Ingegneria e Tecnologie dei Sistemi di Controllo T
Control Systems Technologies

Introduction

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Purpose and Outline

- **Purpose of the Introduction:**
  place this course in the field of automatics and automation and, then, give specific objectives and contents
- **Outline:**
  - **General Objectives “by intuition”**
  - **“Implementation” details:**
    - **Download and messages list**
    - **Audience**
    - **Timetable & Lab practice (?)**
    - **Books and course material**
    - **Exam rules**
  - **Preliminary Concepts: Automatics – Automation and Automation Pyramid**
  - **Detailed Objectives**
  - **Contents**

Objectives

Objectives (by intuition)

- Starting from previous courses on automatic control:

- Basic knowledge of technology architectures and components for control
- Introduction to additional “functions” typical in automation
  - Logic control
  - Advanced modelling techniques

Knowledge

- Deeper study of some parts ➔ Basic Projects

Know-how

“Implementation” details: download & messages list

- PDF copy of these slides (both color and b/w) on:
  amsCampus: https://campus.unibo.it/
- You need to subscribe to “download and message list”:
  christian.conticoni3.CST_2017-2018
  PWD: zxc218$

- Remark: all the material will be in English (I hope…)

“Implementation” details: Audience

- All in Automation Engineering (Almatong) ?

- Others (Master Students in Electrical Engineering)?

“Implementation” details: Audience

- (Basic) Knowledge useful for the course:
  - Operating Systems, Multitasking, scheduling?
    - Automation Engineering: so-so
    - Others: ?
  - A/D D/A conversion?
    - Automation Engineering: Yes
    - Others: ?
  - Communication Networks, ISO-OSI levels, TCP/IP?
    - Automation Engineering: No
    - Others: ?
  - Digital Control Systems
    - Automation Engineering: Yes
    - Others: ?
  - Power Electronics:
    - Automation Engineering: so-so
    - Others: ?
  - Electric Motors and Drives:
    - Automation Engineering: Yes
    - Others: ?

} Correct?

“Implementation” details: Audience

- We will try to fill gaps when necessary
- PLEASE, FEEL FREE TO INTERRUPT THE TEACHER TO ASK FOR CLARIFICATIONS!!

"Implementation" details: Timetable

	Monday	Tuesday	Wednesday	Thursday	Friday
9.00					
10.00					
11.00	**CONTROL SYSTEMS TECHNOLOGIES** (9 CFU) MATTEO SARTINI AULA 5.5 - Piano Primo - Viale del Risorgimento 2 - Bologna	**CONTROL SYSTEMS TECHNOLOGIES** (9 CFU) CHRISTIAN CONFICONI AULA 7.5 - Piano Primo - Via Saragozza, 8-10 - Bologna			
12.00					
13.00			**CONTROL SYSTEMS TECHNOLOGIES** (9 CFU) MATTEO CACCIARI AULA 1.5 - Piano Primo - Viale del Risorgimento 2 - Bologna		
14.00					
15.00					
16.00					
17.00					
18.00					
19.00					

“Implementation” details: Course material and books

- **Course slides (and your own notes)**
  - **Available on ams campus**
    see before…
  - **And your own notes…**
- **Bonivento, Gentili, Paoli**
  “Sistemi di automazione industriale – Architetture e controllo”
  Mc Graw Hill
  - **(in Italian!)**
- **Bonfatti, Monari, Sampieri**
  “IEC 1131-3 Programming Methodology”
  CJ International, Le Saint Georges, France
  - **(for deep study of languages and methodologies for logic control)**

“Implementation” details: Other books

- Chiacchio, Basile
  “Tecnologie informatiche per l’automazione”
  2ª Edizione, McGraw-Hill (in italian)
- Bonometti
  “Convertitori di potenza e servomotori brushless”
  Editoriale Delfino, Milano
  (for electric drives, in italian)
- Fraser
  “Process Measurement and Control”
  Prentice Hall, Upper Saddle River, N.J.
  (for sensors and signal conditioning and acquisition)
- Johnson
  “Process Control Instrumentation Technology”
  Prentice Hall, Upper Saddle River, N.J.
  (for sensors and signal conditioning and acquisition)

“Implementation” details: EXAM RULES 1/2

- **Written Exam (3.5 hours - Mandatory) :**
  - **2 exercises :**
    - **Basic design of an analog acquisition chain for sensors**
    - **Electric drive selection (type and size) according to a given mechanical task**
  - **15 short questions**
- **Development and Presentation of a Project (in team - Mandatory):**
  - **Logic control in CoDeSys for a given plant (short written report is required)**

"Implementation" details: EXAM RULES 2/2

- Oral examination (Optional, on student's request):
  - Questions on all the topics of the course
- Detailed information on exam rules will be available on the course webpage
- No homeworks or on-going partial exams are foreseen

Preliminary concepts

- Some preliminary considerations:

  - to set a shared nomenclature

  - to gain a better understanding of the course contents

  - Function vs Realization of a system
  - Framework: control without humans
  - Automatics e Automation
    - “What are they?” e “How do they relate each other?”
  - Automation Pyramid
    - Introduction to “Logic control”

FUNCTION OF A SYSTEM

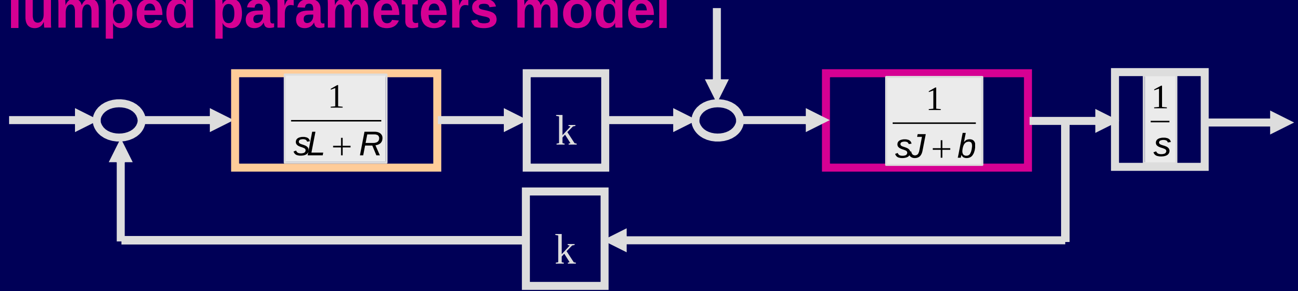
Vs

REALIZATION (PHYSICAL AND TECHNOLOGICAL IMPLEMENTATION) OF THE SYSTEM

Preliminary Concepts

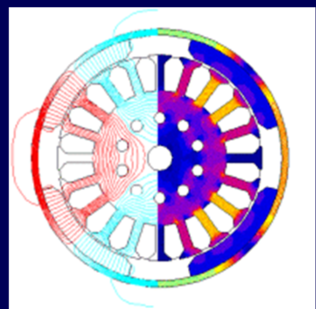
Function vs Realization

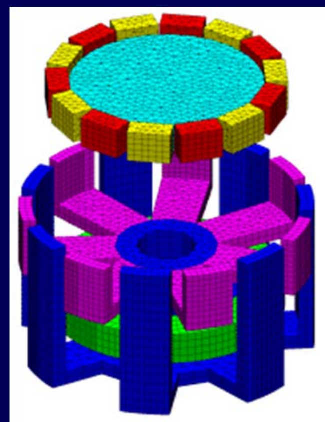
- **Function:**
  - **of a system, a device, etc.**
  - **defines WHAT IT DOES**
    - **And its abstract behaviour (…)**
  - **Examples:**
    - **Data processing: Algorithm/Automaton**
    - **Automatic Controllers: R(s), R(z)**
    - **Plants: Simplified model for control**
      - **DC Motor ➔ lumped parameters model**



Function vs Realization

- **Realization** (Physical/Technological Structure/Implementation)
  - of a system, a device, etc.
  - defines HOW IT REALIZES its function PHYSICALLY
  - Examples:
    - Data Processing → Adopted PC, Adopted O.S., Adopted language and implementing code
    - Automatic Controllers → Computing HW, etc.
    - Plant: Structural models
      - DC Motors
        → Maxwell Equation
        → FEM





Function vs Realization

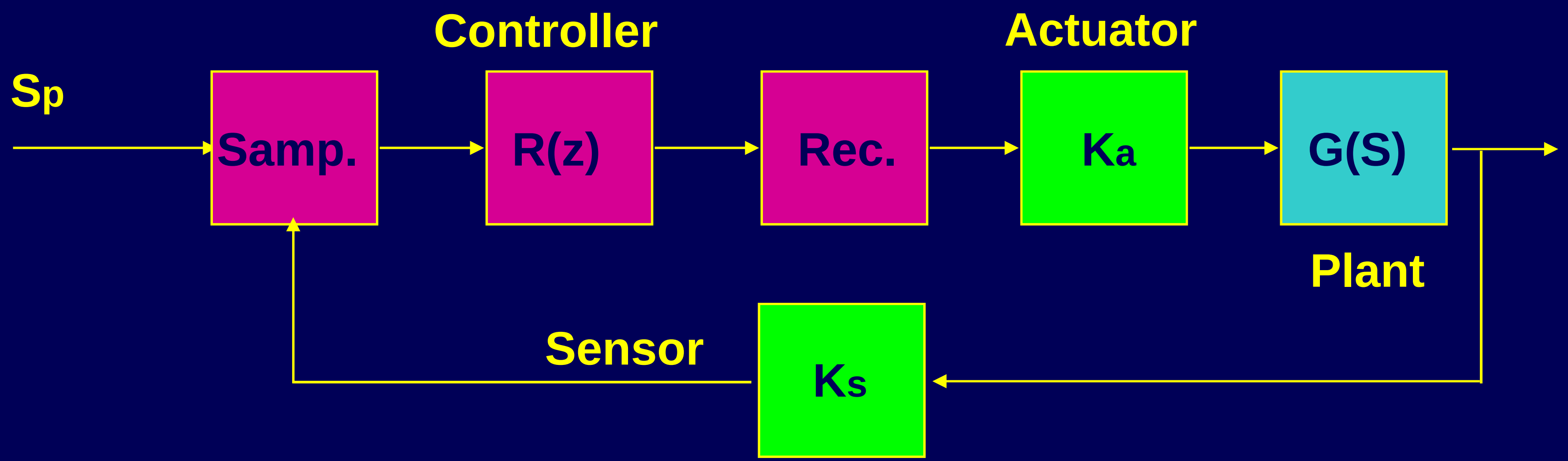
- Engineering = design and realization of systems
- Design Steps for a System or a Component:
  - First: functional/behavioral design
  - Then: implementation/technological design
- Functional design constraints from implementation:
  - Available technologies for implementation, costs…
- Loop can be necessary
  - Implementation constraints not a priori known
  - Anyway functional design is always the first

Function vs Realization

- **Advantages:**
  - **“Optimal” sizing of the system realization**
  - **Possible mapping on different technologies**
  - **Documentation / Reuse**
  - **Etc.**
- **Obvious? Often in industry they don’t work in this way!**
  - **Particular ly in automation field!**
    - **Es: Choice of the electric drives size**
    - **Es: Control systems**

Preliminary Concepts

Example: Functional design of a digital control



- **Block described as:**
  gains, transfer functions ➔ functional modelling
- **From previous courses**

Preliminary Concepts

Example:
Design approach already seen in previous courses

- **From a physical plant to be controlled**

⇩

- **Functional model of that physical plant**
  - **Mathematical model**

⇩

- **Design of the functional model of the controller**
  - **Design techniques and simulation tests**

⇩ **What after?**

Preliminary Concepts

Example: what is still missing ?

- Design of the functional model of the controller

⇩

- “Physical” Controller

- REMARK: as said before, usually in functional design some realization constraints are directly taken into account
  - E.g.: Discrete-time control for digital implementation… CORRECT!!
  - E.g.: Digital-time control: computational delay… CORRECT!!
  - E.g: Controller designed as “code” since it will be implemented using SW… WRONG!!!
    - Not easy to read, oriented to a specific technology
  - Other CORRECT examples?

Preliminary Concepts

Example: What is still missing? (cont'd)

- Final step: from control function to actual controller

⬇

- This final step is a sort of MAPPING from “functional solution space” to “technological solution space”

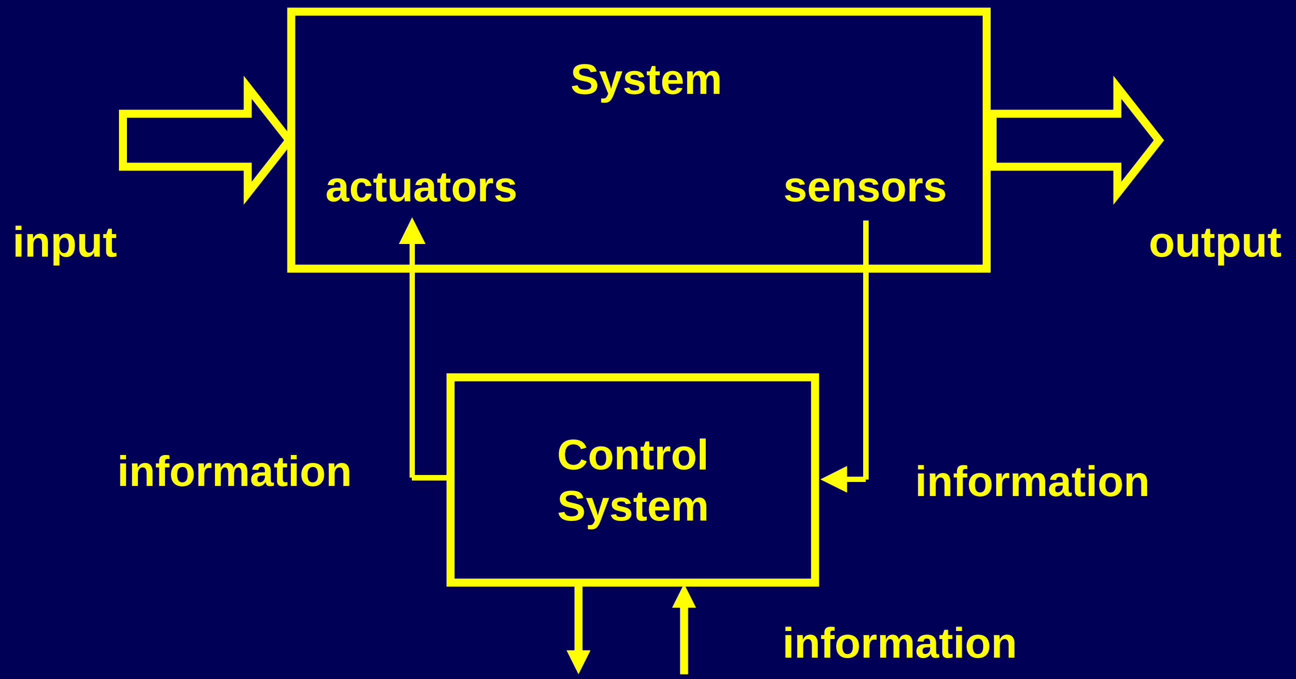
⬇

- Then a general description of this two “spaces” could be helpful
  - Model to describe typical control functional architectures and components
  - Model to describe typical control implementation/technological architecture and components

FRAMEWORK

Preliminary Concepts

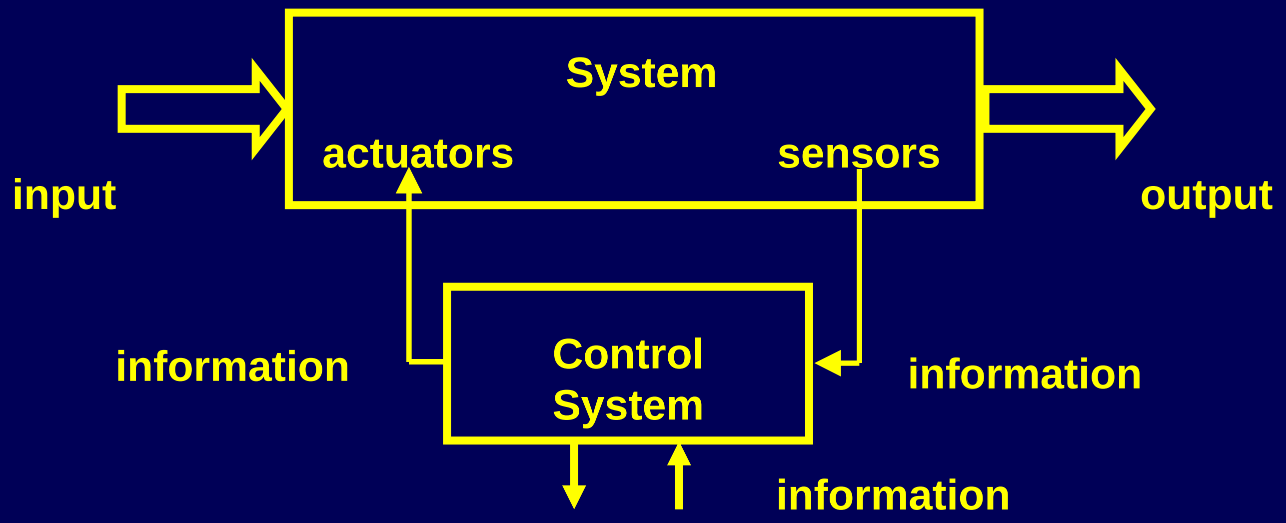
Our framework



- Objective: AUTOMATIC CONTROL at large
  - To impose to the system a desired behaviour “in an automatic way” (i.e. without, or reducing, human actions)

Preliminary Concepts

Our framework



- Both system and control system can be very complex
  - with many components (from both functional and technological viewpoint)
  - far beyond the basic scheme of Automatic control courses…
- The above scheme can be far from physical implementation (function vs. implementation)
  - E.g. Control system components could be not “spatially adjacent”

Preliminary Concepts

Example: Process Industry

Preliminary Concepts

Example: Manufacturing

AUTOMATICS and AUTOMATION

Preliminary Concepts

AUTOMATICS

Engineering area (with strong mathematical basis) where the following main topics are considered:

- Mathem. modelling and identification of physical systems
- Study of structural properties of mathematical models
- Simulation of mathematical models
- Design and verification of control systems (functions)
  - Mainly using mathematical models
  - Physical meaning should be considered…
- Fault diagnosys and fault-tolerant control
  - Mainly using mathematical models
  - Physical meaning should be considered…

Preliminary Concepts

AUTOMATION

“Canonical” Definition (Chiacchio-Basile):

Industrial Automation:

Discipline studying methodologies and technologies which allow to control fluxes of energy, materials and information to realize production processes, without (or with reduced) human actions

- **Generalization: AUTOMATION “at large”**
  Discipline studying methodologies and technologies which allow to control fluxes of energy and/or materials and/or information and/or other variables to realize processes, without (or with reduced) human actions

Preliminary Concepts

AUTOMATION (cont'd)

Engineering discipline dealing with actual realization of systems with automatic control features

- **It covers different engineering disciplines:**
  - **Theoretical basis: Automatics → to define functions**
  - **Computation/Communication: Digital Electronics / Informatics / Telecommunication**
  - **Measure acquisition from sensors: Analog/Digital Electronics**
  - **Actuations: Power Electronics / Electrics / Mechanics**
  - **SYNERGY….**

Preliminary Concepts

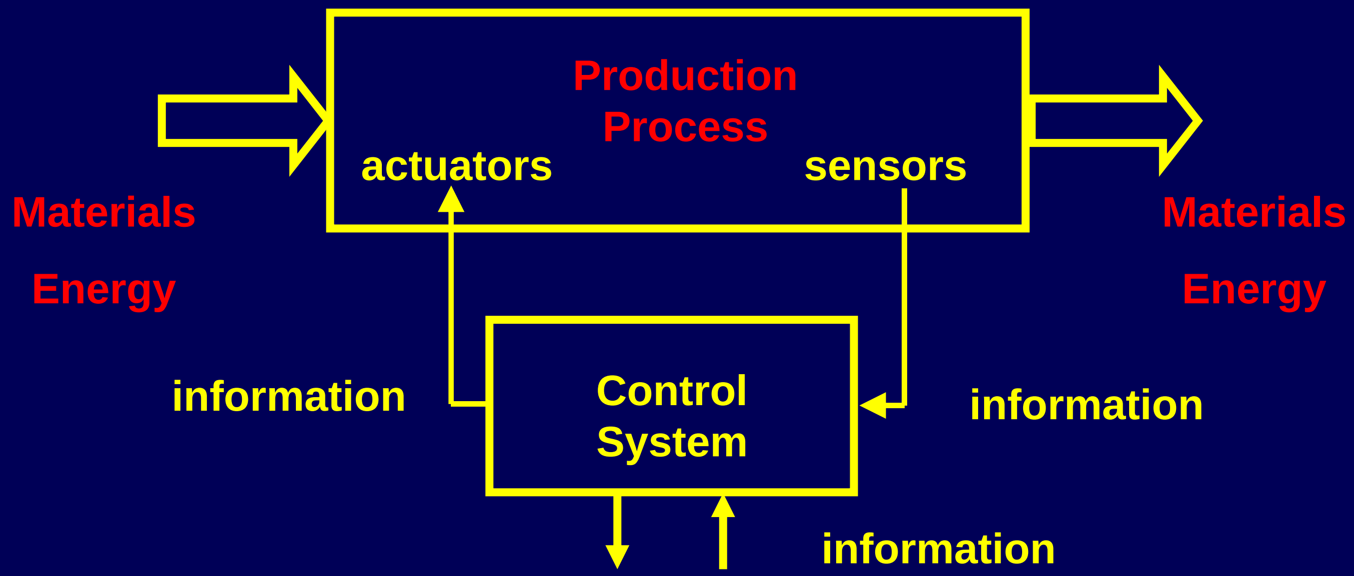
AUTOMATION (cont'd)

- **Interaction with other discipline realizing plants:**
  Plants to be automated can be of various size and type:
  - Plants of Process Industry
    - Chemical Plants
    - Energy Production Plants
  - Plants of Manufacturing Industry
    - Automatic Machines and Machine Tools
    - Assembly lines
    - Industrial robots
  - Non industrial robots (mobile, humanoid, surgery…)
  - Car Systems
  - Avionic systems
  - Power supplies for particles accelerators
  - Electric Drives
  - ….

Preliminary Concepts

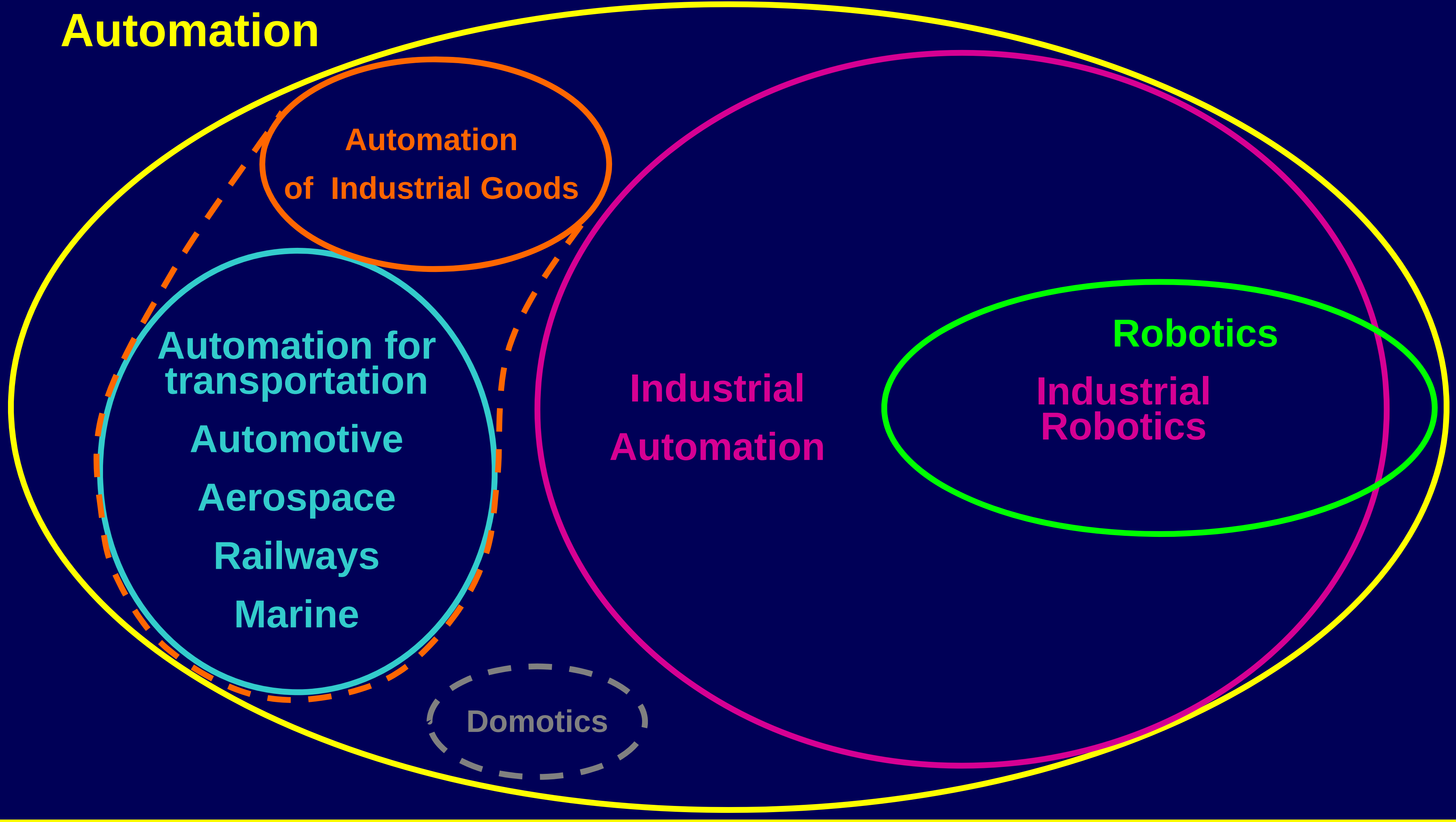
AUTOMATION (cont'd)

- Often "automation" is confused with "industrial automation"
  - They are different!
  - But many things from Ind. Autom. are valid for Automation in general
- In this course we will focus on INDUSTRIAL AUTOMATION
  - Framework becomes:



Preliminary Concepts

Automation vs. Industrial Automation



Preliminary Concepts

AUTOMATION (cont's)

- **Similarities**
  Industrial automation and other fields of automations show similar problems and solutions <u>up to certain levels</u>
  - **see later: automation pyramid**

- **Hence considering Industrial Automation is rather general**

Preliminary Concepts

Remark (.. Disclaimer)

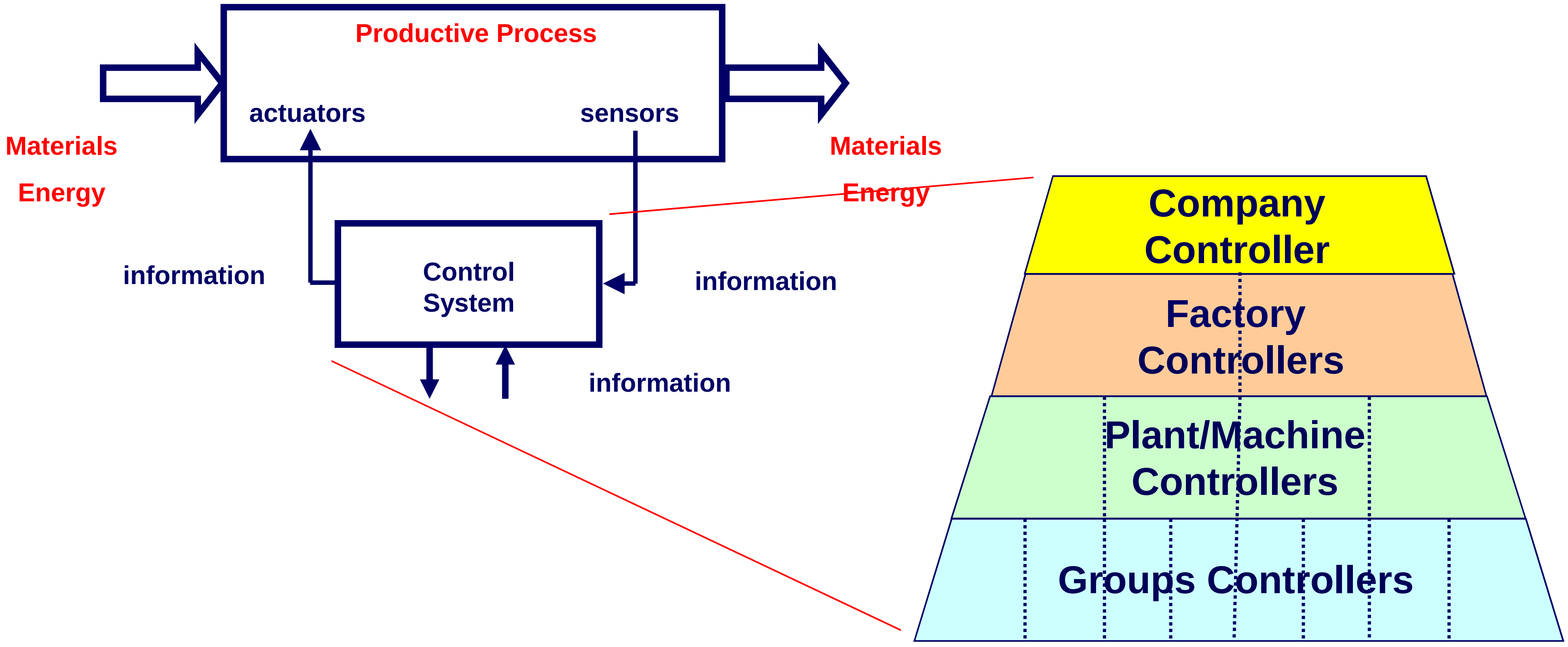
- “Definitions” here reported are not sharp as in mathematics, these are rather “philosophical”…

- Boundaries are not so sharp

- Different opinions can be found…

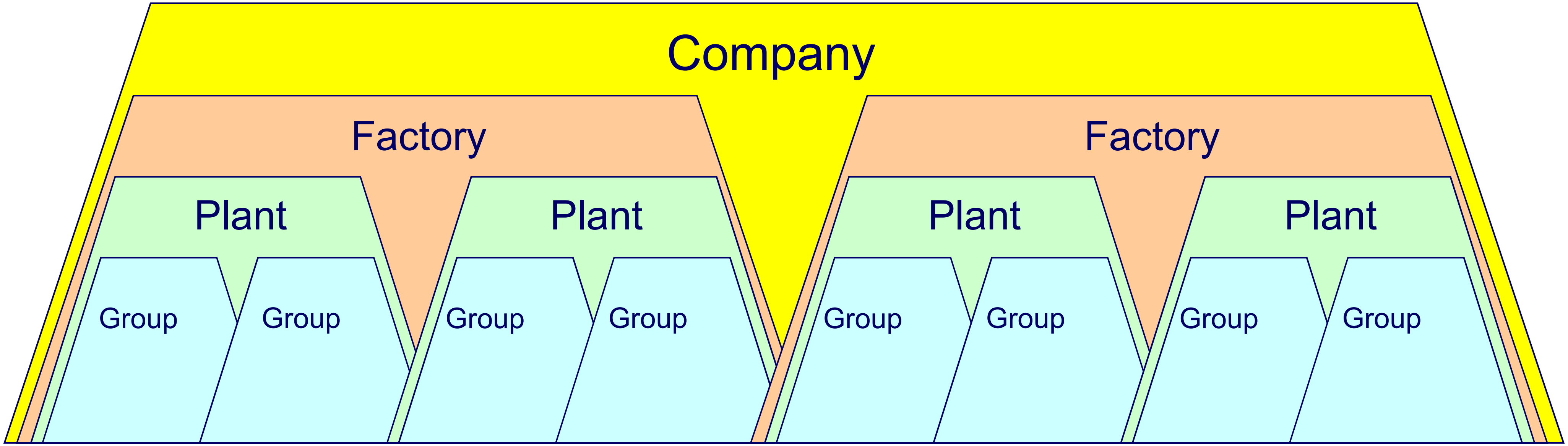
AUTOMATION PYRAMID
AND
LOGIC CONTROL

- **Automation Pyramid:**
  Qualitative representation of the functional architetture of the control system adopted in industrial automation
  - **System to be controlled: company dealing with industrial production (!!)**
  - **Model introduced together with management area (CIM)**



Automation Pyramid

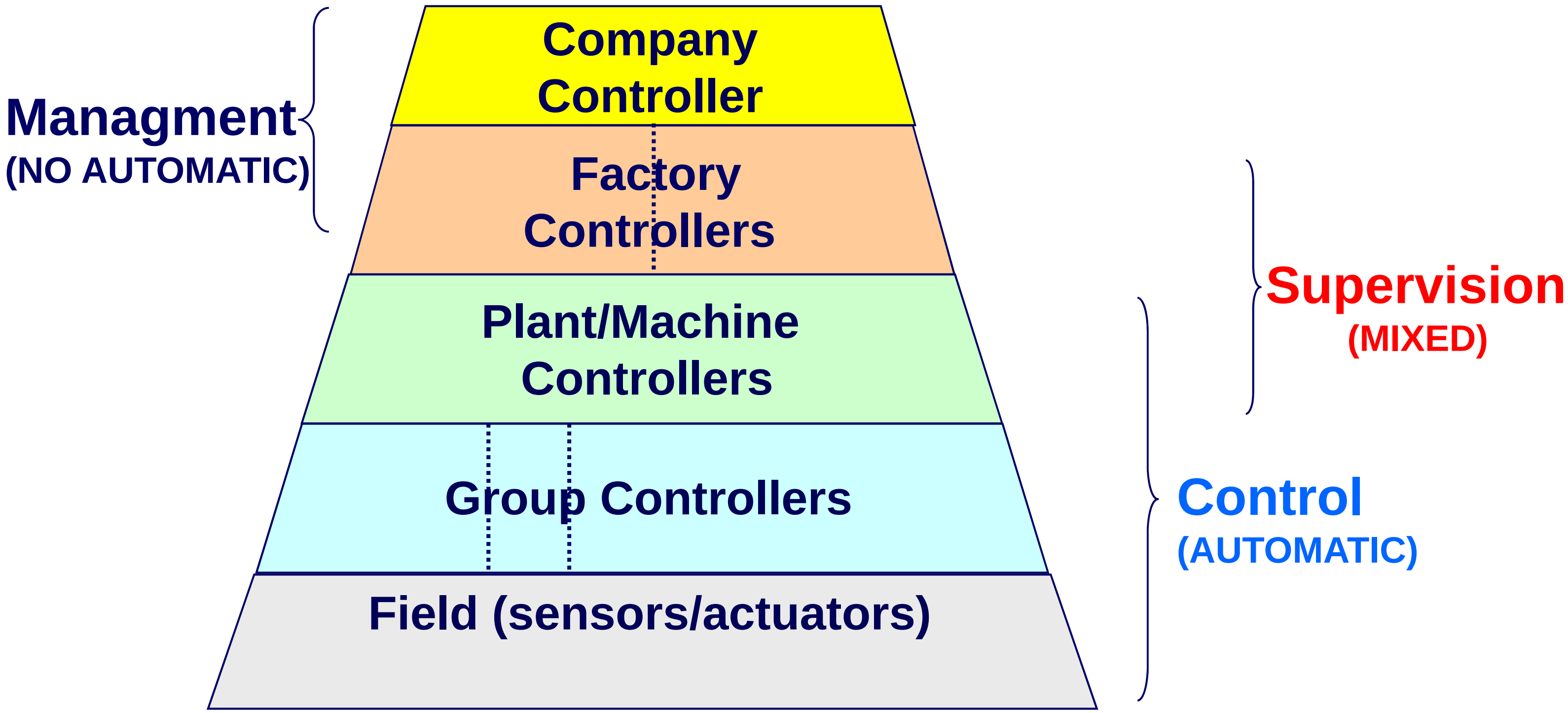
- **<u>Hierarchical</u> and <u>modular</u> architecture ("divide et impera" - divide and rule)**
  - **Follows the structure of system to be controlled**
  - **Quite common strategy to deal with complex systems**
  - **Hierarchical and modular structure simplifies complexity handling (intuitive solution)**
    - **Decomposition and "isolated" of simpler sub-problems**
    - **Re-aggregation**



Pyramid structure is present at each level

Automation degree different at each level

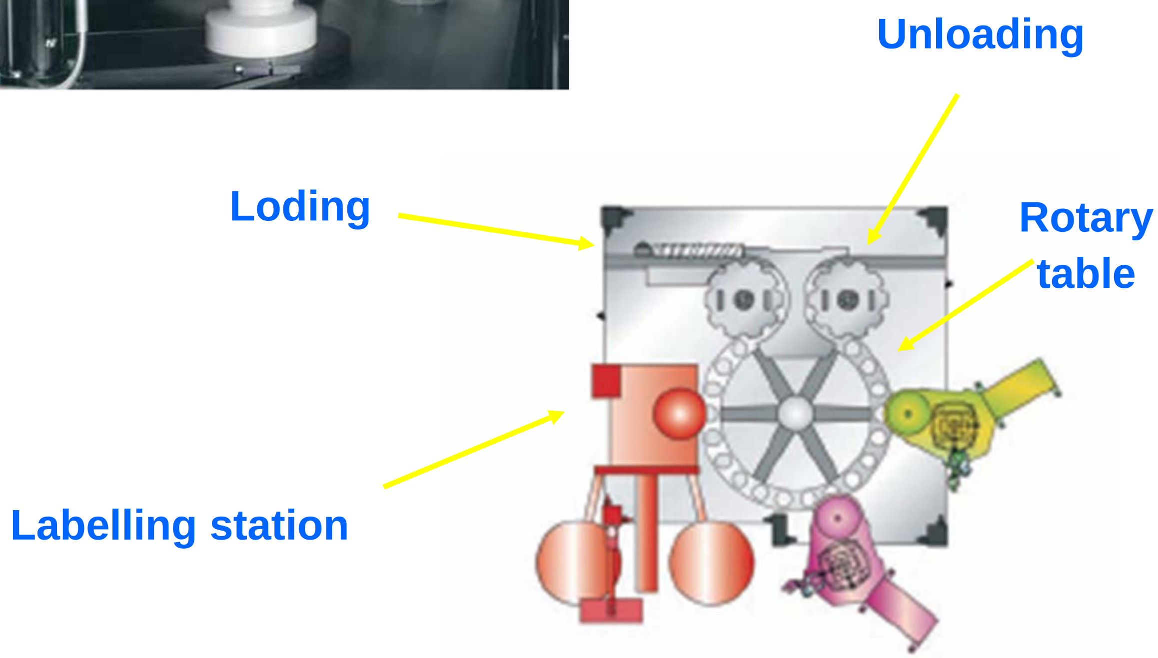
Nomenclature and "Automation grade" in AP



In this course:

- **Focus on Control level (high "automation grade")**
- **Some elements for the Supervision Level**

Automation Pyramid: motivating example



- **Machine for bottle labelling with "electronic cam":**
  some control functions
  - **Motion Ctrl of loading**
  - **Motion Ctrl of unloading**
  - **Rotary table M.Ctrl**
  - **Plates M. Ctrl**
  - **Labelling head Ctrl**
    - **Strength Ctrl of the labelling film**
    - **Cut Ctrl**
    - **(Glue Temp. Ctrl)**
  - **Coordination of all motions**
  - **Bottle Orientation with labelling head (photocell)**

Automation Pyramid: motivating example

- Machine for bottle labelling with “electronic cam”: possible control solutions
  - All in a single “block”
    - Multivariable control or similar
      - Complex
      - Not reusable even if just a component is modified

    Better to divide in subsystems (until possible and profitable)!
  - Subsystems organization:

    All at the same level
    - Coordination split among the different motion controllers
      - Still not so reusable, poor independence, unclear

    Hierarchical:
    - Coordination function clearly separated from motion controllers and higher in hierarchy:
      - Coordination policy easy to be identified

Automation Pyramid: motivating example

- Machine for bottle labelling with “electronic cam”: possible control solutions

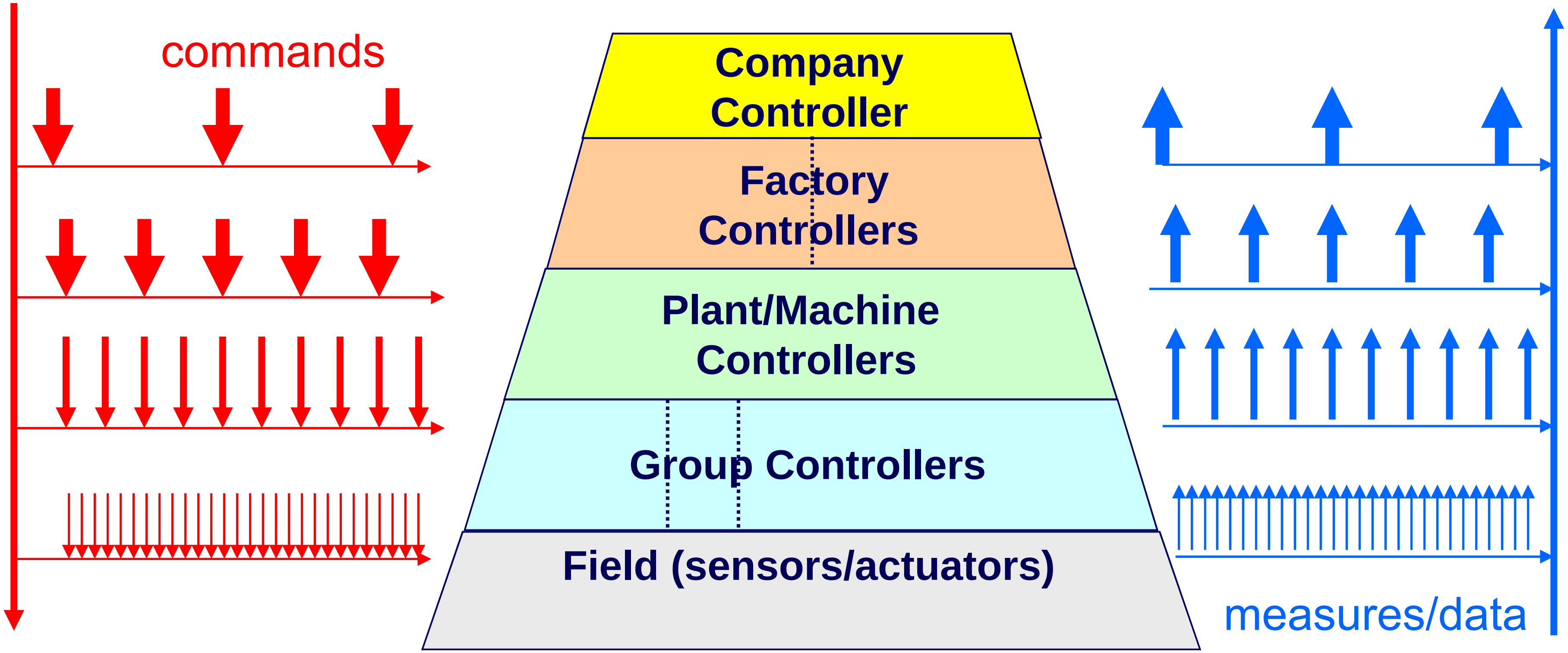
➔ Modular and hierarchical organization

  ➔ Have you seen something similar in Automatic Control?

➔ REMARK: all of the modules for control/coordination are easy to represent as R(s) or R(z)?

  ➔ LOGIC CONTROL (OR SEQUENCE CONTROL)

Information Flow in AP

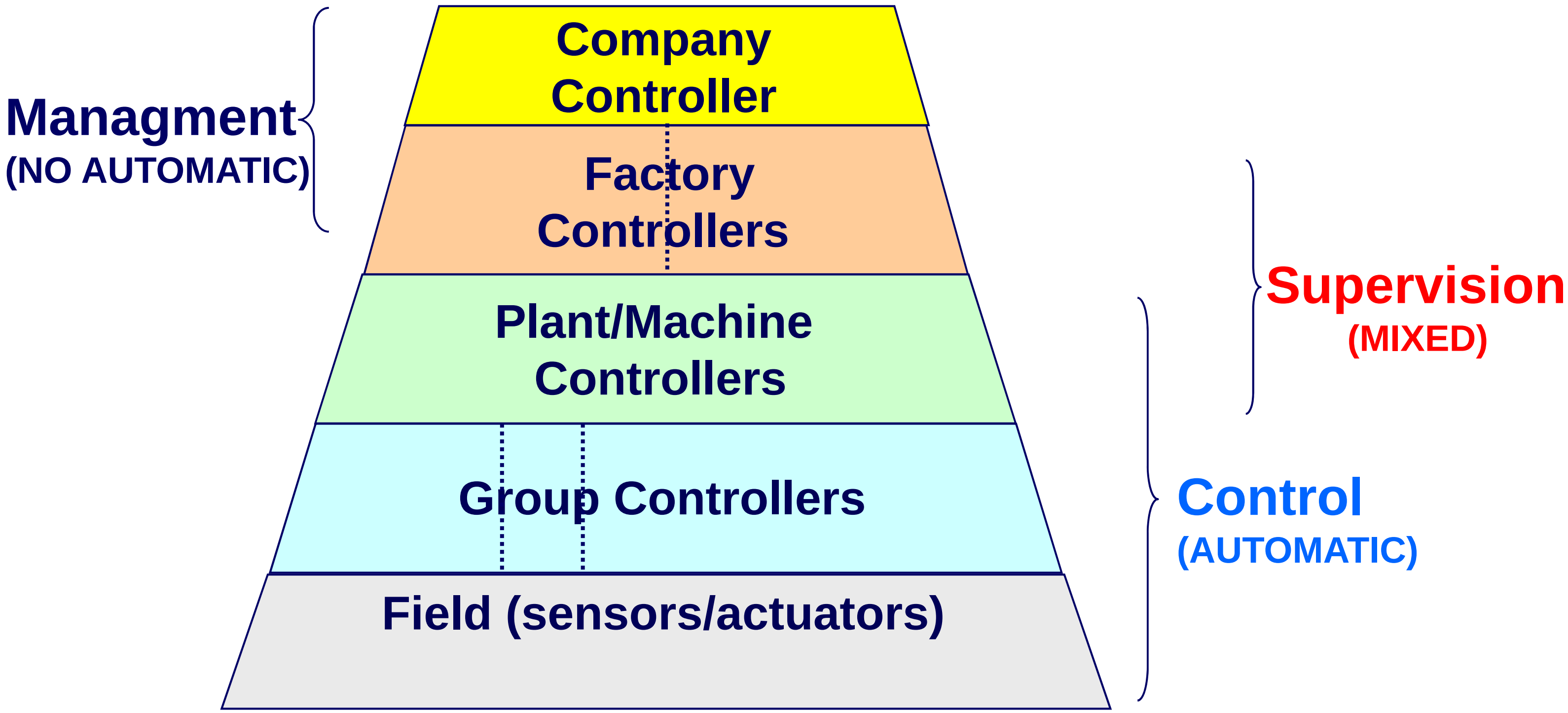


- Commands e measures (virtual)
- Typically vertical (horizontal is unusual)
- Usually higher levels do not measures or acts on real plant but on lower levels controllers
- Different time req. and data size at different levels

Information flow in AP

- **Communication**
  - **At higher levels:**
    - **Complex data**
    - **Low refresh frequency**
    - **No tight temporal constraints (Soft R.T. or non R.T. at all)**
  - **At lower levels:**
    - **Simple data**
    - **High refresh frequency**
    - **Tight temporal constraints (Hard R.T.)**

Our focus:



In this course:

- **Focus on Control level (high "automation grade")**
- **Some elements for the Supervision Level**

“Control Level” in AP

- “Control systems” for lowest levels in AP
  - High automation grade
- Two main control functions at this level:
  - Control of temporal variables (time-dependent systems)
    - Plant and controllers modeled as differential or difference equation
    - See , Controlli Automatici T1 and T2 (Automatic Control 1 and 2), continuous and discrete
    - “Classic Control”
  - Logic Control (or sequence control)
    - Plant and control can be modeled with automata driven by events
    - Similar to Logic Network in principle

"Control Level" in AP vs. Automation at large

- **Defined in Industrial Automation**
- **Large similarities with other fields of automation**
  - **Automation of Industrial goods**
  - **Automation in transportation**
  - **Robotics**
  - **Domotics**
  - **Etc.**
  - ➔ **They show hierarchical and modular architecture**
  - ➔ **Lower levels similar to "control level" in AP**
    - **High automation grade**
    - **Ctrl of time-dependent systems and Logic Ctrl**
  - **in some cases no more levels**
    - **Industrial goods (e.g.: washing machine)**
  - **Different implementation and technology solution but similar basic approach**

Logic Control (or Sequence Control)

- **Sometimes indicated as “supervision” or “management of the operating sequences”**
  - **Shows some similarities with “management” and “supervision” at higher levels.. but the same name is misleading!**
- **Examples:**
  - **Control of sequence of operations to be accomplished by a lift to move from a floor to another**
  - **Control of the washing phases of a washing machine**
  - **Working sequence of an automatic machine:**
    - **Start – Nominal Working – Stop**
- **Basically:**

represented with combinatorial and sequential logic (even very complex)

Logic Control

- Study and rigorous formalization of such subject is still at embryonal stage.

- Developed in both Automatic Control and Computer-Science

- In “real world” automation, approach to logic control is still “practice-driven”
  - It looks intuitive
  - Complexity explosion in large plants, also depending on the adopted formalism.

DETAILED OBJECTIVES AND CONTENTS

Detailed Objectives

KNOWLEDGE

- Technologies to implement “classic” and logic controller
  - HW architectures, technologies and main components
    - Computers, communication, sensors, transducers
- Computing units for automation
  - Processor-based digital electronics
    - Basics of real-time computing for automation
- Communication systems in automation
- Sensors
  - most common
  - evaluation and choice criteria

Detailed Objectives

KNOWLEDGE

- Analog/digital electronics to acquire measures from sensors
- Actuators: (a particular kind)
  - Electric drives
    - Very common
    - Selection criteria

- Modelling framework, Functional Design and Implementation of logic control
  - usually SW implementation
  - Modelling framework and functional design are implement-independent

Detailed Objectives

KNOW HOW

- Basic design of acquisition chains for analog sensors

- Choice of type and size of electric drives given a specific motion task

- Design of medium-complexity logic control by means of a suitable CAD

Contents

- Basics of “technological structure” in control systems
  - Architectures
- Technologies for different components: features and problems Digital Computing units
  - General purpose, Custom
- Real-Time computing for automation
- Typical architectures in industrial automation
- PLC
- Logic Control
  - Automation SW (improperly indicated as..)
  - “Programming” Standard IEC61131-3,
  - CoDeSys
  - Tool for advanced design

Contents

- Basics on sensors and actuators
- Some common sensors in automation
- Basics on interface electronics for automatic control
  - Simple design exercises
- Actuators for automation
  - Electric Drives (Motion Control) => tipologies/size-selction
    - Simple design exercise
- Communication systems in automation (FieldBus)
- Basics of Motion Control
  - Architcture
  - “Programming”, PLC Open Standard

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Introduction
The End

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