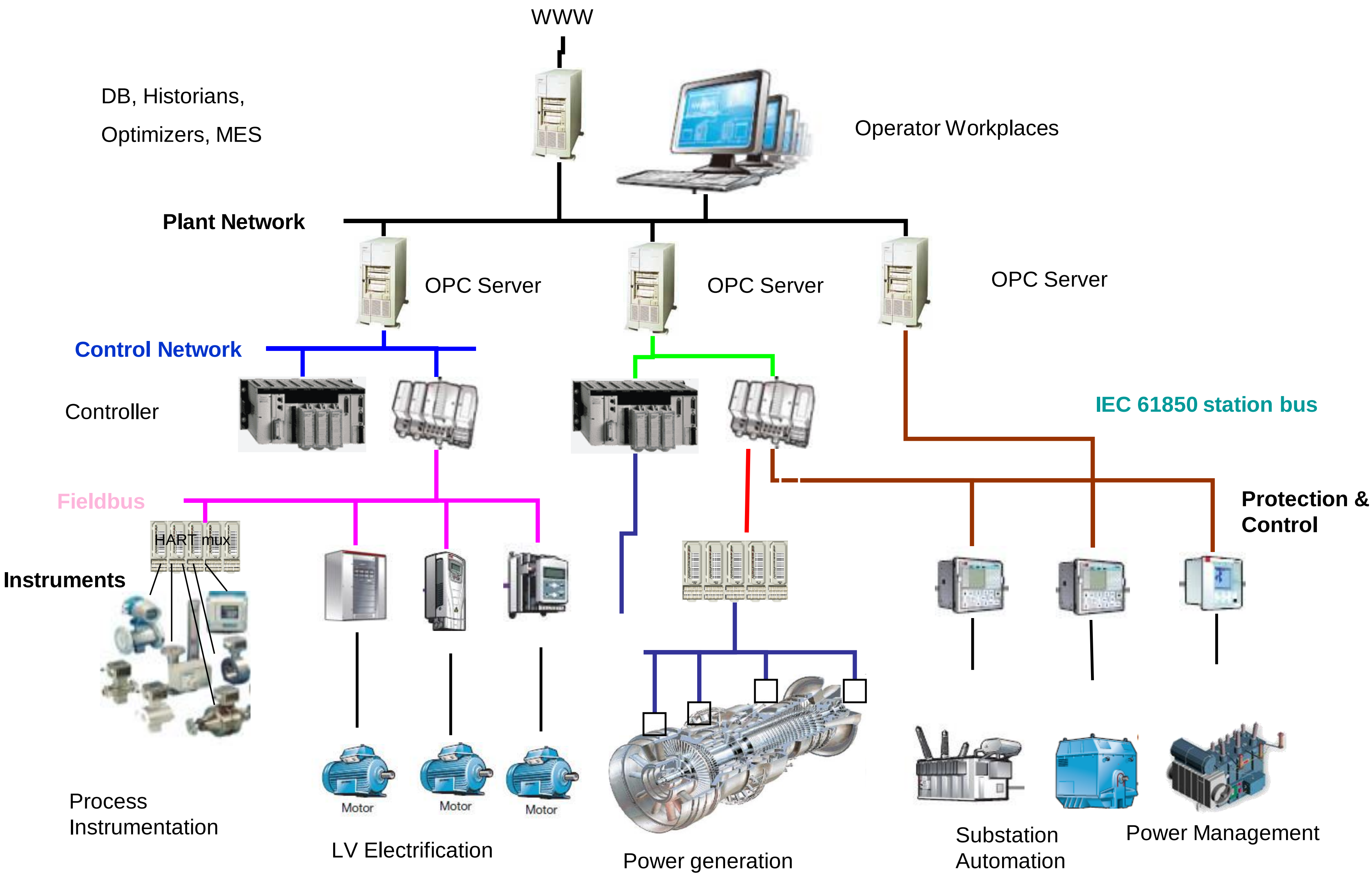
Field

Sensors & actuators

0 Primary technology



Automation as a computer network



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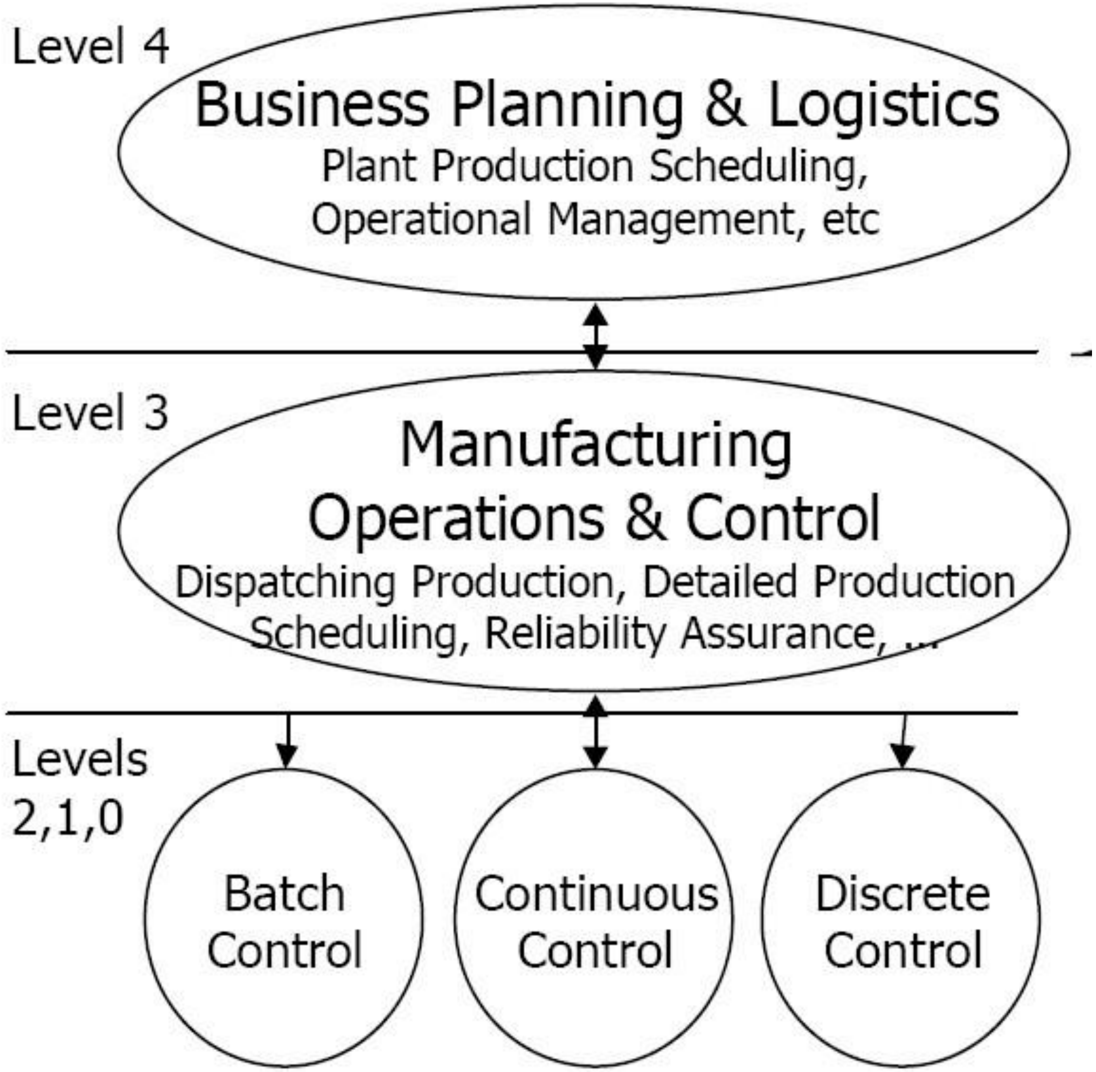
Hierarchy (ISA95, Int. Society of Automation, Purdue enterprice reference architecture)



Hierarchy (ISA95, Purdue reference model)

- **Level 4 (MANAGEMENT/AREA) Business Logistic Systems**
  - **Managing the business-related activities of the manufacturing operation. ERP (Enterprice Resource Planning) is the primary system; establishes the basic plant production schedule, material use, shipping and inventory levels (big data, time unit: day)**

- **Level 3 (AREA/CELL) Manufactoring Operating Systems**
  - **Managing production work flow to produce the desired products. Batch management; manufacturing execution/operations management systems (MES/MOMS); laboratory, maintenance and plant performance mng. systems; data historians and related middleware (big data, second)**

Hierarchy (ISA95, Purdue reference model)

- **Level 2 (CELL) Control Systems**
  - **SCADA supervisory, control and data acquisition; HMI human machine interface; real-time controllers: PLC (factory automation), DCS (industrial processes). (ms)**

- **Level (CELL/FIELD) Intelligent Devices**
  - **Sensors, actuators, pheripherals (0,1ms)**

- **Level 0 (FIELD/PRIMARY TECHNOLOGIES) Physical Process**
  - **Primary technologies (motors, transformers, generators, hydraulic systems, vehicles,…(10ms)**

Hierarchy

- **Administration**
  - Finances, human resources, documentation, long-term planning
- **Enterprise**
  - Set production goals, plans enterprise and resources, coordinate different sites, manage orders
- **Manufacturing**
  - Manages execution, resources, workflow, quality supervision, production scheduling, maintenance.
- **Supervision**
  - Supervise the production and site, optimize, execute operations visualize plants, store process data, log operations, history (open loop)
- **Group (Area)**
  - Controls a well-defined part of the plant (closed loop or operator)
- **Unit (Cell)**
  - Control (regulation, monitoring and protection) part of a group (closed loop except for maintenance)
- **Field**
  - data acquisition (Sensors & Actuators), data transmission no processing except measurement correction and built-in protection.

Hierarchy: power plant

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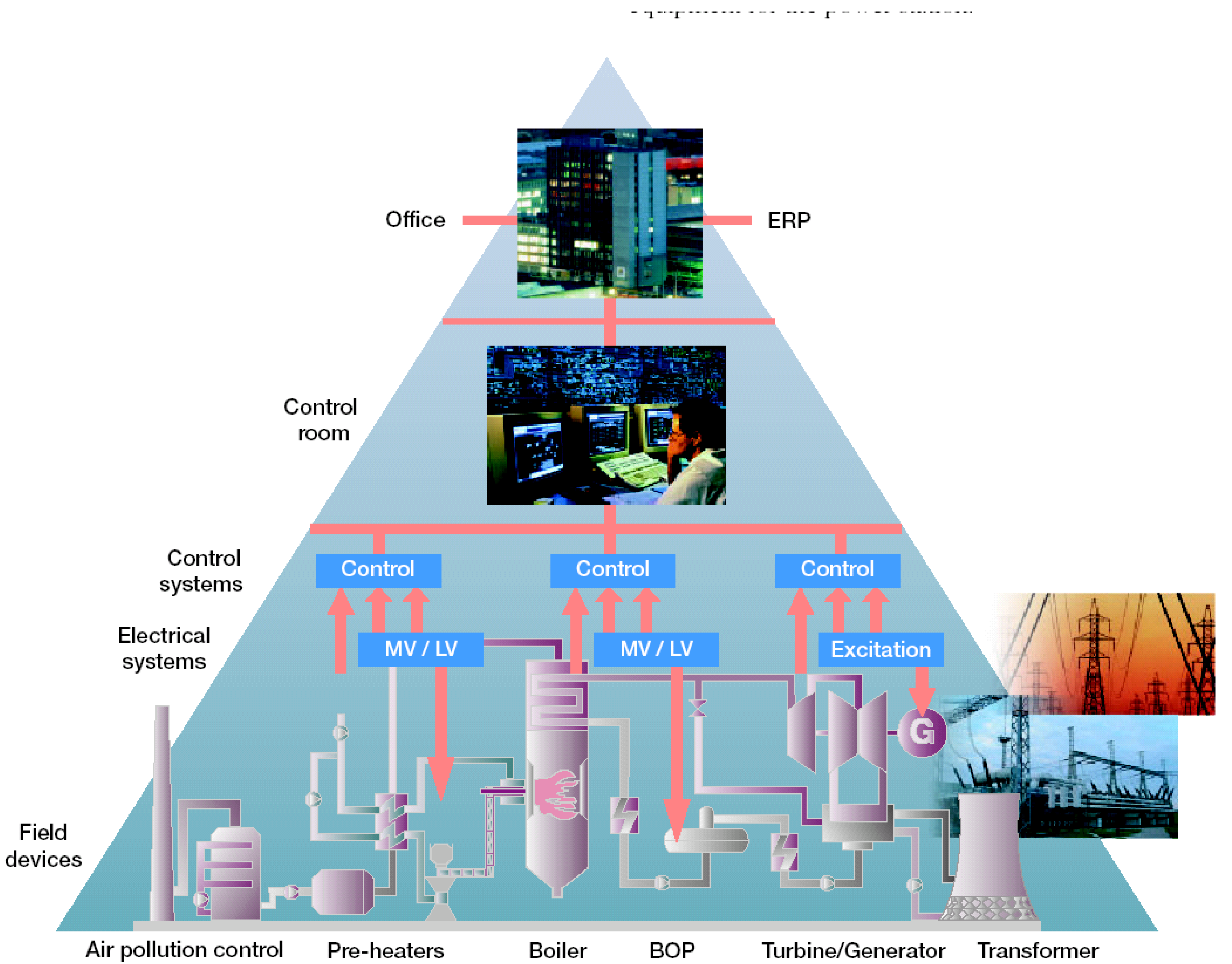

Hierarchy: factory automation (siemens)

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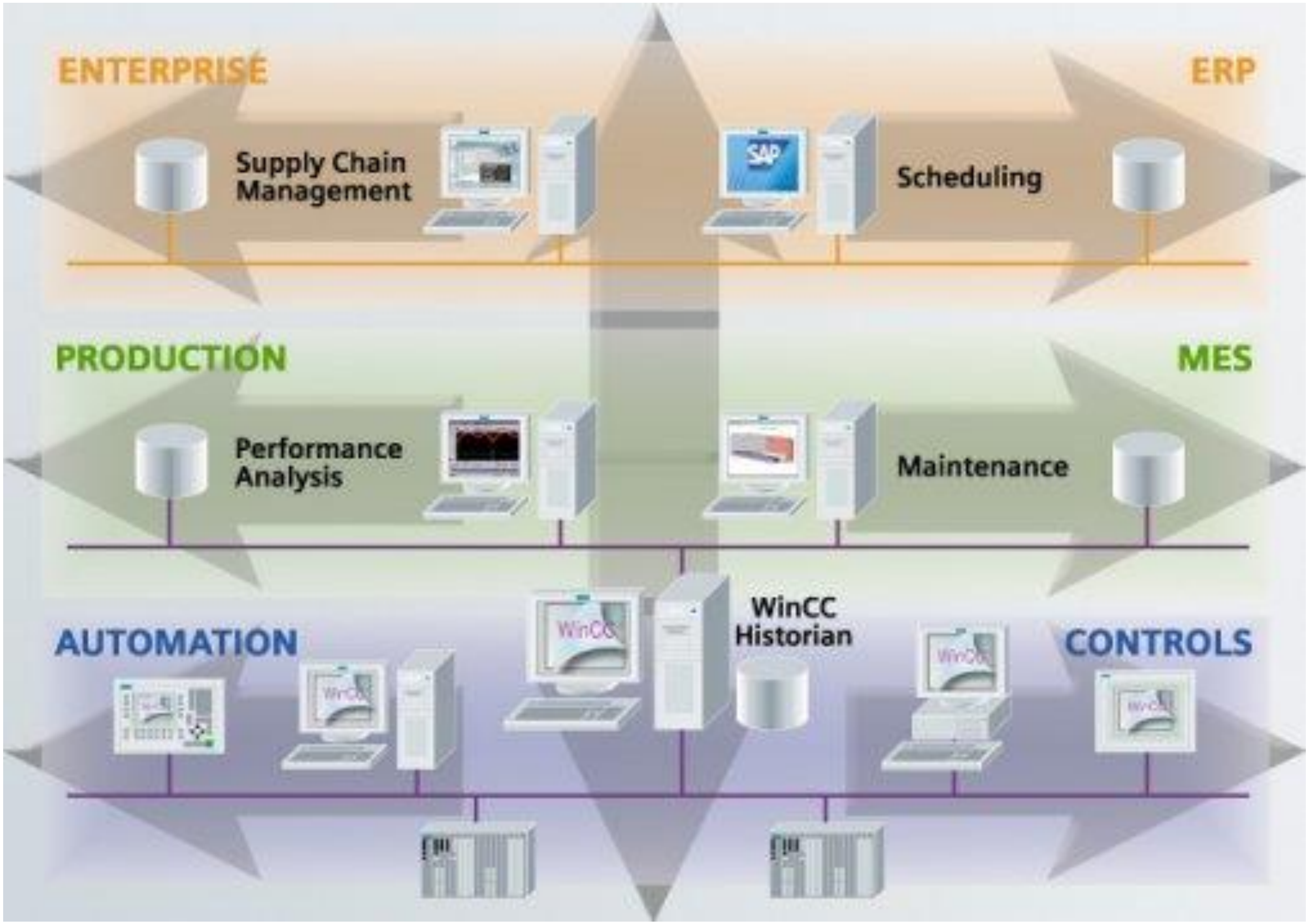

Hierarchy: response time

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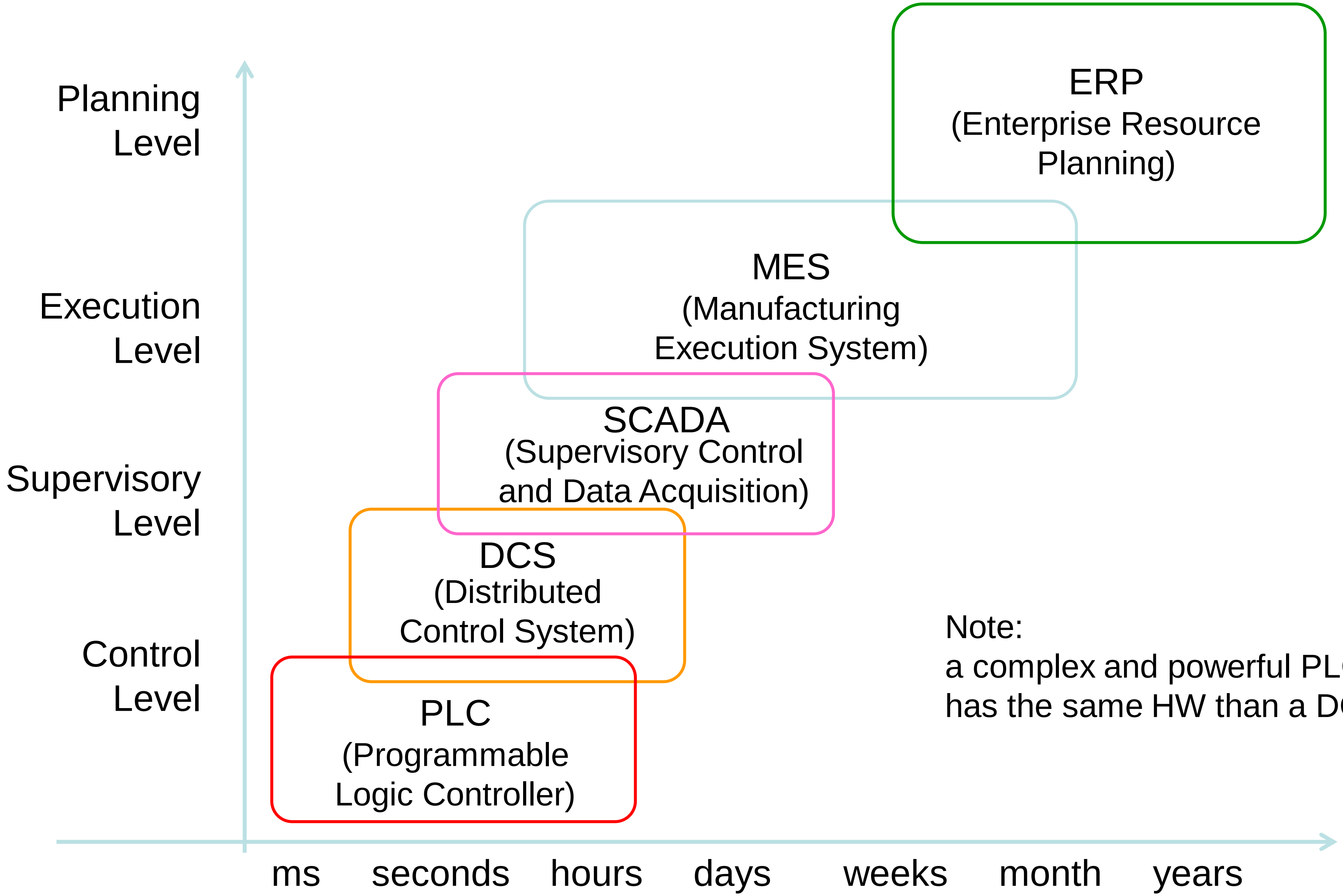

Note:
a complex and powerful PLC
has the same HW than a DCS

Hierarchy: response time and complexity

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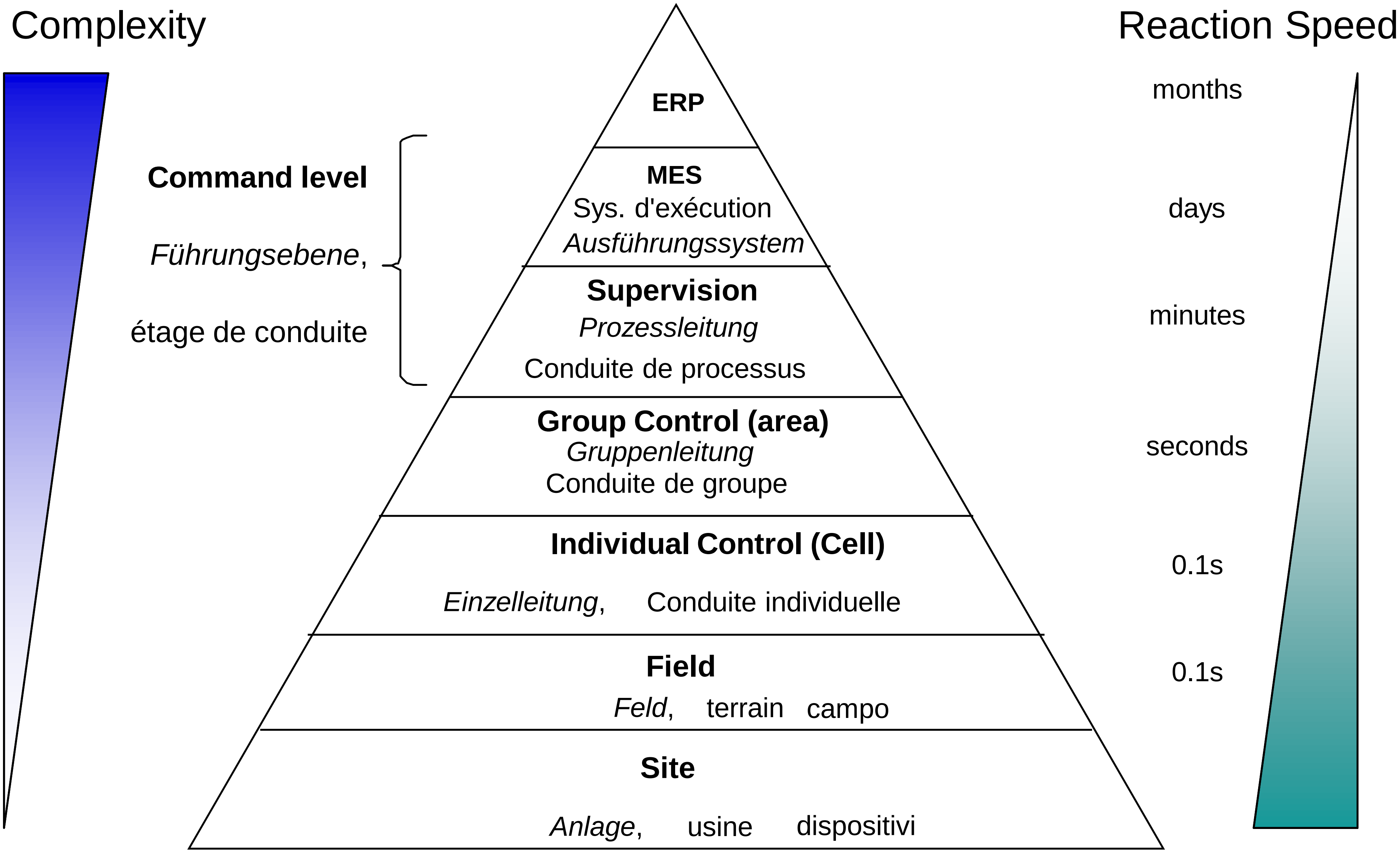

Field level

the field level is in direct interaction with the plant's hardware (Primary technology, *Primärtechnik*)

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Cell level

the cell level normally include a controller and a local Human Machine Interface

Production cell, definitions

- **a processing cell transforms electrical energy into mechanical energy and performs a job, typically by means of an electric motor (or an hydraulic system) on the basis of some references (eg. size) and the deviation of the machining from the references measured by sensors. A machining cell provides processing and handling.**

- **Definitions**
  - **Processing: useful phase to the production of the good (few automation)**
  - **Handling: movements, lost time to be reduced (much automation)**
  - **Electrical network: three-phase system of currents and voltages**
  - **Power Transformer: engines (electric) and pumps (hydraulic)**
  - **Motor drive: electrical and electronic system adapting the electrical network to the needs of the engine (that must go with a certain speed and power to perform the processing -power- or the handling -velocity-)**
  - **Sensor: element that converts physical parameters (size, position, etc.) in electrical quantities at low power allowing the measure**
  - **Actuators: element that converts electrical commands and set points to physical parameters (size, position, etc.) allowing actions**

Area level or Group level

the group level coordinates the activities of several control units (Cells)

the group control is often hierarchical, can be also be peer-to-peer (from group control to group control = distributed control system)

Note: "Distributed Control Systems" (DCS) commonly refers to a hardware and software infrastructure to perform the Controller at level Cell in Process Automation

Courtesy of Prof. Kirmann, EPFL

Local Human Interface at Area level or Group level

sometimes, the group level has its own man-machine interface for local operation control
(here: cement packaging)

also for maintenance:
console / emergency panel

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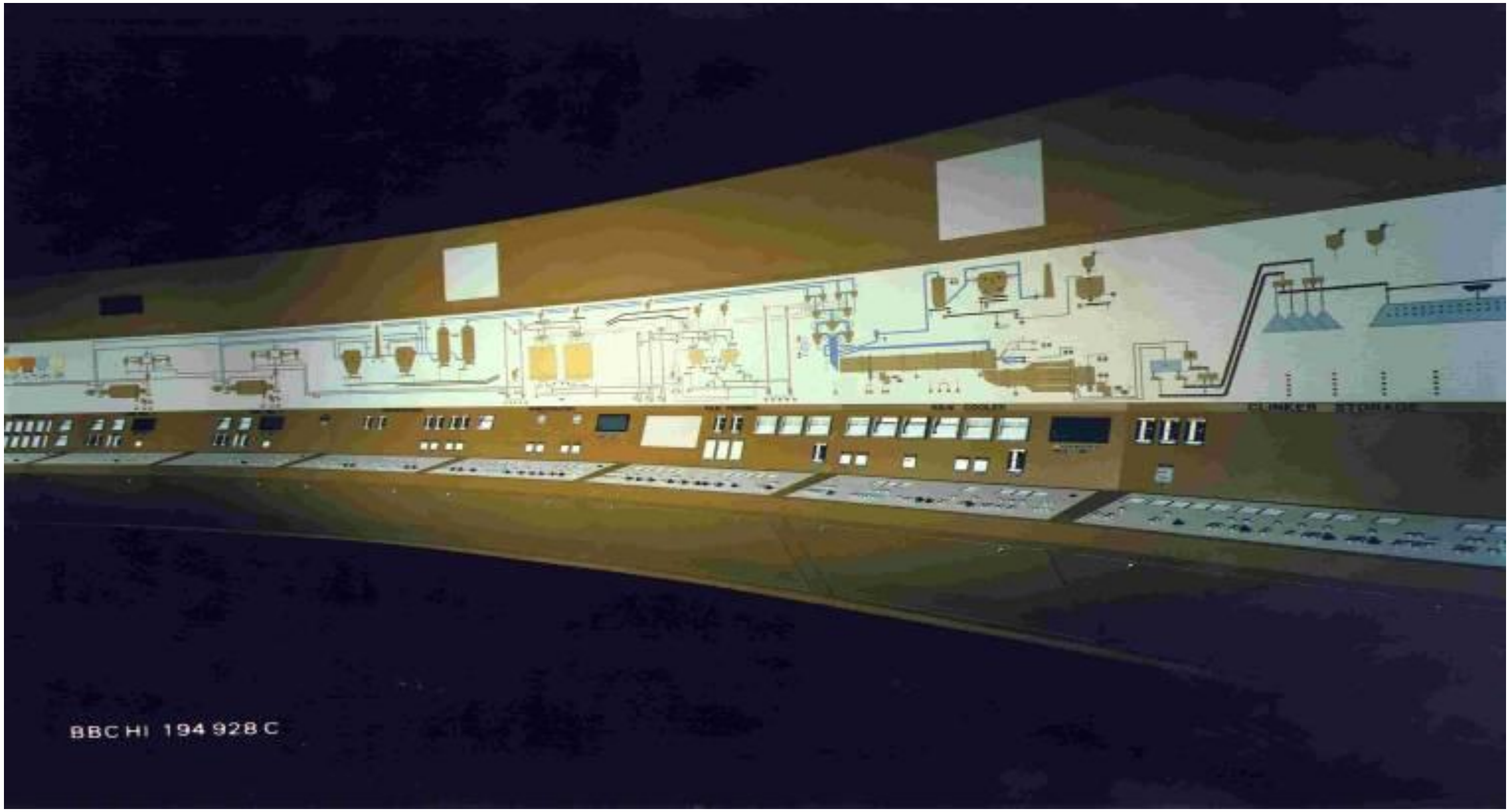
Local Human Interface at Area level or Group level



control room
(mimic wall)
1970s...

formerly, all instruments were directly wired to the control room

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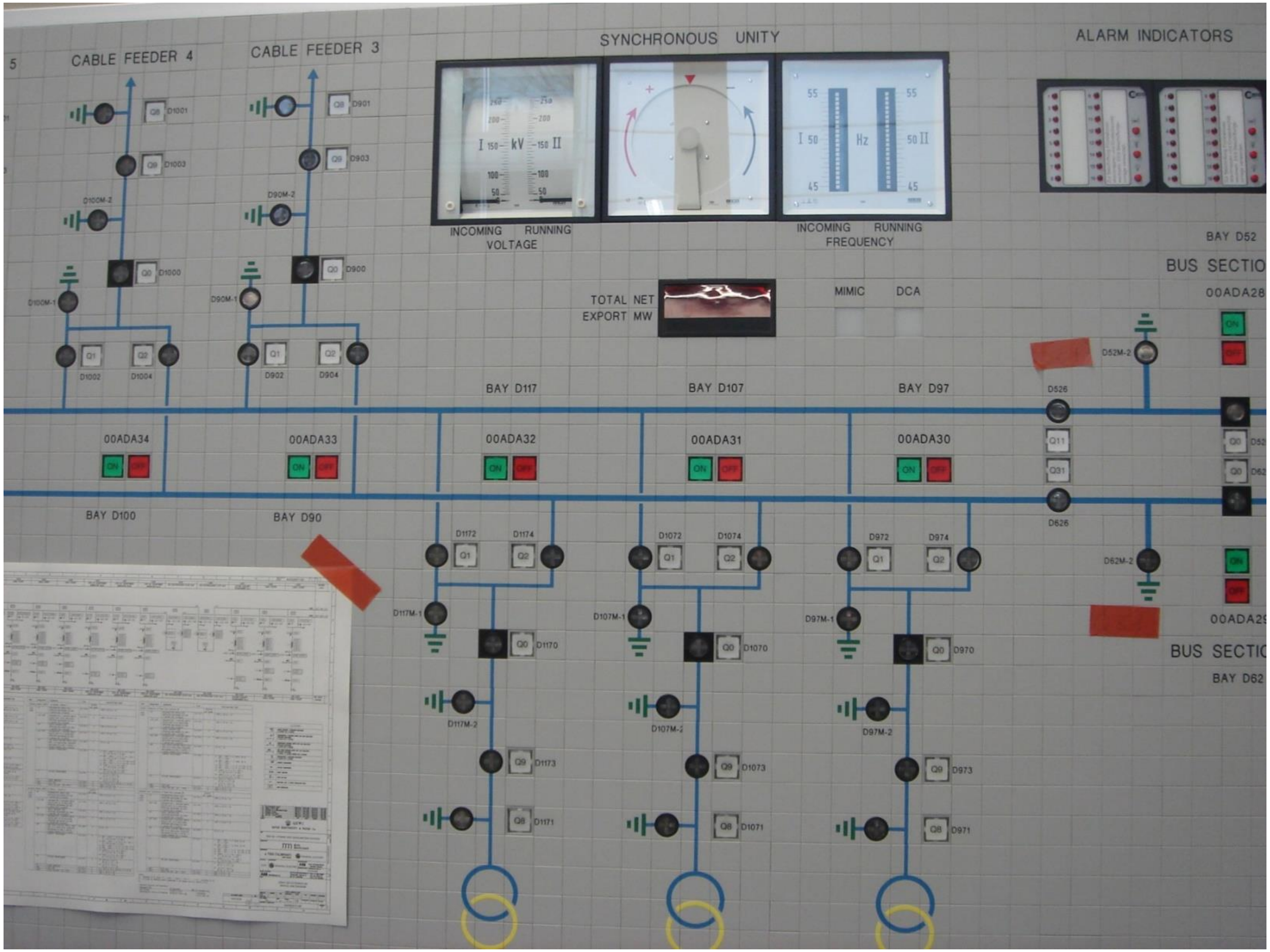
Local Human Interface at Area (or Group) level



Mosaic is still in use, with direct wiring

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Local Human Interface at Area (or Group) level

beamers replaces the mosaics, there is no more direct wiring to the plant.

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Inside and beyond the Area level (ISA95)

- **Level 4 (MANAGEMENT/AREA) Business Logistic Systems**
  - **Managing the business-related activities of the manufacturing operation. ERP (Enterprice Resource Planning) is the primary system; establishes the basic plant production schedule, material use, shipping and inventory levels (big data, time unit: day)**

- **Level 3 (AREA/CELL) Manufactoring Operating Systems**
  - **Managing production work flow to produce the desired products. Batch management; manufacturing execution/operations management systems (MES/MOMS); laboratory, maintenance and plant performance mng. systems; data historians and related middleware (big data, second)**

- **Level 2 (CELL) Control Systems**

- **Level 1 (CELL/FIELD) Intelligent Devices**

- **Level 0 (FIELD) Physical Process**

Level 3, Manufactoring Operating Systems (MOMs)

- **Manufactoring Execution System (MES)**
  - **Planning, tracking, management (quality) and documentation of the production process of transformation from raw or semi-finished material to semi-finished or finished product**
  - **KPI –Key Performance Indicator-**
  - **Fundamental and quite complex software in processes requiring certification (pharmaceutical, food & beverage)**

- **Laboratory Information Management System (LIMS)**
  - **Product traceability and suffered tests. data analysis and data mining IT structure based on different models (client-server, web-based)**

- **Warehouse Management System (WMS)**
  - **Management of warehouses, storages and handling, logistics**

- **Computerized maintenance management system (CMMS)**
  - **Maintenance management**

Level 4, Business Logistic Systems

- **Enterprise Resource Planning (ERP)**
  - An ERP software solution often includes all the following packets
  - From the financial systems (business administration) up to the planning of orders and the use of machinery. Large manufacturers (SAP, Oracle, Micorsoft, ...) and Open Source "local" (Italy: Gazie, Management Open, ..)

- **Product Lifecycle Management (PLM)**
  - From the idea (conceive), to the design, to the realization processes and forward to maintenance and service

- **Process Development Execution System (PDES)**
  - Similar to the PLM but for productive sectors employing special technologies (micro-electronics, nano sensors, biomedical devices, ...)

- **Supply Chain Management (SCM) -material flows-**

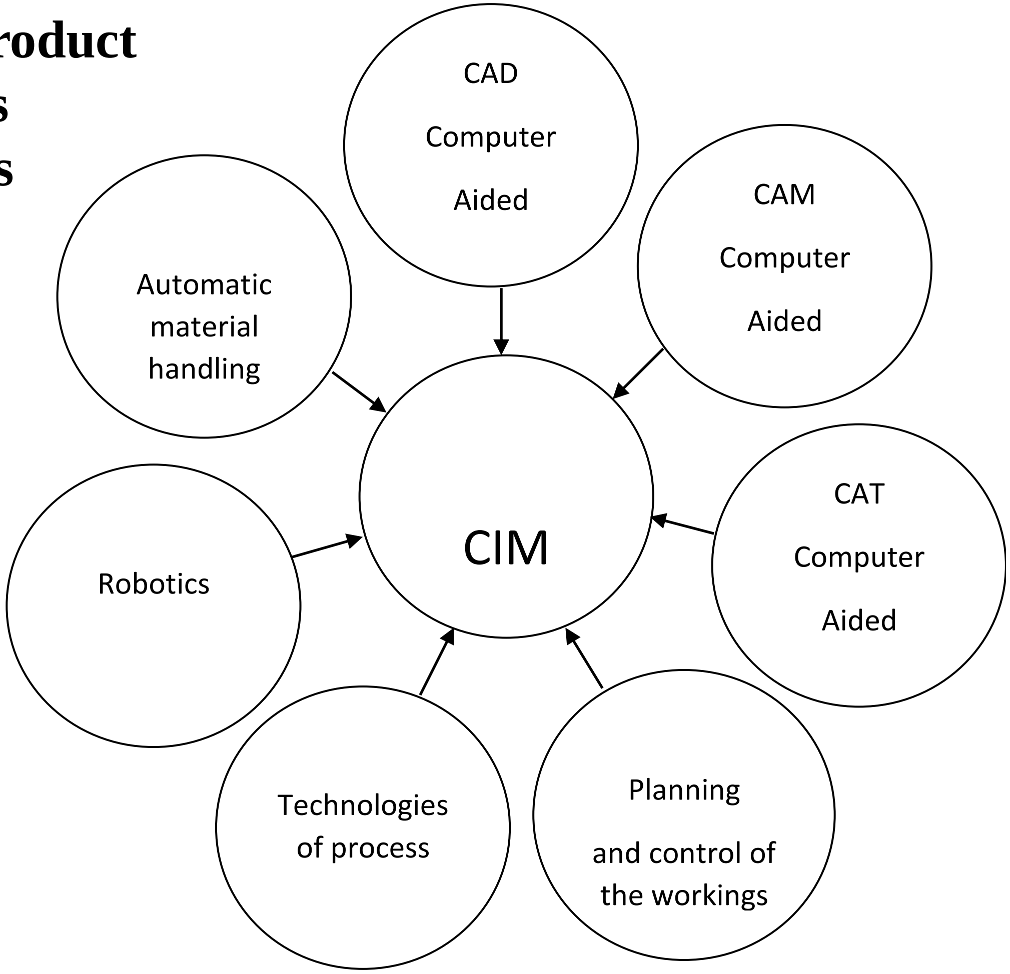
- **Customer Relationship Management (CRM) -customers portfolio-**

- **Human Resource Management (HRM) -customers-**
  - Personnel Management, one of the main indirect costs

Factory Management, Introduction to CIM

- **CIM = Computer Integrated Manufacturing**
  - **Fully automated factory (optimization)**

- **Aims of CIM**
  - **increase the quality 'of the product**
  - **improved flexibility 'business**
  - **reduction in general expenses**
  - **reduction in production time**
  - **inventory reduction**
  - **… optimization of resources**



CIM

- **CAM (Computer Aided Manufactoring)**
  - **Automation in order to reduce hard human work**
  - **DNC (Direct Numeric Control) for high volumes with low variety**
  - **FMS (Flexible Manufacturing System) for automatic reconfiguration of machineries, APT (Automatically Programmed Tools)**
- **CAD (Computer Aided Design)**
  - **Database and software tools (e.g. simulation) to shorten the design time**
  - **See PLM for production line**
  - **If CAD is integrated… fast prototyping, costs estimation, "digital model"**
- **CAT (Computer Aided Test) for failure detection**
  - **Reliable, timely, storable (id. -serial number- of components for returns)**
  - **feedback (the programs must be adapted to the more frequent failures)**
  - **"rough" (built-in test)**
  - **test-oriented design (testability)**
  - **redesign based on the most frequent failures**
  - **restructuring of the production process on the basis of the most frequent failures**

CIM

- **Planning and control of operations**
  - **Organization of production resources on the basis of customer orders**
  - **Planning of maintenance and quality control operations**
  - **Planning of rough materials and subsystems to assembly, warehouse**
  - **General production planning**
  - **Financial, accounting**
  - **Costumer portfolio**
  - **Personnel costs**
  - **General Planning report = MRP = Material Requirements Planning**

- **…"Just-in-time" (from "push" to "pull"), Toyota 1960-70-80**
  - **How to manage the next process just at the end of the previous process**
  - **No waste of time, produce only if it is already sold, no warehouse, so stocks**

- **…Lean Production (or lean manufactoring), Toyota 1990-00**
  - **Philosophy aimed to minimize wastes. Against Fordism**
  - **Annul extraproduction; no defects (Total Quality Management); no stocks; no failures; minimize handling and movements, no waste of time, logistics, standard procedures**

CIM

- **Technologies of processes**
  - CAPP (Computer Aided Process Planning)
  - Hard integration between CAD and CAM
  - Designing a product variant -> a new product
  - Designing a process variant -> a new product (need of high dynamic layout)
  - Group Technologies (a balance between the two strategies) Planning of rough materials and subsystems to assembly, warehouse
  - It is just databases (CAD databases and Process Databases) with an Expert System (SW) optimizing and taking decisions

- **Automatic Material Handling**
  - ASRS (Automated Storage & Retrieval System), good are identified on the base of the storage place
  - AGVS (Automated Guided Vehicle System). Instrumented floor or indoor localization and automated navigation

- **Robotics**
  - Robot = programmable multifunction manipulator

Centralized and distributed production

- **Centralized systems**
  - All information must be transmitted to the central processor (High wiring costs, rigidity of the layout)
  - Each processor has a simple software but that has to be reviewed at each minor change of system (unreliable)
  - Since there are more computers they must anyway communicate (LAN)
- **Decentralized or distributed systems**
  - Several simple systems in place of a single complex system (Reduced wiring, better flexibility and scalability)
  - The need for an efficient communication system (Reliable, fast, able)
- **Response time**
  - Time elapsed between a need and the related action (typically time elapsed between an input event in a place and an output action in a different place)
- **Industrial communications**
  - If the needed response time is >50ms, is TCP/IP (with acknowledge and retry) or UDP/IP (more simple, more fast), otherwise fieldbuses

Industrial communications

- **Communications among computers**
  - **TCP/IP traffic over Ethernet or WiFi (LAN = Local Area Network)**
  - **Response time good for human interface**
  - **Very good firewall to impede attaches (jamming, security)**
  - **Normally industrial communications are really very good protected by firewalls from external attaches, without impeding teleservice**

- **Communications among computers and controllers**
  - **TCP/IP or UDP/IP traffic over Ethernet or WiFi**
  - **Synchronization could be required to share the same sense of time (software synchronization over LAN)**

- **Communications among controllers (Cell level)**
  - **Master-slave approach: the master controller manage communications and slave controllers act like just pheriperals (std solutions & infrastructures)**
  - **Fully distributed approach: communication is more complex and the infrastructures could be HW-assisted**

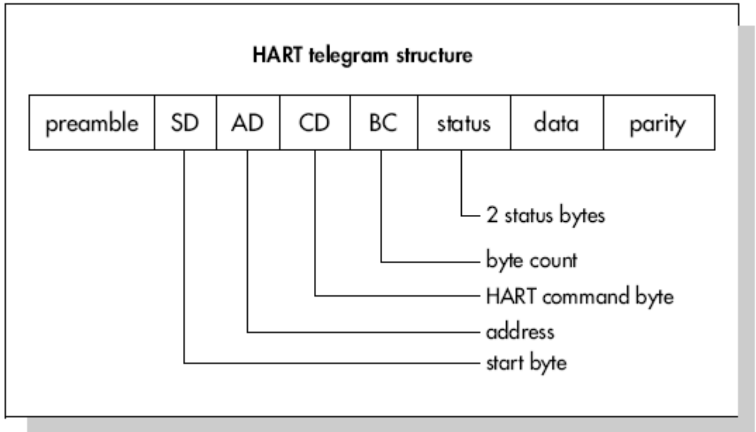
- **Communications among controllers, sensors and actuators (!!!)**
  - **Response time is normally < 50ms**

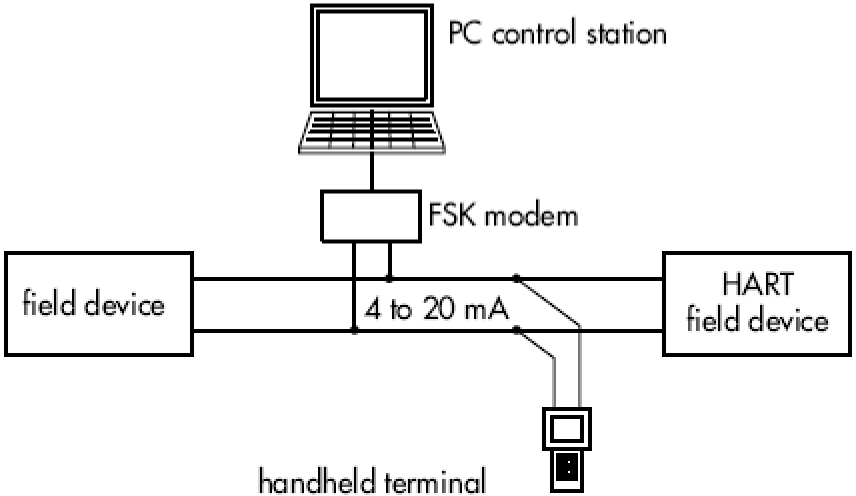
Fieldbus

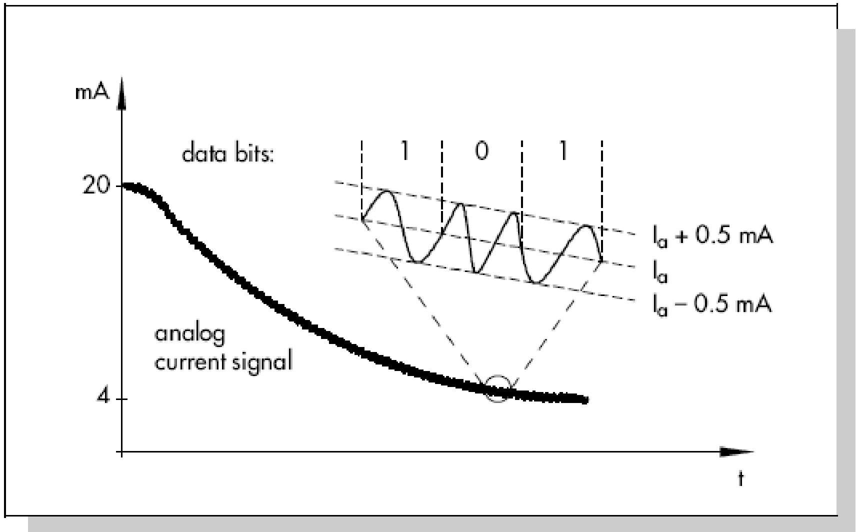
- **communications systems specifically designed for the industrial communication between the controller and intelligent devices**
  - **Simple and economic (should be present within sensors and actuators)**
  - **Robust, reliable, simple to be managed (no infrastructure)**
  - **Fast response time**
- **…without fieldbus**
  - **Digital sensors are connected by robust (but long) digital wiring**
  - **Analog sensors are connected in DC voltage (short and critical wiring), AC voltage (a tuned filter can help), 0-20mA (long wiring) 4-20mA (diagnostic)**
- **Too many fieldbuses (IEC 61158)**
  - **Many different solutions by different players and consortia**
  - **Low performance and high costs if compared to Usb or Ethernet**
- **Real-time Ethernet**
  - **Use of Ethernet (typ. 100BaseT) as fieldbus**
  - **Software solutions (encapsulate the data in the payload of Ethernet or TCP/IP or UDP/IP) and hardware assisted solutions (switches, nodes)**

Fieldbus, HART (for process automation, ~ 1970)

- **11bit UART communication overlapped with the analog transmission 4-20mA** (diagnostic is useful at commissioning and for maintenance)
  - Modem FSK (Frequency Shift Keying)
  - "0": 2200Hz, "1": 1200Hz
  - Data rate: 1200bit /s, up to 15 devices
  - ~ 500ms (master + slave telegram)
  - Today WirelessHART





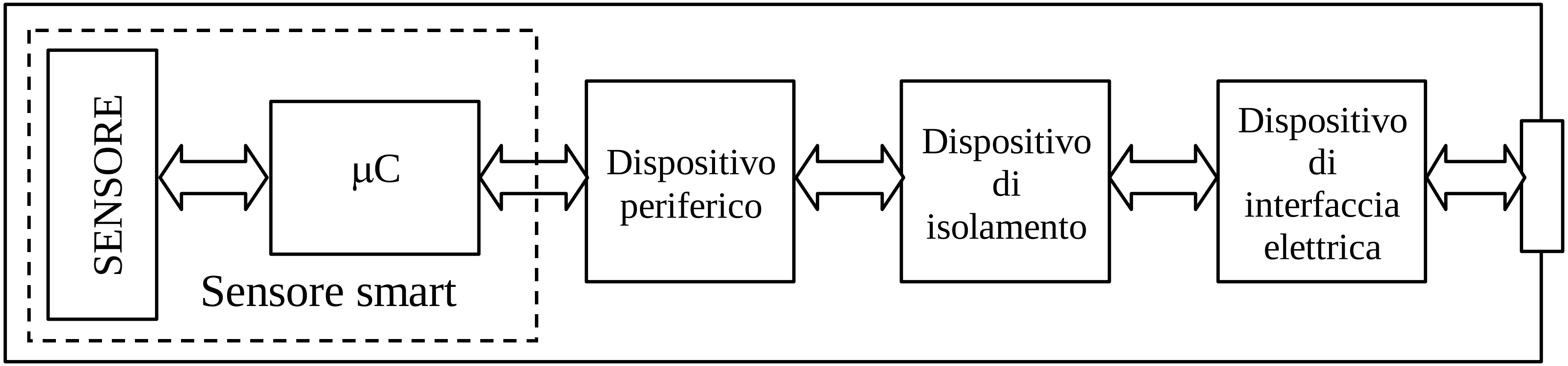


Fieldbus, Modbus (for factory automation, ~ 1980)

- **Master-slave (slave only answers)**
- **1 master, up to 127 slaves**
- **Very simple data management (read register, write register)**
- **Register organization, minimum overload**
- **easy and open source code (Modicon)**
- **Born as defined at ISO-OSI levels 1,2,7**
- **Now encapsulable practically everywhere**
  - **Modbus over TCP, Modbus over Ethernet**
- **Used in SCADA, controllers, motor drives**
- **Used in many application fields**

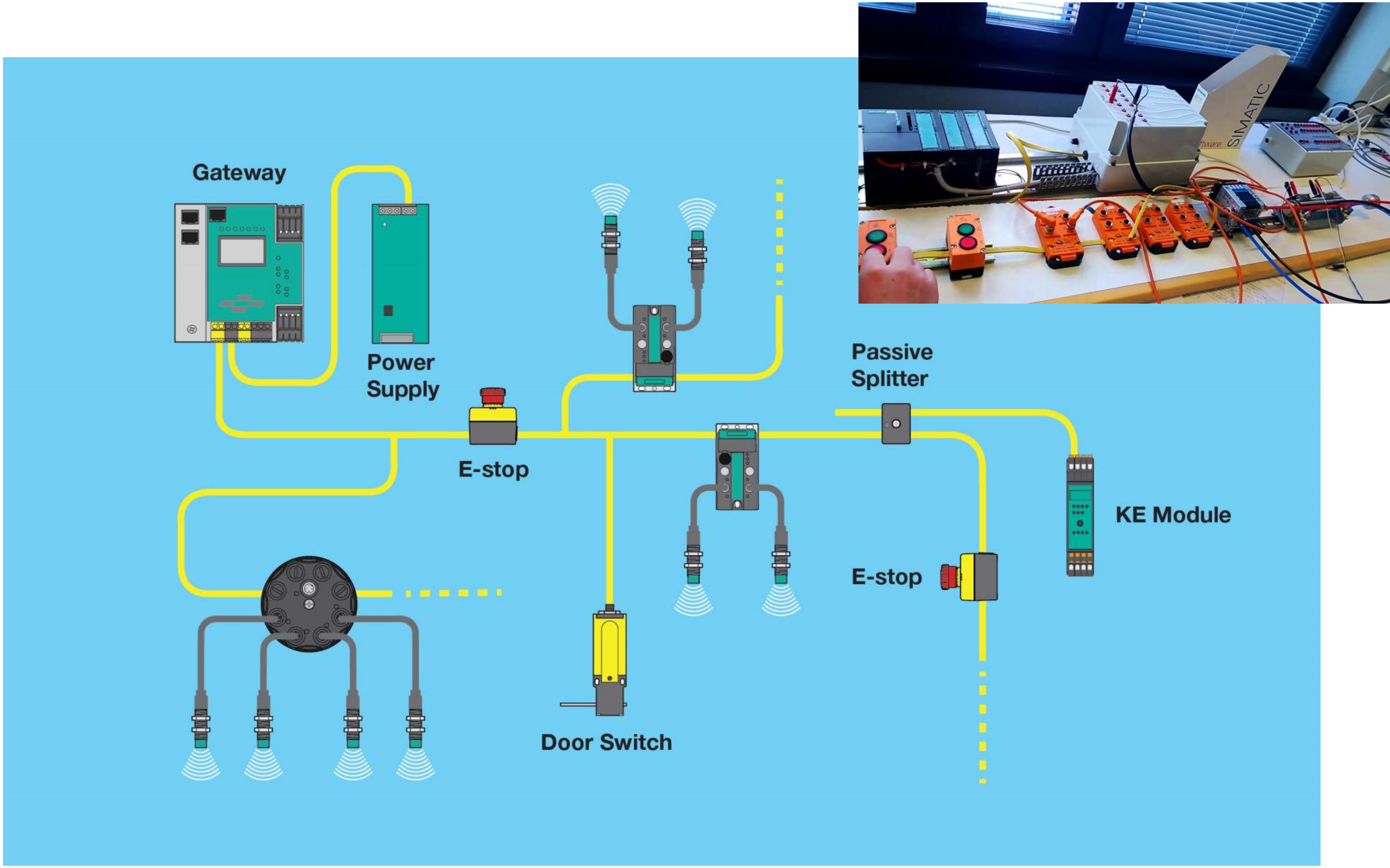
Fieldbus, Profibus (for factory automation, ~ 1980)

- **11bit UART RS485 or fiber master-slave communication**
  - **12Mbit/s, response time (cycle time) on the order of ms**
  - **Request + Response ~ 28μs (Tdata -> Tbyte ~ 1μs)**
  - **Cyclic and acyclic communication**
  - **Up to 4 masters, up to 127 slaves (typ. One master to save response time)**
  - **Profiles to manage particular devices or particular situations (e.g. safety)**
  - **Synchronization among nodes (at I/O level)**
  - **Diagnostic and self configuration (GSD file) of nodes**
  - **A single device to simply provide fieldbus interface to nodes**

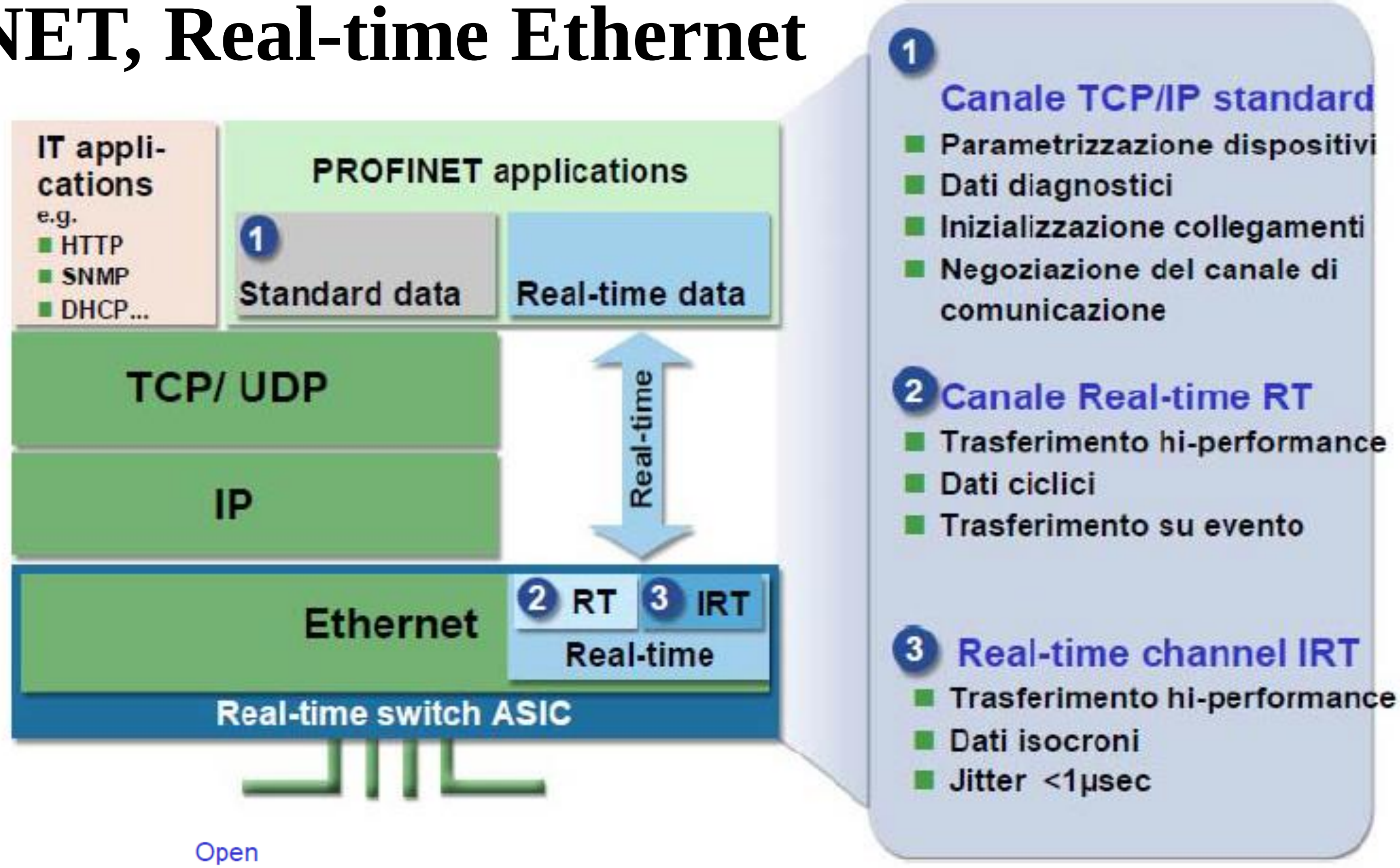


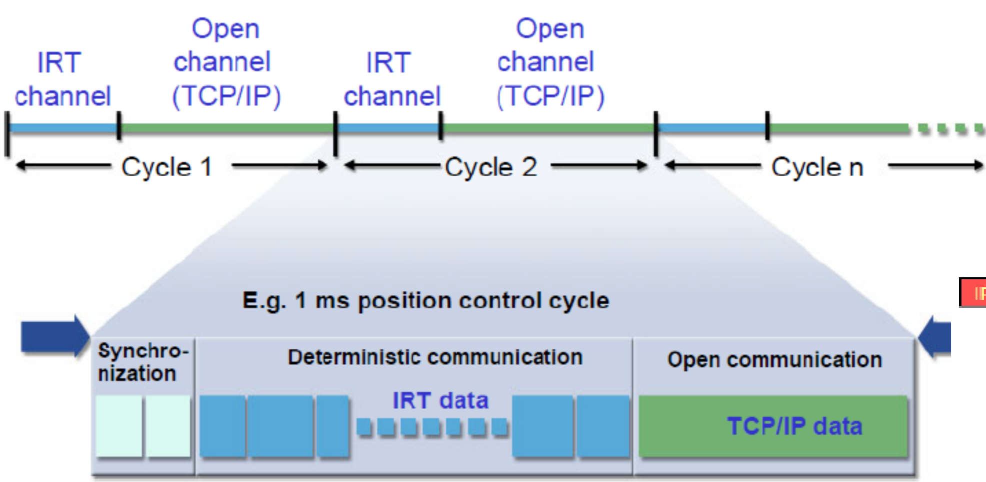
Fieldbus, ASI (for hazardous automation, ~ 1990)

• **Powered communication (no sparks due to grounding of power)**

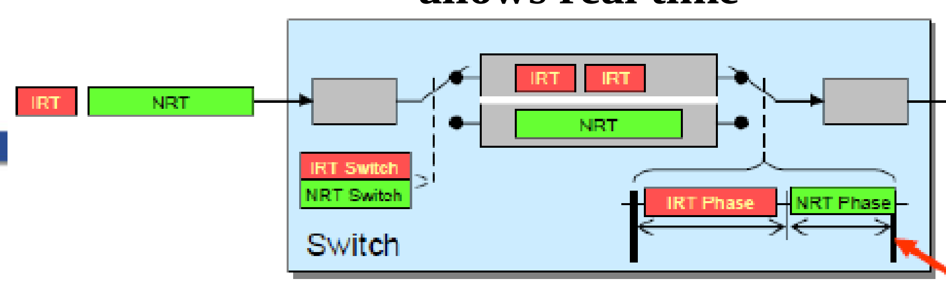


PROFINET, Real-time Ethernet





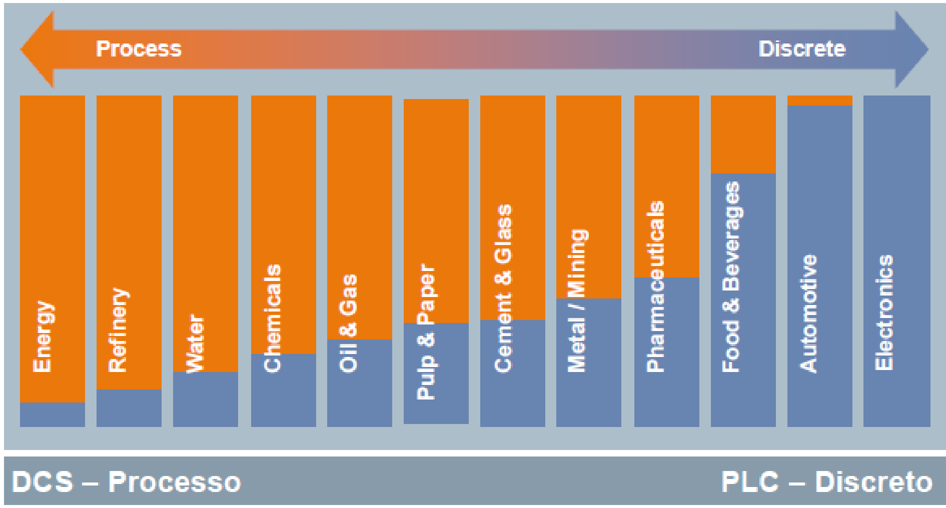
A special synchronized switch allows real time



Back to differences between Factory and Process

- **Factory Automation (or factory automation infrastructure)**
  - **Repetitive sequence to perform a job used in the production of goods.**
  - **General engineering and manufacturing environment that is defined by its ability to manufacture and/or assemble goods mainly by <u>machines</u>, integrated assembly lines, and <u>robotic arms</u> (*<u>open loop control</u>*)**
  - **Manufactoring speed, lean production and diagnostic are mandatory (more speed, more product in the same time, less expensive product)**

- **Industrial Processes (or process automation)**
  - **A systematic series of mechanical or electrical or physical or chemical operations that produce or manufacture or distribute something on a <u>very large scale</u>, often in <u>hazardous areas</u>.**
  - **Chemical processes, Heat processes and Electrolysis, Cutting (laser, water,..), Stamping, Forging, Casting, Moulding, Welding, Separation**
  - **Safety is mandatory, as well as «green behaviour»**
  - **Many sensors, *<u>closed control loop</u>***



Open loop and closed loop

Courtesy of Prof. Kirmann, EPFL

Sensorless (faster!)

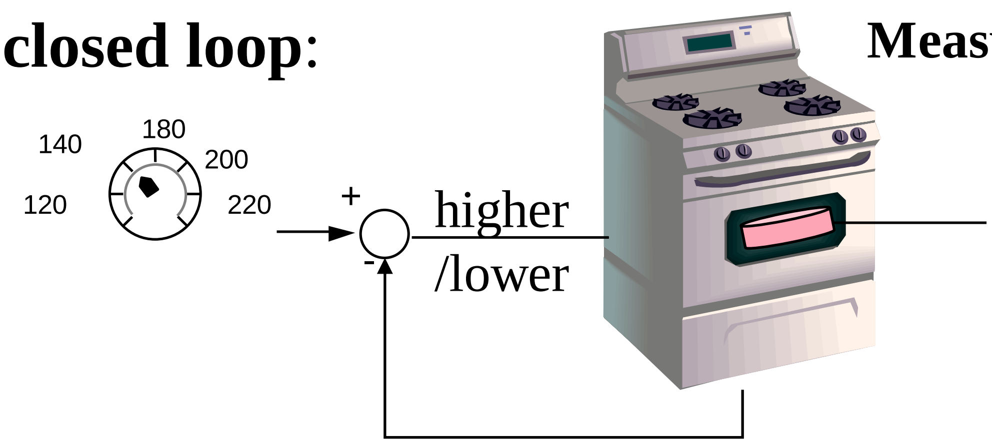
open loop:

Temperature (diagnostic)

temperature is imprecise, depends on ambient temperature and cooking quantity, <u>but time of heating can be modulated</u>. Sensors for online diagnostic and online calibration (thermal signature, time to reach ΔTo)

closed loop:

Measurement/sensor (temperature sensor)



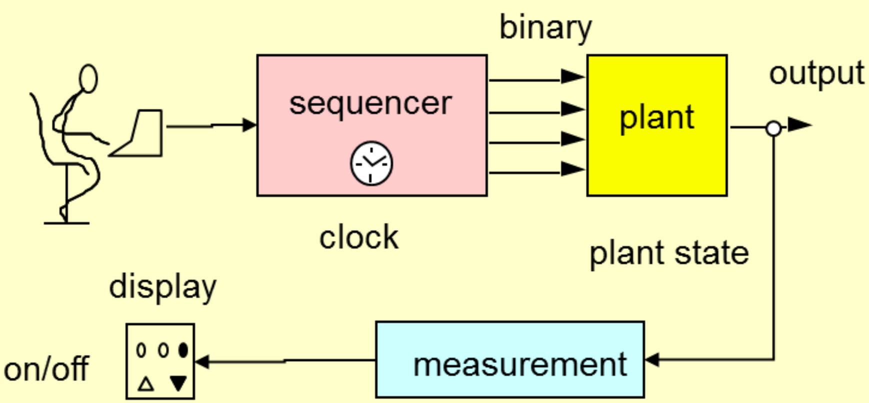
temperature closely controlled (e.g. PID), requires measurement of the output variable (temperature)

Open loop and closed loop

Courtesy of Prof. Kirmann, EPFL

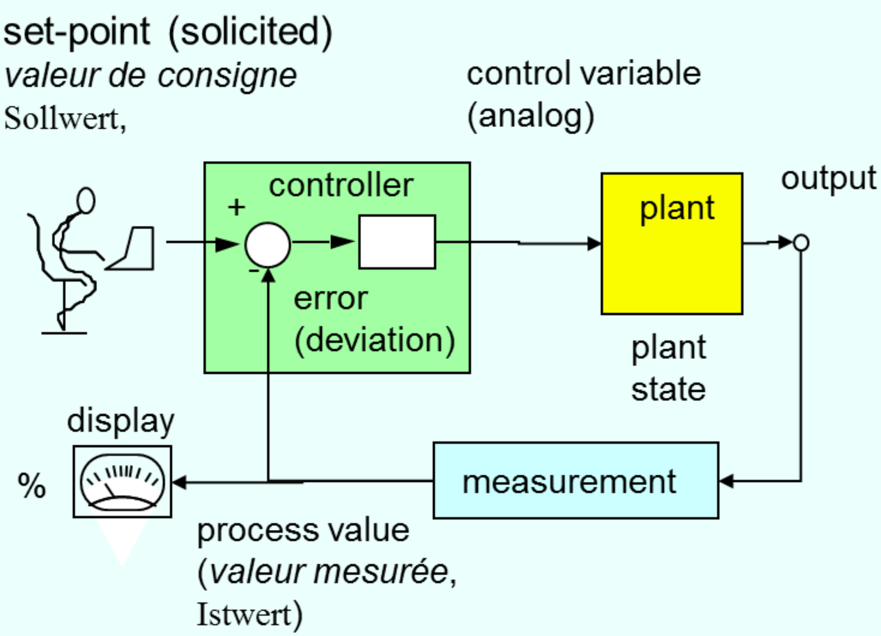
open-loop control / command
(commande / pilotage, steuern,)

keywords: sequential / combinatorial, binary variables, discrete processes, "batch control", "manufacturing"



closed-loop control / regulation
(régulation, Regelung)

keywords: feedback, analog variables, continuous processes, "process control"



Open loop and closed loop control

- **Open loop functions (no accurate sensors)**
  - Data acquisition and pre-processing
  - Data transfer between plant and operator, display the plant state
  - Logging and history recording, simulation and training
  - Process optimization algorithms

- **Open loop (or discrete) regulation (no accurate sensors)**
  - If event, change state and events to be tested
  - Discrete plants are described by finite state machines with abrupt transitions

- **Closed loop functions (many accurate sensors)**
  - Protection and interlocking (prevent dangerous actions)
  - Regulation
  - Process-driven sequential control
  - The control system acts directly and automously on the plant

- **Closed loop (or continuous) regulation (many accurate sensors)**
  - Measure, compute, actuate
  - Continous plants (processes) have states that can be described by a continuous (analog) variable
  - Continuous plants are mostly reversible and monotone (linear systems, transfer functions described with Laplace or Z-transform)

Time-based control: Open or closed loop control?

Task: fill a bottle

- **Open loop control**
  - Open the flow for time T1 (T1 received by the SCADA) then close
  - Check for a correctly filled bottle: if OK go on, otherwise discharge
  - If too many discharges then Warning
  - Note: very fast, low-cost (sensorless, on-off valve), inaccurate

- **Closed loop control**
  - Check for correct position of the bottle (by a position sensor)
  - Open a little flow and check if level changes (by a sensor level)
  - Read level Lev and regulate flow as a consequence untile Lev = Lev_set
  - PI regulation: read Lev; Err_old<=Err; compute Err = Lev_set-Lev; set Flow = Kp*Err + Ki(Err – Err_old)/Ts (Ts is the sampling time)
  - Note: slow, costly (sensors, proportional valve)
  - Note: analog sensors with Overflow (32767=118,5%, 27648=100%)

- **Time-based control**
  - Check for correct position of the bottle
  - Set a threshold sensor at 20%
  - Open flow enabling a timer and wait for event (within a time, otherwise Stop): if event, read the timer (Tx) and stop the flow when timer is 5Tx
  - Note: Internet of Things approach means Time-based control in background

Continuos and batch processes, manufactoring

- **Continuous processes -> "Process control"**
  - **Continuous flow of material or energy (Electrical power, water, Oil&gas, Cement, glass, paper,…)**
  - **Main task: regulation**

- **Batch processes -> "Batch control"**
  - **Discrete processes with handling of individual elements (mixed) (Some machines, bottle filling, Food&beverage, Metals&mining, fine chemical, Pharma,…)**
  - **Main task: command with few time-limited regulations**

- **Discrete Processes -> "manufactoring or factory automation"**
  - **Mostly discrete processes, associated with transformation and assembly of parts. (automotive, electronics, packaging)**
  - **Main task: command**
  - **E.g. ON-OFF control. If Var<T0 then Turn ON, if Var>T1 then Turn OFF, otherwise memory effect**

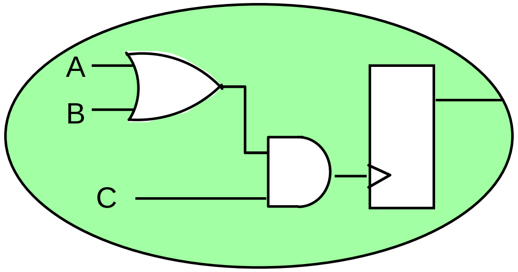
PLC: Matching the analog and binary world

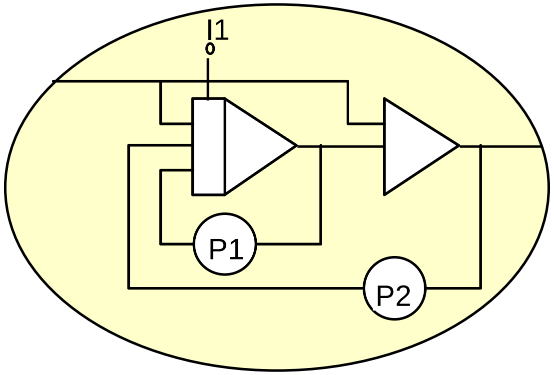
discrete control

analog regulation

PLC evolution

Binary World	Analog World
relay controls, Relay control pneumatic sequencer	Pneumatic and electromechanical controllers





combinatorial → sequential

Regulation, controllers

discrete processes

continuous processes

Programmable Logic Controllers

(Speicherprogrammierbare Steuerungen, Automates Programmables)

Continuous Plant (reminder)

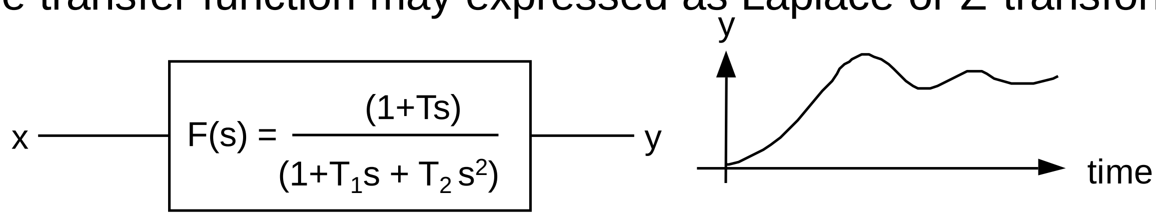
Example: traction motors, ovens, pressure vessel,...

The state of continuous plants is described by continuous (analog) state variables like temperature, voltage, speed, etc.

There exist a fixed relationship between input and output, described by a continuous model in form of a transfer function F.

This transfer function can be expressed by a set of differential equations.

If equations are linear, the transfer function may expressed as Laplace or Z-transform.



Continuous plants are normally reversible and monotone.
This is the condition to allow their regulation.

The time constant of the control system must be at least one order of magnitude smaller than the smallest time constant of the plant.

the principal task of the control system for a continuous plant is its regulation.

Continuous Plant (PI)

One of the most used controller is the PI –Proportional Integrative

The target is to have Val reaching Ref, that is Err = Ref – Val = 0
Err = Ref-Val; Out = (Kp + (Ki/s))·Err

Z transform: $s = (1-z^{-1})/Ts$ where Ts is 1/fs (fs is the sampling frequency) and $z^{-1} \cdot A_k = A_{k-1}$

$Out_k = Kp \cdot Err_k + Ki \cdot Ts \cdot Err_k/(1-z^{-1})$

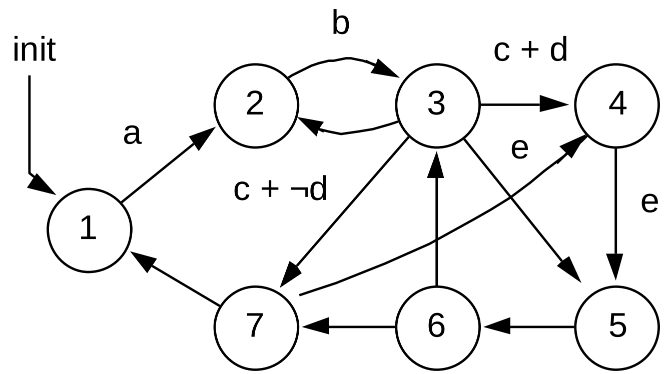
A simple program
Measure Val_k and receive Ref_k;
$Err_k = Ref_k - Val_k$;
$Integral_k = Integral_{k-1} + Err_k$; // $Derivative_k = Err_k - Err_{k-1}$;
$Out_k = Kp \cdot Err_k + Ki \cdot Ts \cdot Integral_k$ // $Out_k = Kp \cdot Err_k + Ki \cdot Ts \cdot Integral_k + Kd \cdot Derivative_k$;
That is (PI only) $Out_k = Out_{k-1} + Kp \cdot (Err_k - Err_{k-1}) + Ki \cdot Ts \cdot Err_k$

Bilinear Z transform: $s = 2(1-z^{-1})/(Ts \cdot (1+z^{-1}))$
$Err_k = Ref_k - Val_k$;
$Integral_k = Integral_{k-1} + (Err_k + Err_{k-1})/2$; // smoothing action
$Out_k = Kp \cdot Err_k + Ki \cdot Ts \cdot Integral_k$

Thumb rule: Set Ki=0 and tune Kp at the oscillating limit (Kp_{cr}) and measure oscillating period T_{cr}, then set Kp=0,4Kp_{cr} and Ki=12,5·Ts[s]/T_{cr} then adjust manually

Discrete Plant (reminder)

Examples: Elevators, traffic signaling, warehouses, etc.



The plant is described by variables which take well-defined, non-overlapping values.
The transition from one state to another is abrupt, it is caused by an external event.
Discrete plants are normally reversible, but not monotone, i.e. negating the event which caused a transition will not revert the plant to the previous state.

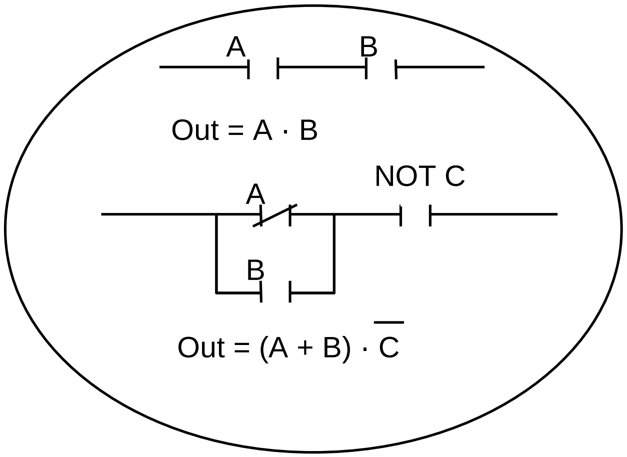
Example: an elevator doesn't return to the previous floor when the button is released.

Discrete plants are described e.g. by finite state machines or Petri nets.

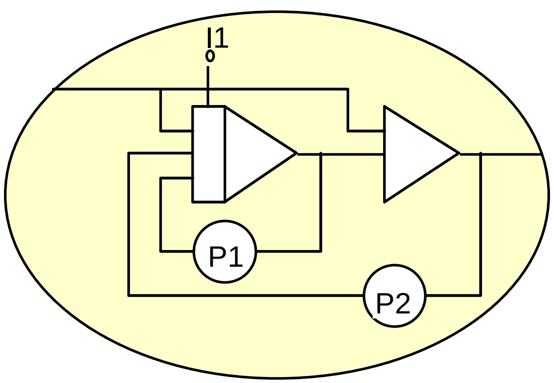
the main task of a control system with discrete plants is its sequential control.

Continuous and Discrete Control (comparison)

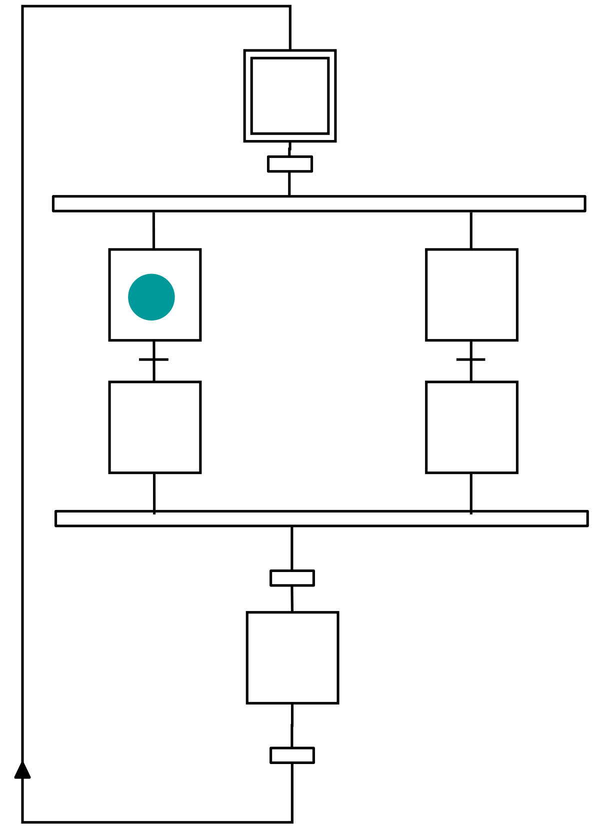
"combinatorial"[1]	"sequential"
e.g. ladder logic, CMOS logic	e.g. GRAFCET, Petri Nets



ladder logic

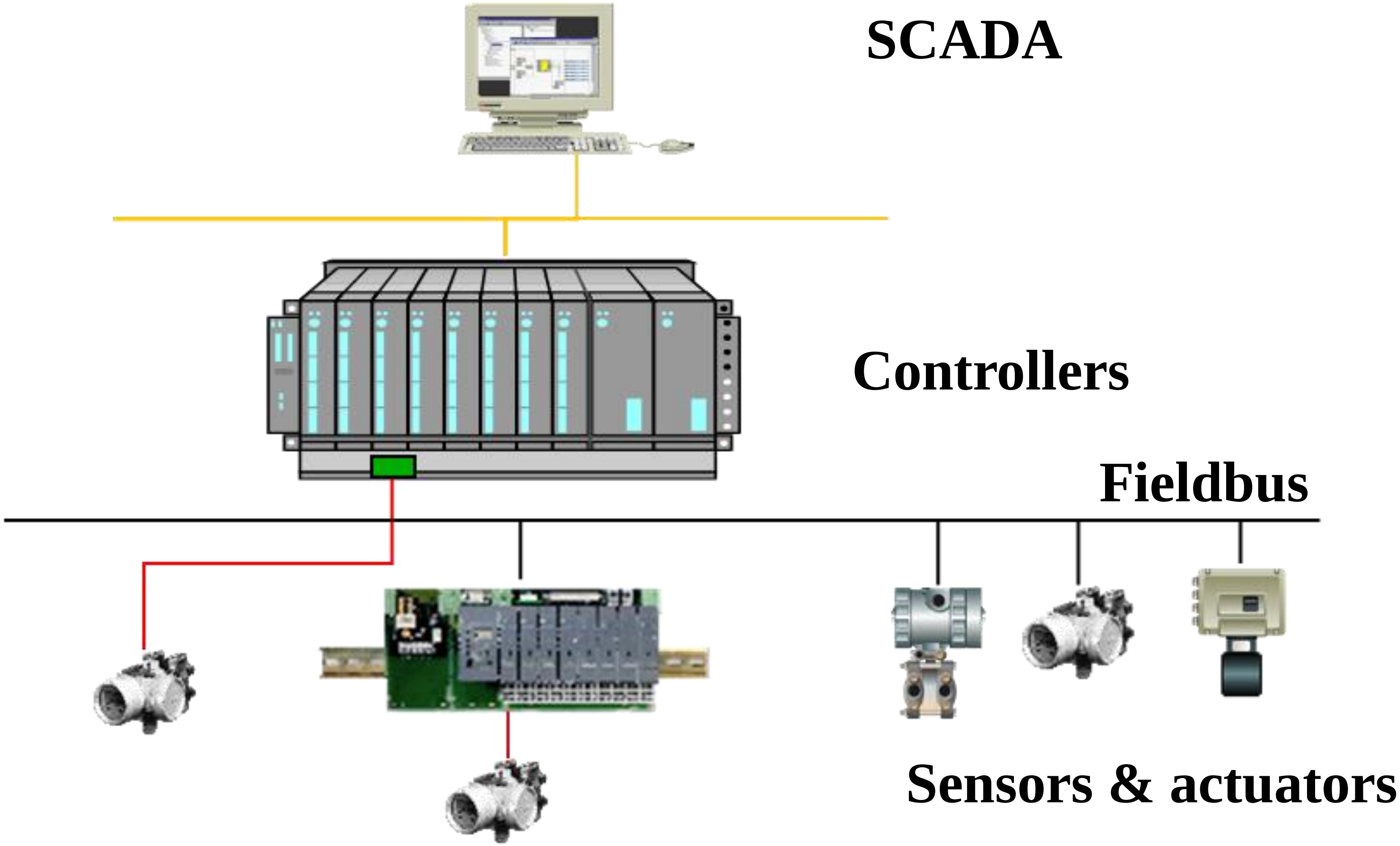


analog building blocs



1) not really combinatorial: blocks may have memory

Low levels of automation in process control and factory automation



Courtesy of Prof. Kirmann, EPFL

Sensors and actuators

- **Process control**
  - Safety-proof, anti-explosion (Ex), no spark (powered by the fieldbus or battery powered –wireless-)
  - Expensive, hard environment (IP67)
  - Not fast (regulation is slow) but accurate
  - Redundant (measurement is the heart of regulation)

- **Factory automation**
  - Fast, reliable, inexpensive
  - not so much accurate, oversampling and digital filtering if needed

Fieldbus

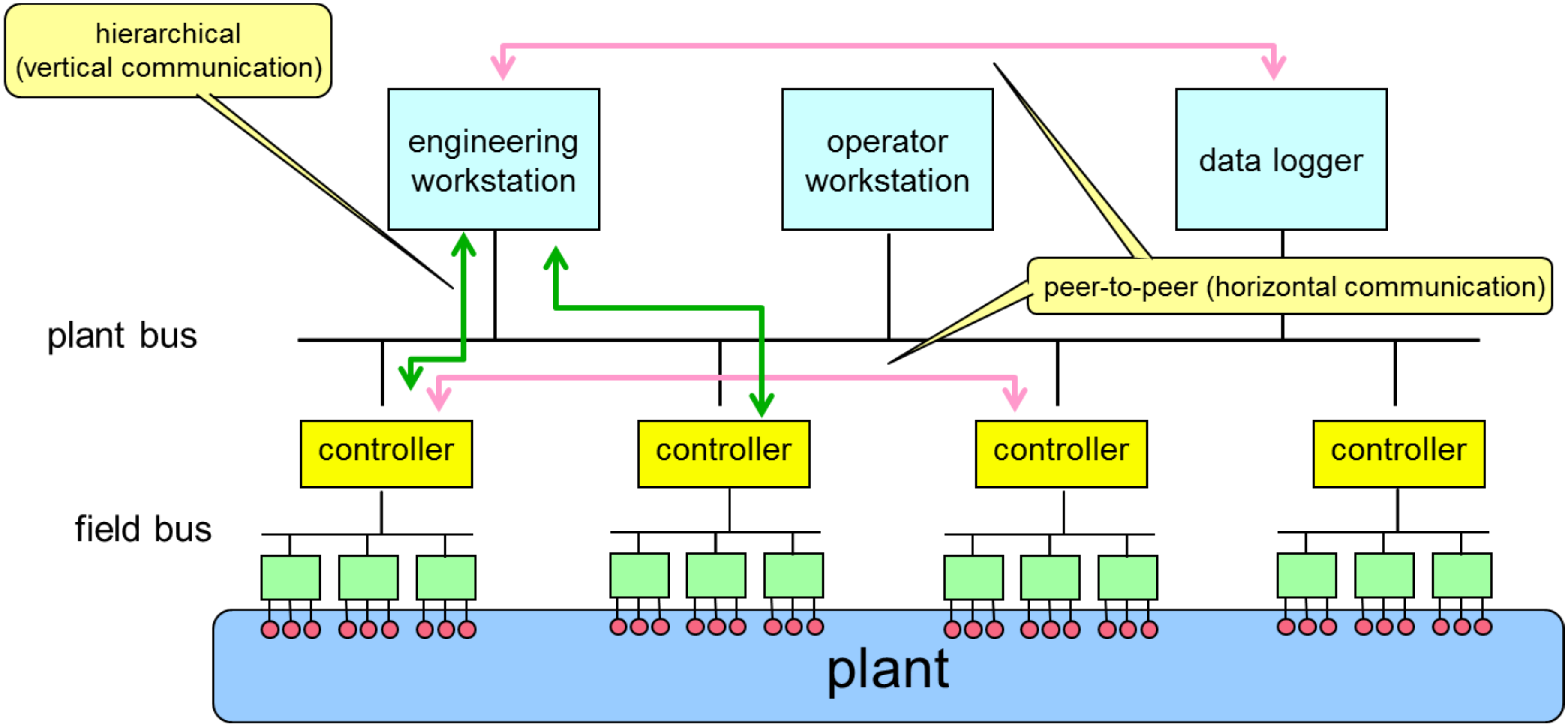
- **Process control**
  - Long distances, powered, diagnostic
  - Slow, wireless (cable is a problem!) and battery powered (modulation, mesh)

- **Factory automation**
  - Fast, reliable, inexpensive
  - not so much accurate, oversampling and digital filtering if needed

Controllers

Courtesy of Prof. Kirmann, EPFL

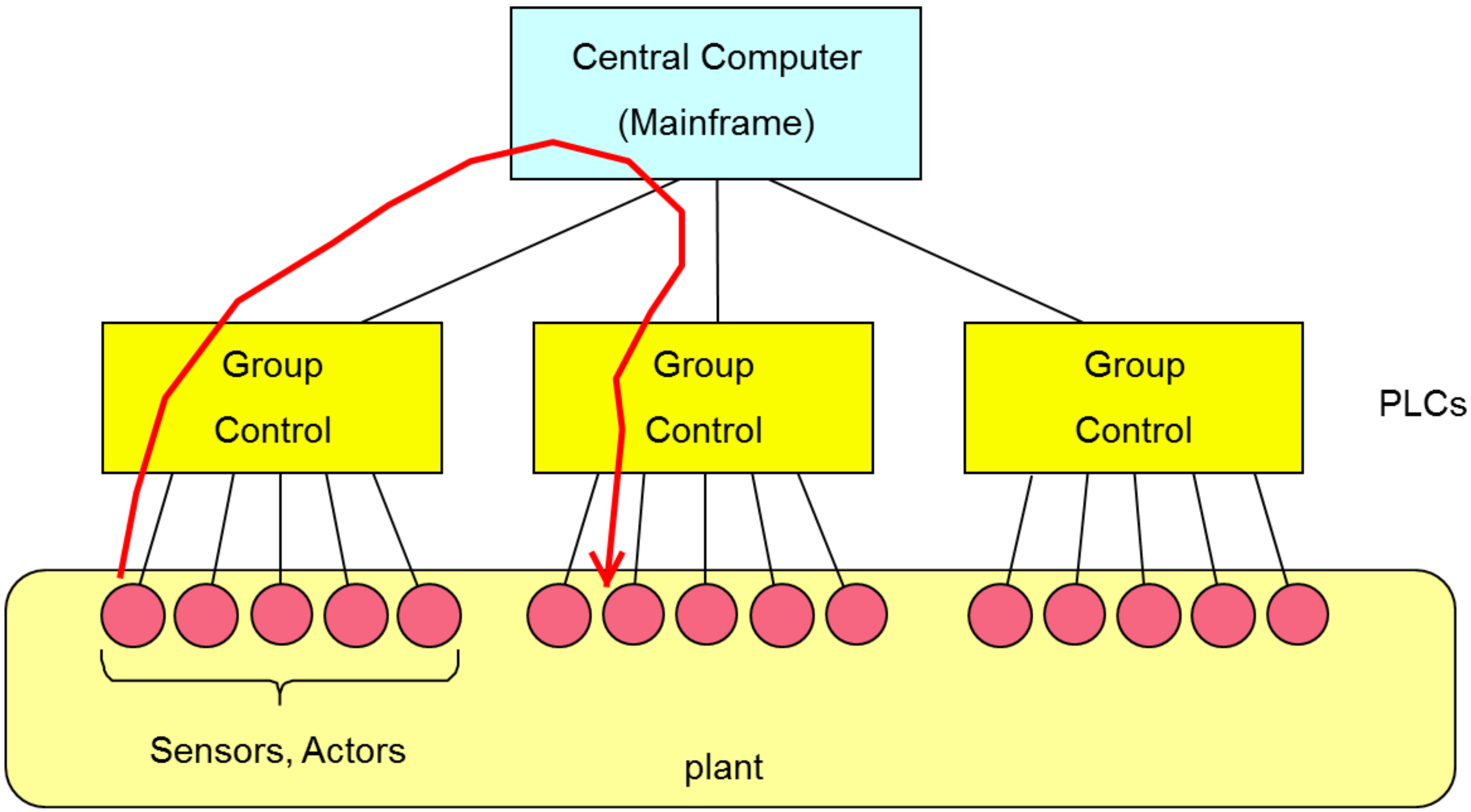
- **Process control**
  - **Large area -> distributed control (Decentralized Control System DCS)**
  - **Main task: regulation**
  - **Redundancy, peer-to-peer architecture**



Controllers

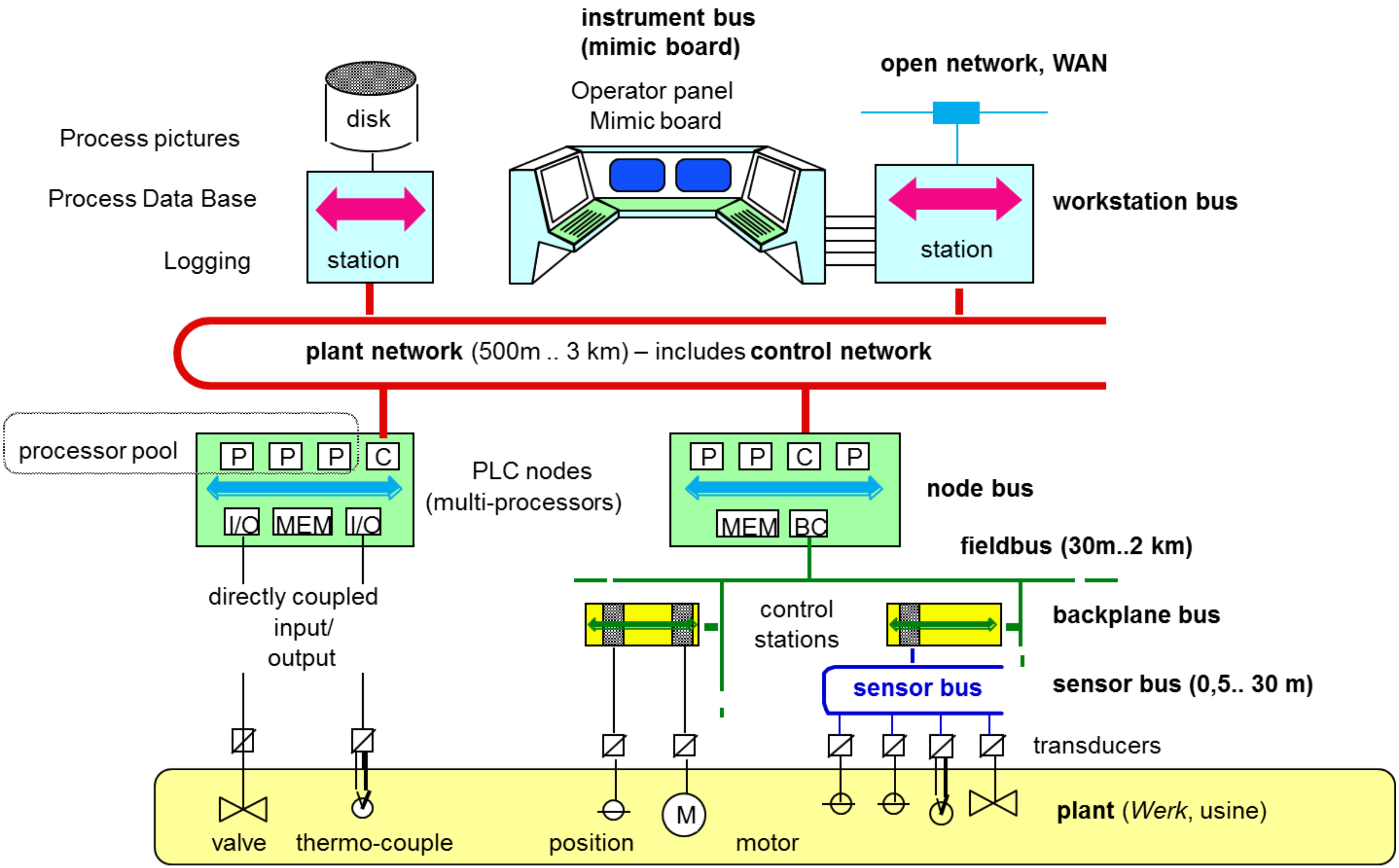
Courtesy of Prof. Kirmann, EPFL

- **Factory automation**
  - **Simple, reliable, fast, hierarchical, mainly centralized architecture**
  - **Programmable Logic Controller –PLC**
  - **Main task: timing, command**



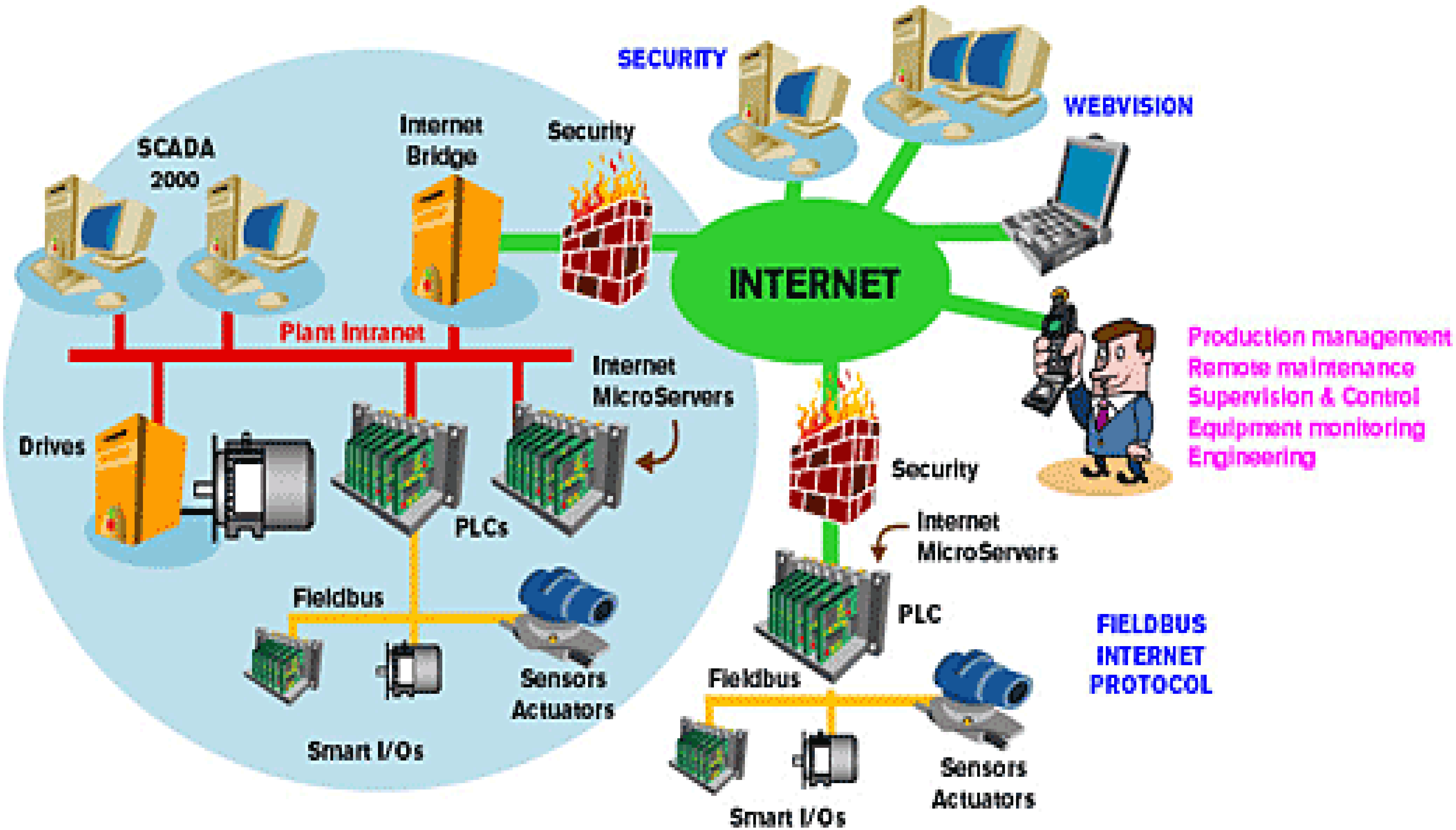
Controllers, distances

Courtesy of Prof. Kirmann, EPFL



Controllers, internet connection

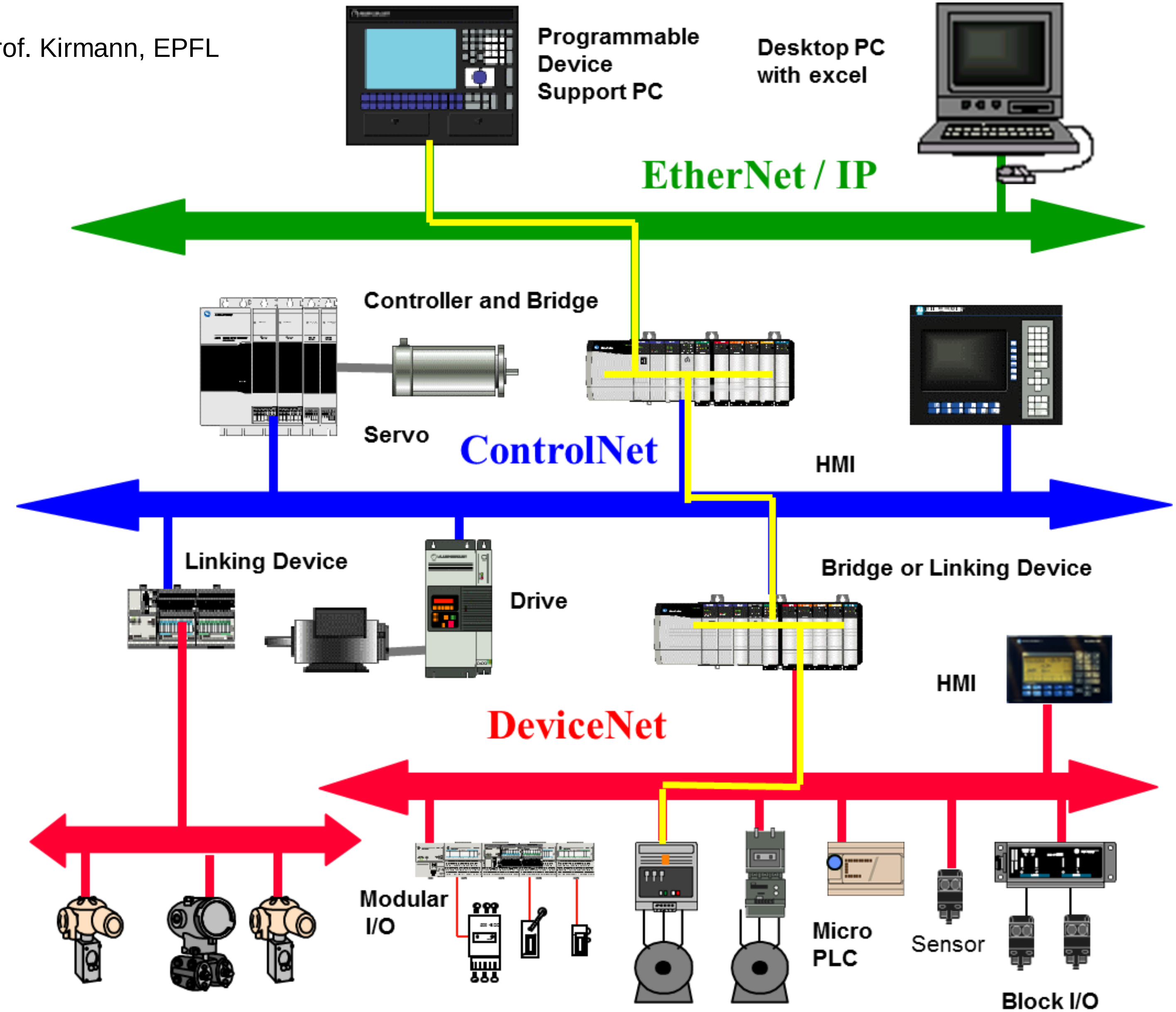
Courtesy of Prof. Kirmann, EPFL



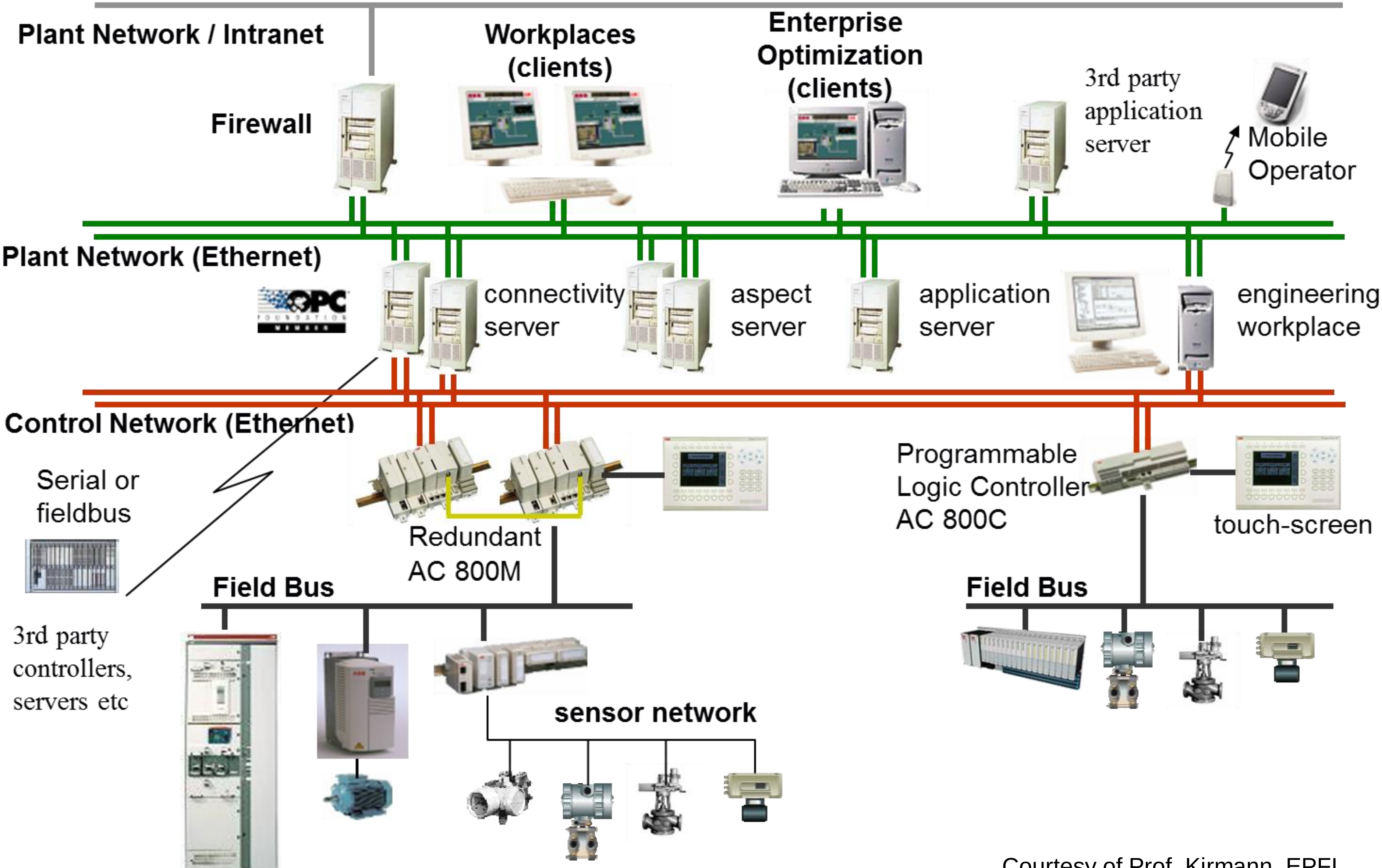
The ALSTOM e-Control Architecture

Controllers, factory automation (e.g. Rockwell)

Courtesy of Prof. Kirmann, EPFL



Controllers, industrial plant (e.g. ABB)



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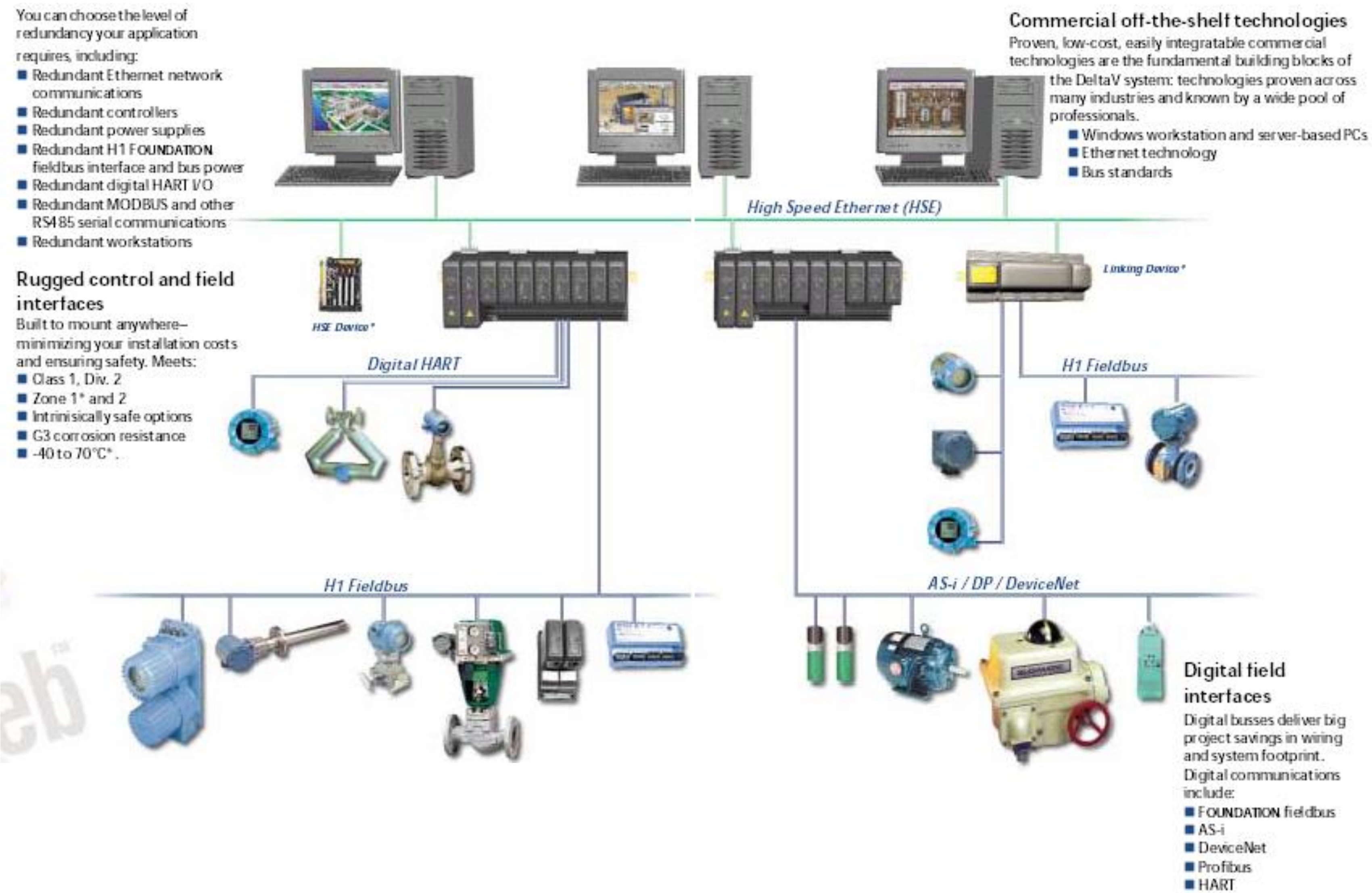
Controllers, Process Plant (e.g. Emerson's)



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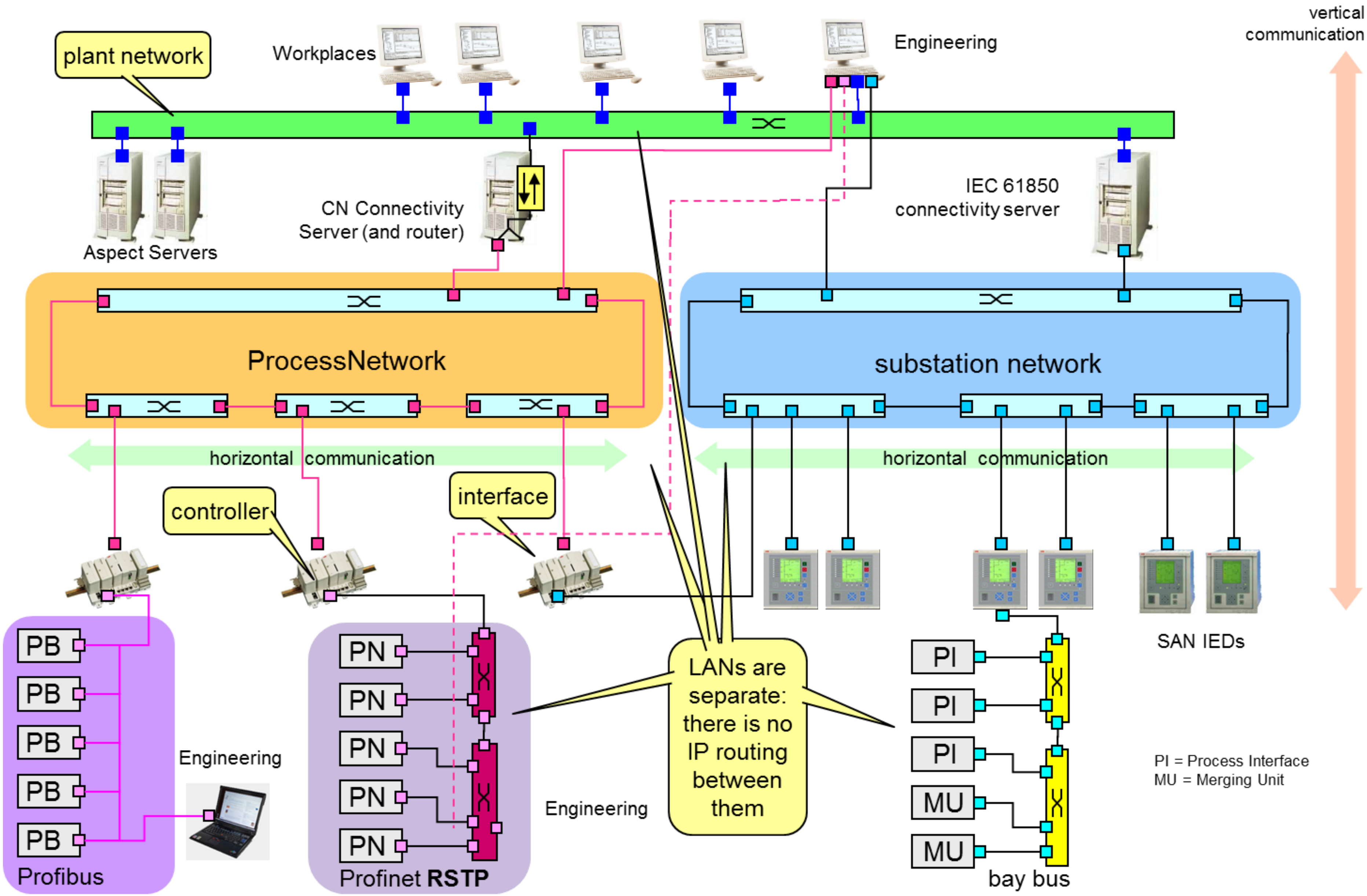
Controllers, plant with chemical and electrical



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