

MCTR 701_1

Master Advanced Mechatronics

Lecturer : Luc Marechal

2025

Contents

Lecture 1

**MECHATRONIC & COMPLEX PRODUCT :
SPECIFICATIONS,
PRODUCT LIFECYCLE,
UNDERSTANDING OF STANDARDS**

- What is Mechatronics
- Mechatronic product
- Product life cycles
- Designing a mechatronic product
- Examples of mechatronic product

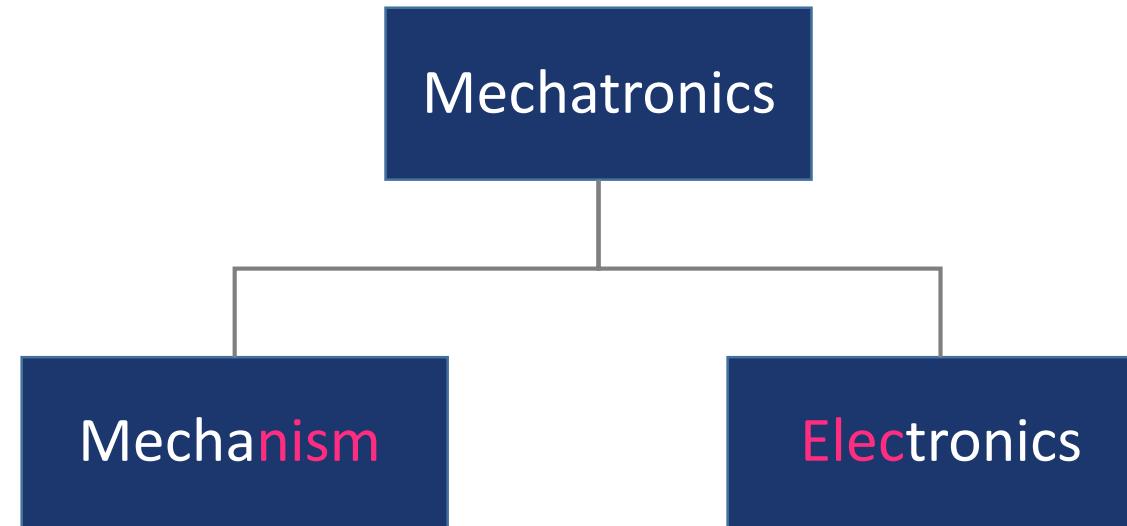
What is Mechatronics ?

- Please give your definition :



What is Mechatronics ? – Definitions and meaning

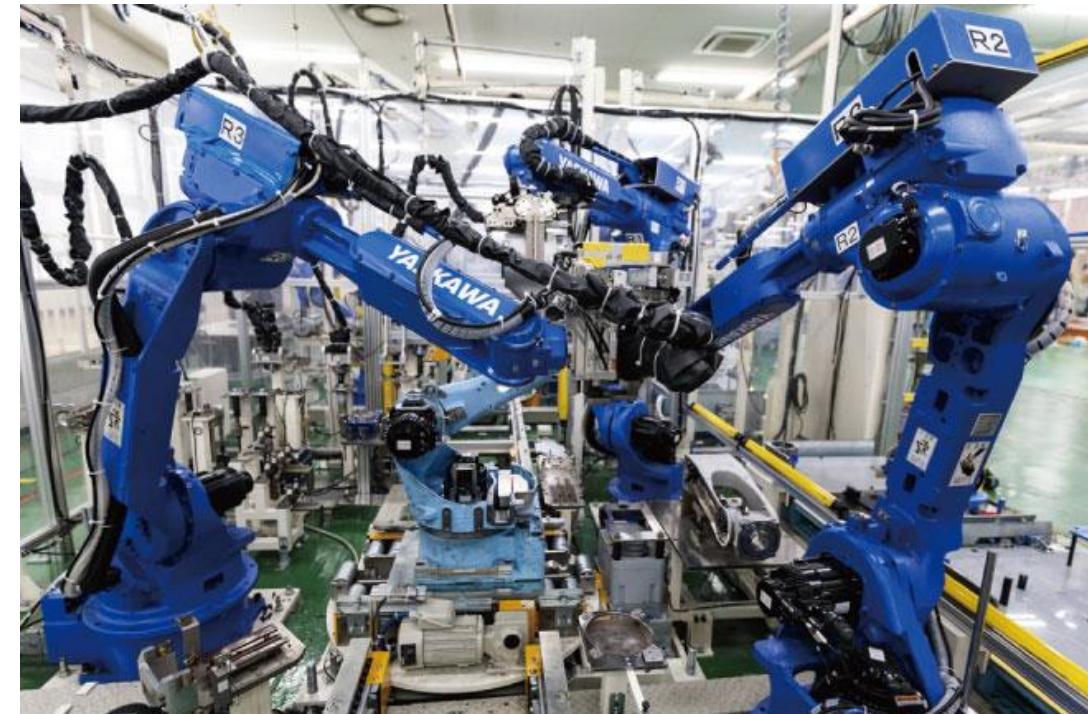
- The word, mechatronics, is of Japanese origin and is composed of “mecha” from mechanism and the “tronics” from electronics.



What is Mechatronics ? – Definitions and meaning

1969

- First proposed by Tetsuro Mori, an engineer from Yaskawa Electric Co. in Japan, to designate the control of electric motors by computer [Yaskawa Electric, 1969].



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EDITORIAL

The subject of mechatronics is receiving increasing attention in the U.K. At the end of last year two important events took place. The first was an international conference on "Mechatronics—Designing Intelligent Machines". This conference, sponsored by the IMechE, was held in London in December 1990 and attracted speakers from all over the world. The second was an "Expert Conference", again sponsored by the IMechE in conjunction with the SERC. At this event a number of internationally acknowledged mechatronics experts discussed their interpretations of the mechatronics design philosophy and made predictions about future trends.

The obvious growing interest in mechatronics led a number of U.K. workers to discuss the possibility of setting up a Mechatronics Forum to act as a base for both academics and industrialists to promote the subject area. This Forum has now been established, the first meeting having taken place at IMechE headquarters earlier this year. It is hoped that all future activities in mechatronics in the U.K., including responses to initiatives from abroad, will be co-ordinated through the U.K. Forum. The first Chairman of the Forum is Professor Jack Dinsdale of the University of Derby.

Further information on the Forum and on how to join it can be obtained from Fred Misk at the IMechE, 1 Birdcage Walk, London (tel.: 071-222-7899).

Number 2 in this volume of *Mechatronics* contains an interesting spread of papers. Alberto Rovetta, one of Italy's leading researchers, contributes personal views of mechatronics and its social implications. Other contributions range from a symbolic approach to modelling of systems (Ju and Hsu) to a simple and practical pneumatic actuator involving a novel drive system (Zhao and Jones), and they are in keeping with the declared philosophy of the Journal to emphasize real devices and systems whose design is based upon mechatronic principles.

R.W Daniel, J.R. Hewit, Editorial. *Mechatronics*, 1(1): i–ii, 1991

What is Mechatronics ? – Definitions and meaning

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1994

- Official definition of the Industrial Research and Development Advisory Committee of the European Community in 1994 and proposed by the international journal *IEEE/ASME Transactions on Mechatronics* in 1996 :

“Mechatronics is the synergistic combination of precision mechanical engineering, electronic control and systems thinking in the design of products and manufacturing processes.”

[Comerford, 1994]

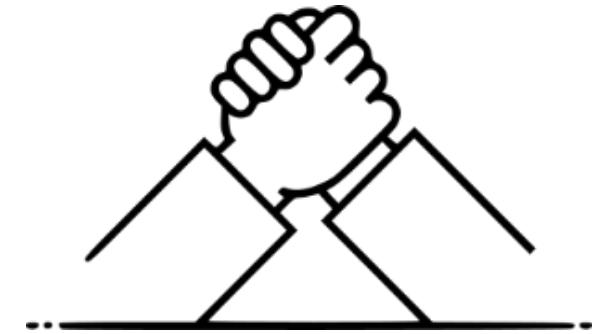
What is Mechatronics ? – Definitions and meaning

- Mechatronics is not inherently a science or technology: it must be regarded as an **attitude**, a fundamental way of looking at and doing things, and, by its nature, requires a unified approach [Millbank, 1993].
- The Mechatronics **methodology** is used for the **optimal design** of electromechanical products.
- A mechatronic system is **not just a mix** of electrical and mechanical systems and is more than just a control system; it is a complete integration of all of them.



What is Mechatronics ? – Definitions and meaning

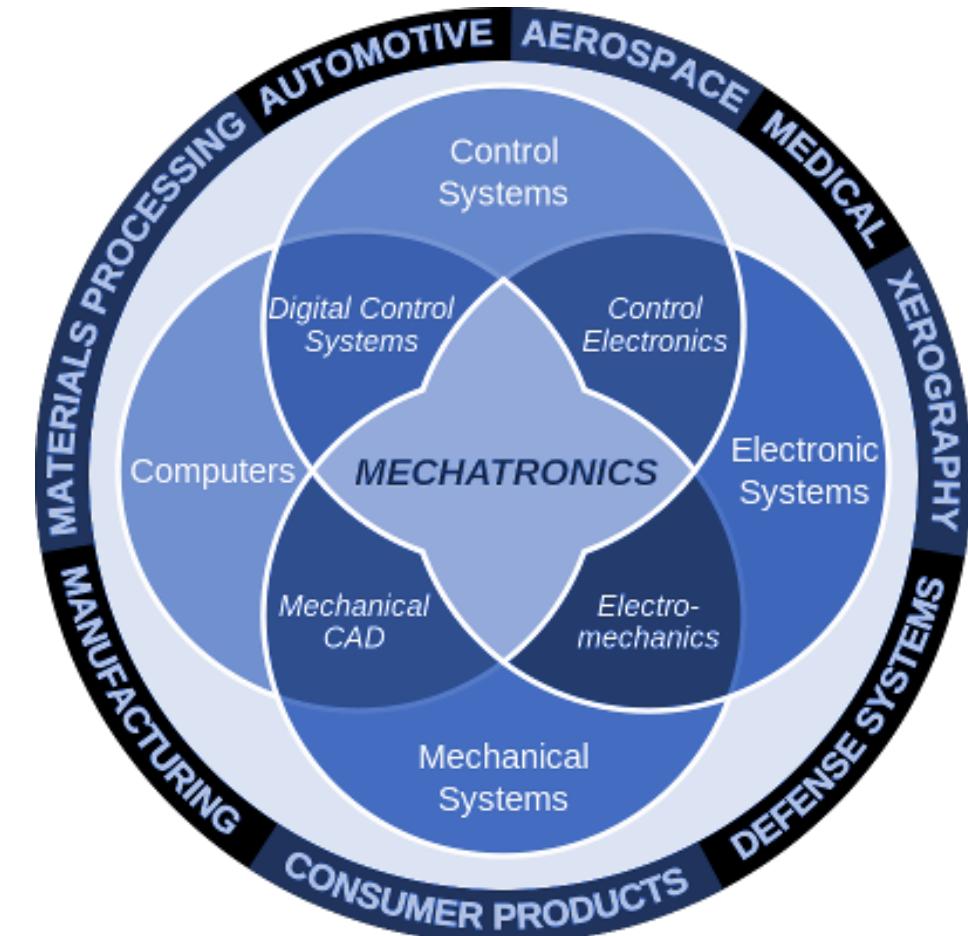
- It aims at developing products, processes and systems with **greater flexibility**, ease in **redesign** and ability of **reprogramming**.
- It is the **synergistic*** integration of mechanical engineering, with electronics and intelligent computer control in the design and manufacturing of industrial products and processes.
- An **approach** for product and manufacturing system
- Leads to solutions **with higher performance** that cannot be obtained in separate applications [Shetty and Kolk, 1997] [Breedveld, 2004].



* the combined power of working together that is greater than the power achieved by working separately.
[Cambridge Dictionary]

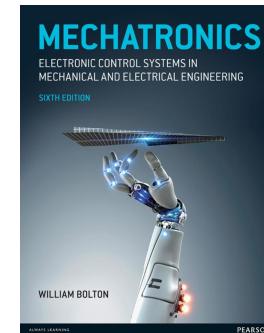
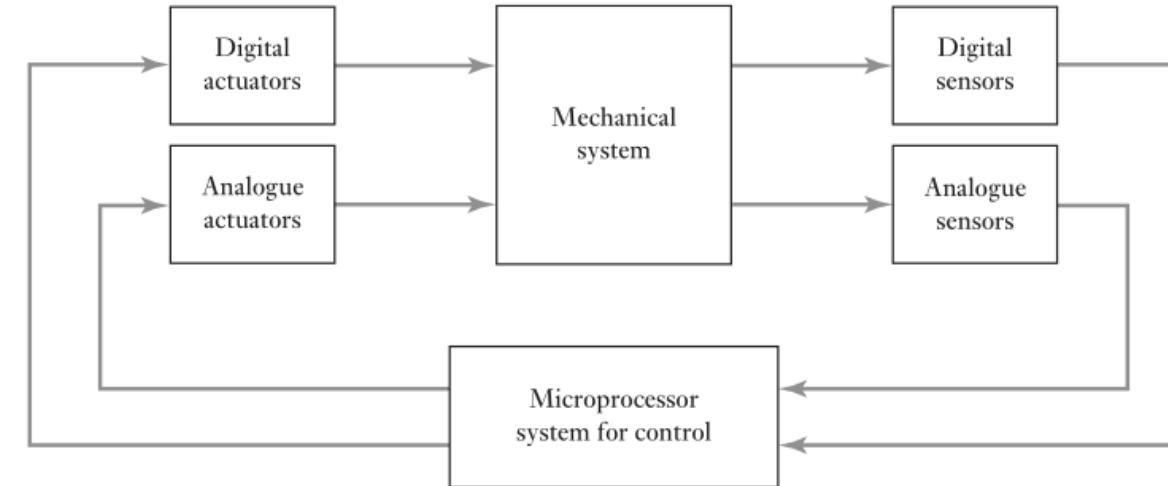
What is Mechatronics ? – Definitions and meaning

- The multidisciplinary nature of mechatronics combines several sectors of different technologies in the designing and manufacturing of a product.
- Disciplinary Foundations of Mechatronics :
 - Mechanical Engineering
 - Electrical Engineering
 - Electronics Engineering
 - Computer Engineering
 - Information & Technology Engineering

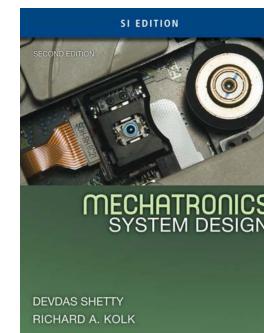
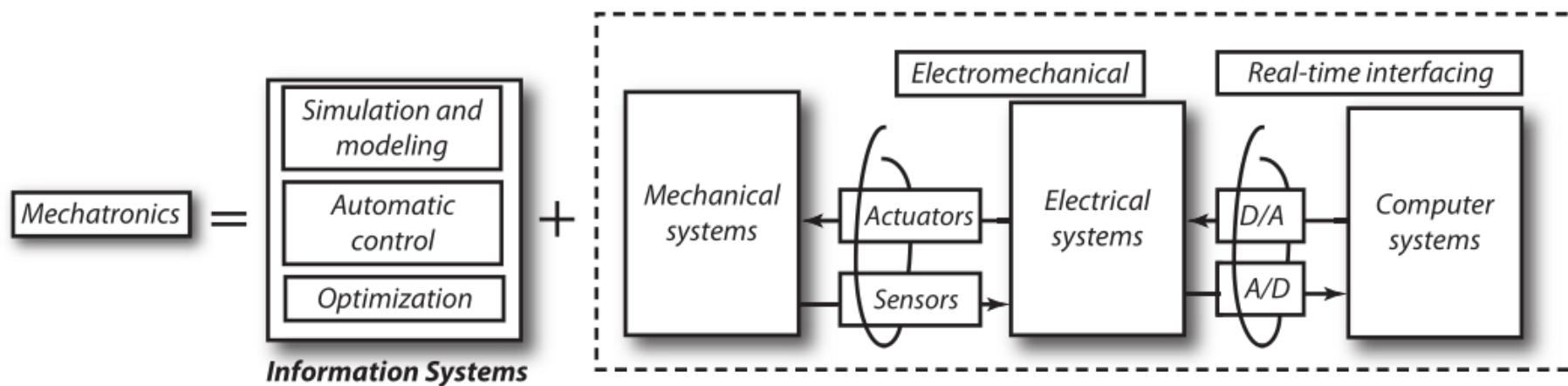


Basic elements of a mechatronics system

Figure 1.1 The basic elements of a mechatronic system.



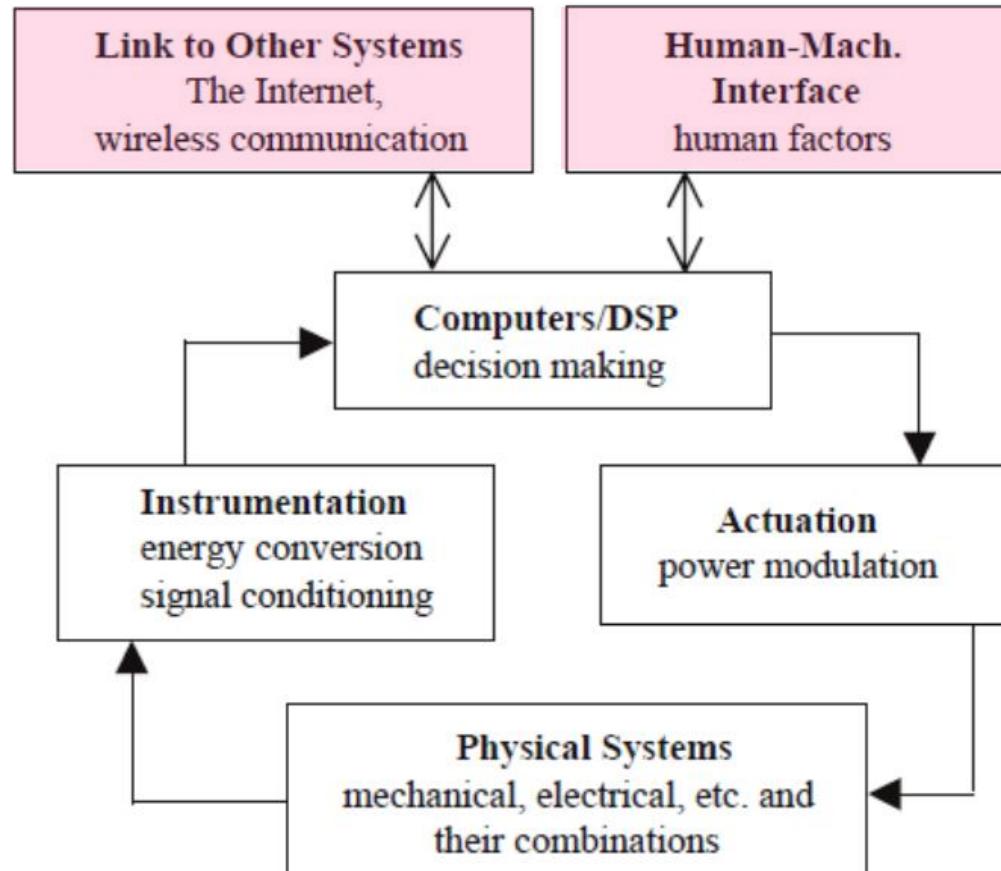
Mechatronics: Electronic Control Systems in Mechanical and Electrical Engineering, 6th Edition, W. Bolton



Mechatronics system design, Devdas Shetty

Basic elements of a mechatronics system

Do not forget the user !



Control Engineering Practice
Volume 10, Issue 8, August 2002, Pages 877-886



Mechatronics: from the 20th to 21st century

Masayoshi Tomizuka

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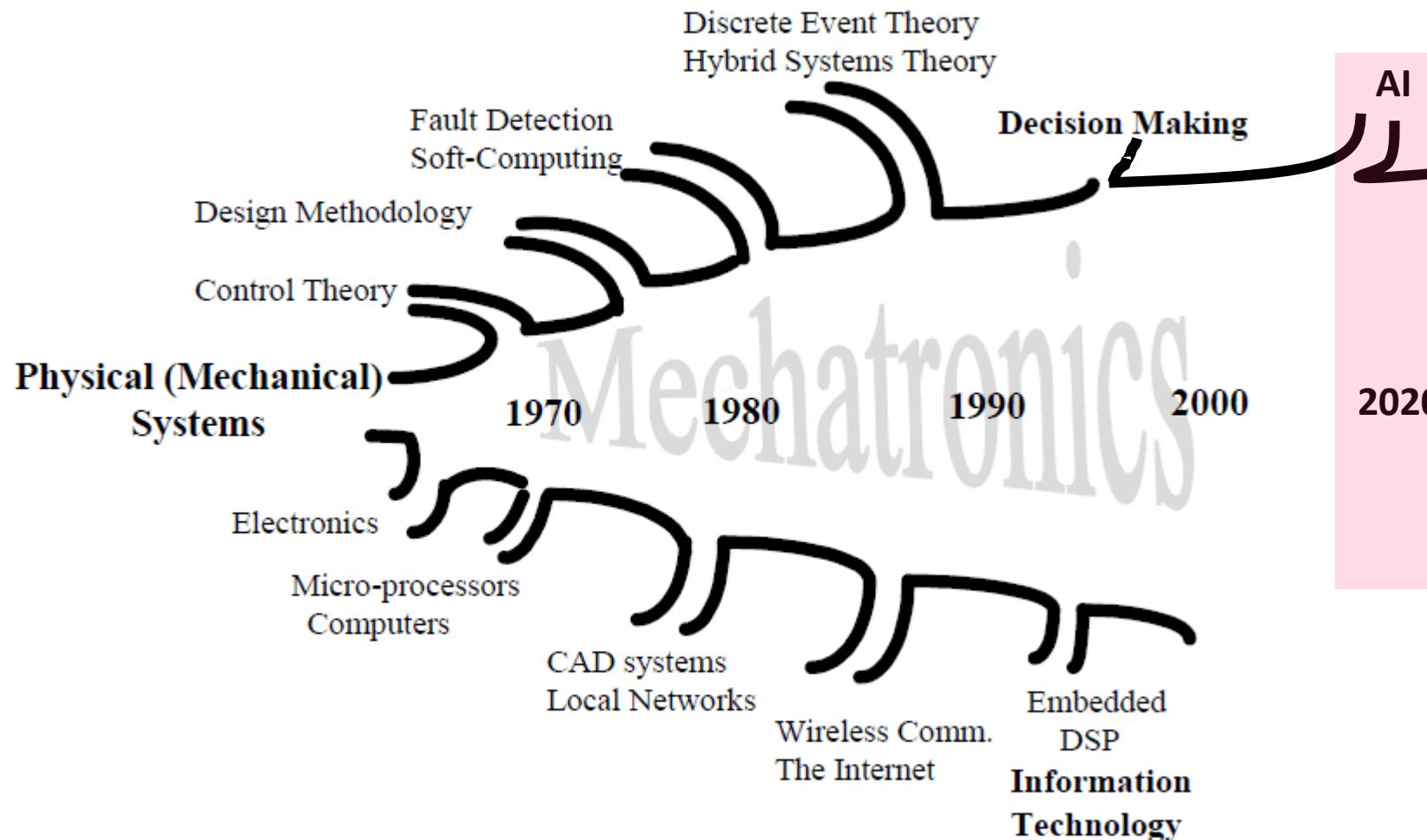
Abstract

This paper presents a Year-2000 (Y2K) status report of mechatronics. The Y2K definition of mechatronics is “the synergistic integration of physical systems with information technology and complex-decision making in the design, manufacture and operation of industrial products and processes.” Mechatronics may be interpreted as the best practice for synthesis of engineering systems, and it covers a broad area and scope. Vehicle lateral control for automated highway systems, hard disk drives and media handling mechanisms for printing engines are reviewed as examples of mechatronics research. Engineering students should be exposed to mechatronics and to the culture of working in teams.

Masayoshi Tomizuka, Mechatronics: from the 20th to 21st century, Control Engineering Practice, Volume 10, Issue 8, August 2002

Evolution of mechatronics

Future of Mechatronics



Mechatronics is still evolving



Control Engineering Practice
Volume 10, Issue 8, August 2002, Pages 877-886



Mechatronics: from the 20th to 21st century

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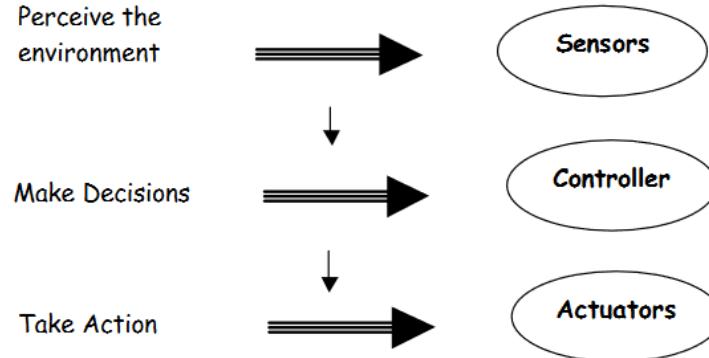
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Abstract

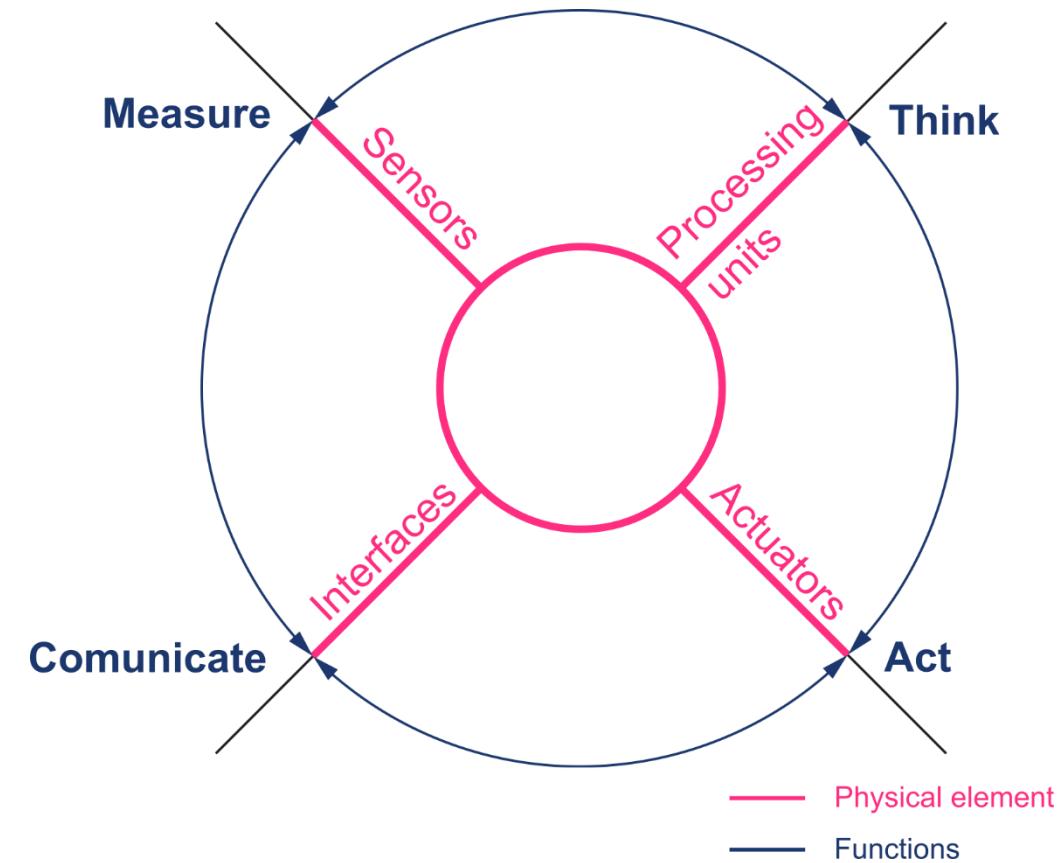
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Couplings between major supplementary functions



A mechatronic system could be characterized by the added values of the **functions couplings**.

The density of couplings present in the mechatronic system therefore appears to be a determining factor of the system compared to non-mechatronic systems.

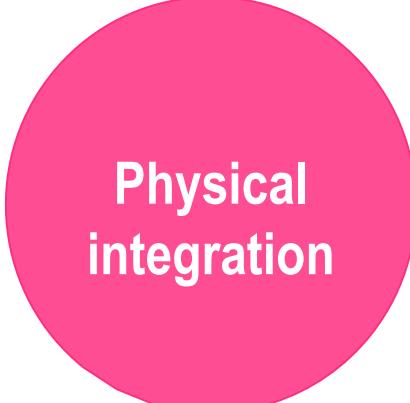


Mechatronic product

“ A product with the ability to **perceive** its environment, to **process** information, to **communicate** and to **act** on its environment, and with a complete level of **mechatronic integration**, from a **functional** and **physical** point of view. ”

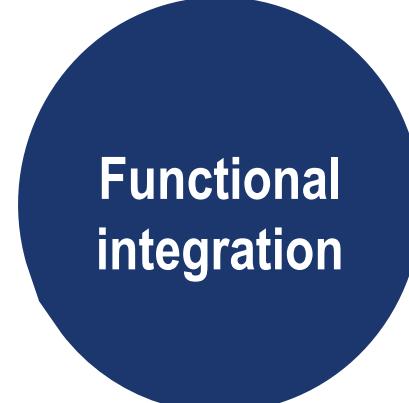


Interpenetration of mechanical
and electronic components



Physical
integration

Addition of sensing, communication,
information processing and feedback functions
to basic mechanical functions



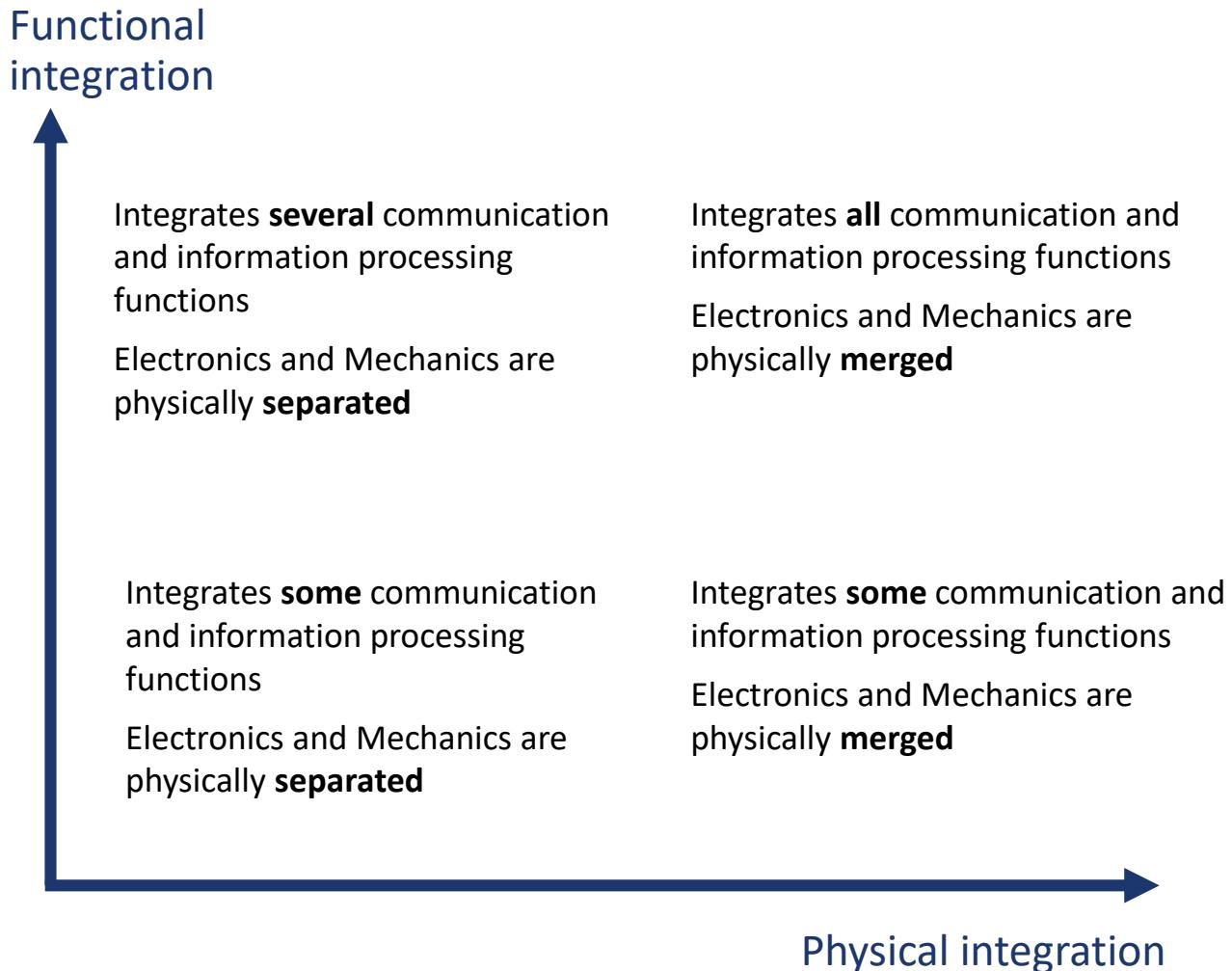
Functional
integration

From complex systems to mechatronic systems

- Traditionally, the transition from **component to product** is made through the addition of functionalities that give the component more and more autonomy.

But

- Mechatronics imposes, in addition, the interpenetration between the supports
 - = **strong technological coupling**
 - = the mechanical, electronic parts,... are **physically merged**.



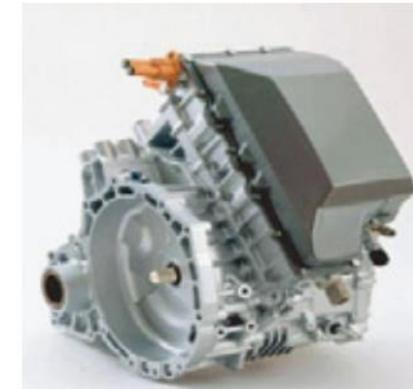
Level of mechatronic systems integration

Mechanics and Electronics

Separated



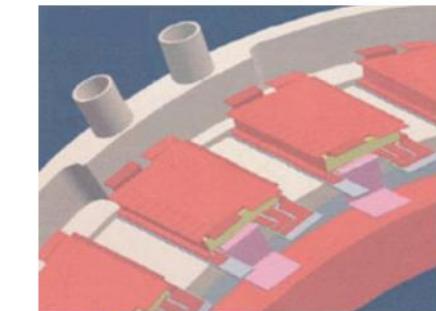
Mechanics and Electronics
Joined



Mechanics and Electronics
Included



Mechanics and Electronics
Merged



Intégration croissante



Level of mechatronic systems integration

Primary Level Mechatronics : Integrates electrical signaling with mechanical action

at the basic control level for e.g. fluid valves and relay switches

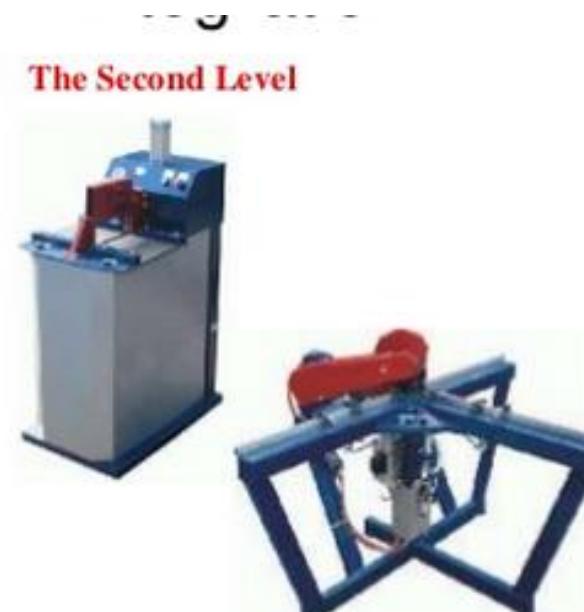


- Conveyors
- Rotary tables
- Auxiliary manipulators



Level of mechatronic systems integration

Secondary Level Mechatronics : Integrates microelectronics into electrically controlled devices for e.g. cassette tape player.



Friday, April 1, 2016



- operated power machines (turbines and generators),
- machine tools and industrial robots with numerical program management

22

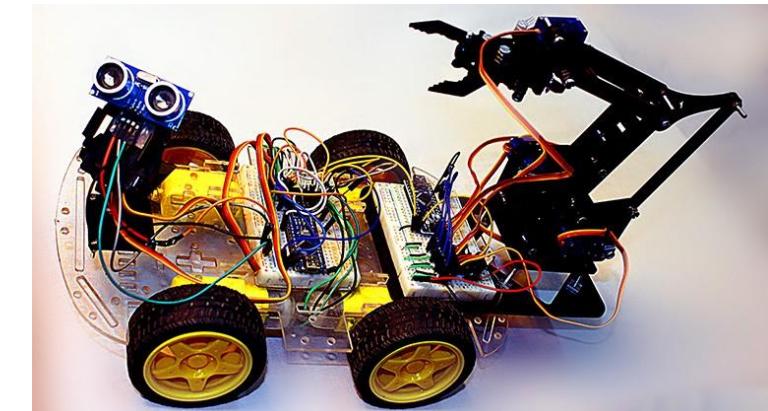
- Operated power machines (turbines & generators)
- Machine tools & industrial robots with numerical program management

Level of mechatronic systems integration

Tertiary Level Mechatronics : Incorporates advanced control strategy using microelectronics, microprocessors and other application specific integrated circuits for e.g. microprocessor based electrical motor used for actuation purpose in robots.

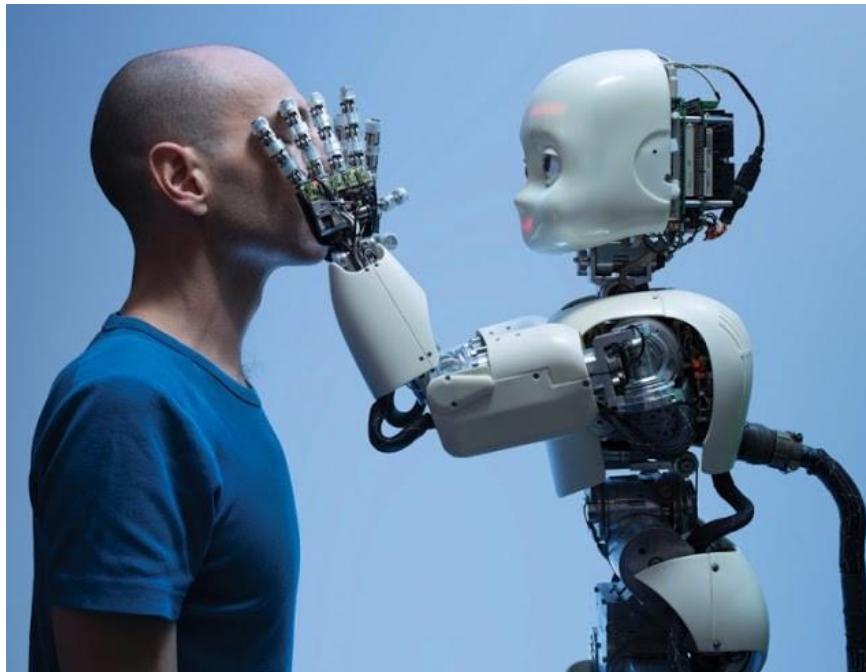


Specific Integrated Circuits' (ASIC), Control of electrical motor used to actuate industrial robots, hard disk, CD drives, automatic washing machines are typical examples



Level of mechatronic systems integration

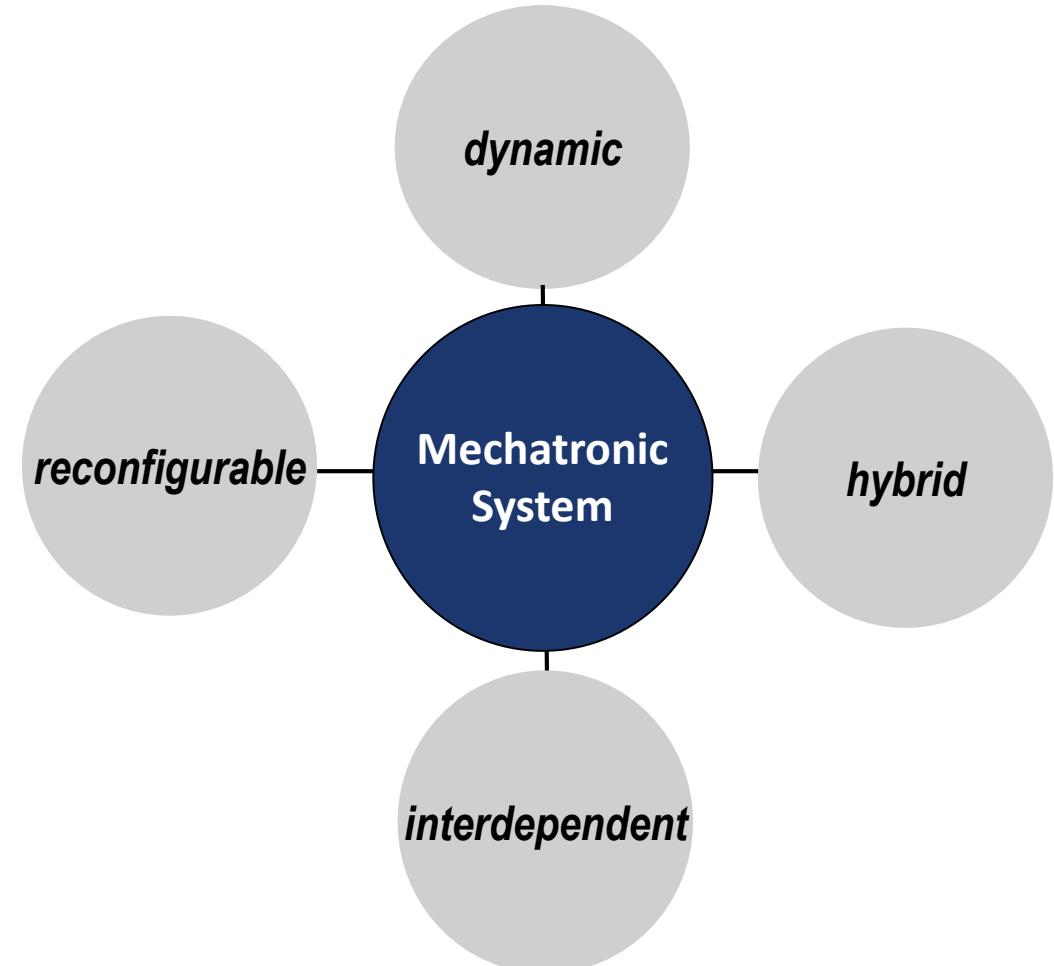
Quaternary Level Mechatronics : This level attempts to improve smartness a step ahead by introducing intelligence (artificial neural network and fuzzy logic) and fault detection and isolation (F.D.I.) capability into the system



Mechatronic system

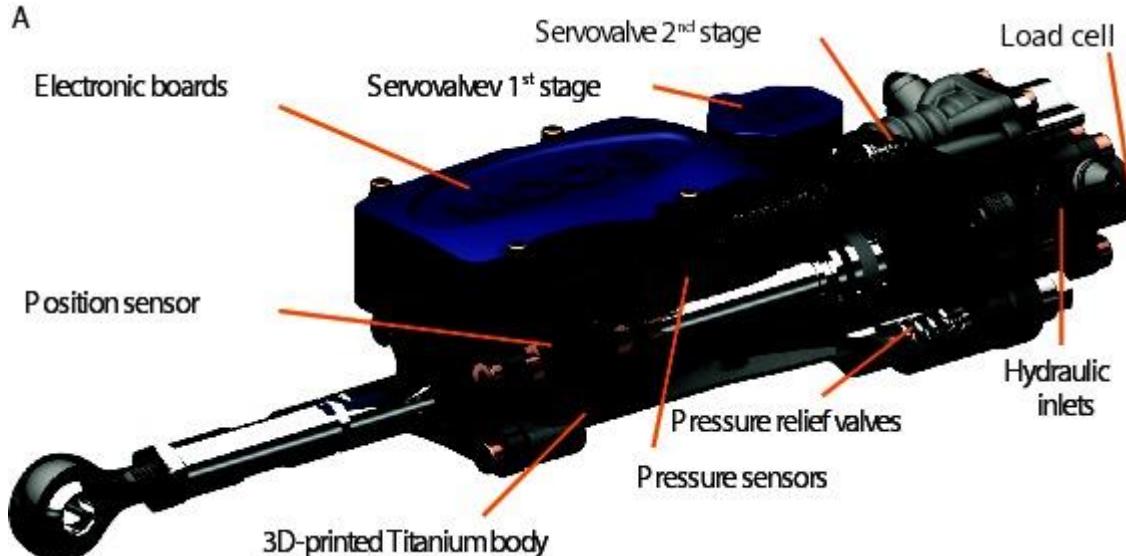
A complex system with **functional & physical integration**.

Characterized by four concepts:

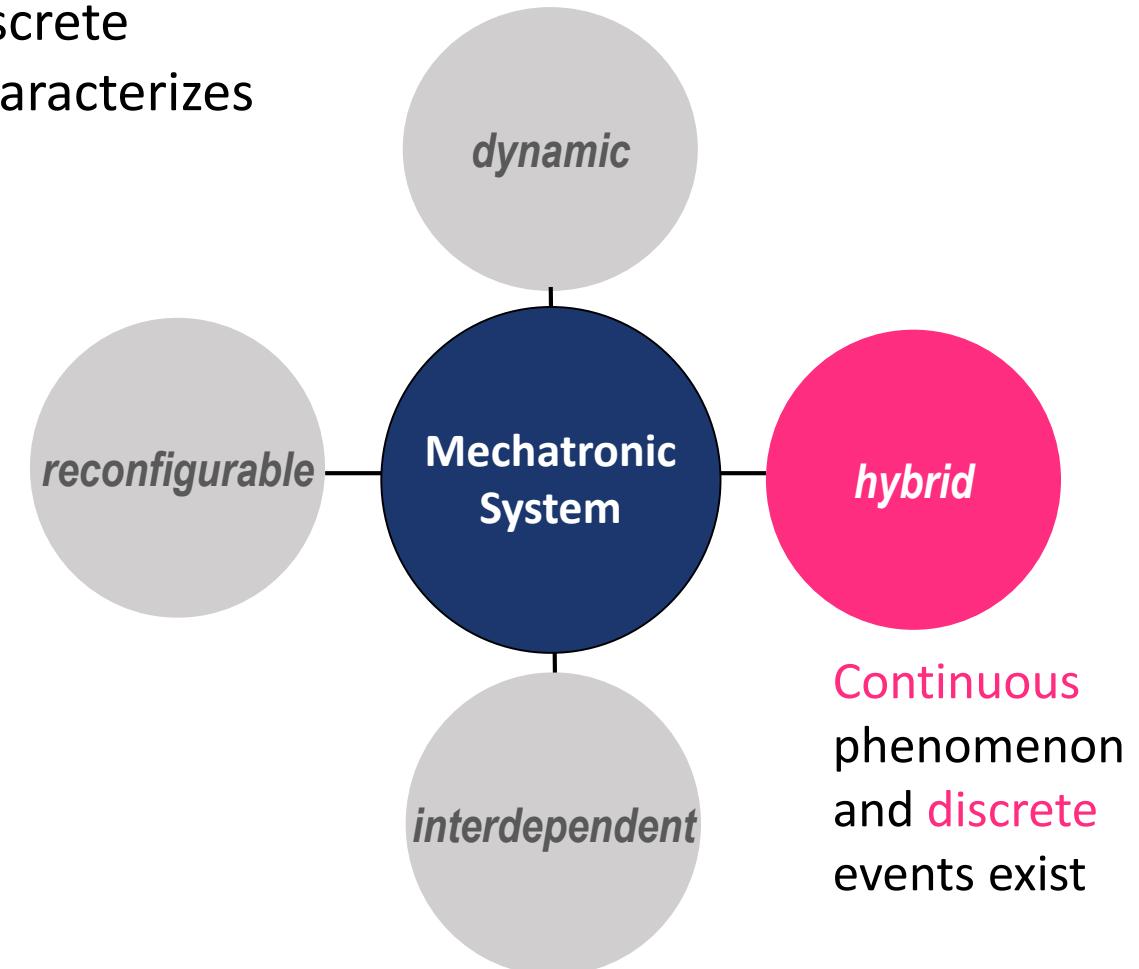


Mechatronic system - hybridity

The presence of continuous phenomena and discrete events into the different states of the system characterizes the hybrid concept.



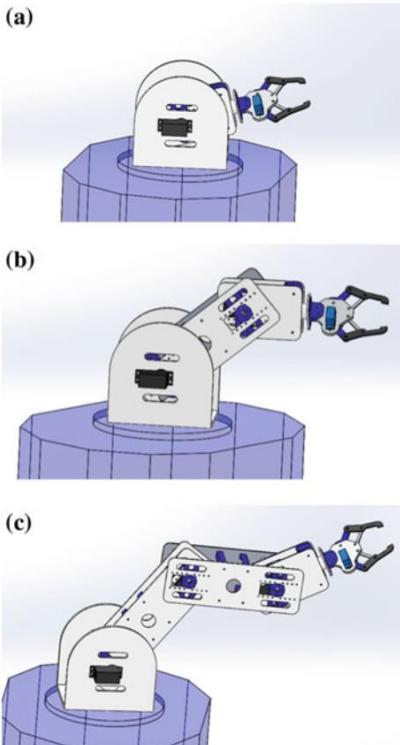
Smart actuator : Continuous monitoring if a part is in front of it or not and can have a discrete action.



Mechatronic system – re-configurability

It is intended to perform several functions alternately or a function by using its resources in several different ways.

For example, to ensure safety, a reconfiguration of the control system is carried out without interruption of the mission.



Assume *different functions*
alternatively or a function using
its resources in different ways

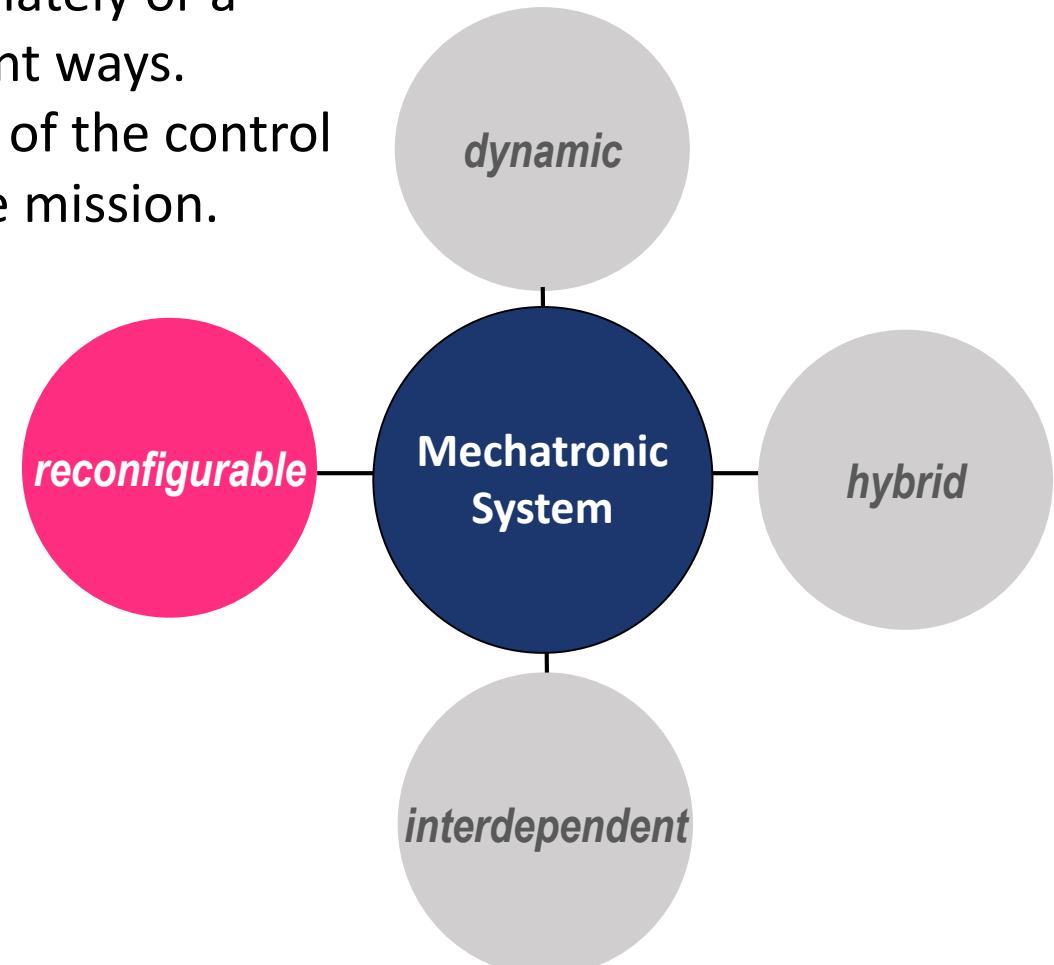


Fig. 5 Reconfiguration of
the robotic arm. a 1 DOF,
b 2 DOF, c 3 DOF configurations

Mechatronic system – re-configurability

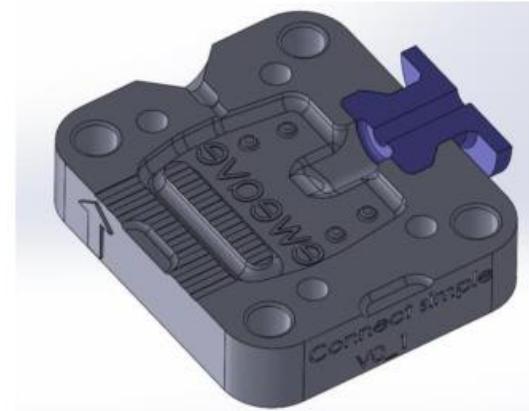
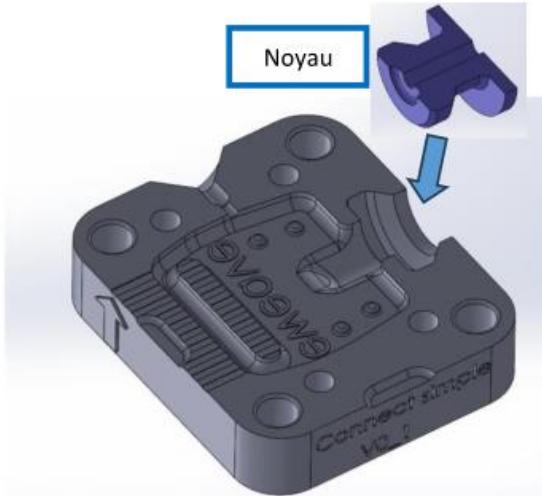
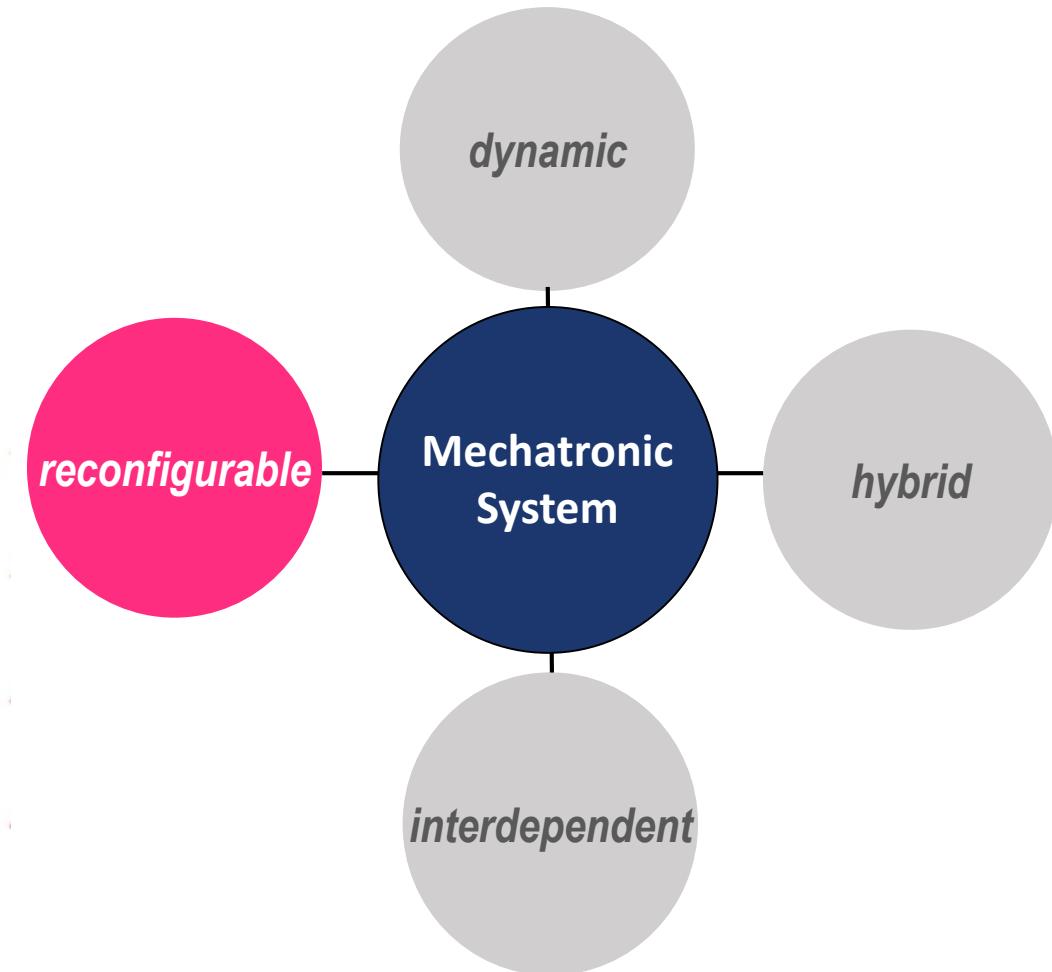
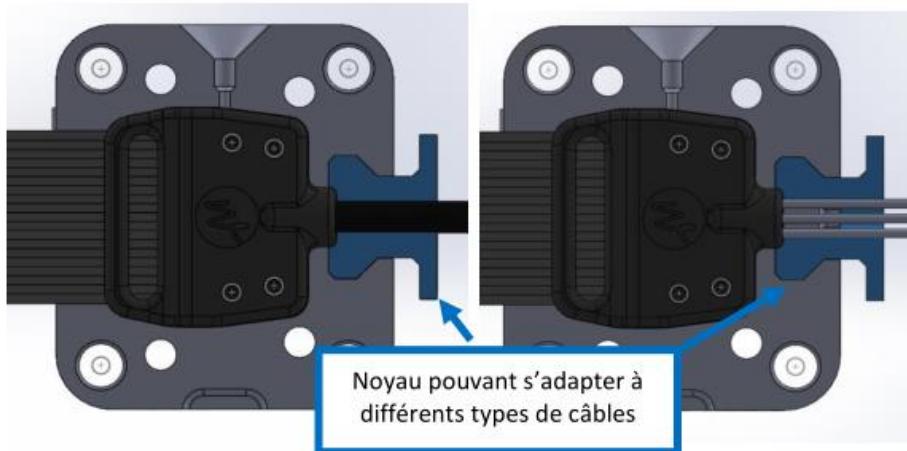


Figure IV.17 : Mise en place du noyau dans le moule

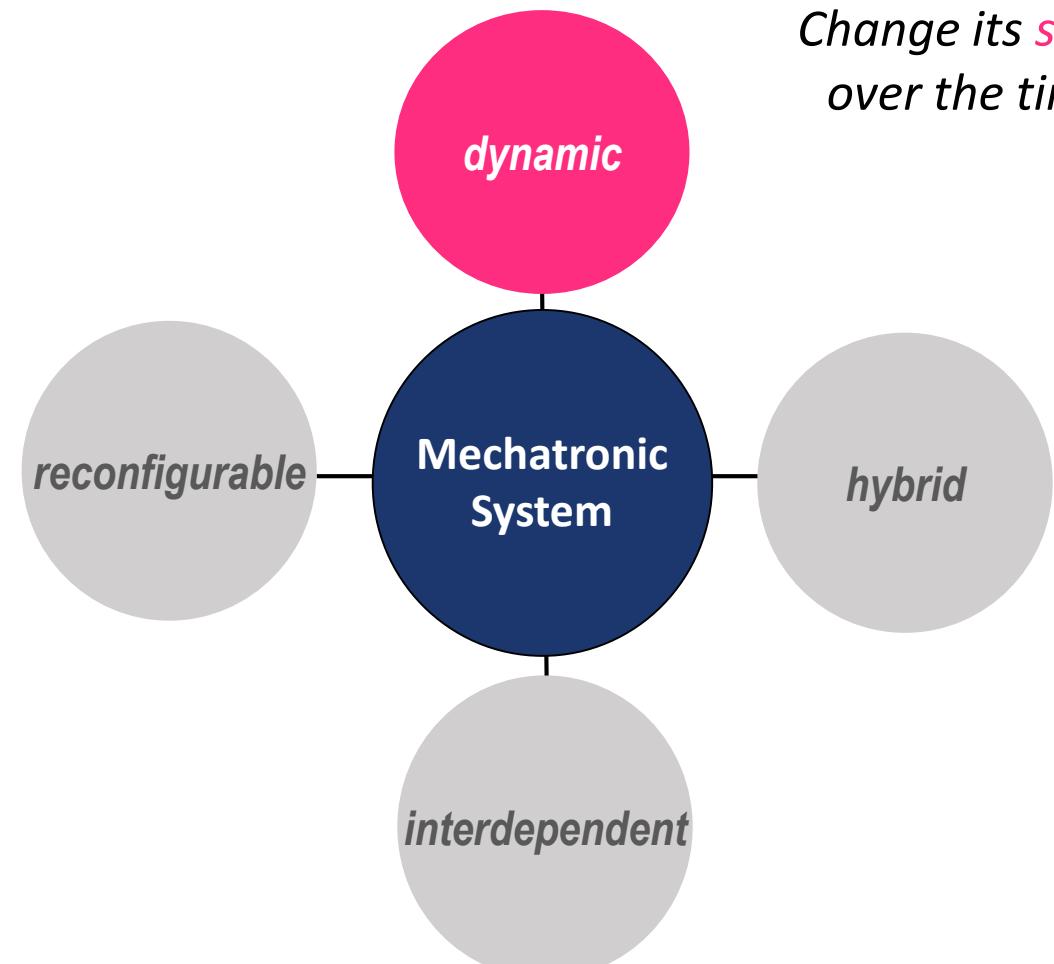
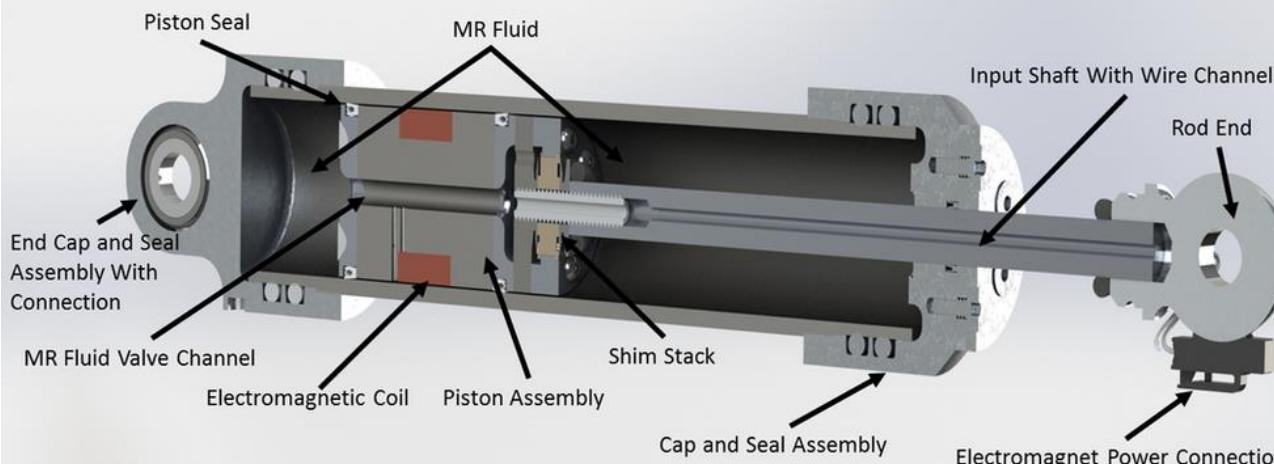


Mechatronic system - dynamic

This characteristic lies in its aptitude to change its state during time.

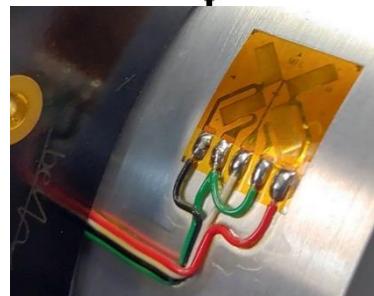
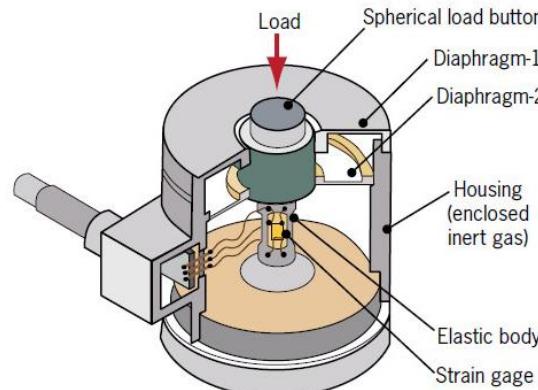
*Change its **state** over the time*

Anatomy of a Magnetorheological Damper



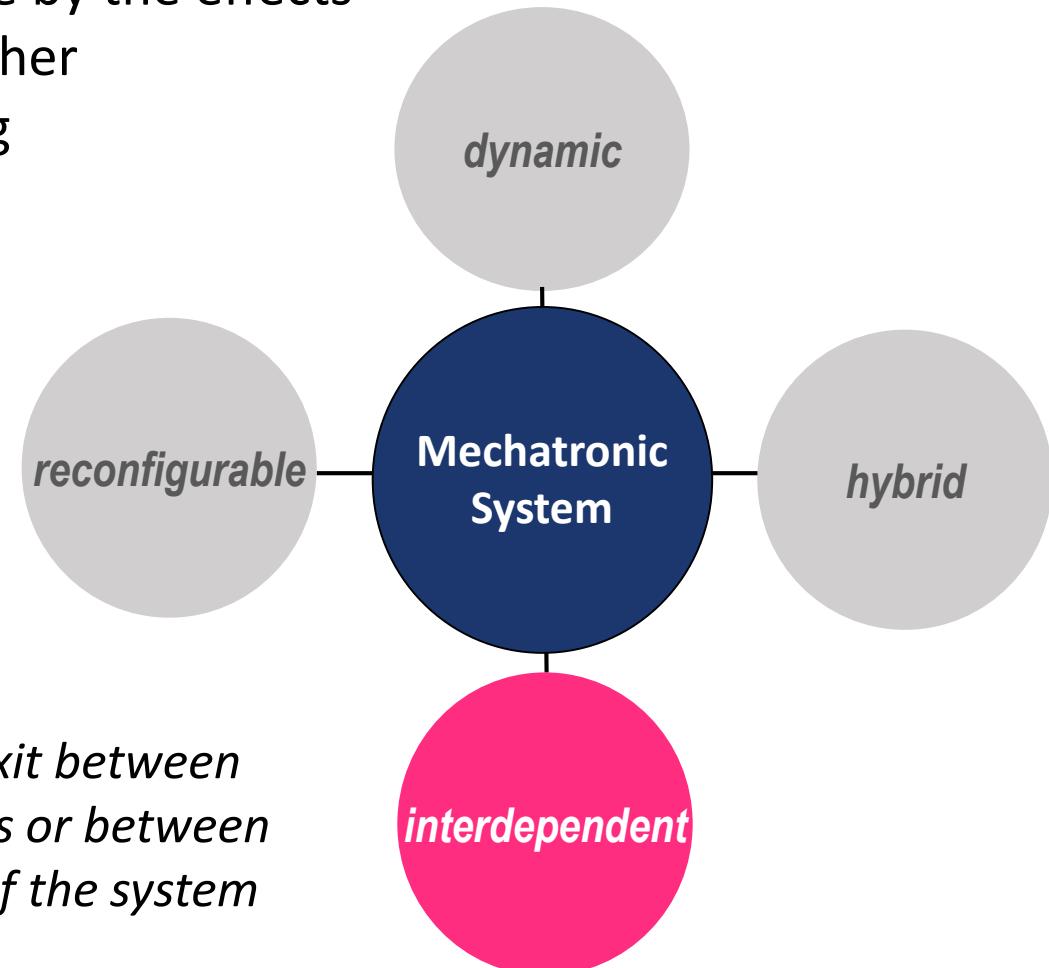
Mechatronic system - dependency

The dependency or interaction is described here by the effects produced by the action of a component to another component in the system changing its operating performances, in terms of degradation.



Interaction between the mechanical structure and the strain gauge

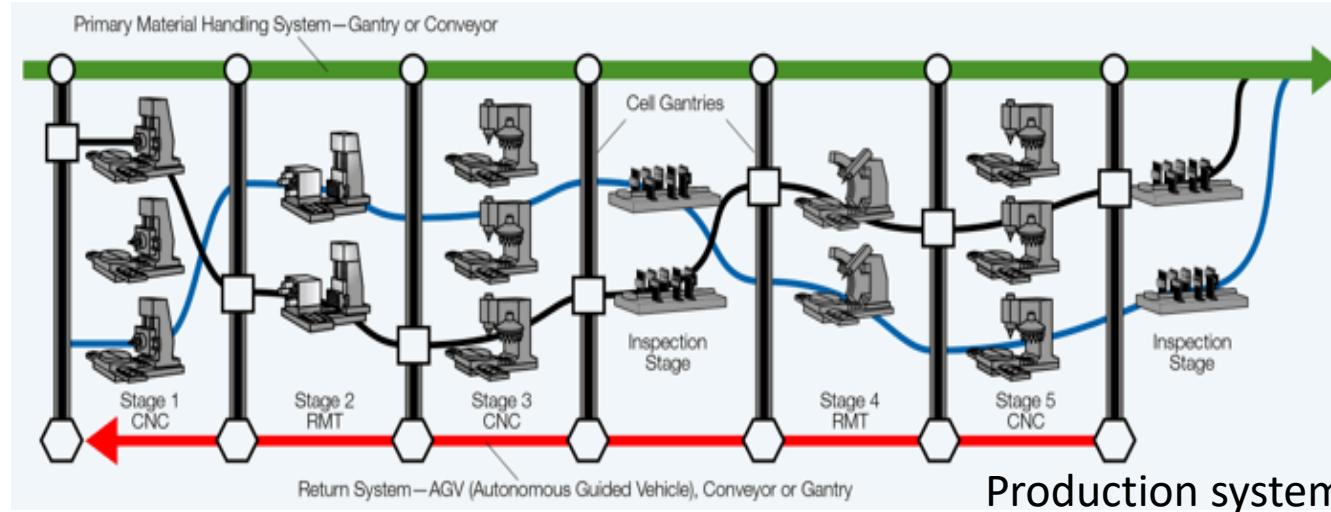
Interactions exist between the components or between the functions of the system



Mechatronics – constraints & benefits

- leads to new constraints, such as:
 - High Initial cost
 - The incorporation of several technologies,
 - The interactions between different functional entities,
 - Taking into account the dynamics of the system,
 - Taking into account the inability to perform exhaustive tests, etc.
- brings undeniable benefits such as:
 - Cost effective and good quality products
 - Size and weight reduction
 - Customer satisfaction by the proposed innovative solutions,
 - The positive response to societal demands increasingly important (pollution, consumption, safety)
 - High degree of flexibility to modify or redesign

Examples of mechatronic systems

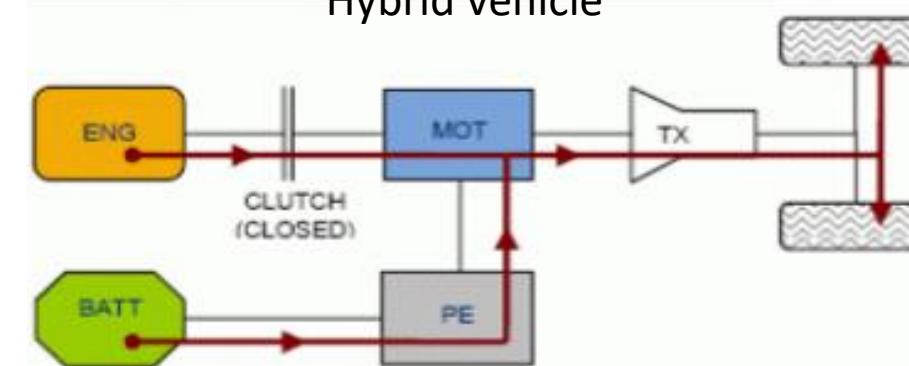


Landing system



Amperemeter/Voltmeter...

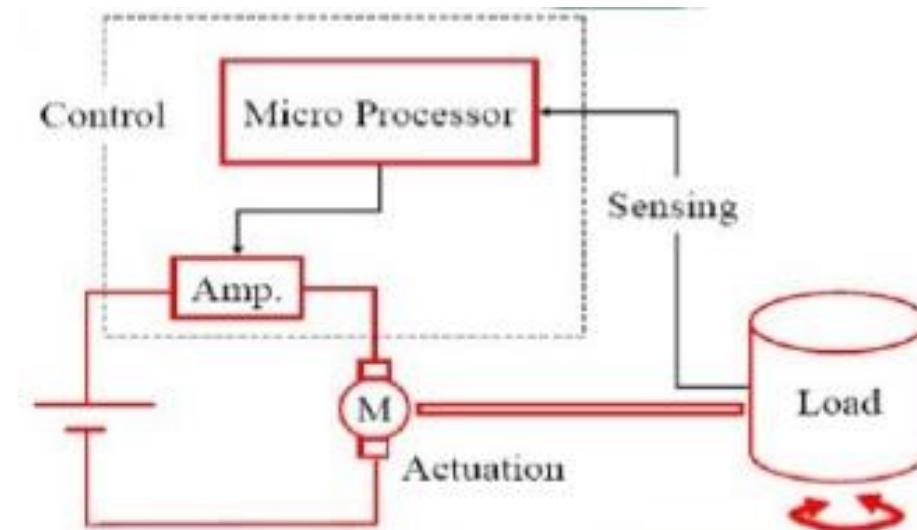
Hybrid vehicle



Examples of mechatronic systems

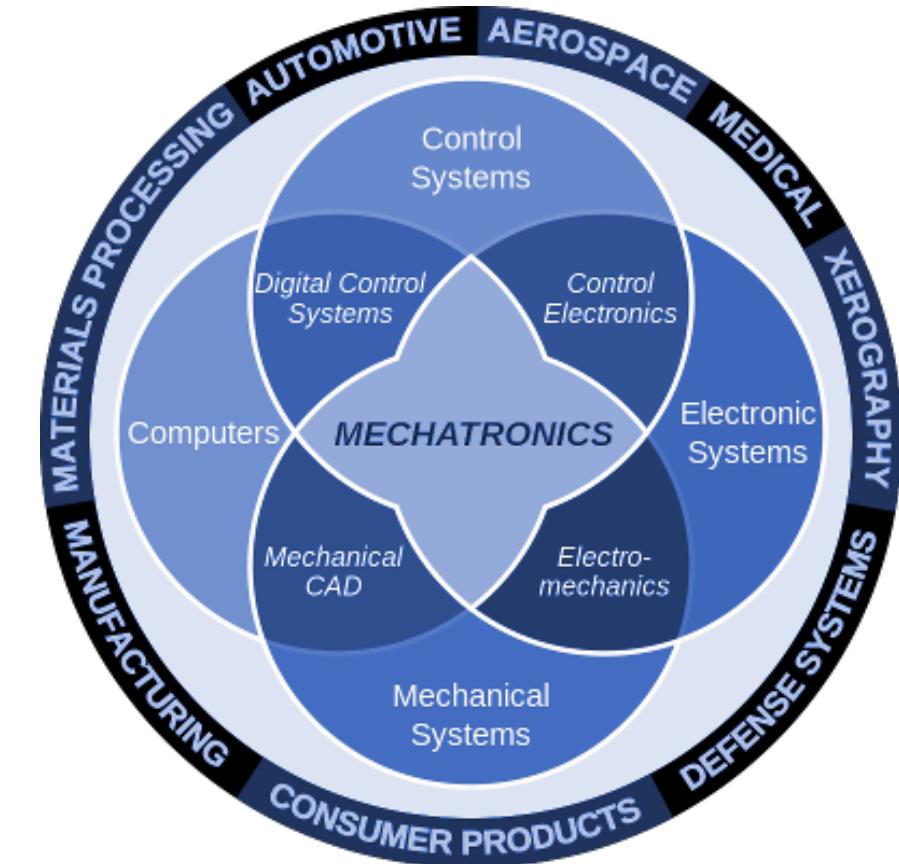
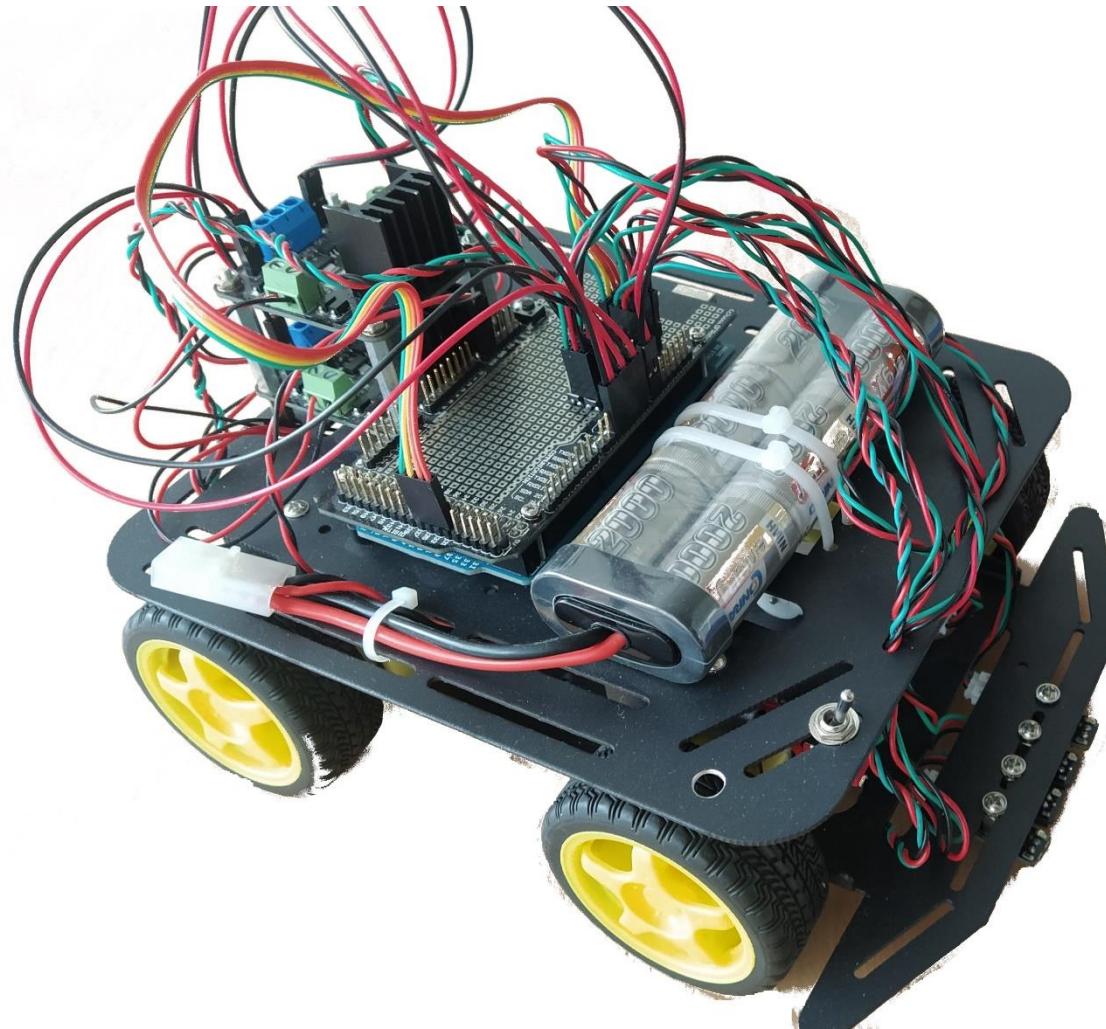


- System Requirements
 - Understanding of load sizes
 - Receptacle to hold clothes
 - ‘Plumbing’
 - Agitation of drum
 - Ease of use, Reliability
 - Low Cost
- Actuators
 - AC or DC Motors
 - Water inlet/drain
- Sensors
 - Water level
 - Load speed/balance
- Control
 - Choice depends on design



Exercise

- Find out which discipline is involved



Exercise

Spot which system is/are **NOT** mechatronic



Computer



Drone



Car



Consumer Electronics



MEMS

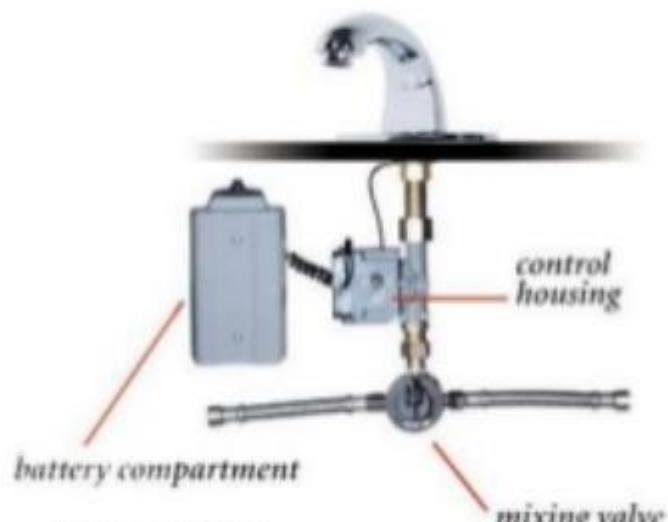
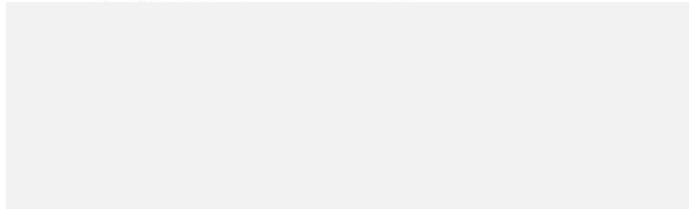


Ski bindings

Exercise

Sanitation Applications

System Uses



Advantages

Multi-/Cross-/Inter-disciplinary

- When a design requires inputs from more than one discipline. It can be realized through following types of interactions :

Multi-disciplinary: This is an additive process of bringing multiple disciplines together to bear on a problem.

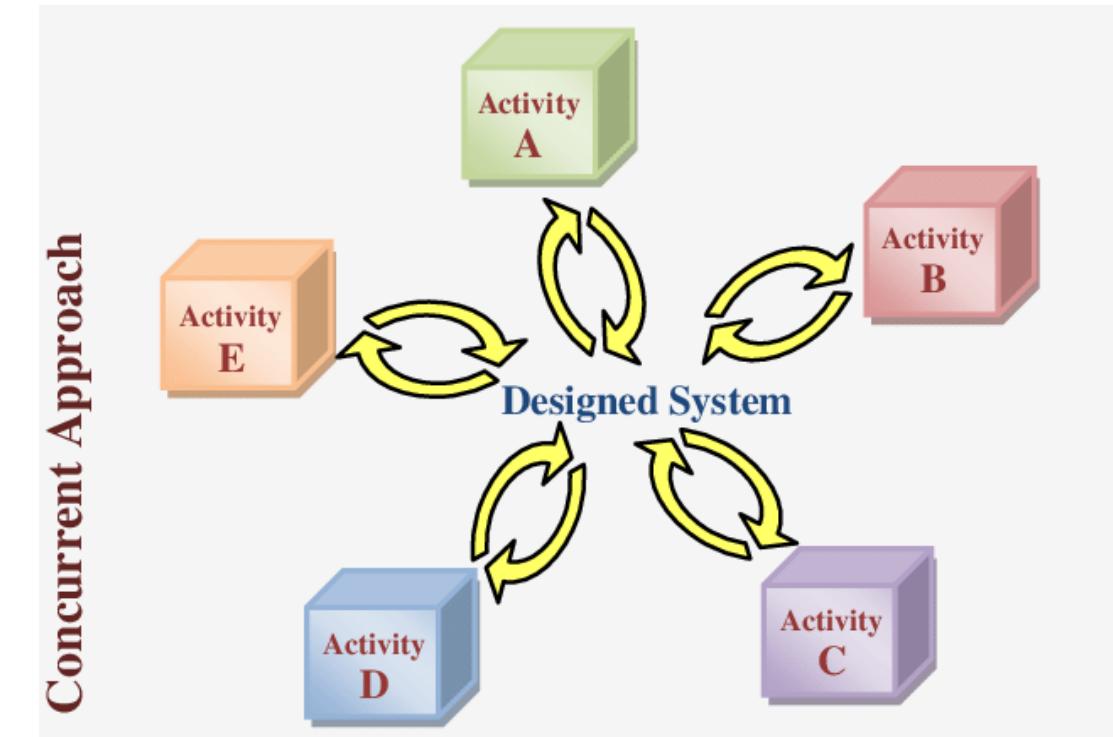
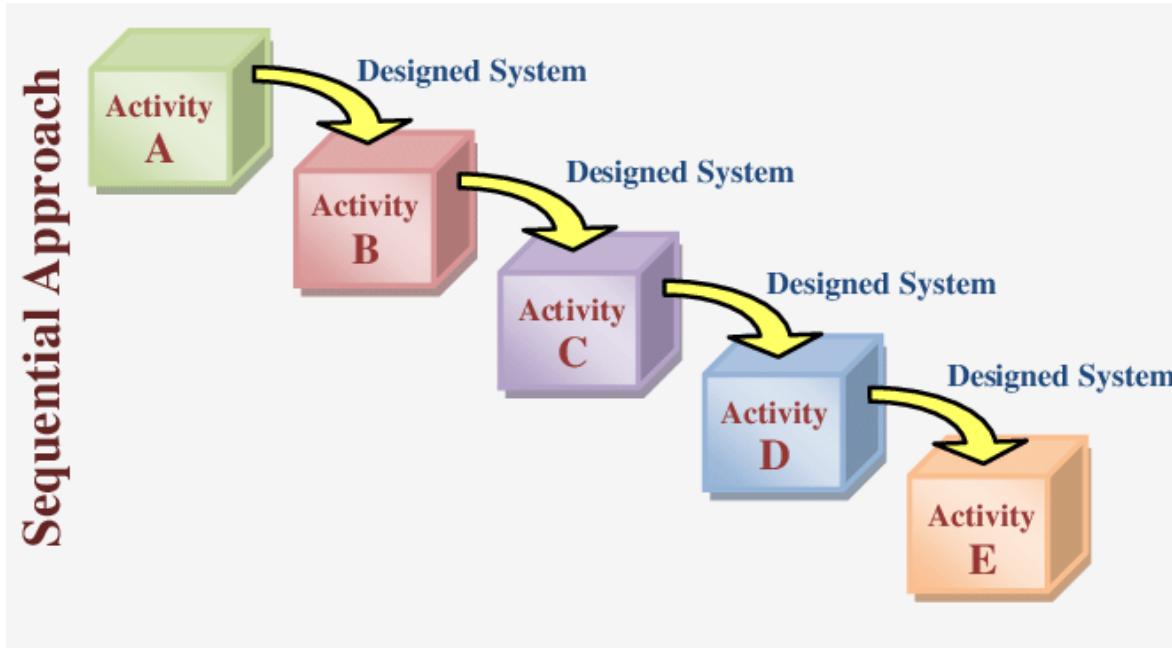
Cross-disciplinary: In this process, one discipline is examined from the perspective of another discipline.

Inter-disciplinary: This is an integrative process involving two or more disciplines simultaneously to bear on a problem

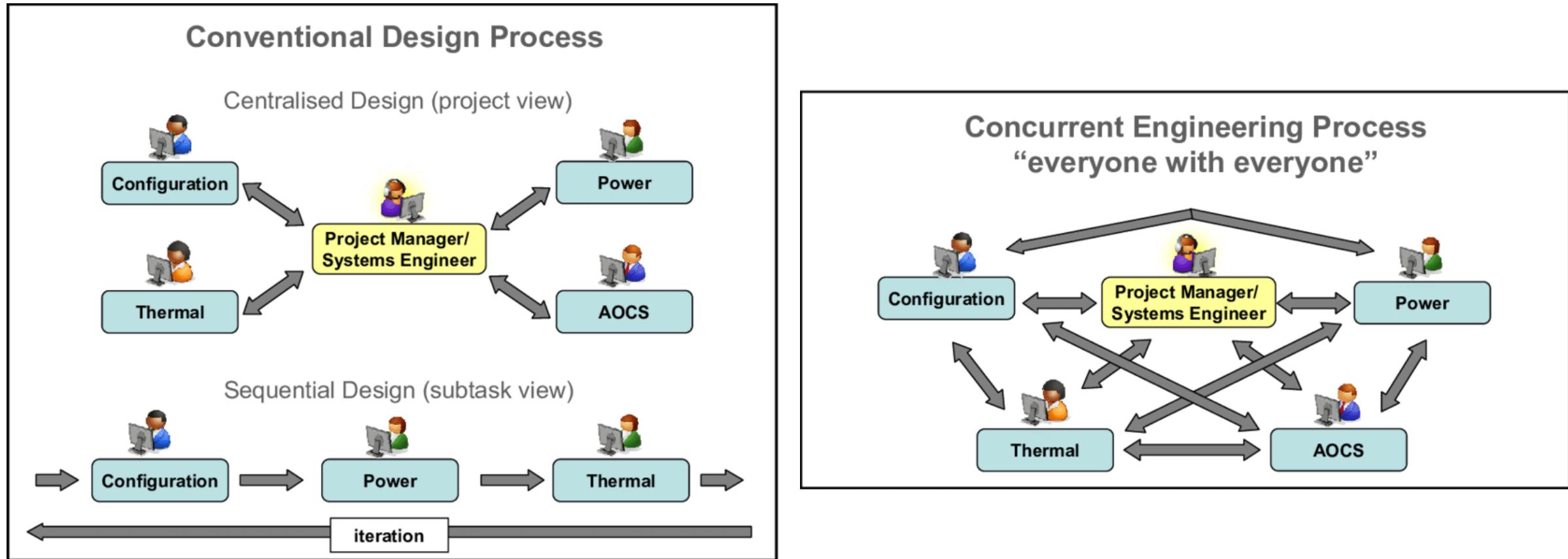
Mechatronic vs. Multidisciplinary

- The difference between a mechatronic system and a multidisciplinary system is not the constituents, but rather the **order** in which they are designed.
- Multidisciplinary system design employed a **sequential** design-by-discipline approach.
- Mechatronic design methodology is based on a **concurrent** (instead of sequential) approach to discipline design, resulting in products with more synergy.

Sequential vs. Concurrent Engineering



Conventional vs. Concurrent Engineering



Sequential vs. Concurrent Engineering

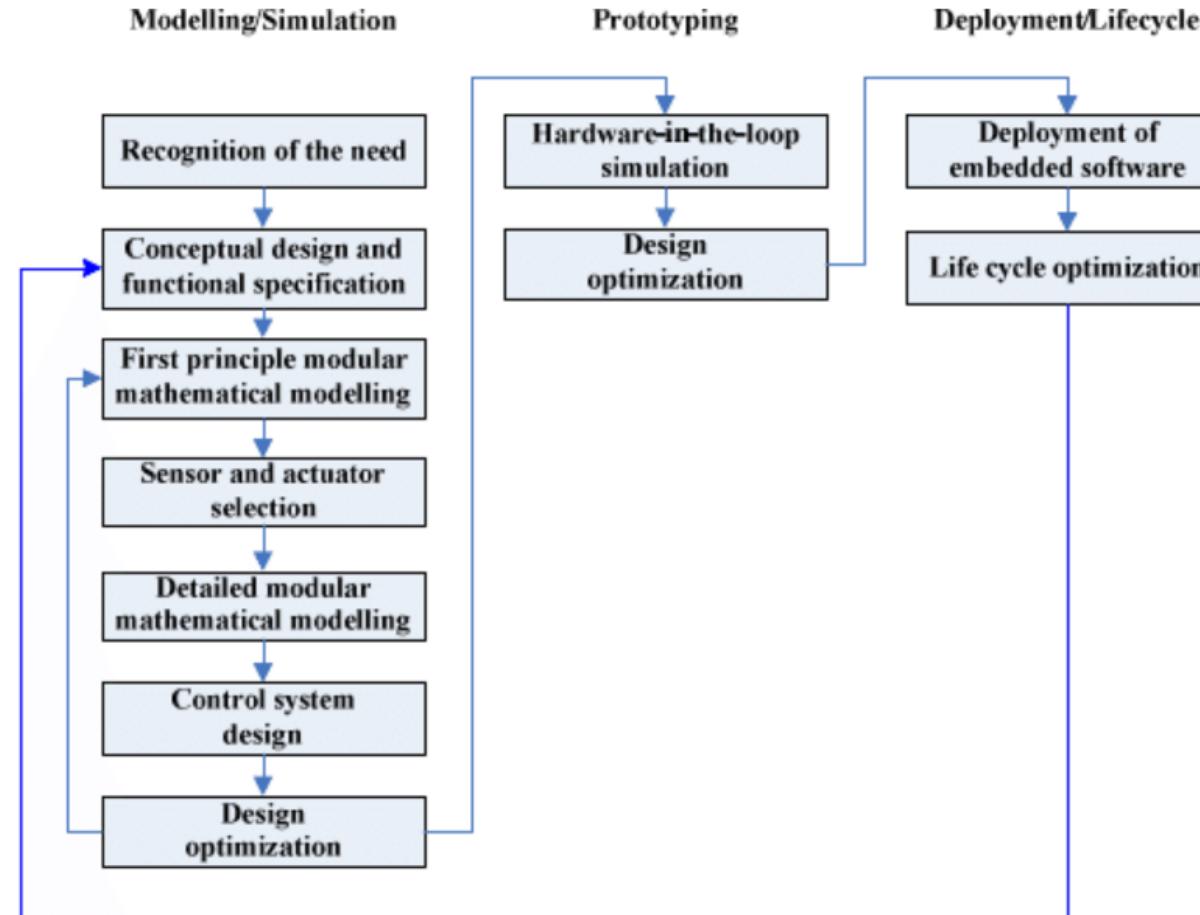
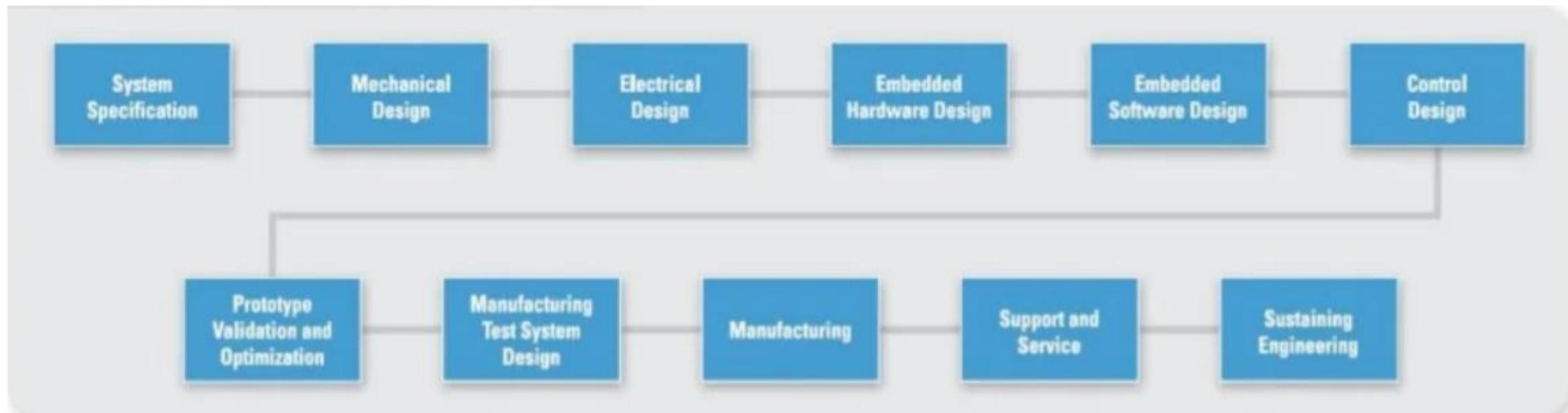
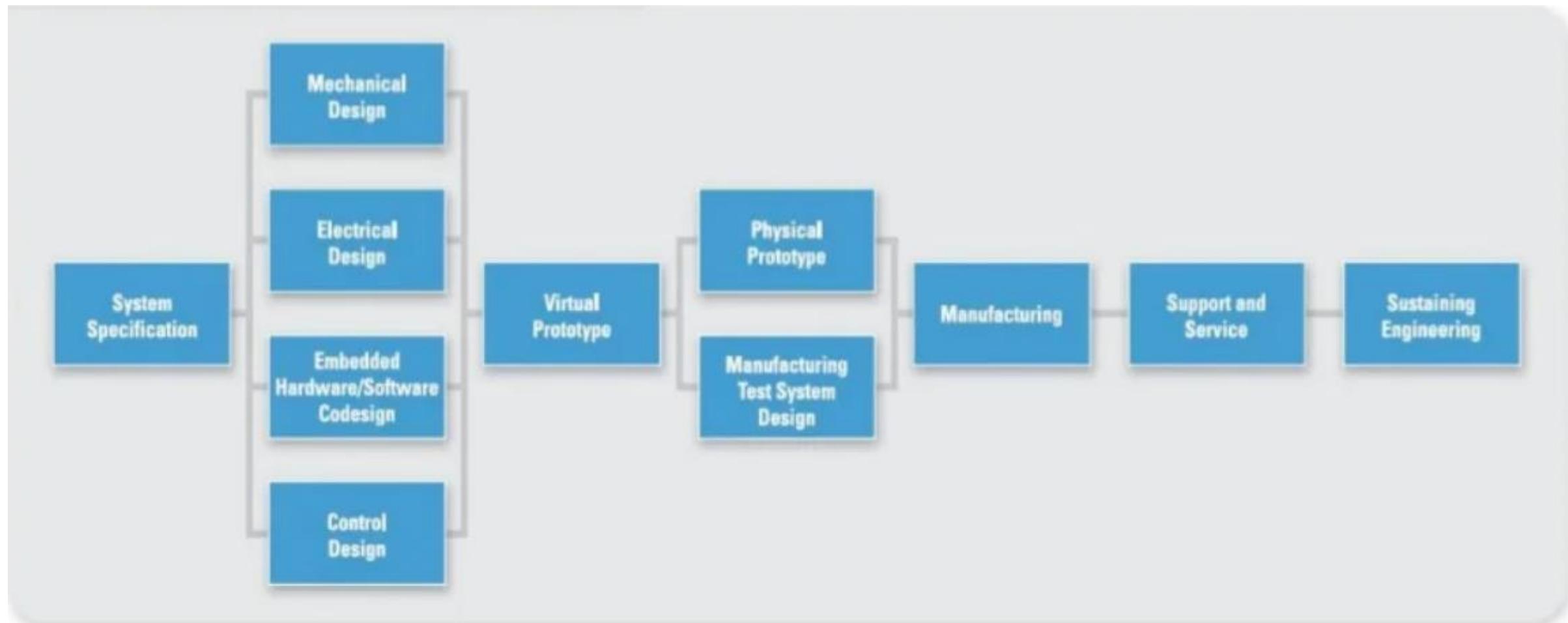


Figure 3. Sequential design model [Shetty et al, 2010]

Traditional Sequential Engineering

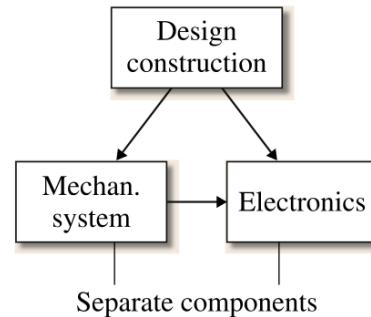


Concurrent Engineering



Conventional Design vs. Mechatronics Design

a) Conventional procedure



b) Mechatronic procedure

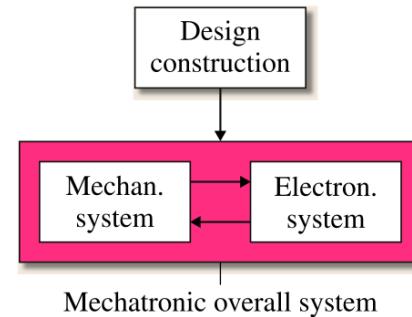


Fig. 19.4a,b Interrelations during the design and construction of mechatronic systems

Conventional Design	Mechatronics Design
Bulky componentized system	Compact integrated systems
Cable problem	Bus or wireless communication
Simple control	Integration by information processing (software)
<ul style="list-style-type: none"> • Stiff construction • Feedback control, linear (analog) control • Precision through narrow tolerance • Non measurable quantities changes arbitrarily • Simple monitoring • Fixed abilities 	<ul style="list-style-type: none"> • Elastic construction with damping by electronic feedback • Programmable feedback, (nonlinear) digital control • Precision through measurement and feedback control • Control of non-measurable estimated quantities • Supervision over fault diagnosis • Learning ability
Centralized processing & control	Hybrid control: Adaptative and/or Multi-architecture control (e.g, Centralized, Centralized processing & control Decentralized and Distributed)
Constant speed drives	Variable speed drives
Mechanical Systems	Mechanical, Computer, Electronic, Software, and/or Network interface and/or control of physical, chemical, biological and/or neurological systems

Sequential vs. Concurrent Engineering

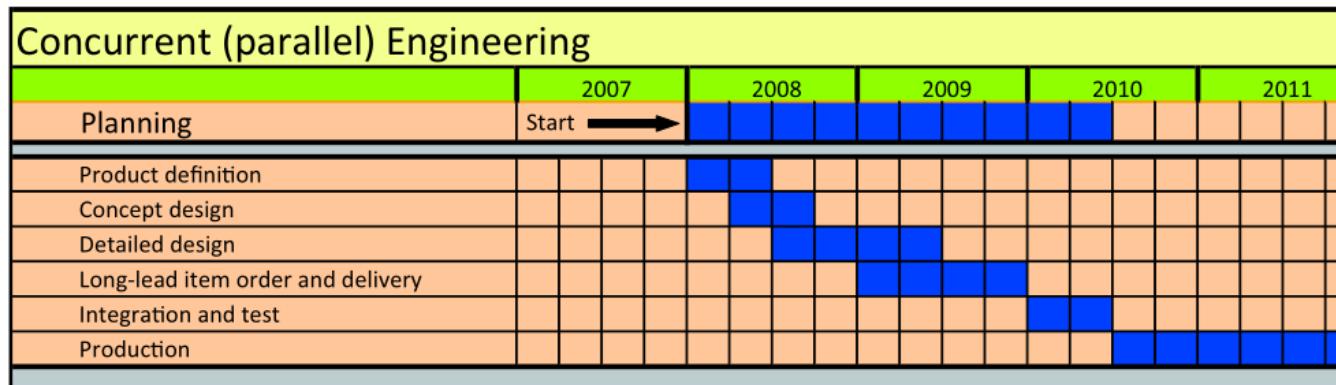
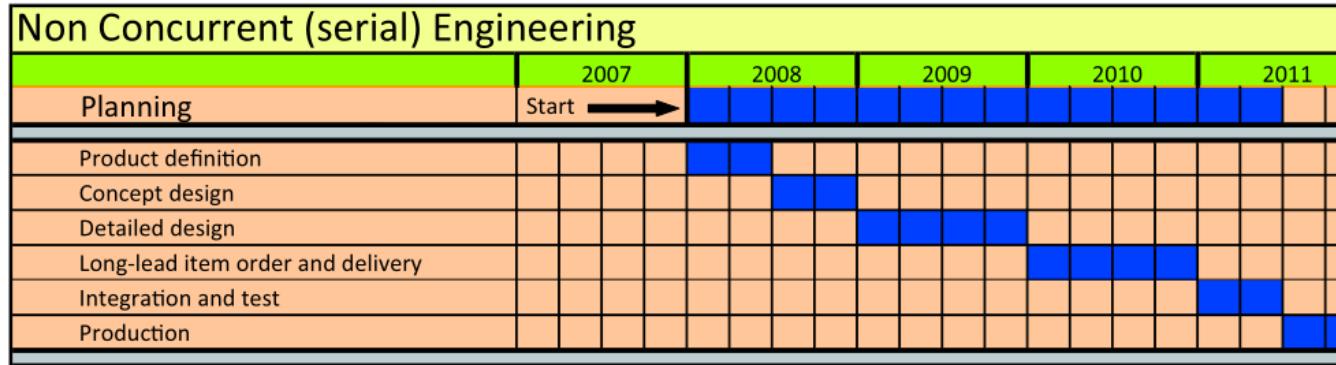
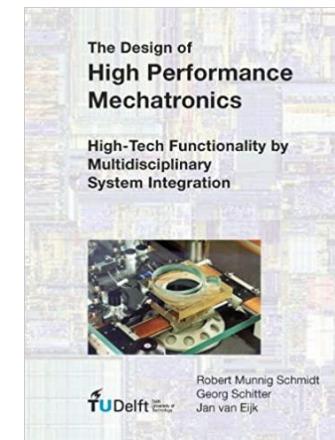
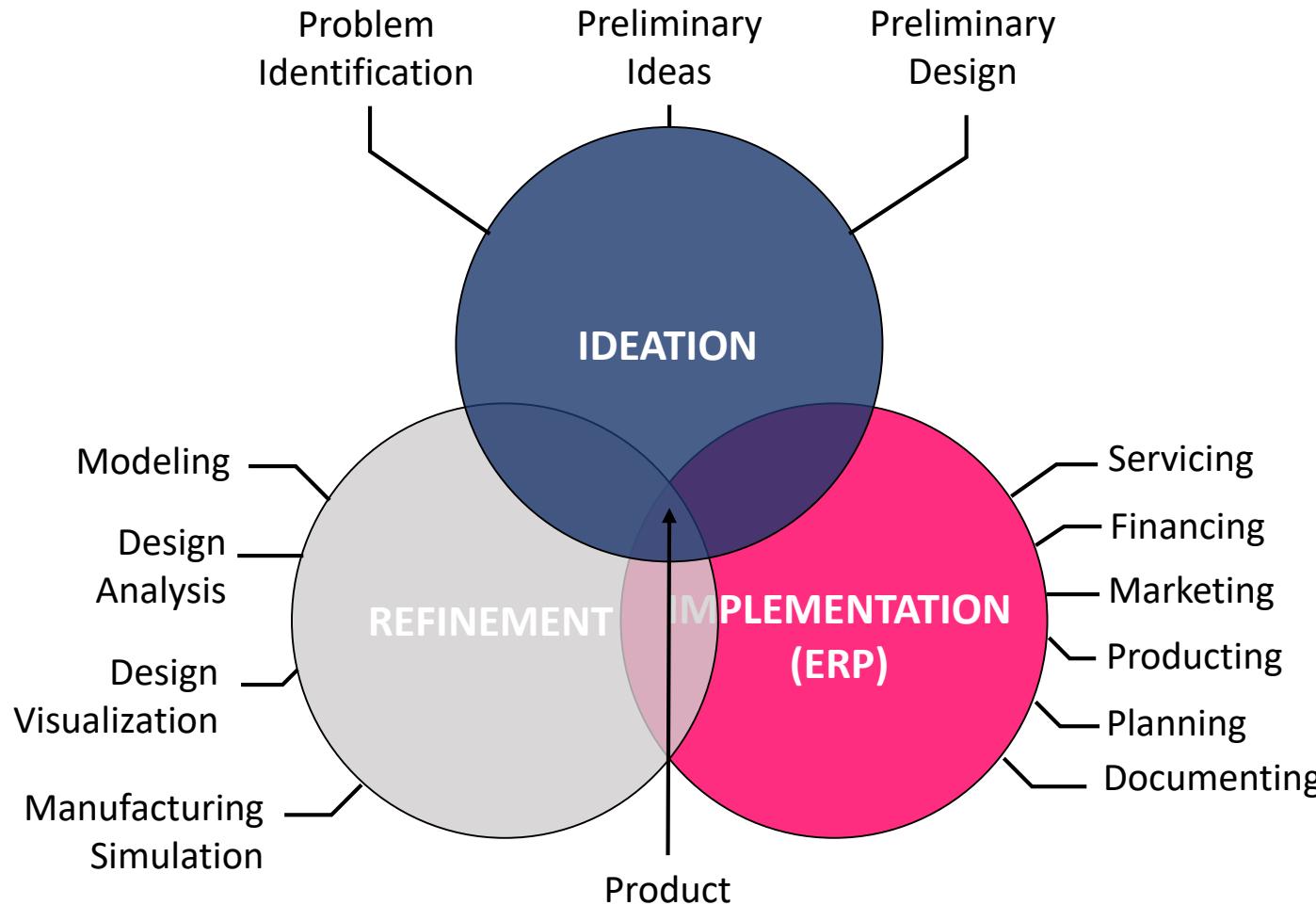


Figure 1.24: Concurrent engineering results in shorter lead times by working in parallel on different phases of the project. It requires a high discipline in communication and change control.

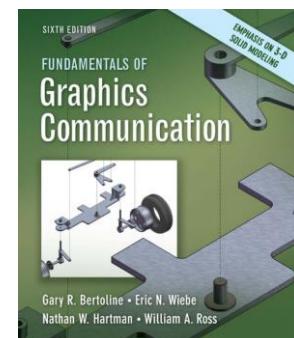


Concurrent Engineering



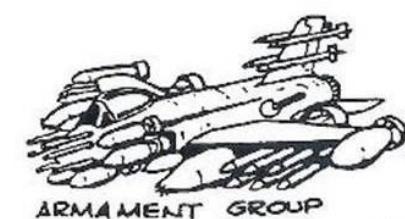
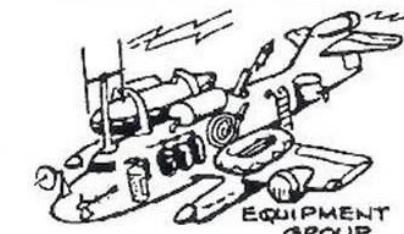
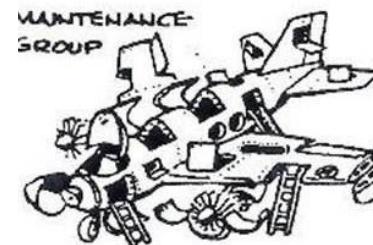
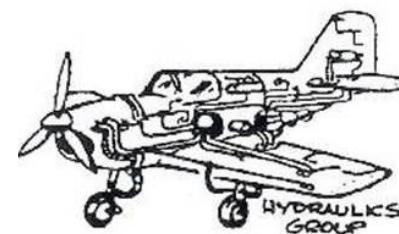
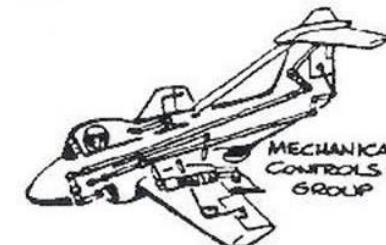
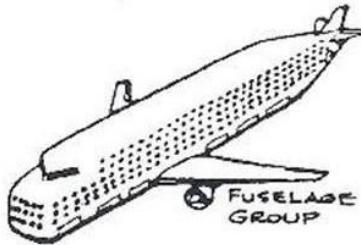
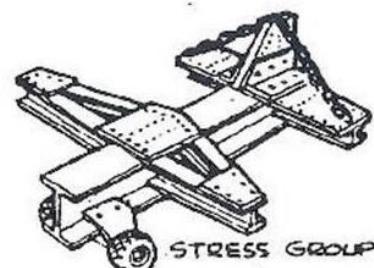
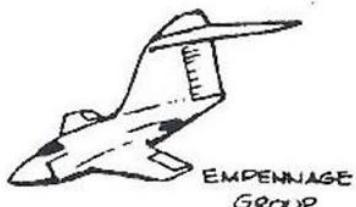
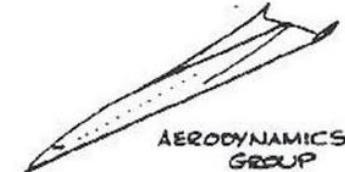
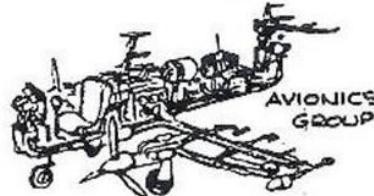
Through the **sharing of information**, it is possible for all areas of the enterprise to work simultaneously on their particular needs as the product is being developed

Bartoline, G.&Wiebe, E.(2005). Fundamentals of graphics communication. (4th ed.), Boston, McGraw-Hill

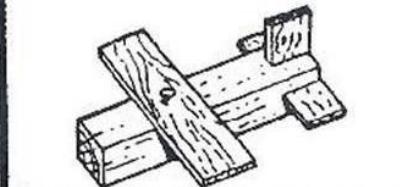
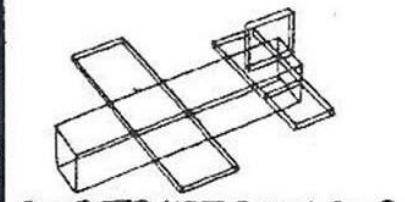
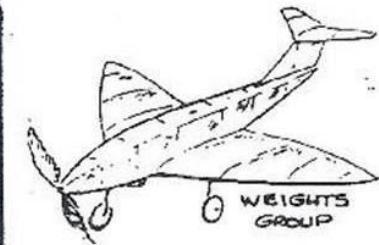


Concurrent Engineering

Communication between departments is the key !



IDEAL
PLANES
OR WHAT
CAN HAPPEN
IF ONE OF
THE TEAM
GETS ALL
THEIR OWN
WAY!



Concurrent Engineering

Epic Fails in Mechatronics design

Google glass (2013-2015)



- \$1,500 for pair of glasses
- Public backlash over privacy concerns
- Product looked like “dorks”

Leasson learned : Product designers need to solve problems that customers care about and are willing to pay to resolve.

Juicero Press (2017)



- \$400 internet-connected juicer that used single-serving packets of chopped organic fruits
- Over-engineered device, which mechanism delivered 4 tons of force
- Does a juice machine truly need to be connected to the internet?

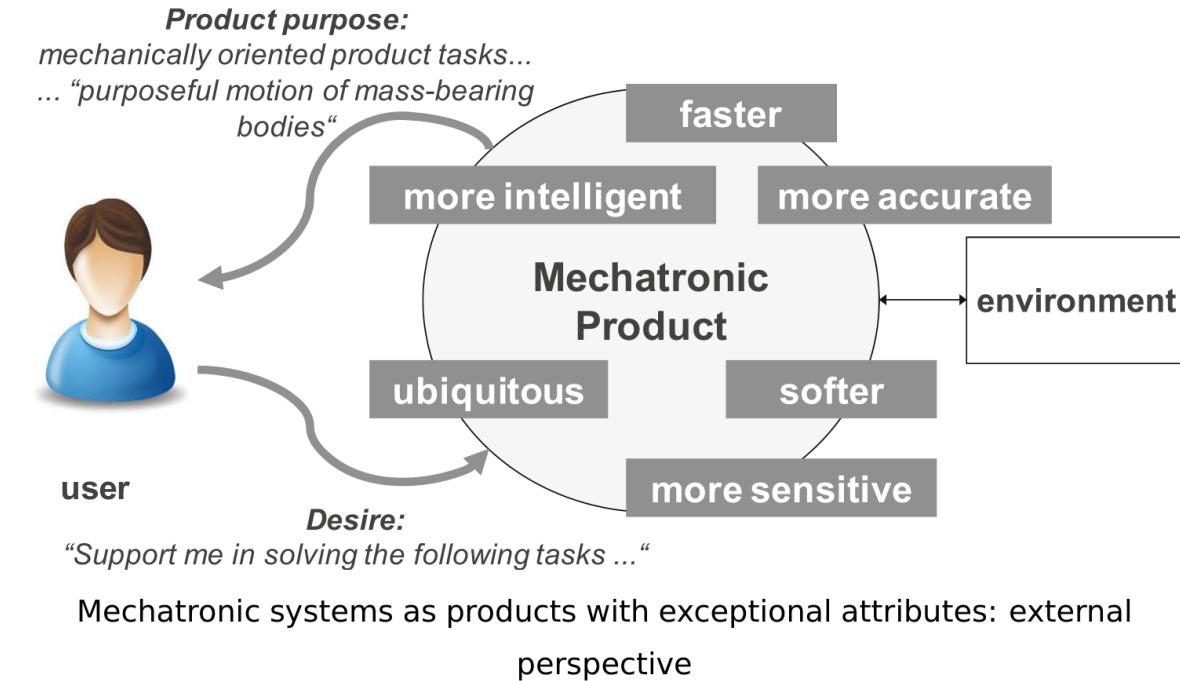
Leasson learned : Successful innovation is not about creating solutions in search of a problem. Seek “simple” solutions for even “complex” problems.

Product-Oriented Perspective

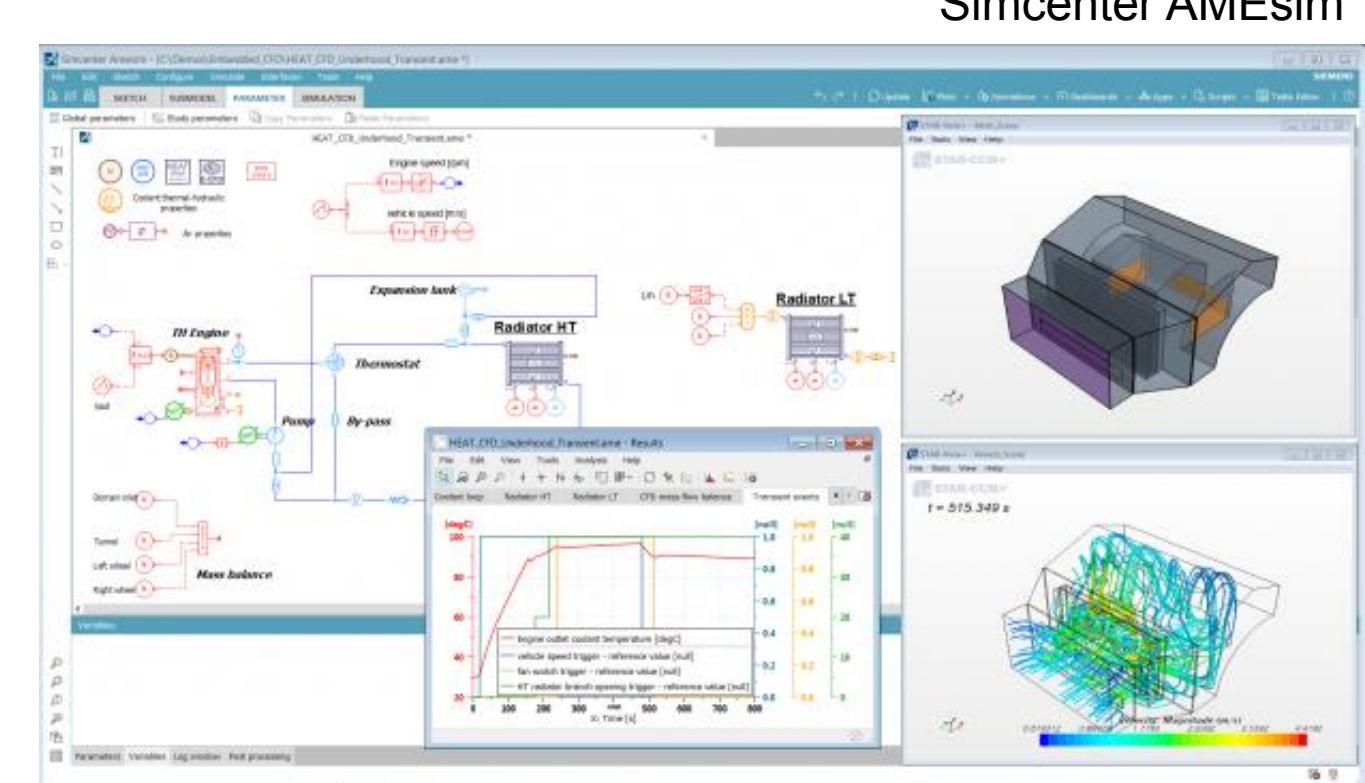
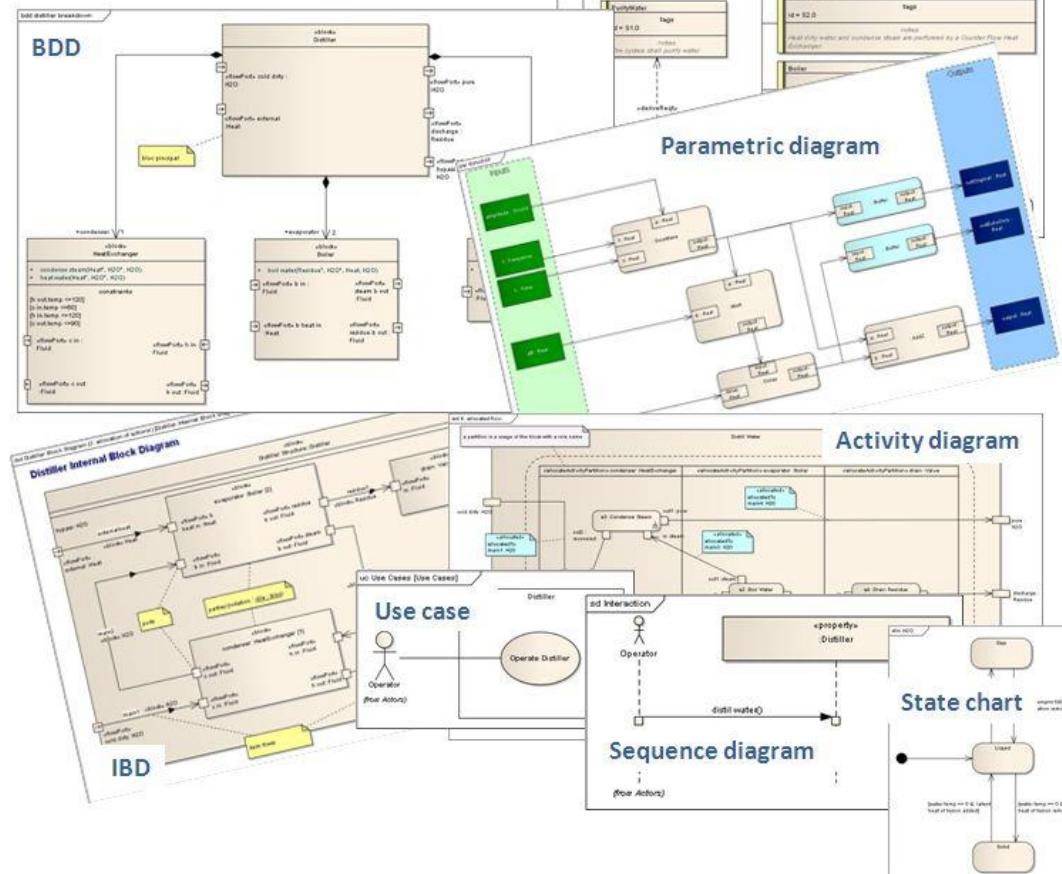
Mechatronics Engineering is the

- Analysis
- Design
- Manufacturing
- **Integration**
- and maintenance

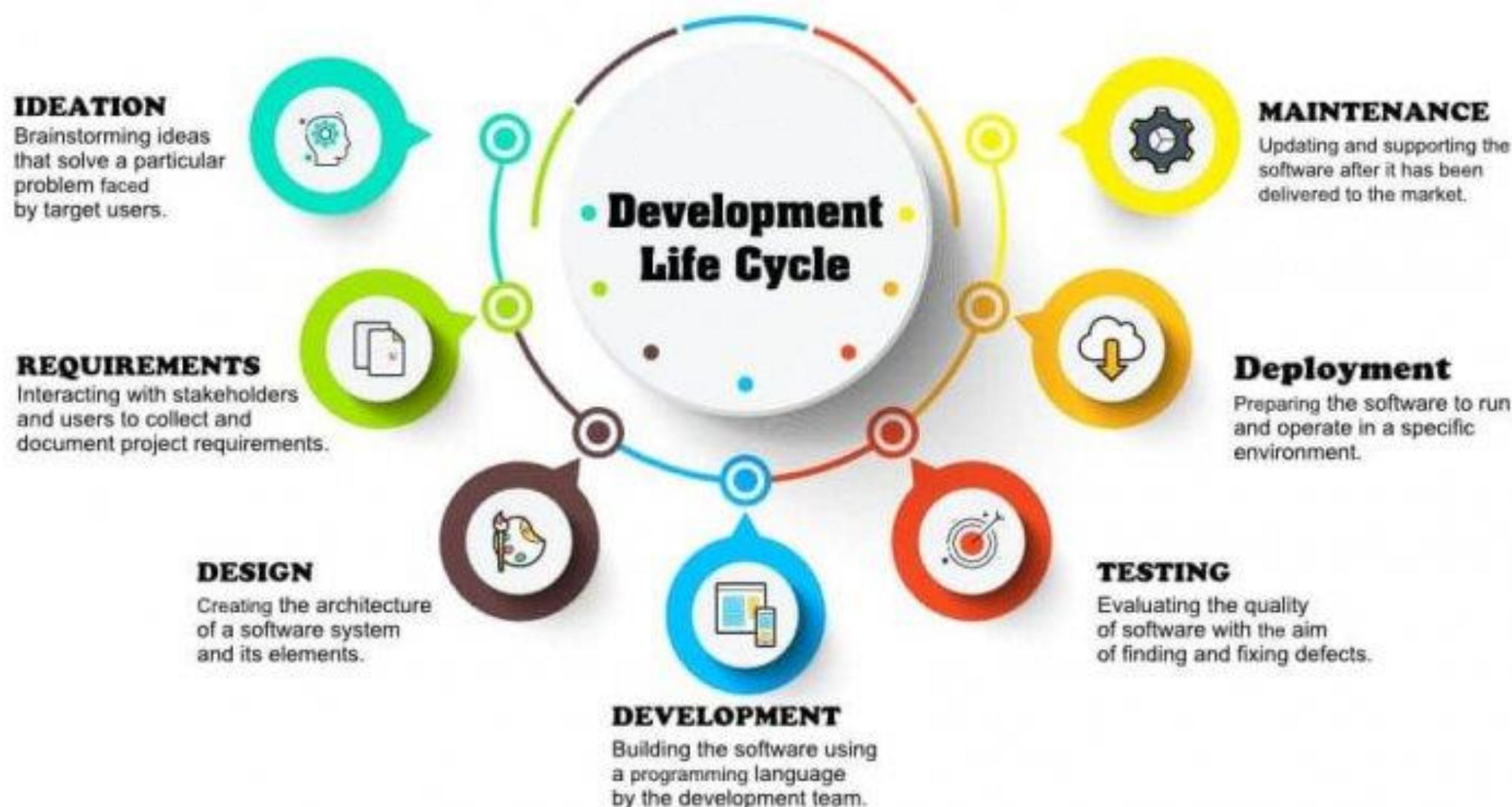
of mechanics with electronics through intelligent computer control.



Tools



Designing a mechatronic system

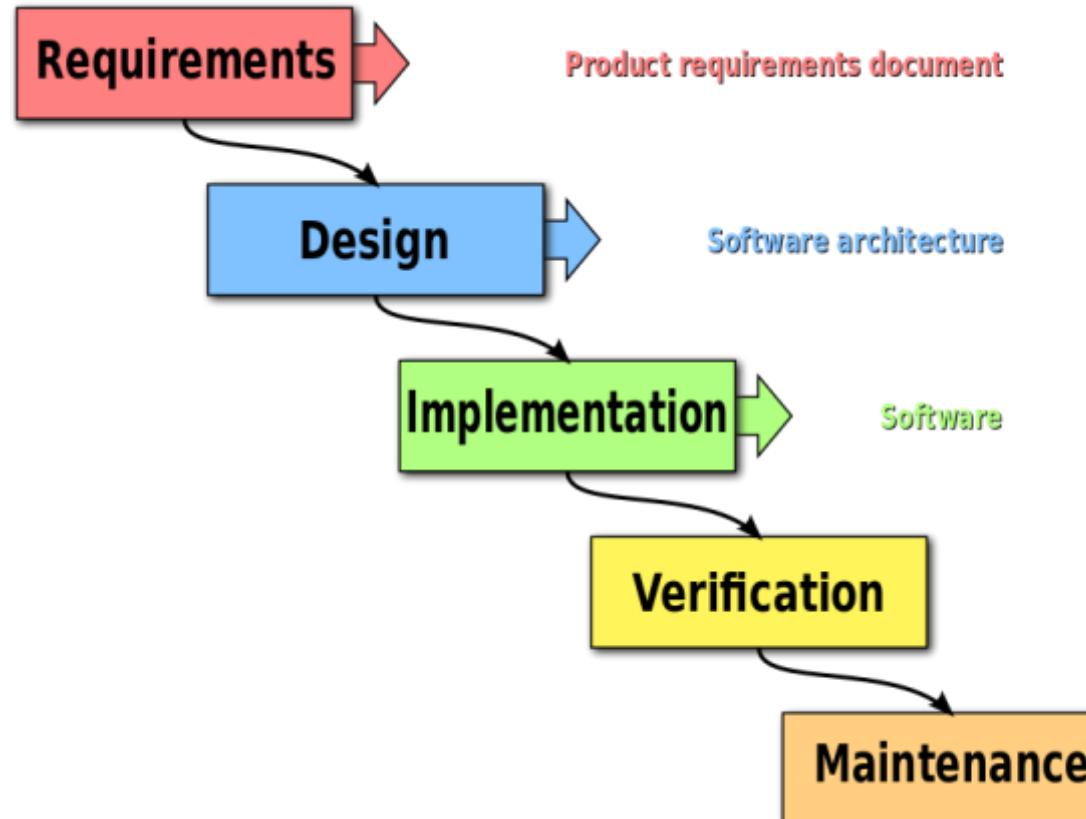


Designing a mechatronic system

- A systems development life cycle is composed of a number of clearly defined and distinct work phases to plan for, design, build, test, and deliver information systems.
- Different kinds of models :
 - *The linear models (waterfall model, V-cycle);*
 - *The iterative models (incremental model, spiral model and by-prototype model).*
 - *Agile (new trend)*

Product life cycle: the waterfall cycle

- It is a **sequential non-iterative** design process



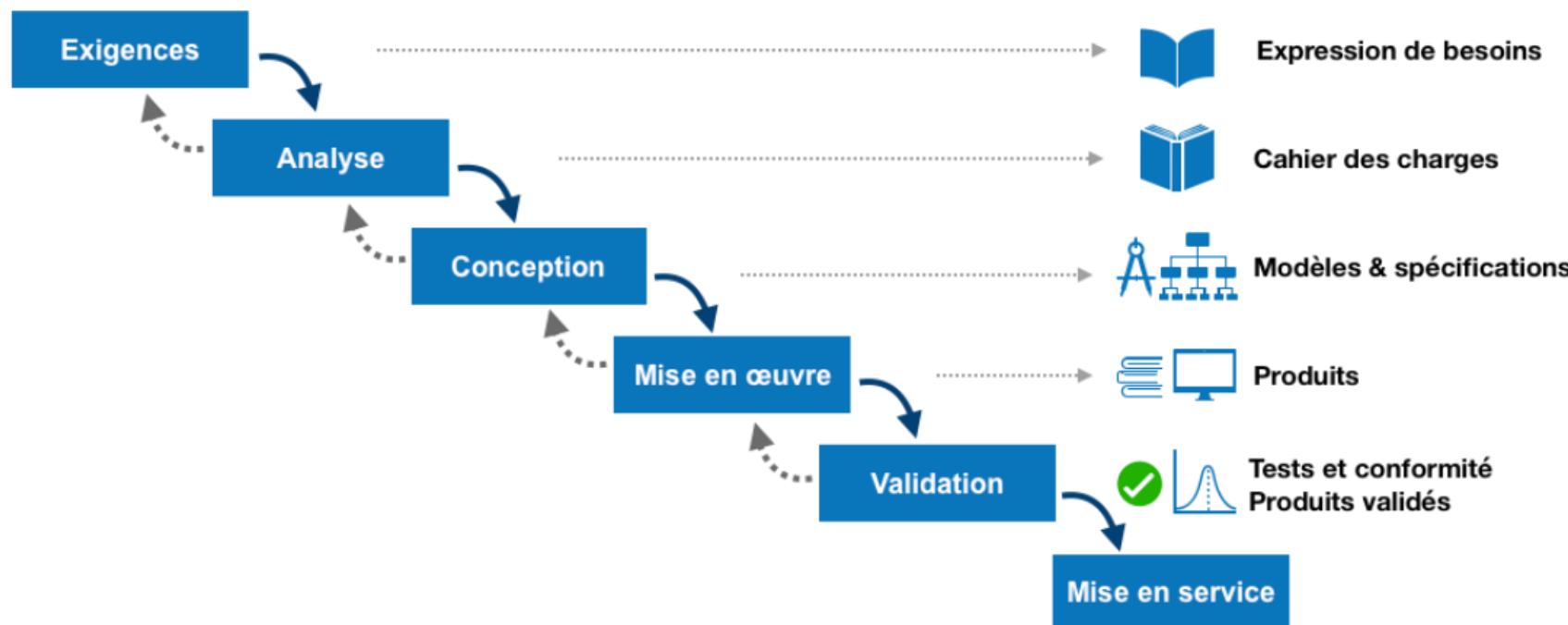
Manufacturing, construction
and software industries

- ☺ adapted for designing simple products
- ☹ not adapted for designing complex ones

The **waterfall model** is a breakdown of project activities into linear sequential phases, where each phase depends on the deliverables of the previous one and corresponds to a specialisation of tasks.

Product life cycle: the waterfall cycle

- It is a **sequential non-iterative** design process



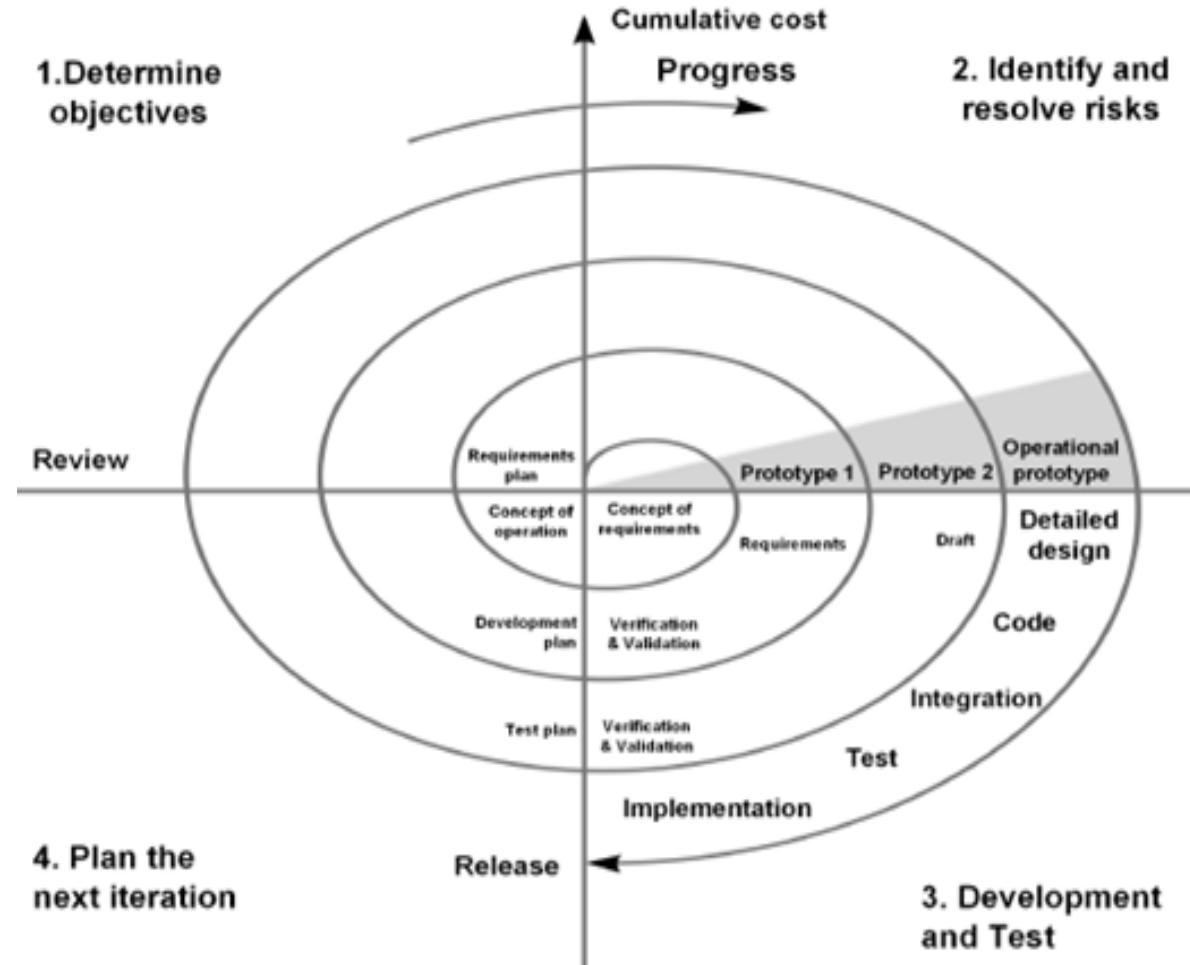
Manufacturing, construction
and software industries

- ☺ adapted for designing simple products
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The **waterfall model** is a breakdown of project activities into linear sequential phases, where each phase depends on the deliverables of the previous one and corresponds to a specialisation of tasks.

Product life cycle: the spiral model

- It is a **risk-driven process** model

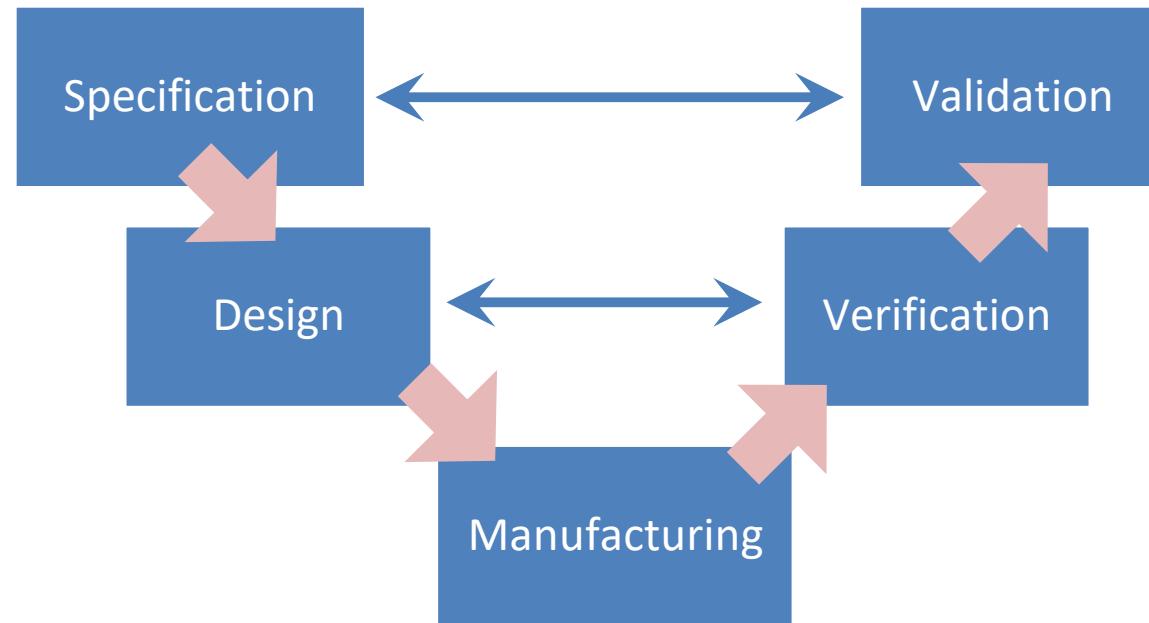


Software industry

- 😊 short-time steps
- 😊 continuous dialogue with the customer and the user.
- 😊 risk minimization
- 😢 cost increase
- 😢 time increase

Product life cycle: the V-cycle

- It is a rigorous development lifecycle model and a project management model.



First used as a model of development in different technologies: mechanics, electronics, and software.

- ☺ an overall methodology with shared stages to the different technologies
- ☺ common terminology
- ☺ generalized to the development of complex systems
- ☹ maintenance and repair not taken into account

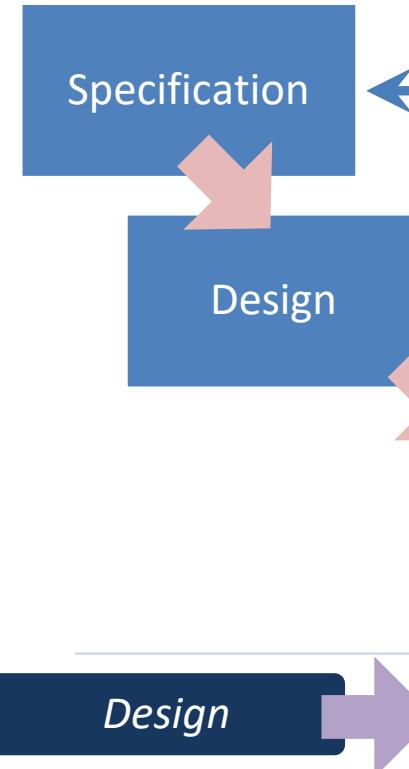
The horizontal axis represents time

The vertical axis represents the level of integration of the system

The left side of the "V" represents the decomposition of requirements, and creation of system specifications. The right side of the "V" represents integration of parts and their validation.

Product life cycle: the V-cycle

- Design phase



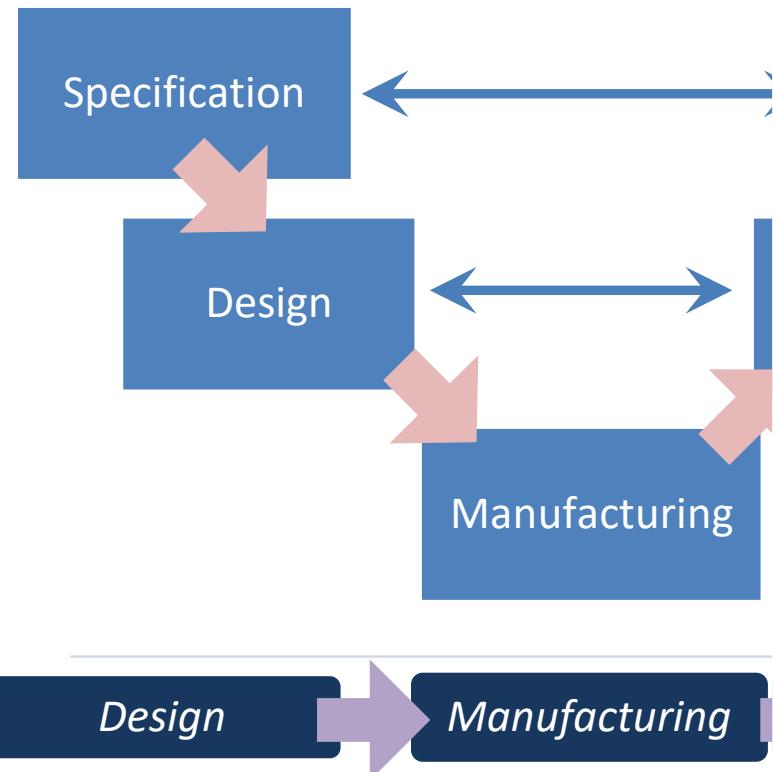
For a mechatronic system, the major difficulty is the **translation** of the global system specification into specifications for each component with different technologies.
[Rieuneau, 1993], [DesJardin, 1996]

Then, it is increasingly necessary to integrate **security** in the first phase of the development cycle.
[DesJardin, 1996]

This integration leads to develop a **collaborative methodology** that promotes their inclusion in projects and through the different communities.

Product life cycle: the V-cycle

- Manufacturing phase



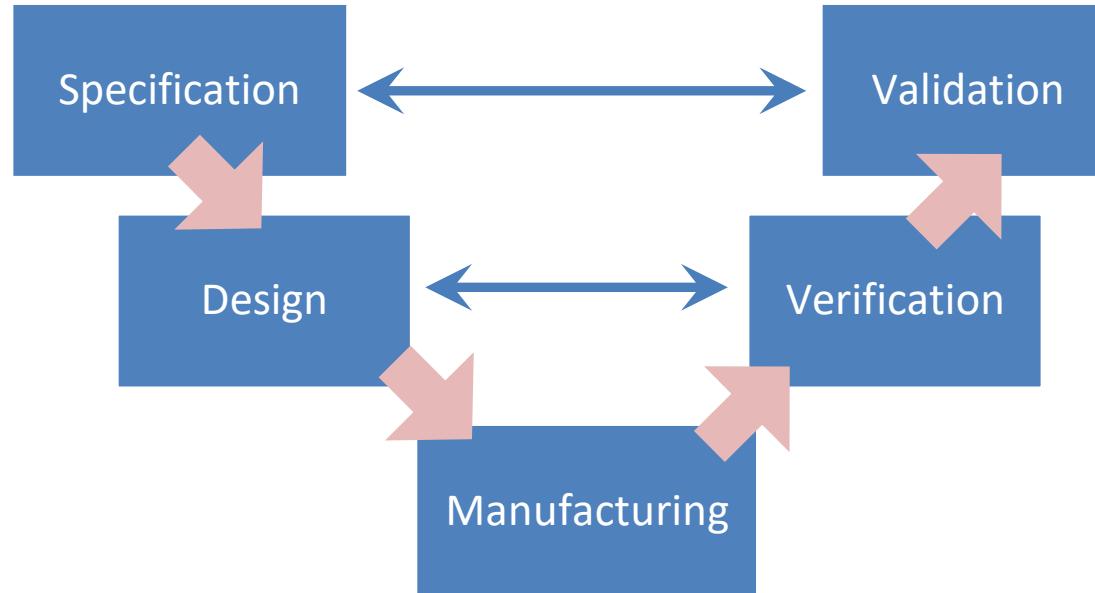
The manufacturer specifies not only the functionality but also the objectives in terms of **dependability**.



Must be studied during the design phase

Product life cycle: the V-cycle

- Verification & validation phase



This phase intends to show the functional validation of the sub-systems and of the whole system. Quality must be compared to the specifications.

The interactions between the different technologies must be characterized. This step may help to obtain return data and feed the database.



Product life

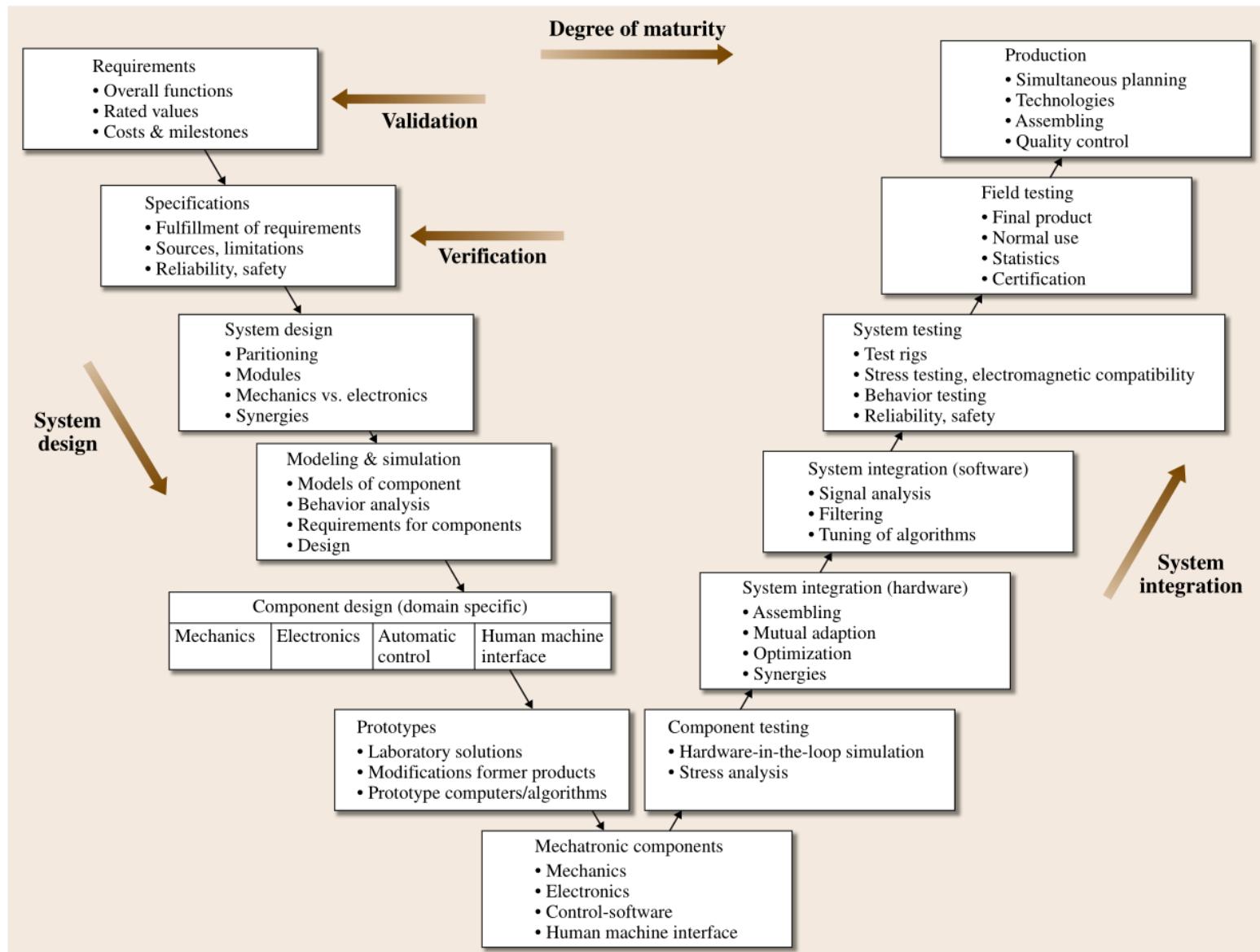
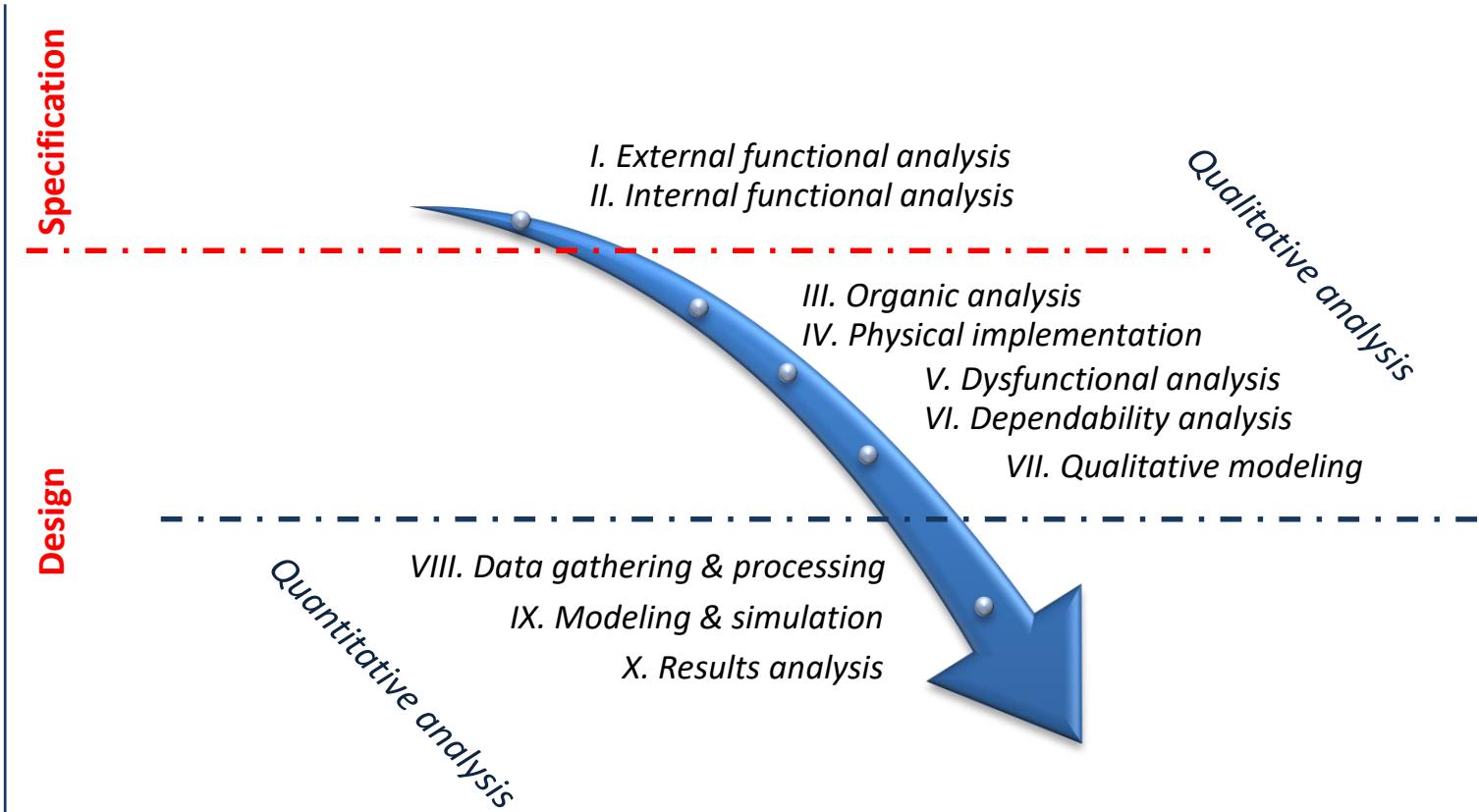


Fig.19.11 A “V” development scheme for mechatronic systems

Designing a mechatronic product

- It is necessary to develop a collaborative methodology very early in the project
- New approach for the first phases of the V-cycles



This method will be detailed
in Lecture 2

Examples of two industrial products

□ Simple mechatronic systems

- Smart actuator



- Medical imaging & robotics
- Bio prosthesis
- Ultra rapid Optronics
- Scientific Instrumentation
- Electrodynamic actuators
- ...

- Instrumented wheel bearing



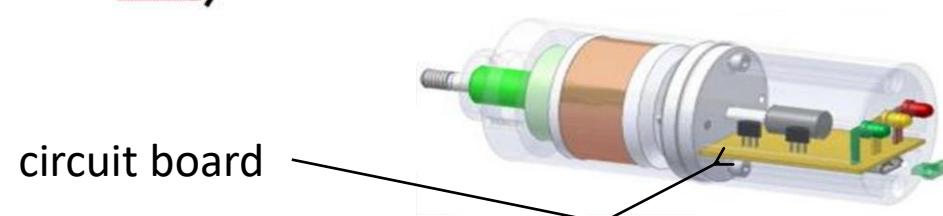
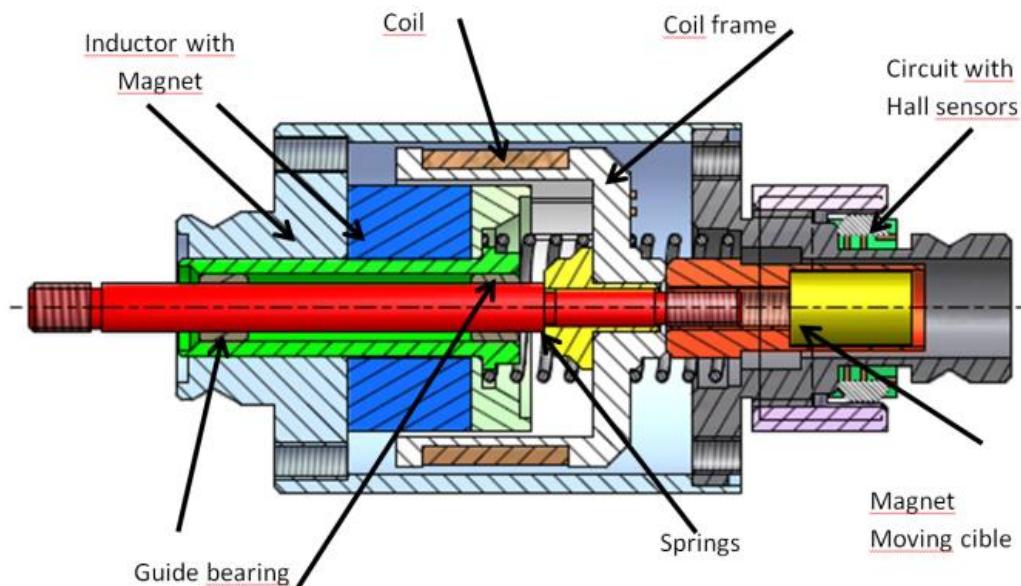
- Sensors & magnetic rings
- Ball bearings
- Bearing units

For aerospace, automotive, rail,
steel industry, wind energy,...

Example: smart actuator

Continuous sorting on a production line

- The wagons carry parts from a station to another of the chain in continuous motion
- The **smart actuator** contributes to the realization of the function of wagons unloading



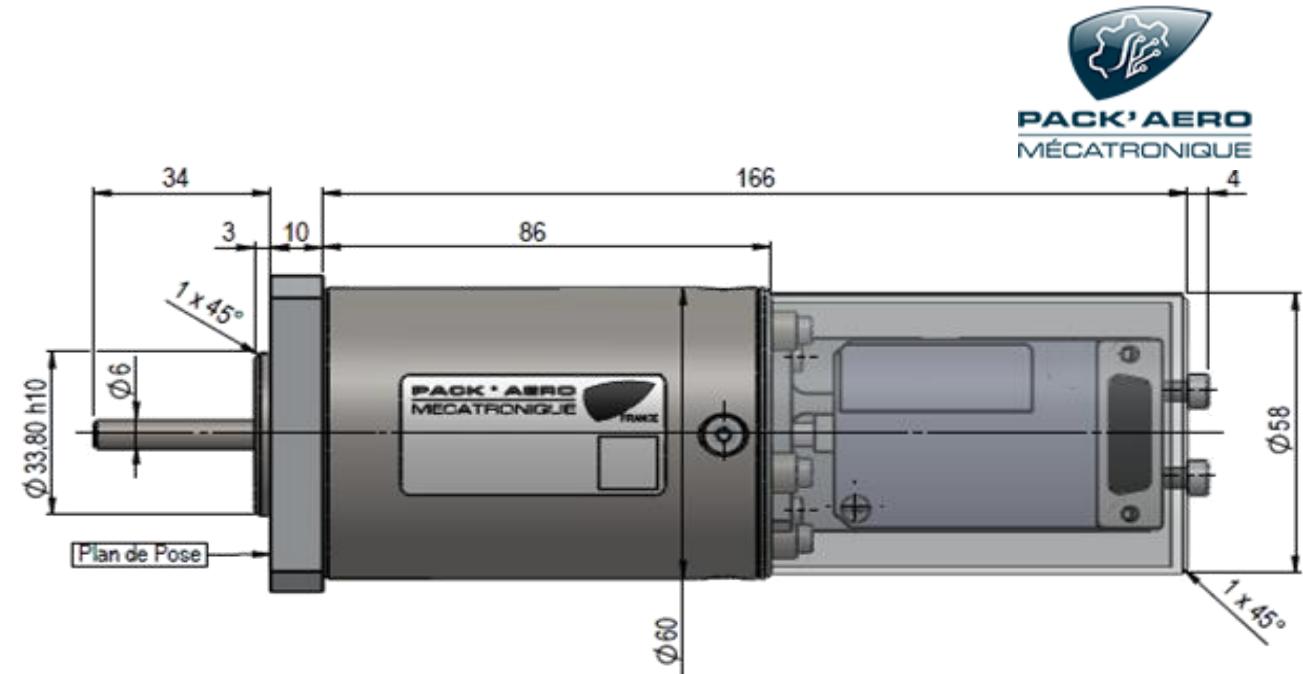
The finger of the smart actuator is used as a stop to open the shutter and release the load of wagon without stopping

Example: smart actuator

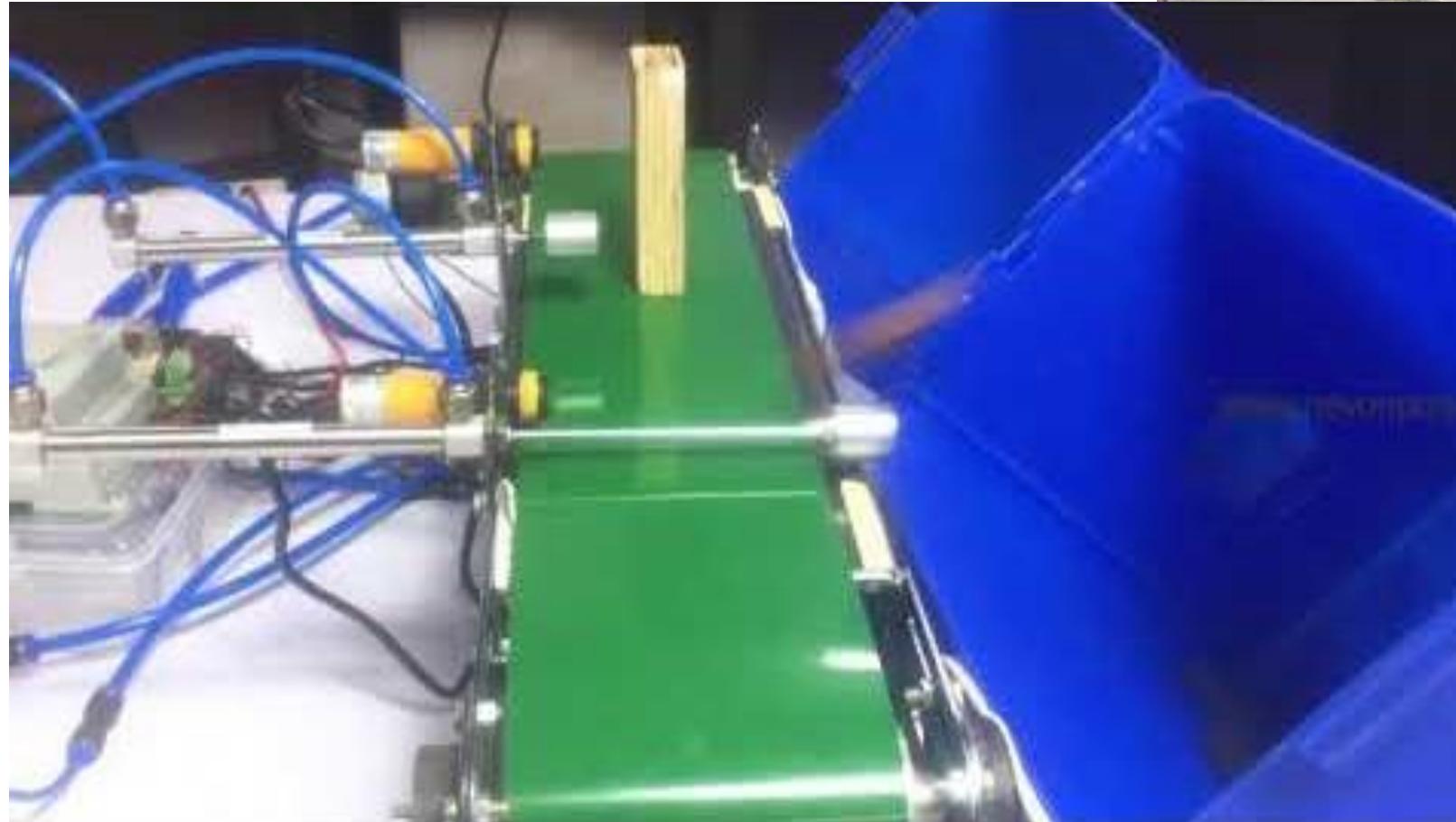
□ Specifications

In addition to be a classical actuator, the smart actuator assumes additional functions such as operating, monitoring, communicating, data processing, etc.

- > Transition from passive state to **active** state
- > Using a linear direct action instead of a linear indirect one
- > **Optimization of the immediate answer** according to the needs
- > Integration of **electrical locking functions** with or without electricity consumption



Example to illustrate



Example: smart actuator

a mechatronic product ?

- Incorporate several technologies?
- Physical integration?
- Functional integration?

what about its intrinsic characteristics

- Dynamic?
- Reconfigurable?
- Hybrid?
- Interactive/interdependent?

- > Transition from passive state to **active state**
- > Optimization of the immediate answer according to the needs
- > Integration of **electrical locking functions**
- > ...

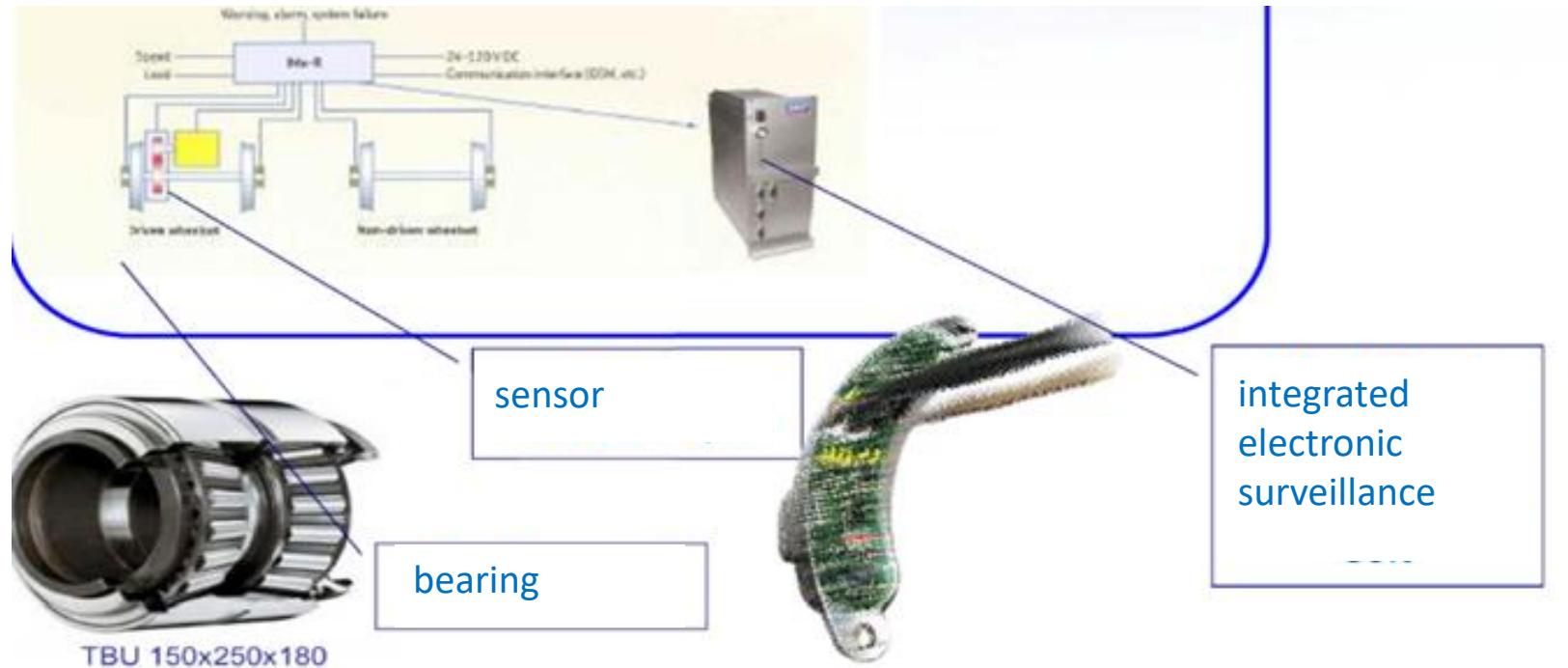
Example: instrumented wheel bearing

Using context



Fixed on axle tree

Integrated electronic surveillance



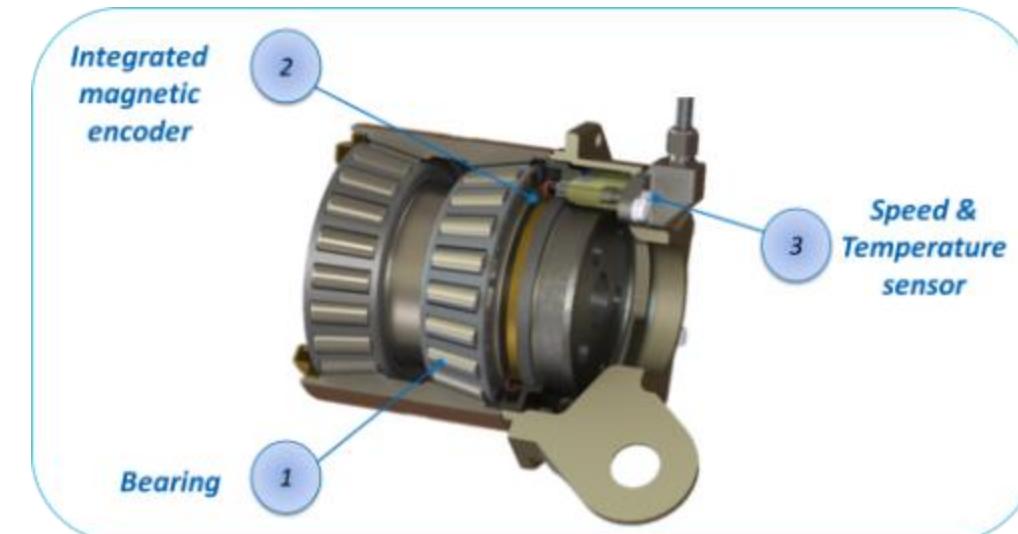
Example: instrumented wheel bearing



□ Specifications

In addition to be a classical wheel bearing, the instrumented wheel bearing assumes additional functions such as temperature and speed measurements.

- > One sensor for both measurement
- > Two electronic circuits are working in parallel (active redundancy)
- > The speed measurement is working from 0 km/h (high security)
- > Measured data are saved by the calculator



Example: instrumented wheel bearing



a mechatronic product?

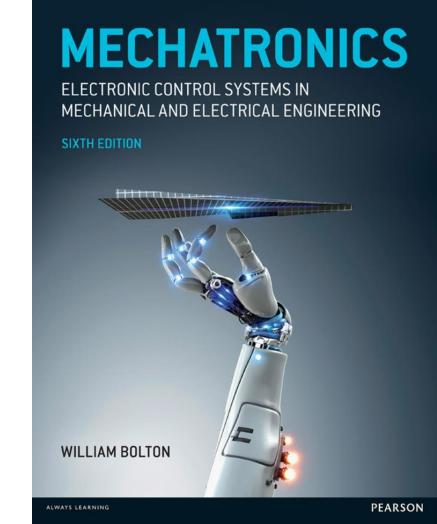
- Incorporate several technologies?
- Physical integration?
- Functional integration?

what about its intrinsic characteristics

- Dynamic?
- Reconfigurable?
- Hybrid?
- Interactive/interdependent?
- > Transition from passive state to **active** state
- > Active redundancy
- > Continuous phenomenon and discrete events
- > ...

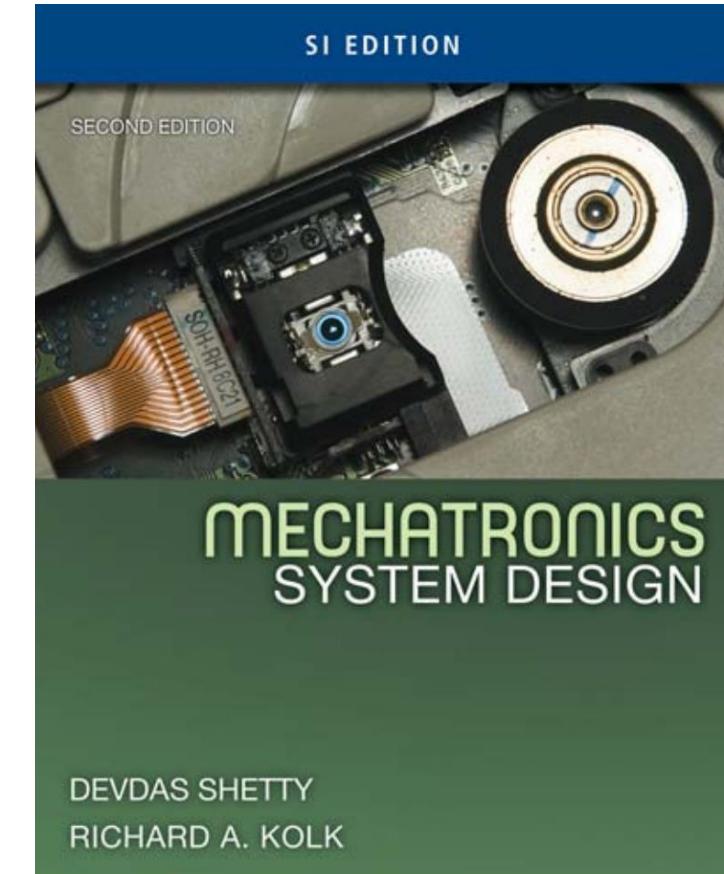
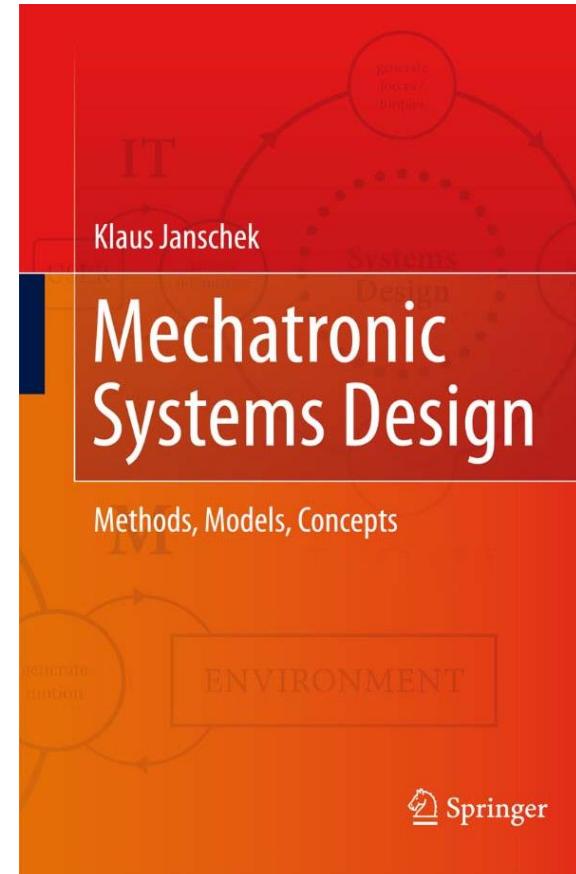
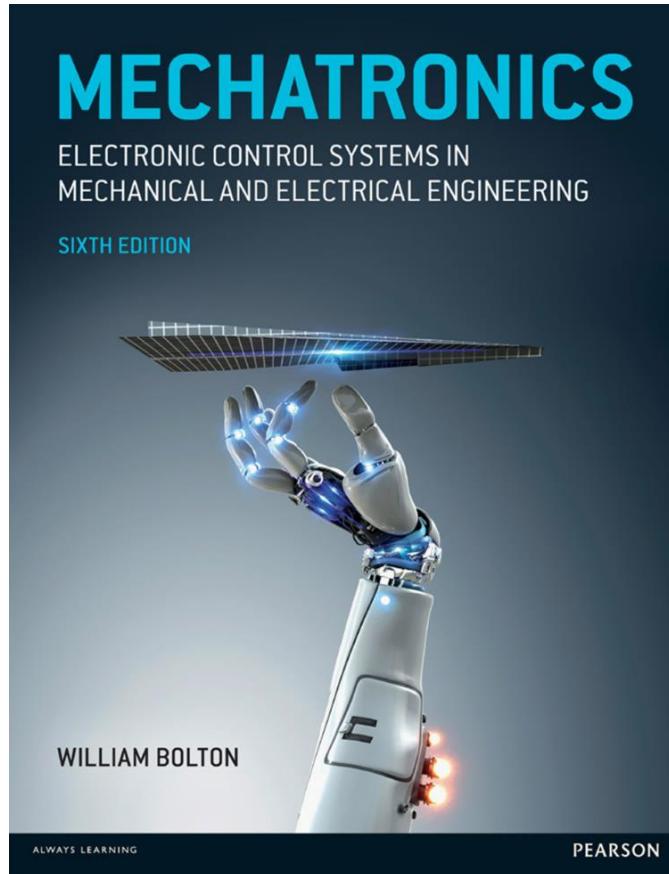
Assignment 1

- Read [Chapter 1 of the book MECHATROMICS, W. Bolton](#)
- [Read this web page on Software Development Life Cycle](#)
- Answer the Quizz Assignment1 on the Moodle plateform
- Find on the internet an example of a **smart actuator**
- Due to Monday October 4, 2021. (10am max. deadline)
- This will count towards 10% of the final grade.



**Software development
life cycle: definitions,
phases, models, and
simple examples**

Relevant books



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SYMME

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for the original writing of this lecture