# Problematics and challenges of SYSTEMS ENGINEERING

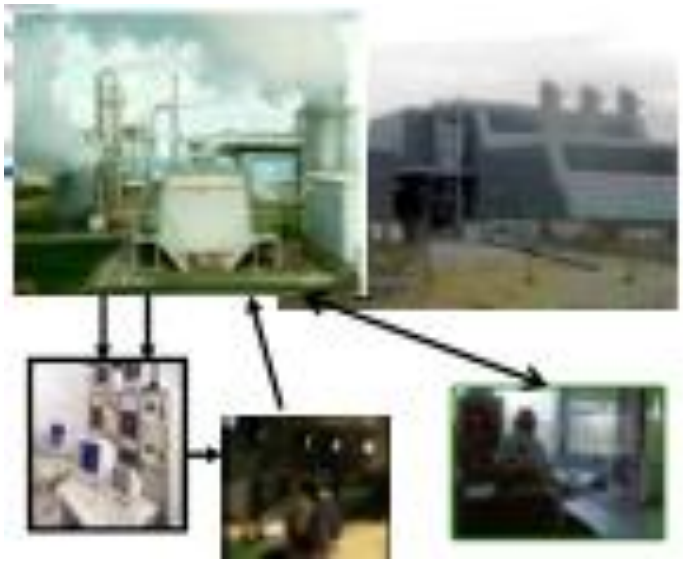
Based on Alain Faisandier course (MAP)

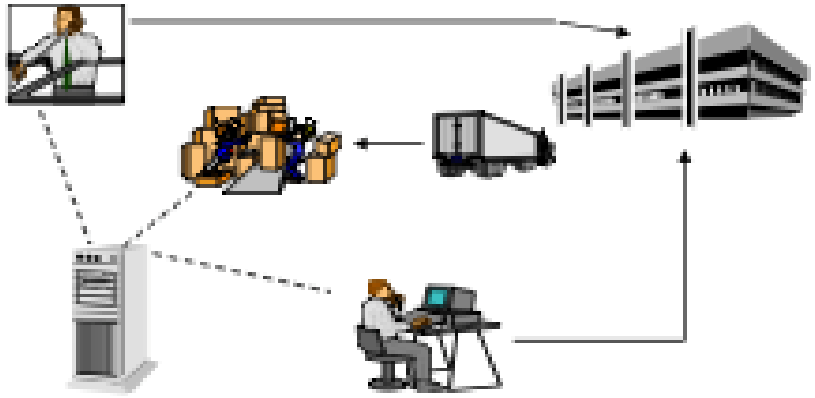
# Course overview

1. From system to systems engineering.
2. Systems engineering.
3. The process.
4. The system project.
5. Project management.

**What does the word “system” represent for you?**

# A system





*« Entreprise étendue »*

*Système d 'observation*

*Système de santé régional*

# System and systemic

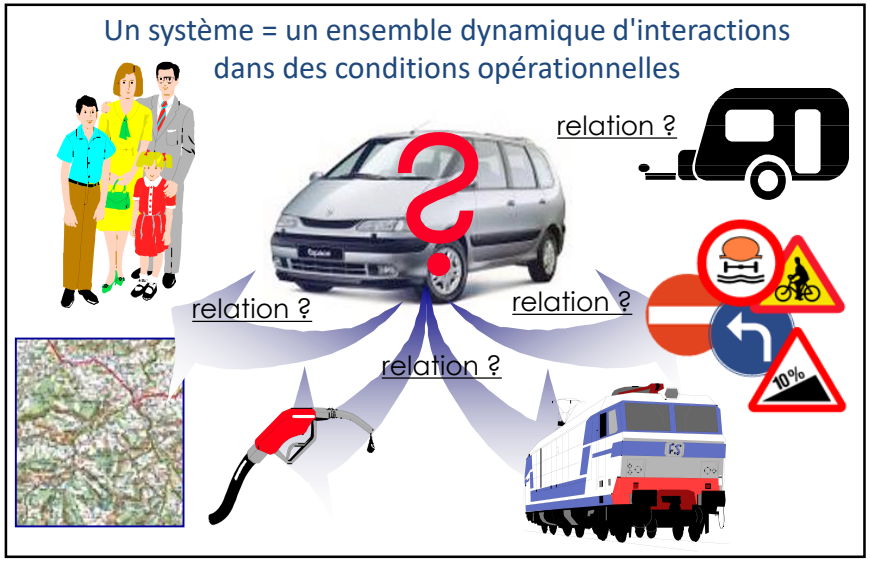
The term "system" is used in the past in philosophy and metaphysics; it is the source of the "systemic".

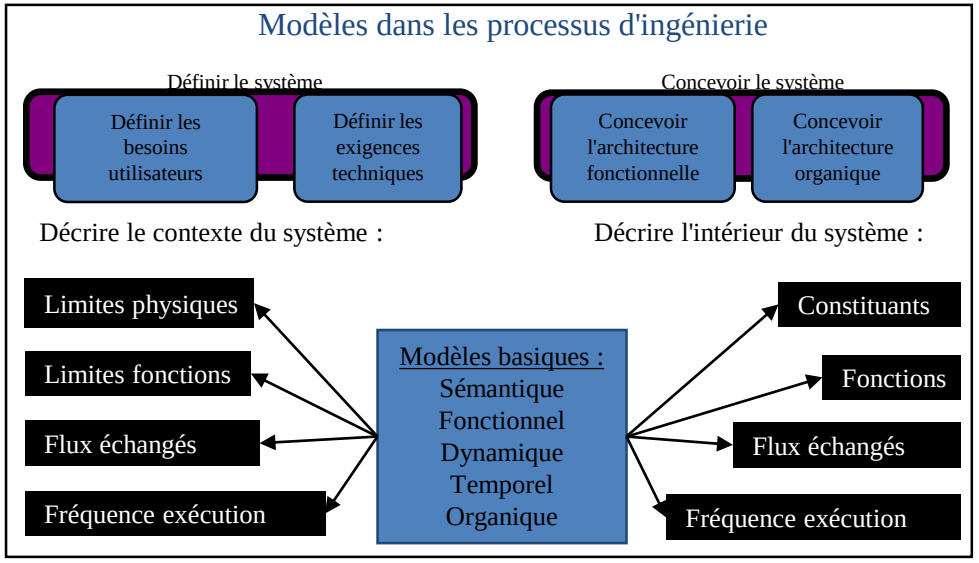
Today, the systemic is interested in:

- The general theory of systems (generic model of the world and phenomena)
- Methods for modeling the abstract view of complex products

System Engineering takes into account these two axes:

- The system vision of products and services
- Basic models and generic processes to model



# Définitions

**ISO/IEC 15288 definition**

***A system is a combination of interacting elements organized to achieve one or more stated purposes.***

- ***NOTE 1: A system may be considered as a product or as the services it provides.***
- ***NOTE 2: In practice, the interpretation of its meaning is frequently clarified by the use of an associative noun, e.g. aircraft system.***

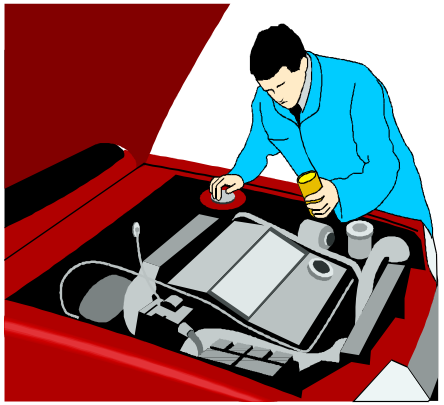
**Formal**

**Intuitive**

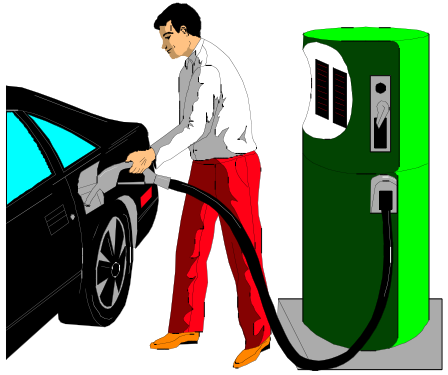
A system is a construction that meets a purpose in a given environment

# A system = a dynamic in an environment

Vehicle system

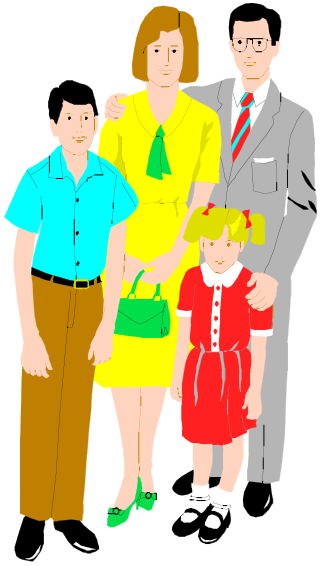


- Motor
- Functions
- Wheels
- Software
- Doors
- Scenarios
- . . .



Dynamics makes a whole a "system"

# A system = a set of relationships



relation ?

relation ?

relation ?

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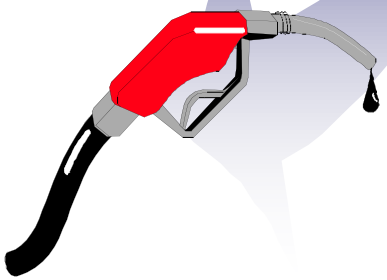
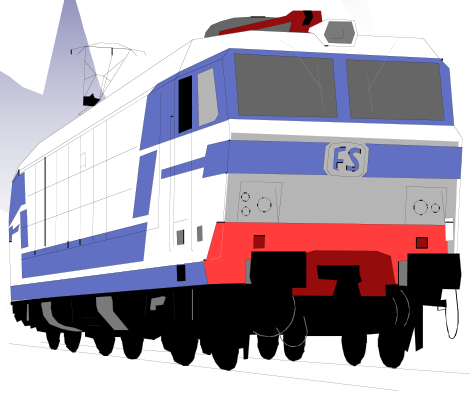


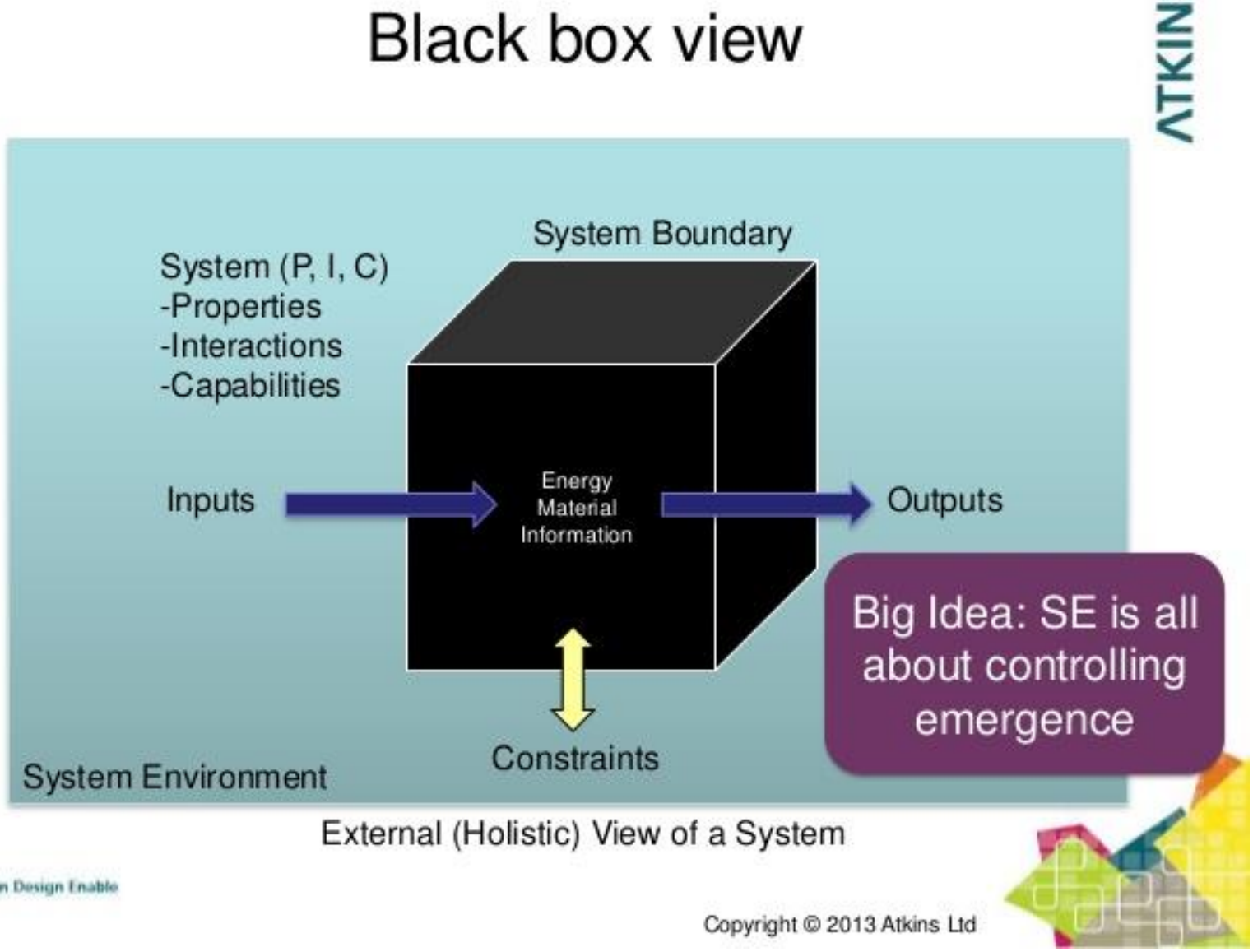


# Systemic: points of view

- ✓ **External point of view:** black box
- ✓ The system is in an **environment**
- ✓ It has a **purpose (WHY?)**
- ✓ It provides **services** to the environment

- ✓ **Internal point of view:** white box
- ✓ Content provides a solution

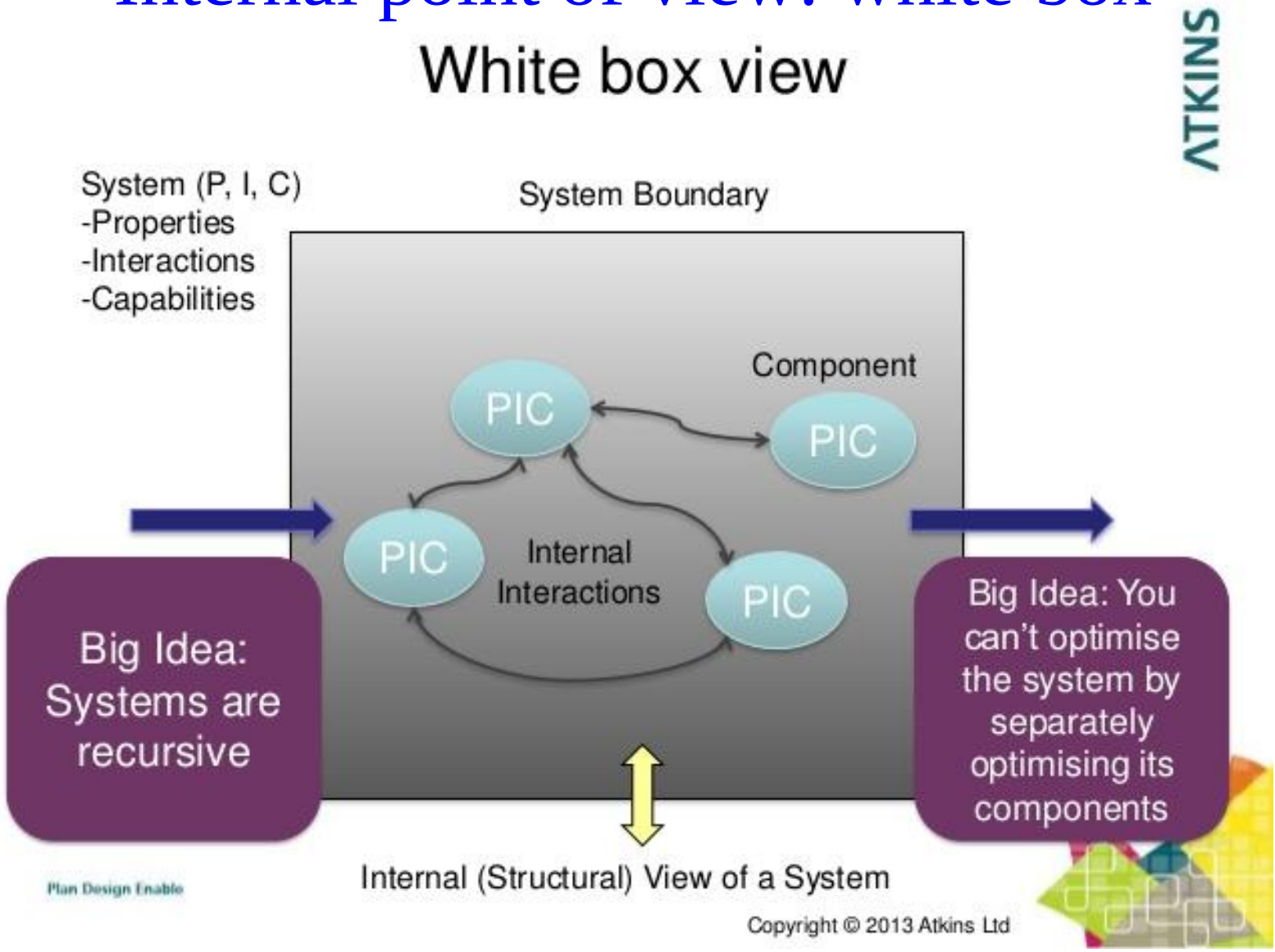
# External point of view: black box






Source Mike Wilkinson (APM / INCOSE)

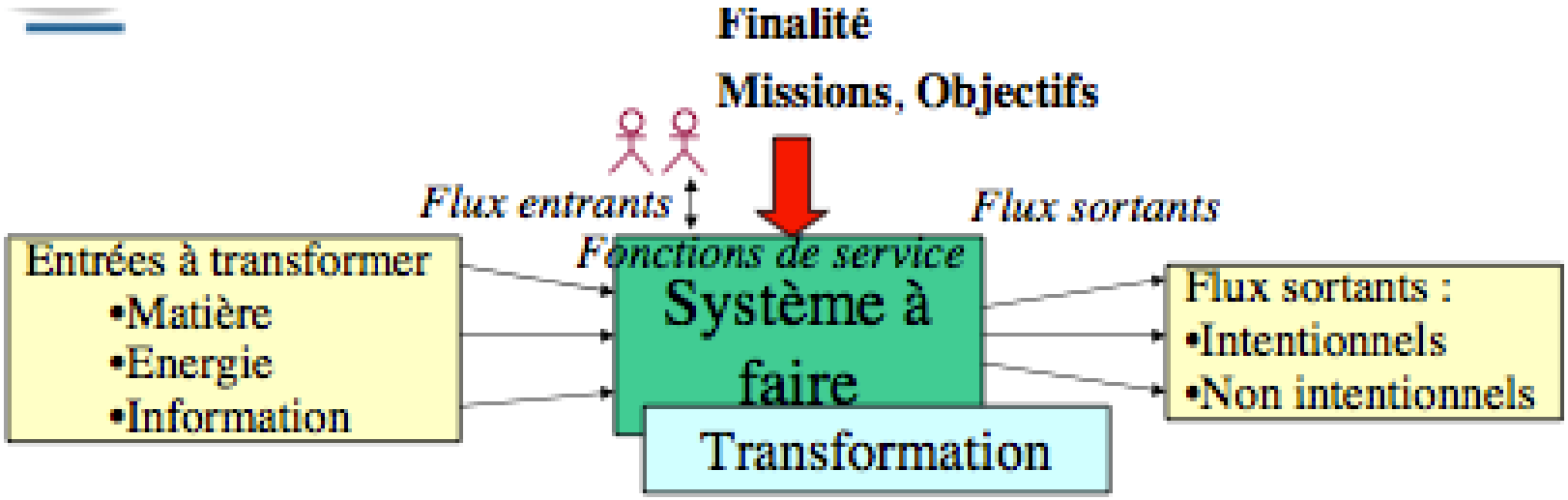
# Internal point of view: white box





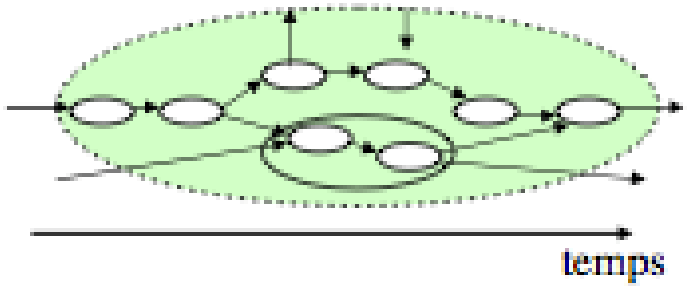

Source Mike Wilkinson (APM / INCOSE)

# The system and its environment




Finalité ⇨ Missions, objectifs ⇨ Fonctions de service

**Fonction de service** ⇨ définition de produits, de « processus » interne, de régulation




Source CNAM

# The system and its environment

## Direct environment

- **Human:** active or passive users
- Other systems
- The physical environment
- Interfaces

## Indirect environment

**Constraints:** regulation, security, environment.

# Requirements of a system

Requirements and constraints on the system to be done

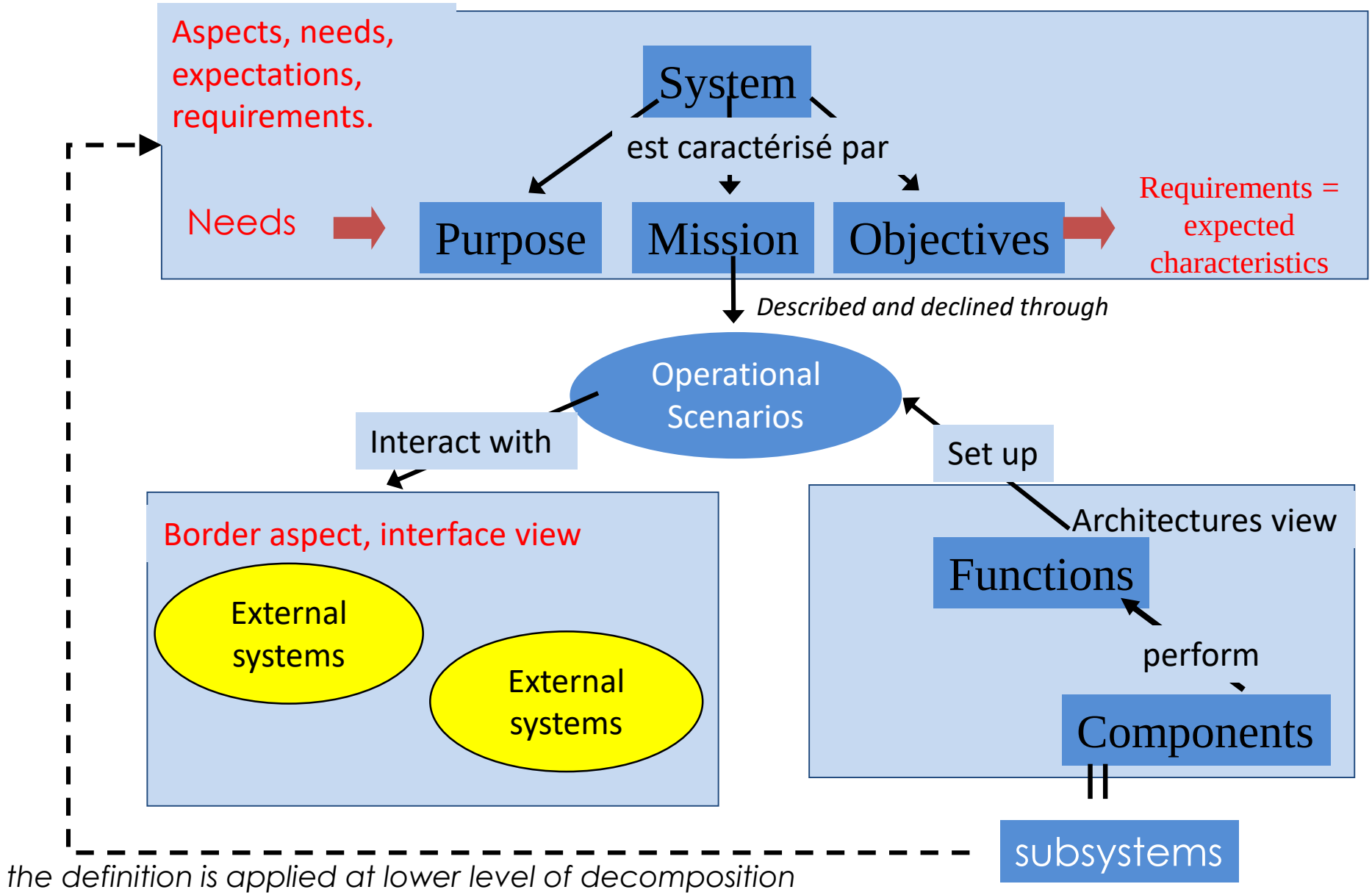
- Functional requirements (what the system MUST do)
- Non-functional requirements (what must the system be)
- ISO IEC 9126 (reliability, performance ...)

Constraints of the direct environment

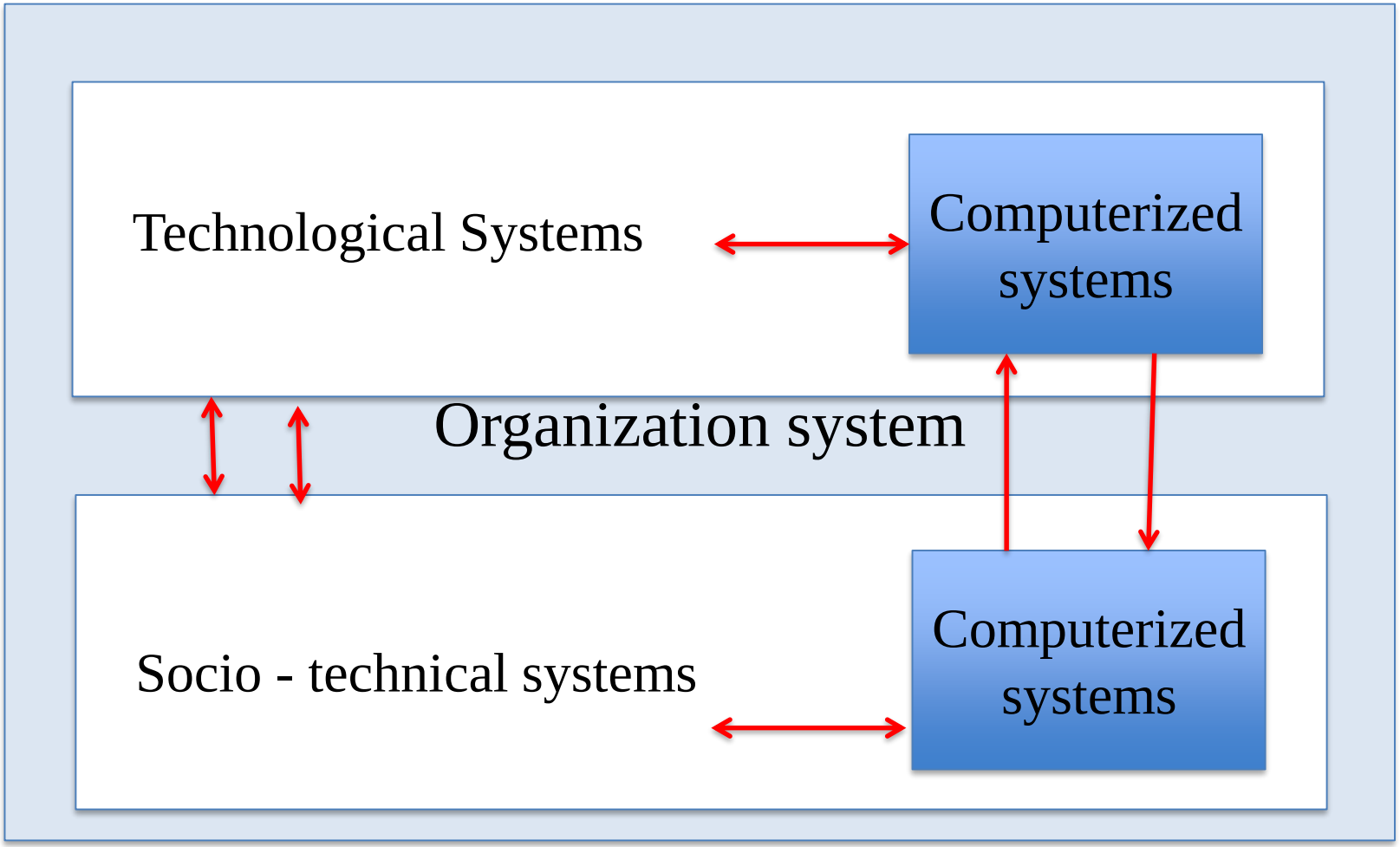
Indirect environment constraints

(political, economic factors ...,)

# The system vision: a model of the definition



# System of systems



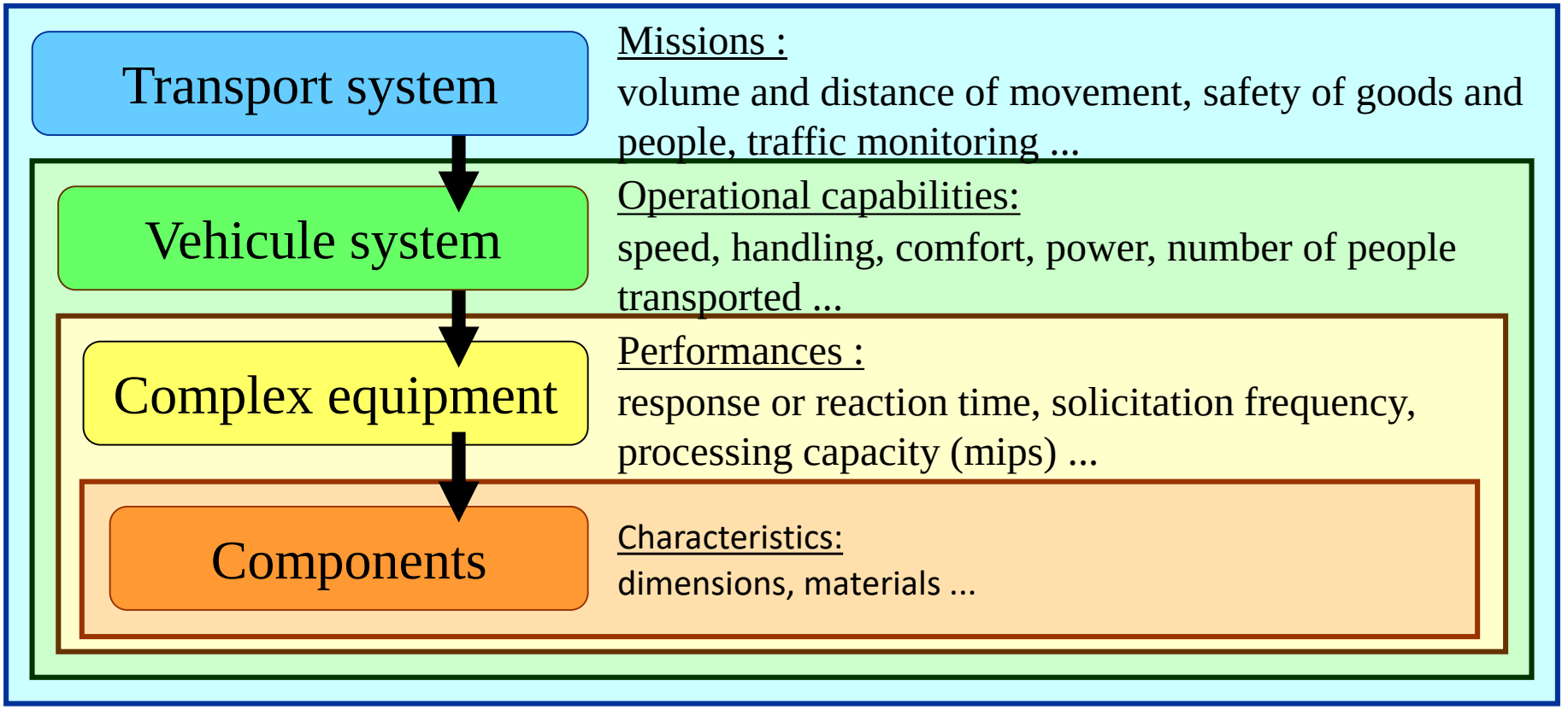



Source CNAM

# Hierarchical view of the systems

Abstract systems are refined into layers of systems, each system being characterized by its purpose, its mission, its objectives ...

✓ the system definition is recursive



# In its life cycle, a SYSTEM needs "contributor" services

## THE GOAL

Vehicle System

must be

Designed
DEVELOPED

must be

RECYCLED


must be

FABRICATED/
PRODUCED

must be

SUPPORTED

SOLD

must be

# The "contributor" services are also realized by systems

## THE GOAL

Vehicle System

requires a

DESIGN SYSTEM

requires a

RECYCLING SYSTEM


nécessite un

PRODUCTION SYSTEM

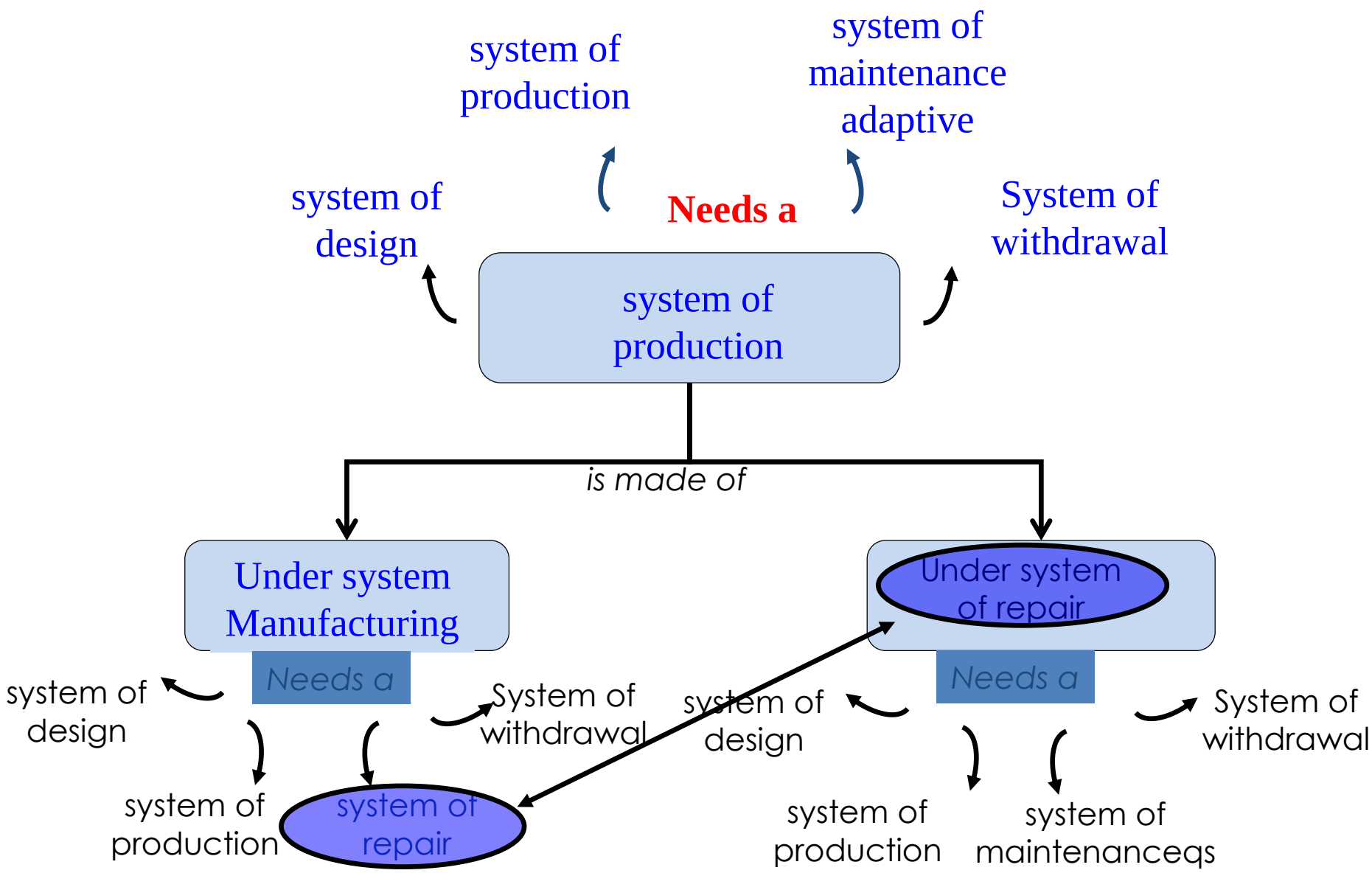
requires a

SUPPORT SYSTEM

SELLING SYSTEM

requires a

# Exemple


system of production
system of maintenance adaptive
system of design
Needs a
System of withdrawal
system of production
is made of
Under system Manufacturing
Under system of repair
Needs a
Needs a
system of design
System of withdrawal
system of design
System of withdrawal
system of production
system of repair
system of production
system of maintenanceqs

# Systems engineering

# Three major views to do systems engineering

The view **"need and requirement"**

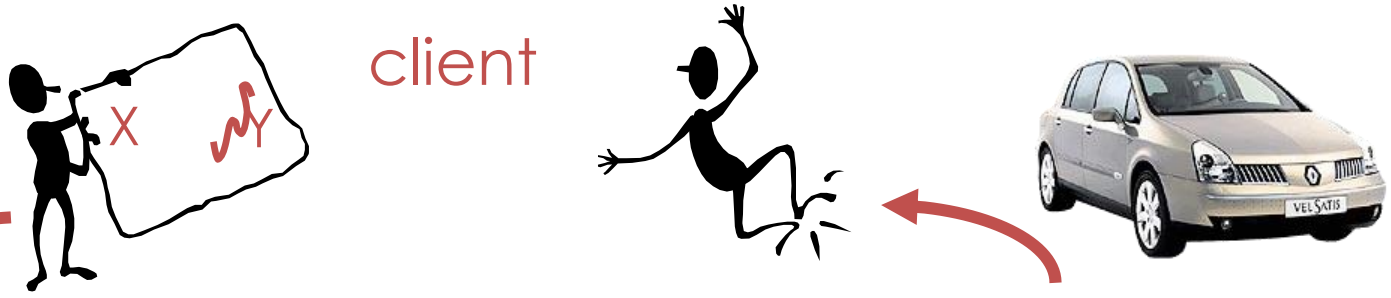
- **Purpose** = Why does the system exist? Its relevance in the context
- **Mission** = What does it do? What it transforms, the service it renders
- **Objectives** = How many elements does it deal with ...? Its efficiency

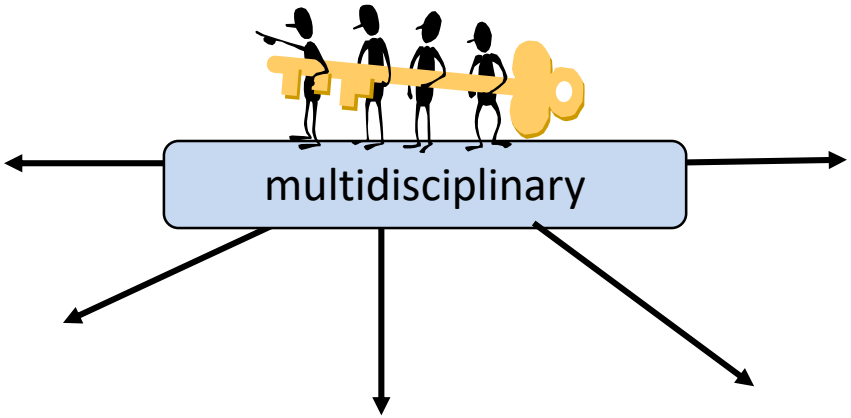
The **architecture** view

- **The functional architecture** is a function structure that allows the system to execute all operational scenarios identified over the life cycle; includes flow exchanges between functions and with the outside
- **Organic architecture** is a set of concrete constituents that support functions and interactions between constituents; includes physical connections

The **"border and interface"** view

- Physical connections
- Functional interfaces (flows)




Field of need viewpoints : user, operator...

Area of specialties: SdF, performances, ergonomics ...

Field of production: assembly, logistics, supply, scheduling ...

Field of geniuses and trades: mechanics, electronics, software ...

Support domain: training, maintenance ...

# Une méthode de résolution de problèmes complexes

# From an idea to the production line

Needs & expectations

Specification Technical (RSS)

Preliminary Definition System (RDP)

Detailed Definition System (RCD)

Production

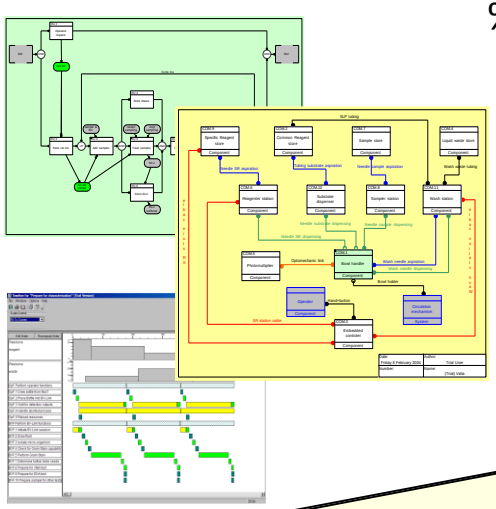
Intégration

Usage

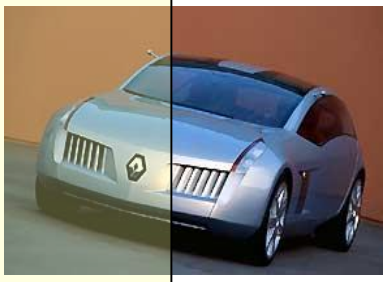
Withdrawal

Information with which the system is known and can be understood

% of information on abstract elements



% of information on physical elements



time

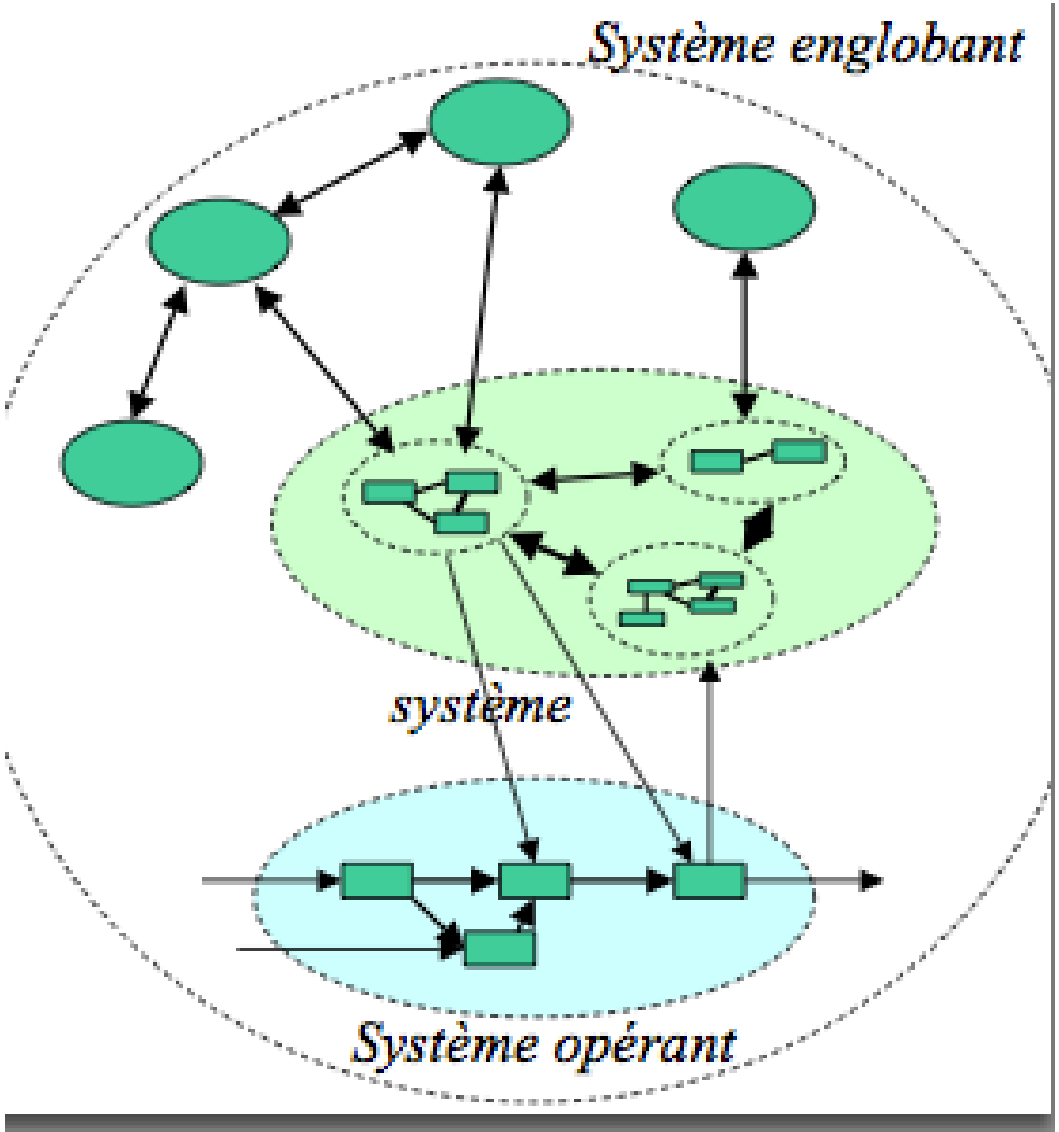
**model / architecture concept System Engineering**

Virtual Product CAD

Product real

Source MAP système

# The system engineering process



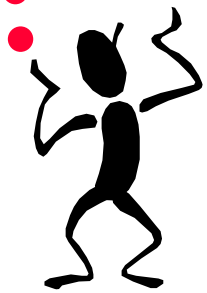

Taking into account the system encompassing

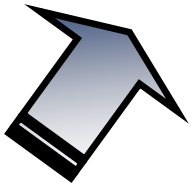
Taking into account the operated operating system

To take in consideration the whole life cycle

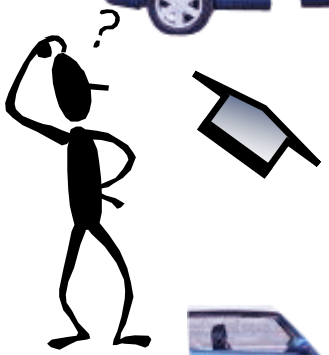
# Integration - reverse engineering - engineering

Corrections

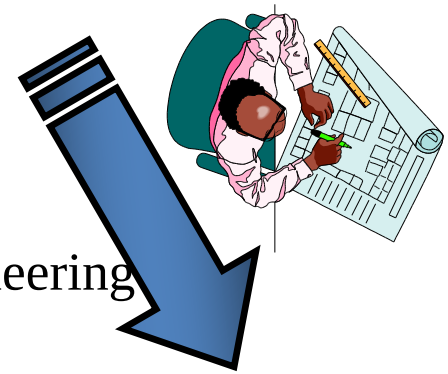




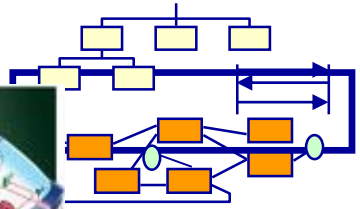
Intégration



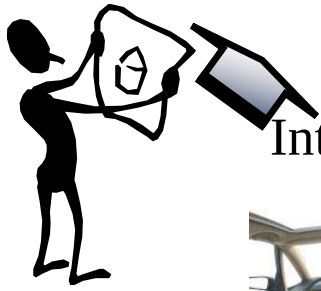
Existing pieces



Engineering



modeling (representation of reality using symbols)

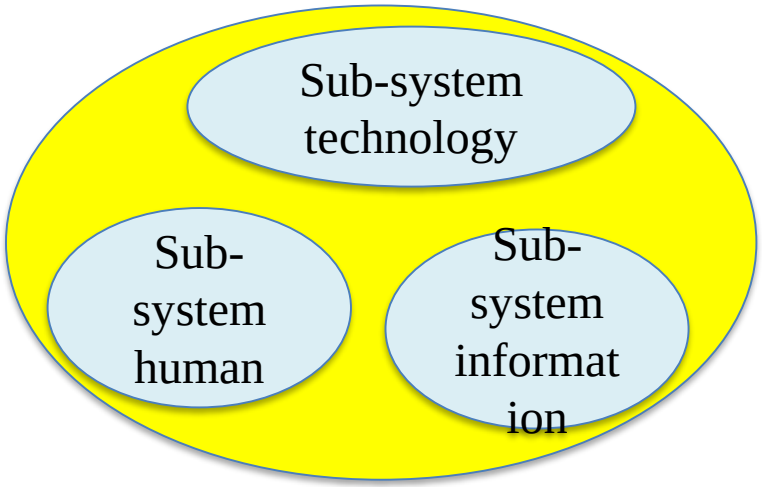


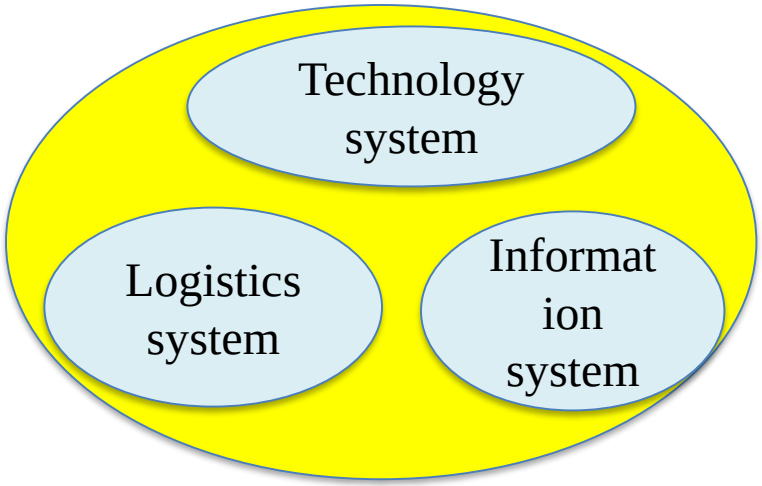
Integration

Existing pieces

# The challenges of integration

| | |
|---|---|
| System technical | System driving |
| System organization | System of information |

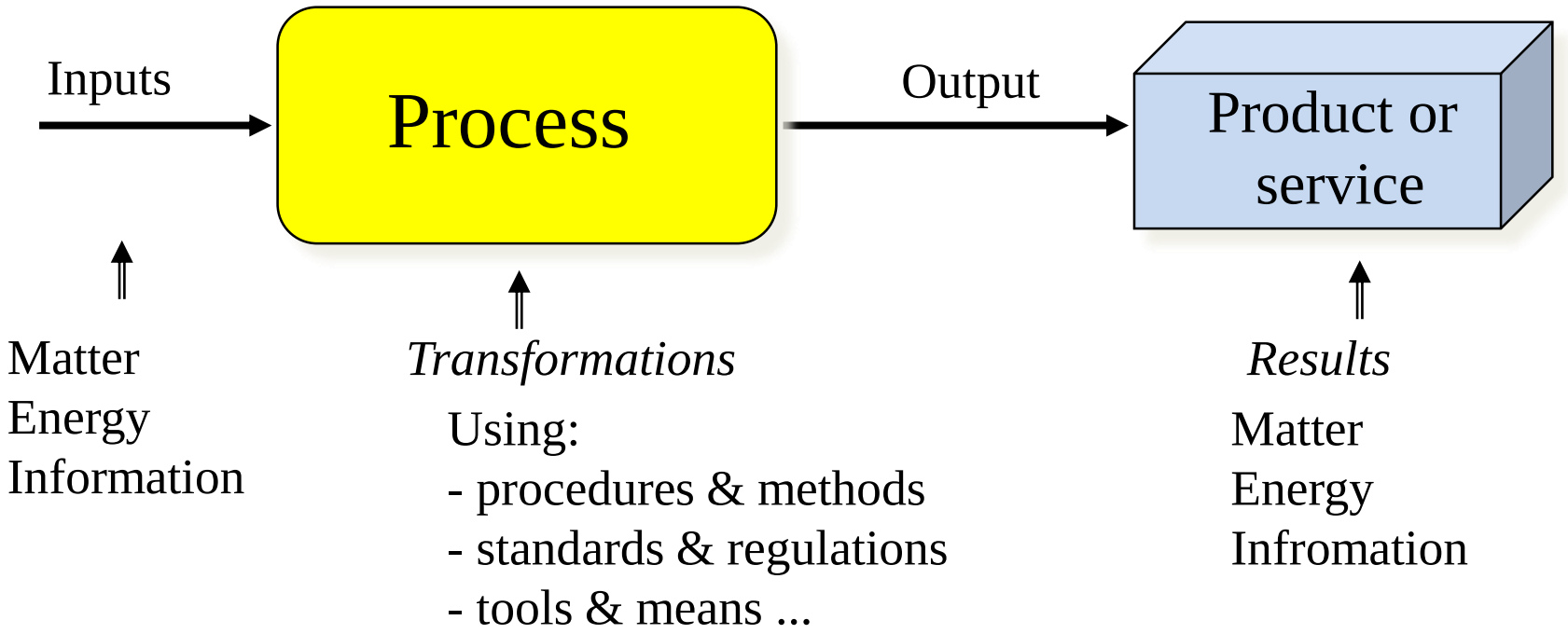


# The process

# What is a process?

- A process transforms inputs to output adding value
- Transformation is about matter, energy or information
- Transformation is done on form, in space or in time using resources or means



# What is a process?

- Characteristics:
- A process is an organized whole:
  - it includes structured tasks between them
  - it has a modularity: a precise function and defined limits
  - it is executed according to a PDCA cycle
  - it is managed by actors, responsible persons; a budget is assigned to him

- A process is a dynamic set of synchronized, serial and / or parallel tasks

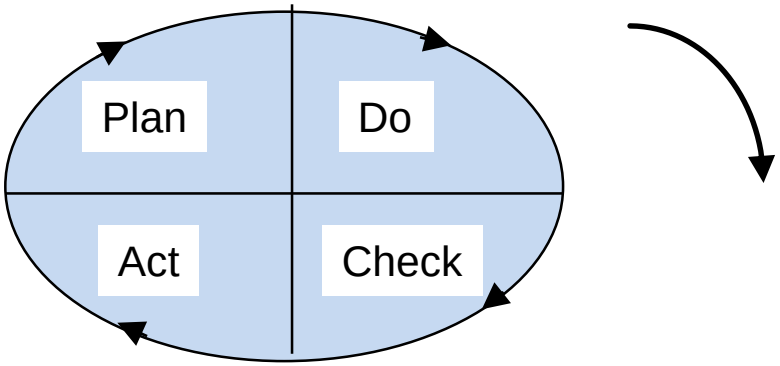
- Each elemental task is performed by a single actor, or a single person or group under a single authority

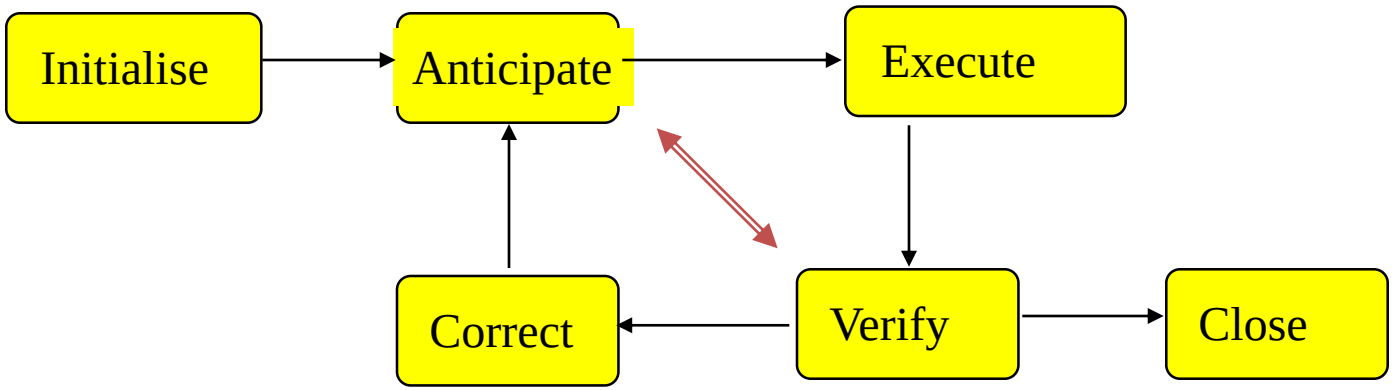
- A process is a chain of activities that fits into a "claimant-provider" relationship

# Process execution

Any process can be run in a PDCA cycle:

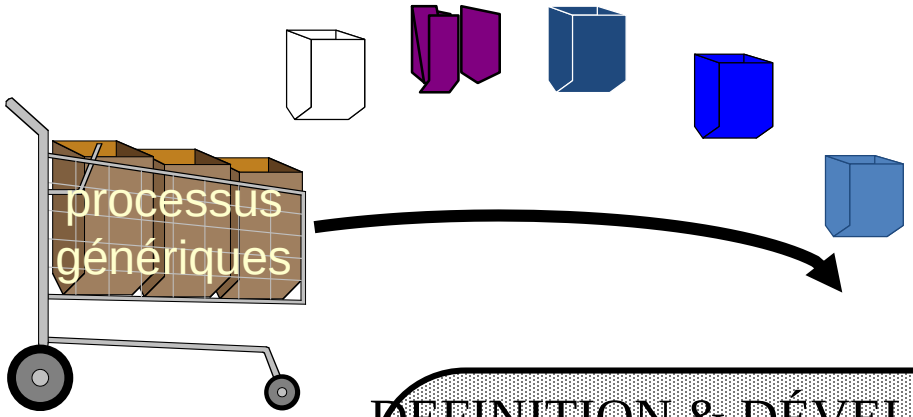
Or:



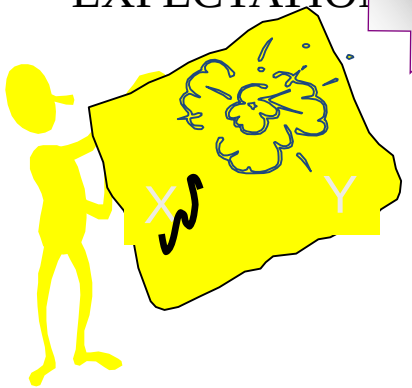
# How to define and develop a system?

Needs | Feasibility Definition | Development | Production Commissioning | use Maintenance | Withdrawal




DEFINITION & DÉVELOPPEMENT

EXPECTATIO




Specification

Conception

Realization

Support of engineerin g

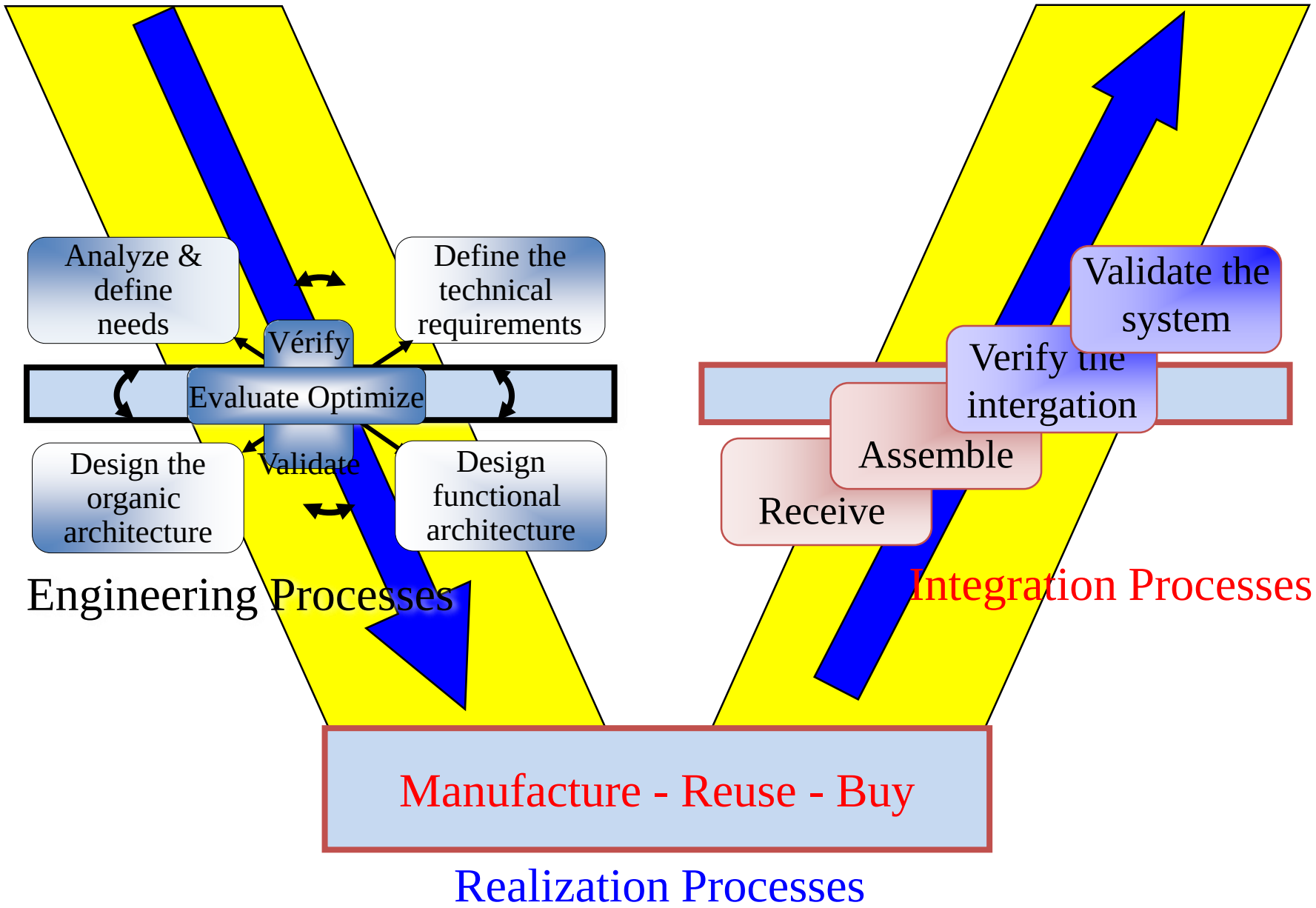
SYSTEM REALIZED
does not include the serie

# How to define and develop a system?

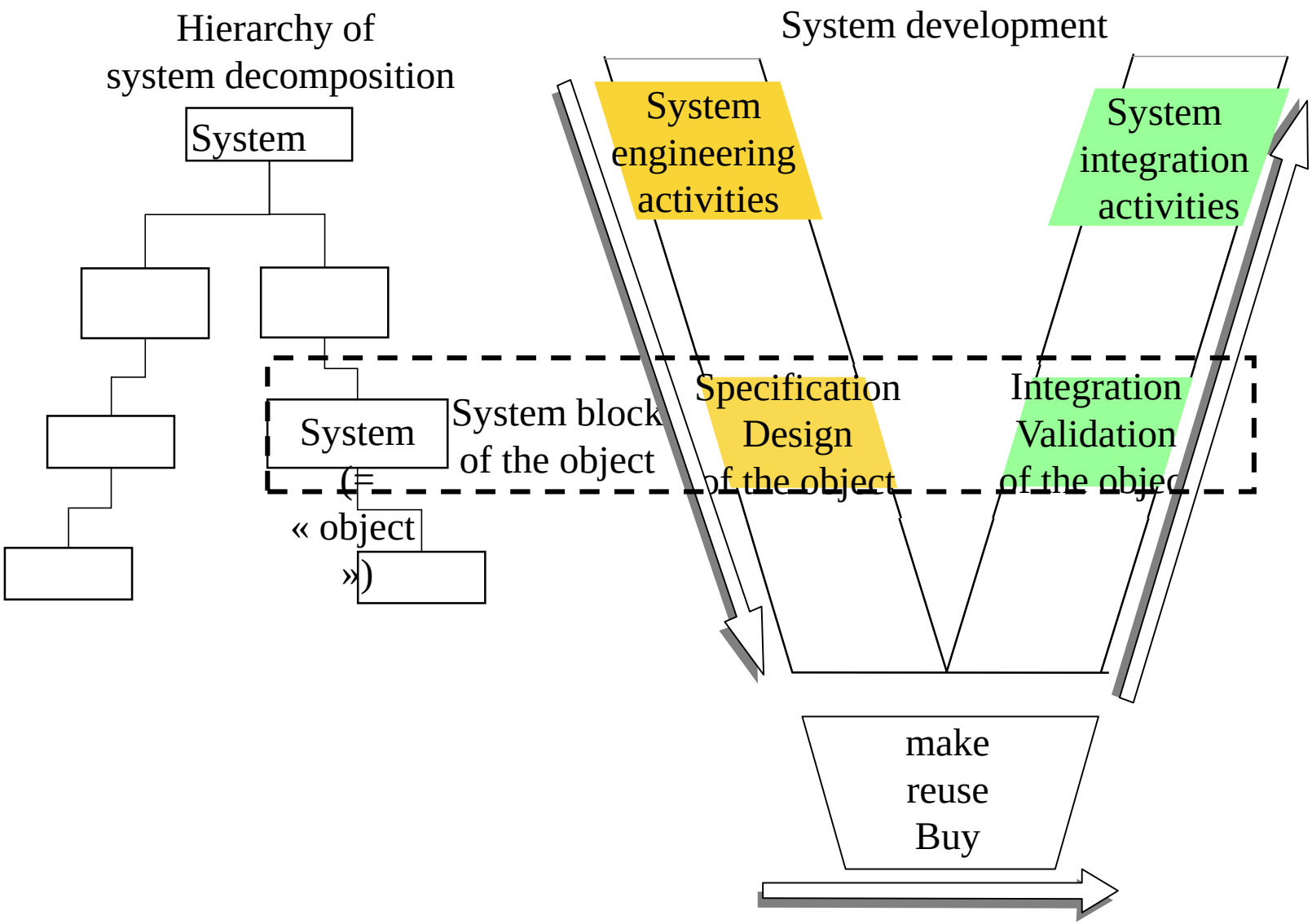
| DOMAINS | PROCESS |
| --- | --- |
| Specification | Analyze and define needs |
| | Define the technical requirements |
| conception | Design functional architecture |
| | Design the organic architecture |
| Réalisation | Realize the constituents |
| | Integrate / validate |
| | Activate |
| Engineering support | Evaluate & Optimize |
| | Check & validate |

Generic processes of product development

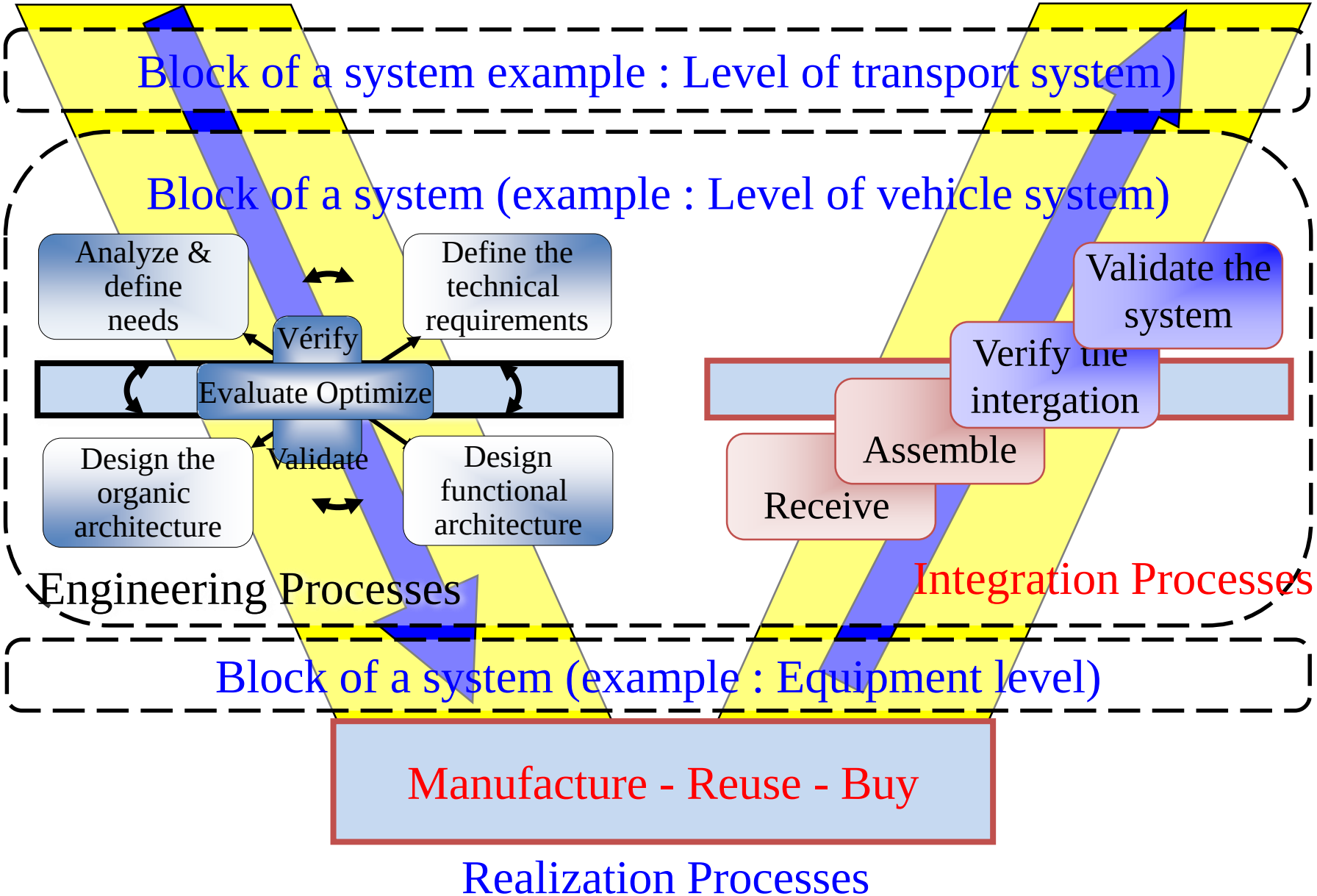
# Engineering process and integration process



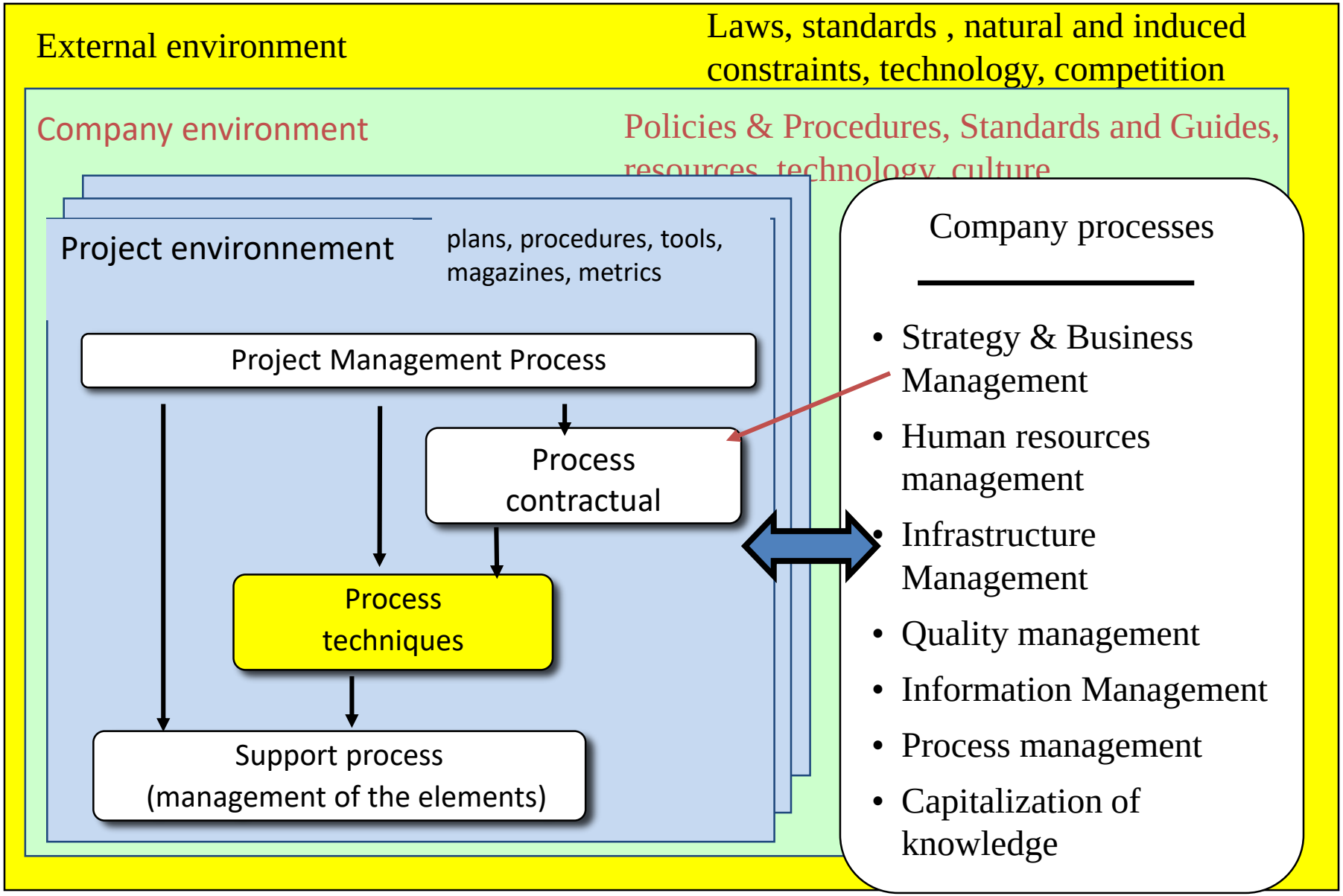
# Concept of system block



# Develop by levels with recursive processes



# Generic processes: context



# Generic process basis

**MANAGEMENT**

- Plan preparation
- Assess monitoring
- Control decision

**CONTRACTUAL**

- Acquire
- Provide

**Technical processes for development**

**ENGINEERING**

- Define the need of stakeholders
- Define the requirements techniques
- Design the architecture functional
- Design the architecture organic

**SUPPORT ENGINEERING**

- Evaluate - Optimize
- Check & validate

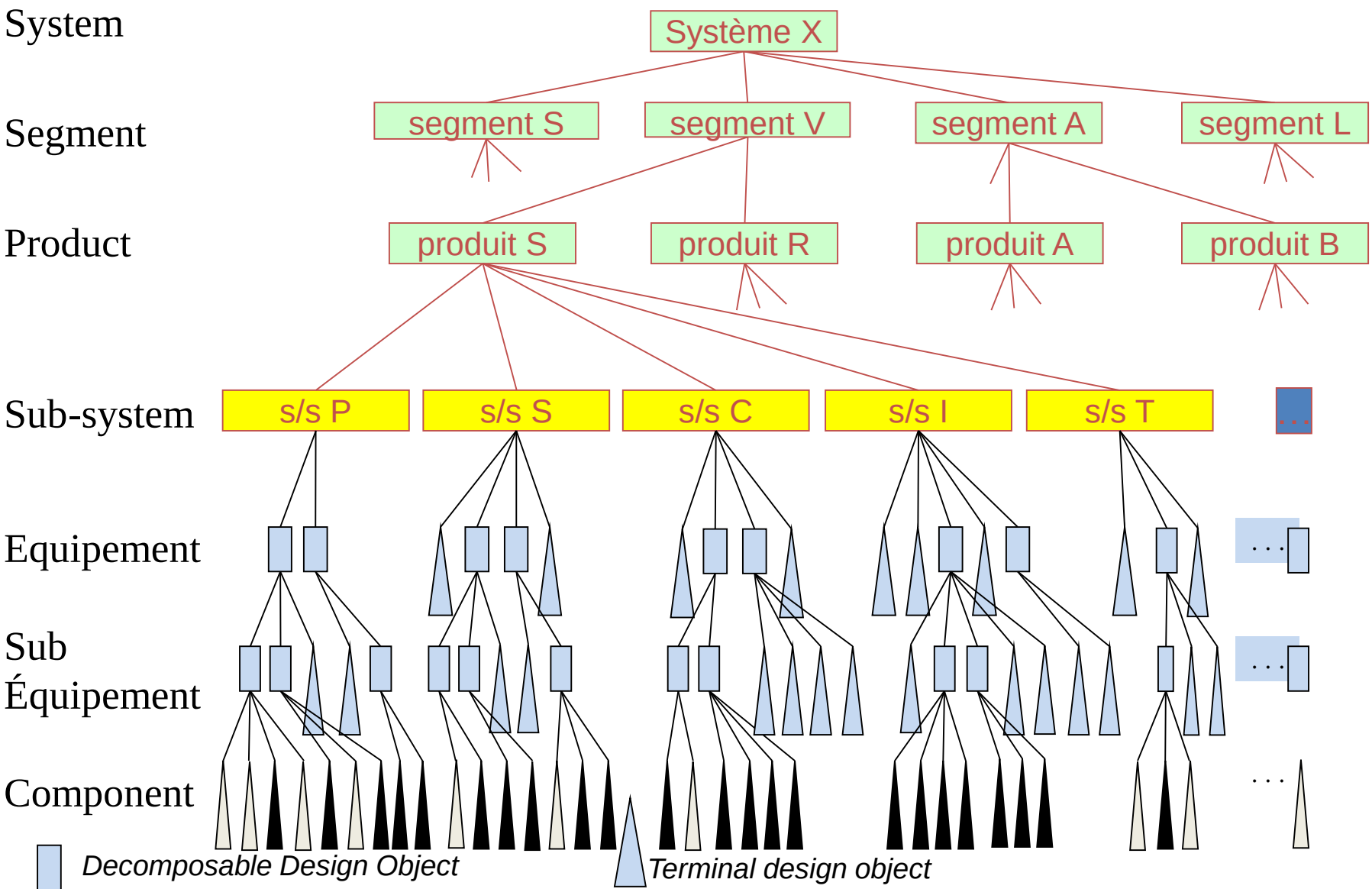
**PRODUCTION**

- Realize the constituents
- Integrate the system
- put in service

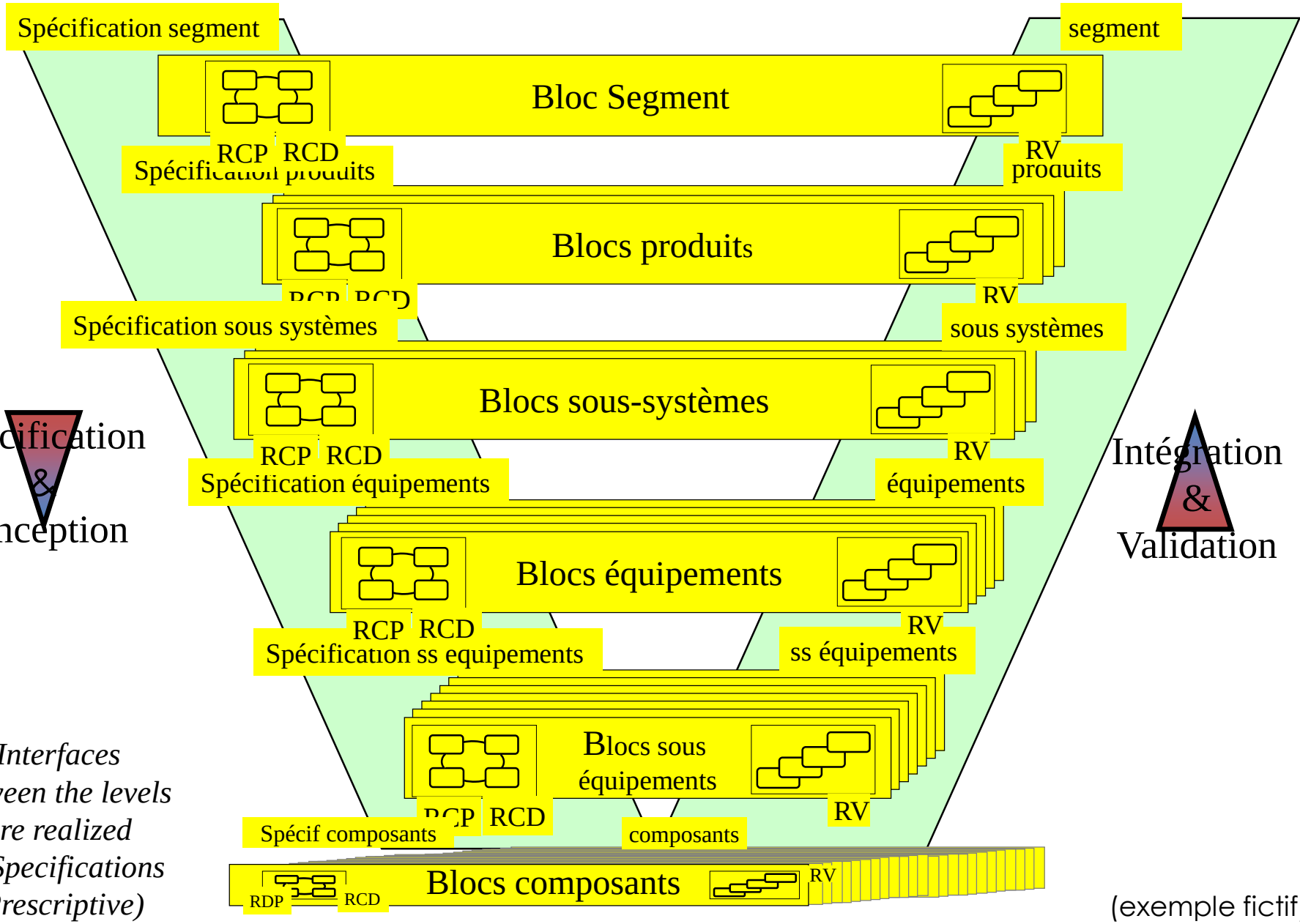
**ELEMENT MANAGEMENT**

- Manage configuration
- manage documentation
- Analyze & manage risks
- Identify and solve problems
- Manage the quality

# Engineering deals with the decomposition into constituents ...



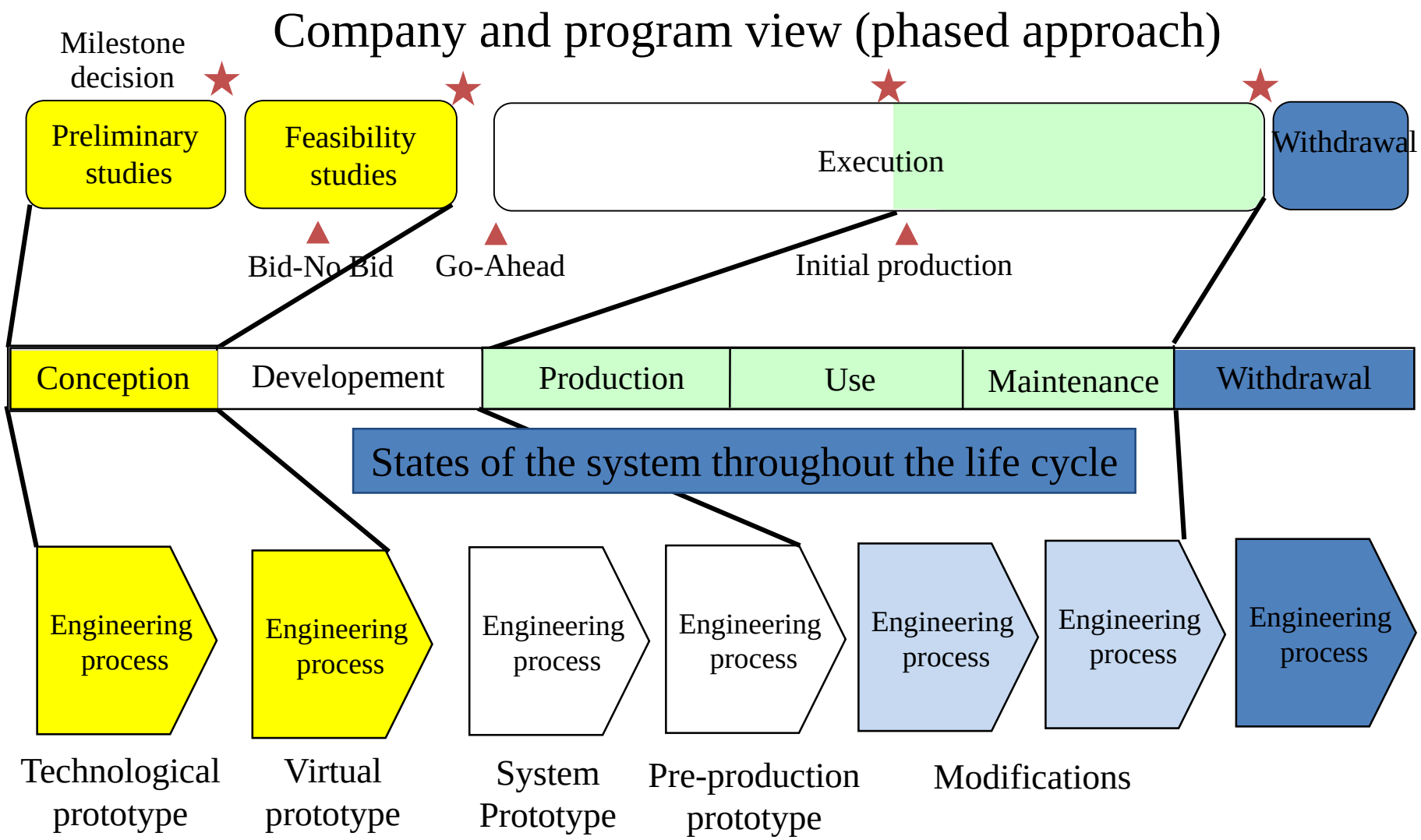
# the management deals with the division into system blocks




*Interfaces between the levels are realized by Specifications (Prescriptive)*

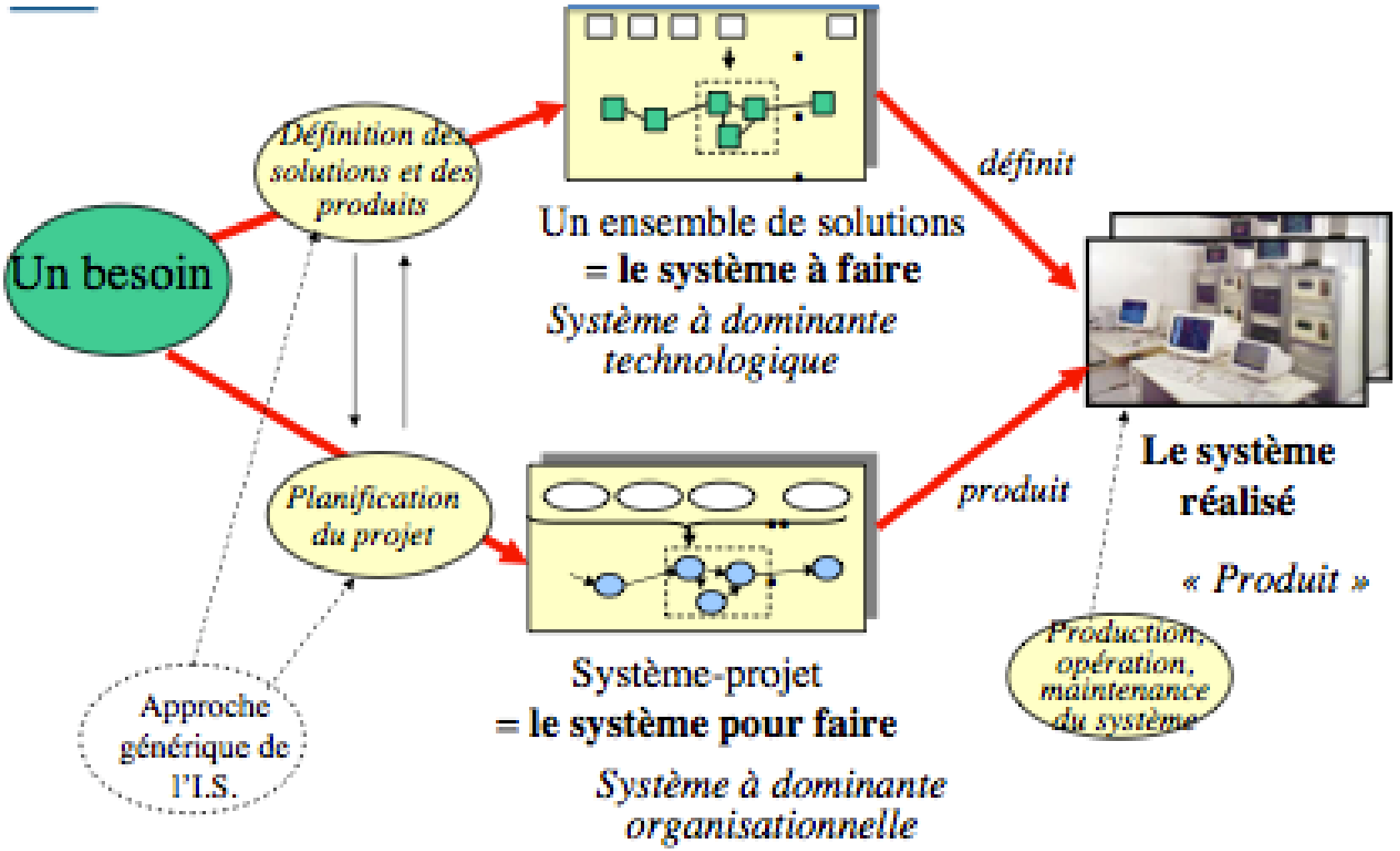
(exemple fictif

# Phased approach and process approach




Source ISO/IEC - TR 19760

# The 3 IS systems




Source CNAM

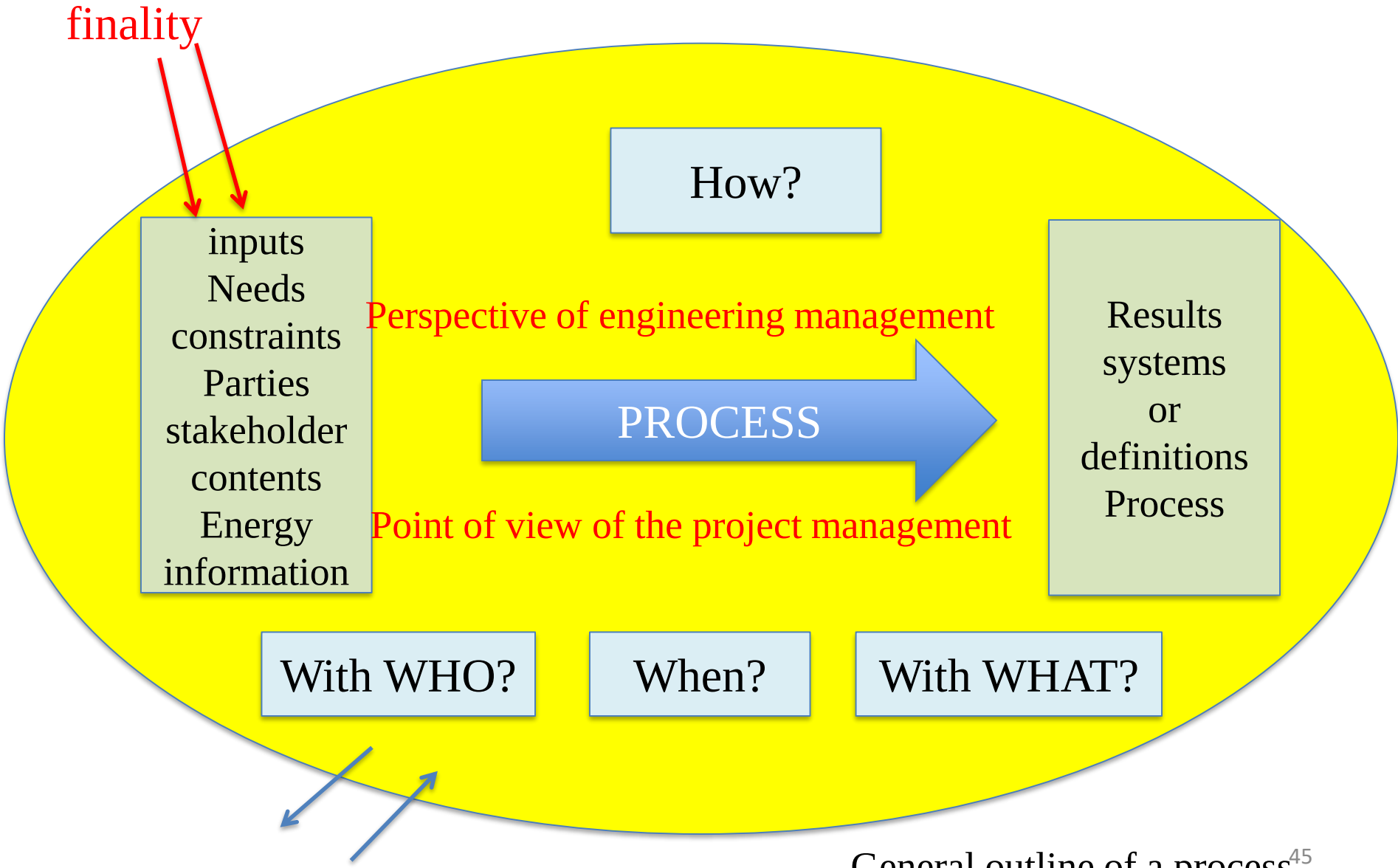
# The project (to do)

# Project

Systems are usually unique objects that respond to a particular need: PROJECT

Customer Organization: MAITRE d'OUVRAGE
Supplier Organization: Project manager

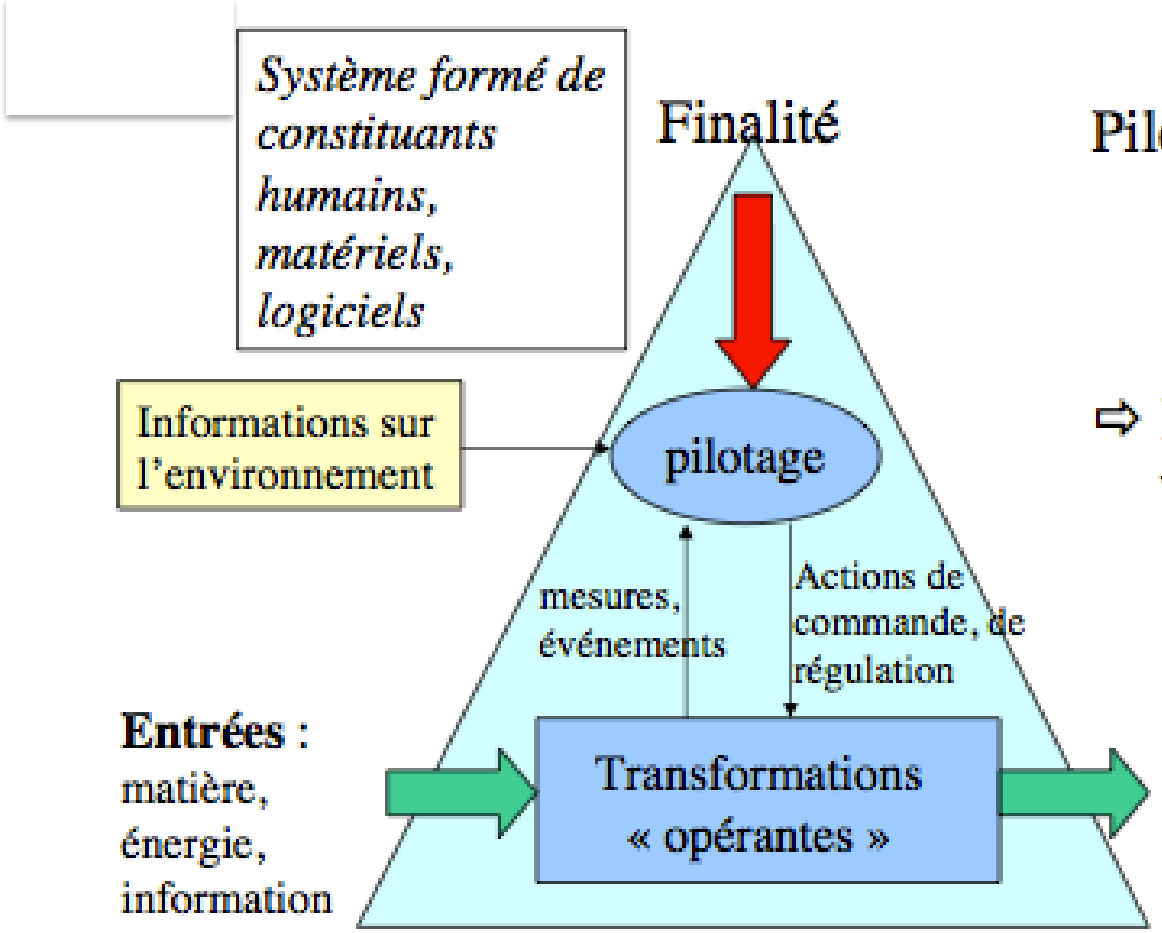
# The project




General outline of a process

# Le pilotage

# Pilotage d'un système



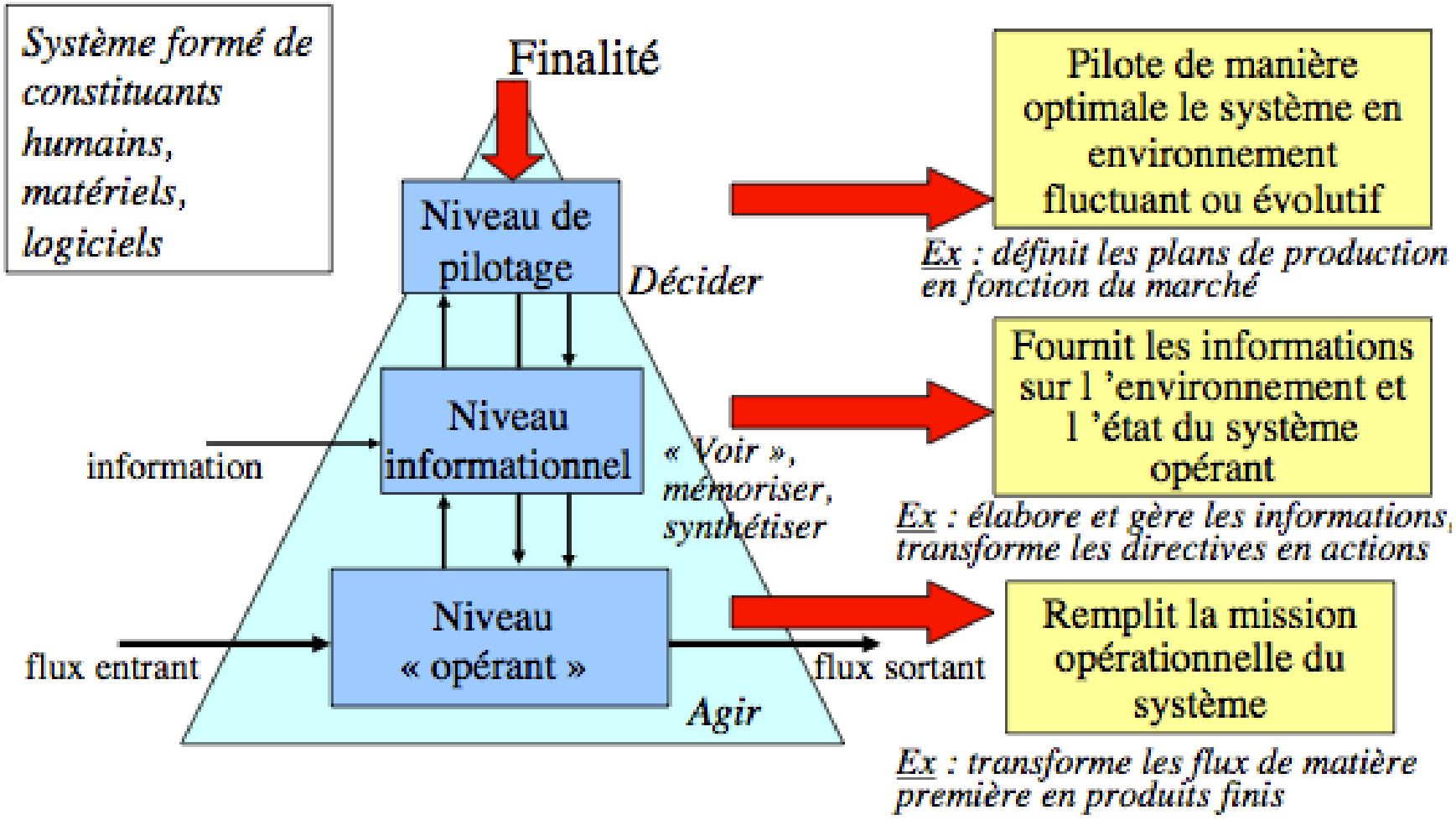

Pilotage :

- Interne (auto pilotage)
- Externe
- mixte

⇨ Degré d'autonomie vis à vis de l'environnement

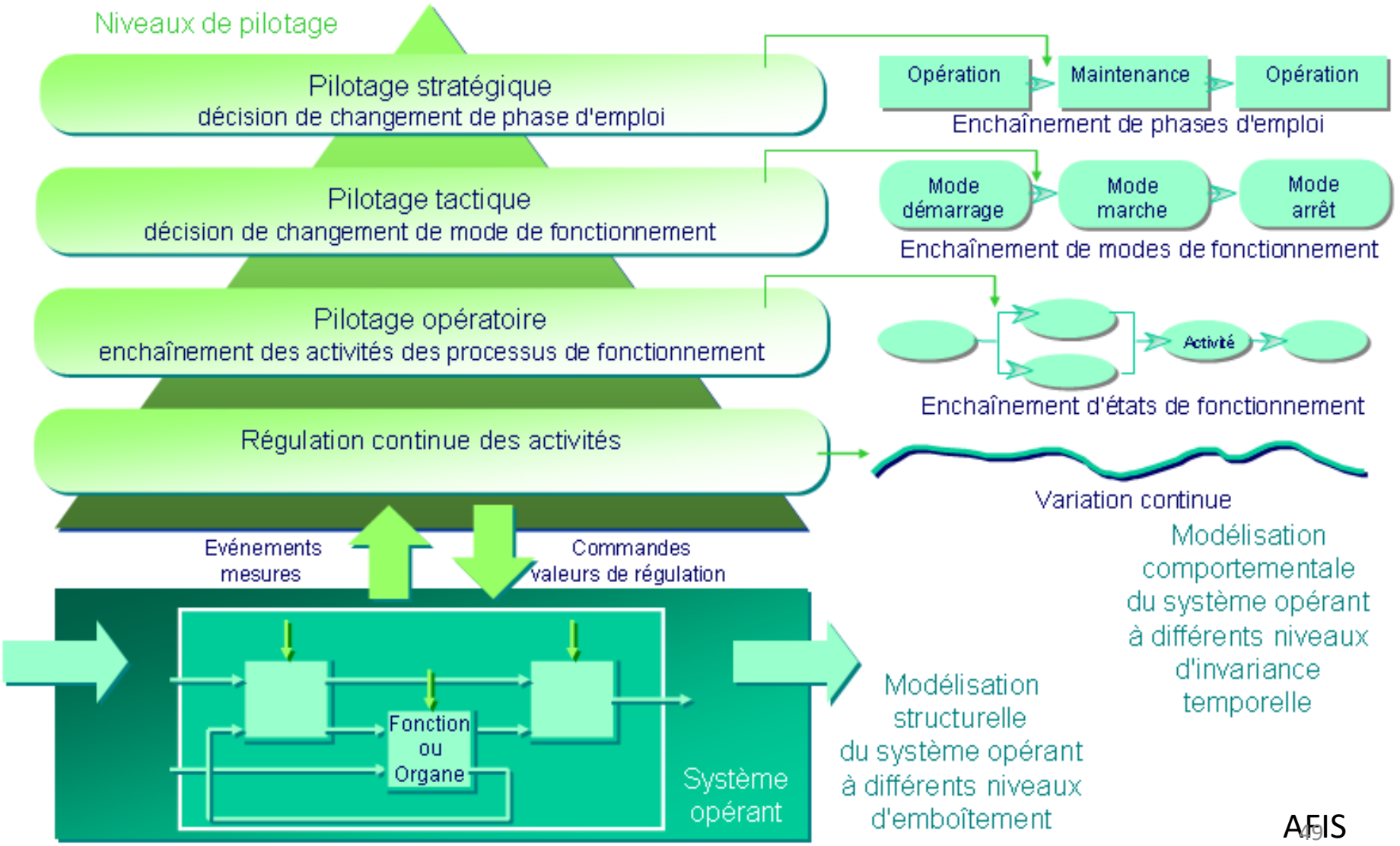
Source CNAM

# Niveaux de pilotage




Source CNAM

# Niveaux de Pilotage

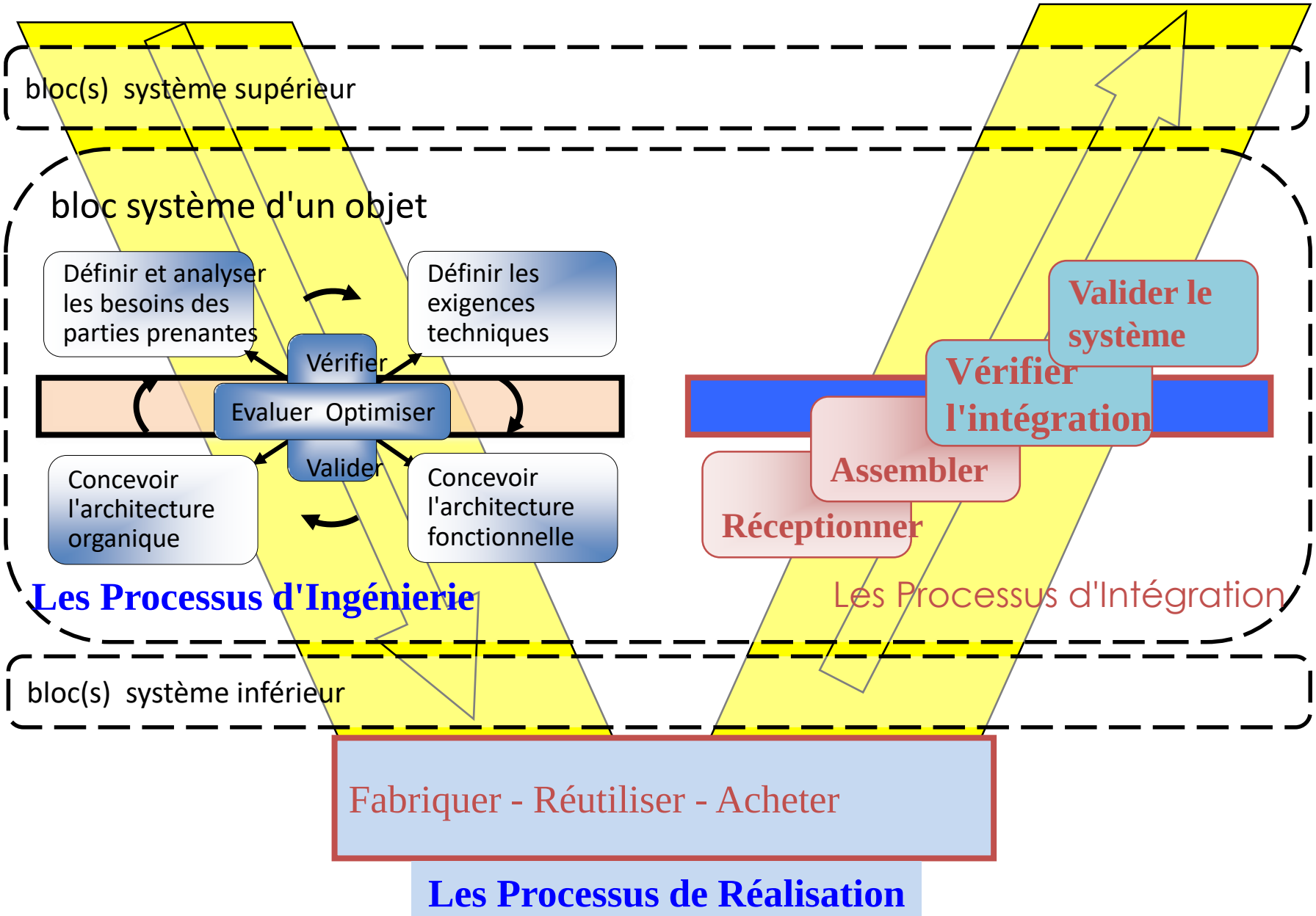


# Requirements and exigences engineering

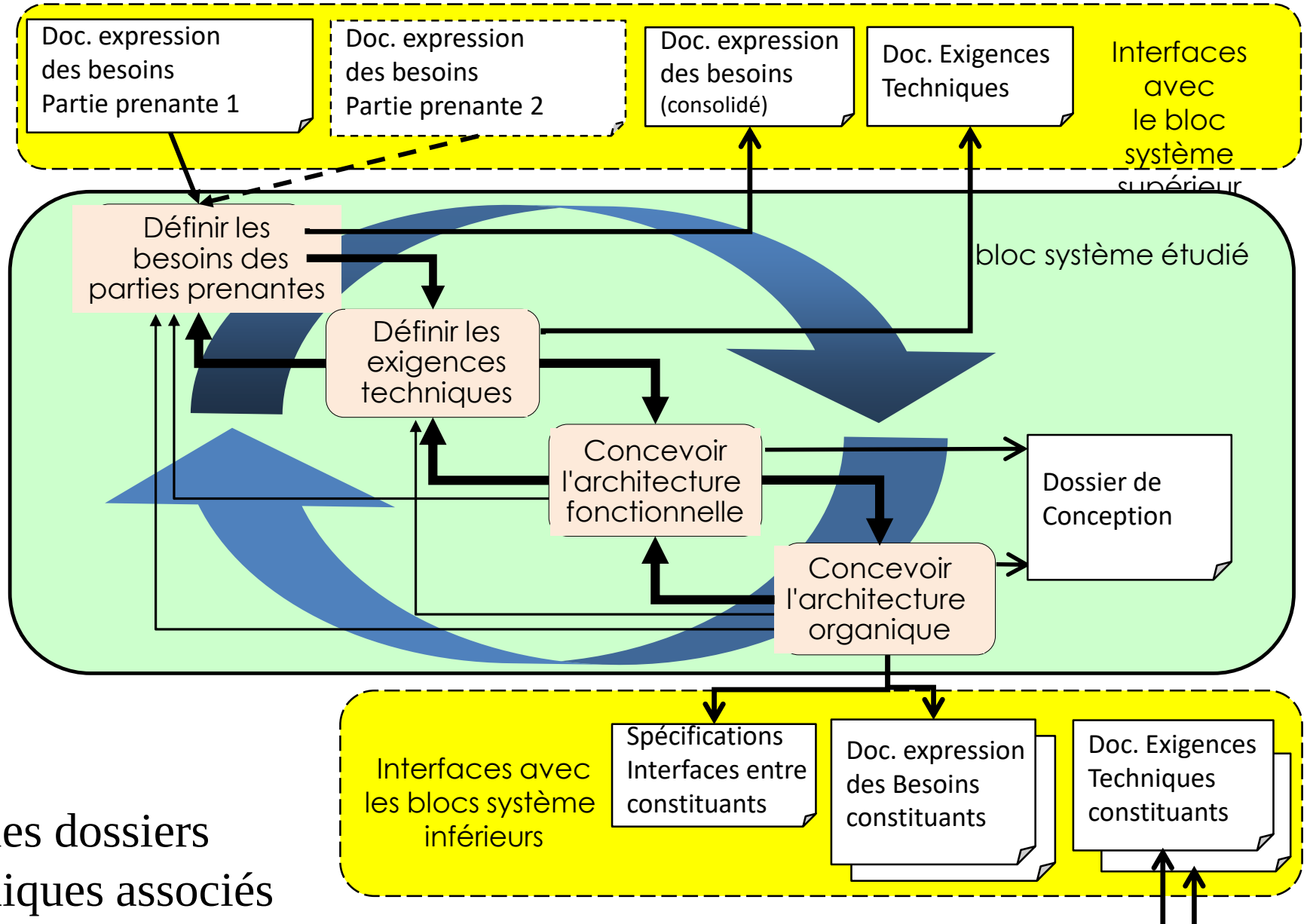
1. L’analyse du besoin

2. L’Ingénierie des exigences

# Principaux processus d'Ingénierie de Système



# Logique d'enchaînement des processus d'ingénierie




... et les dossiers techniques associés

# L’analyse des besoins

# Les enjeux

- Quelle est la première perception que nous avons de la qualité d'un produit ou d'un service ?
- L'aptitude à satisfaire les besoins exprimés ou non.

SAVOIR COLLECTER LES BESOINS

SAVOIR EXPRIMER LES BESOINS

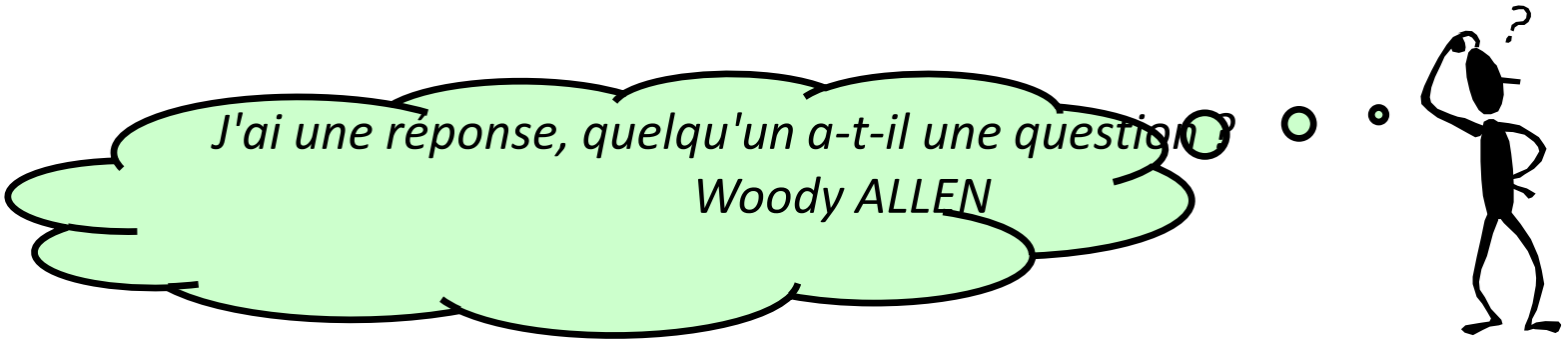
La complexité des systèmes créés par l'homme
fait que l'expression d'un problème est devenue un problème !

# Principales difficultés rencontrées

Comment exprimer correctement un besoin ?
Comment faire pour qu'il soit compris ?

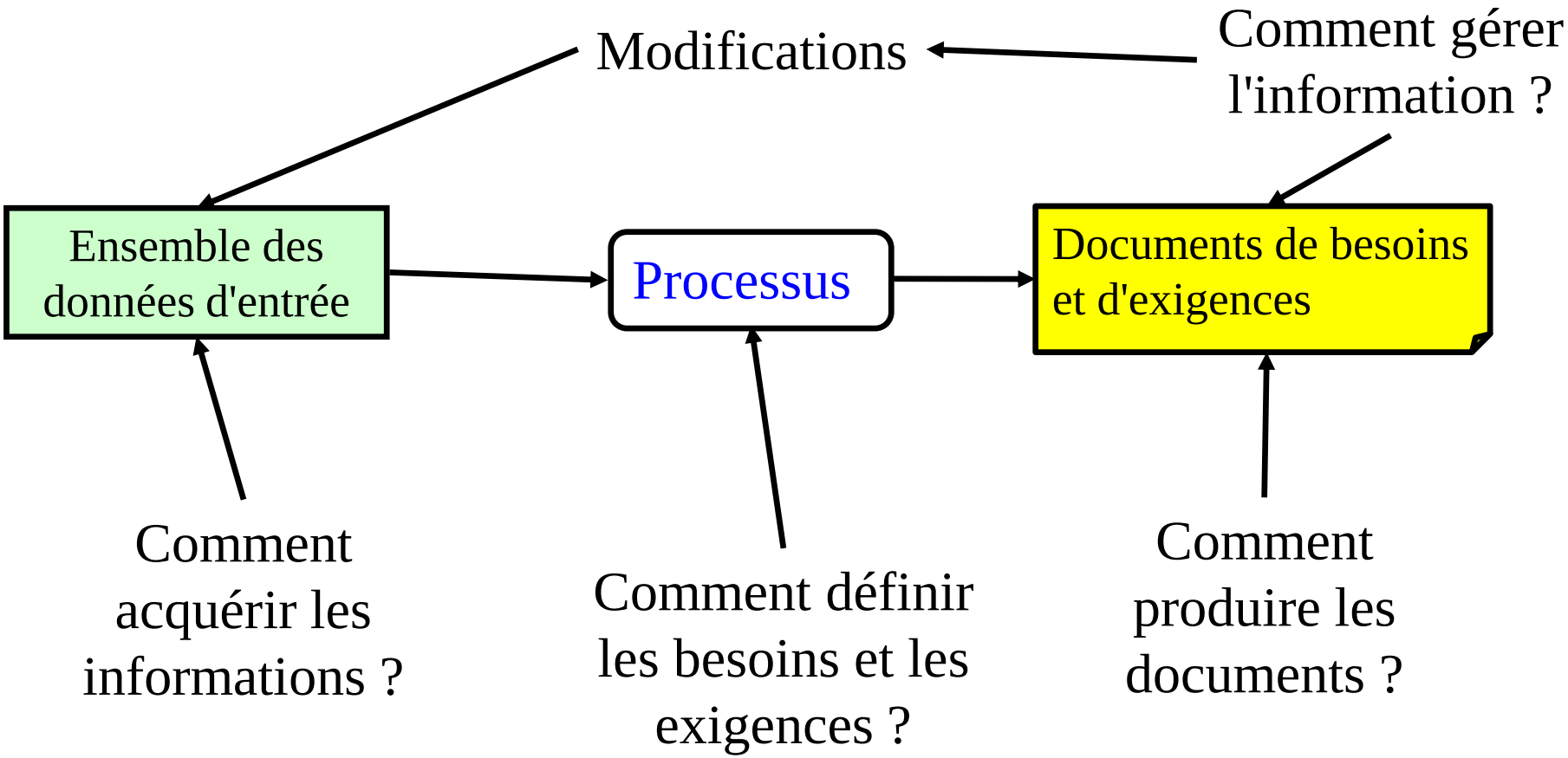
D'où peut provenir la non satisfaction des besoins ?

- Le besoin n'est pas clairement identifié, défini et exprimé
- Mauvaise compréhension de la relation client - fournisseur
- Pas de séparation nette entre problème et solution (quoi ? / comment ?)
- Difficulté de communication (outil de dialogue) entre les parties prenantes
- La perception négative du problème à résoudre



# Réponses aux difficultés

- Établir les activités d'ingénierie
de définition des besoins, des exigences techniques
et les documents correspondants



# Quelques définitions (1)

Besoin (need and expectation – "stakeholder requirement" – user requirement)

Nécessité, contrainte, désir éprouvé et exprimé par un utilisateur, une partie prenante, un maître d'ouvrage

- Exprimé dans le langage de la maîtrise d'ouvrage
- Service, objectif, capacité attendu du système futur souhaité par la maîtrise d'ouvrage

Exigence (technical requirement – system requirement)

Expression clarifiée d'un besoin présenté dans un langage formel (informatique, graphique, mathématique, …) ou naturel. Elle doit être réalisable et vérifiable.

- Traduction des besoins dans le langage de la maîtrise d'œuvre en vue de pouvoir développer une solution

Produit (Product)

- Ce qui est ou sera fourni à un utilisateur pour répondre à son besoin.
(NF X 50 150)

- Résultat d'un processus. (ISO 9000 : 2005)

# Quelques définitions (2a)

Cahier des Charges (CdC) : Expression du besoin utilisateur

(User Requirements Document - URD, Stakeholders Needs Document - SND)

Document par lequel le demandeur exprime son besoin (ou celui qu'il est chargé de traduire) en terme de services et de contraintes (interfaces avec l'environnement et contraintes sur la solution). Son établissement implique que des études aient permis de cerner avec précision les besoins des utilisateurs. (NF X 50 150)

Spécification technique (ST) (Technical Requirements Document - TRD)

Document à caractère contractuel entre demandeur et fournisseur, établi par le fournisseur d'un produit à l'intention du concepteur et par lequel il exprime les exigences techniques applicables.

Elle doit exprimer :

- ce que l'on attend du produit en terme de fonctions, de performances, d'interfaces,
- les contraintes d'utilisation, d'environnement et de maintenance,
- les contraintes pour la conception , la production et la validation du produit (les conditions de vérification du respect des exigences) …

# Quelques définitions (2b)

Partie prenante (stakeholder)

Partie ayant un droit, une part ou une prérogative qui fait que le système ou certaines de ses propriétés doivent satisfaire les besoins ou les attentes de cette partie.
(NF Z67-288 : 2003, ISO 15288 : 2008)

Fournisseur (supplier)

Partie signataire d'un contrat conclu avec un acquéreur pour la fourniture d'un produit ou d'un service. (NF Z67-288 : 2003)

Acquéreur (acquirer)

Partie prenante qui fait l'acquisition ou l'achat d'un système auprès d'un fournisseur.
(NF Z67-288 : 2003)

Utilisateur (user)

Individu ou organisme qui bénéficie de l'exploitation du système.

(NF Z67-288 : 2003, ISO 15288 : 2008)

# Questions about the needs and solutions

There is no need if there is no problem to solve!

Why create a system?



Context analysis
- Operational environment
- Definition of the problem
- collection of expressions

**PURPOSE**
**(Why?)**

What is the system going to do?

Defintion :
- of expected services
- of performance tools
- of operating modes
- of interfaces …

**MISSION**
**(What?)**
**OBJECTIVES**
**(How much?)**

How is the system built?



Constraints (of realization)
- means
- use
- cost

**SOLUTION**
**(How?)**

# A quoi servent les besoins ?

- Avoir une compréhension commune du problème à résoudre

❑ Pour la maîtrise d'ouvrage :
  - Définir clairement ses besoins, ses attentes
  - Être compris par la maîtrise d'œuvre

❑ Pour la maîtrise d'œuvre :
  - Comprendre clairement ce qu'il y a à faire et pourquoi
  - Être compris par la maîtrise d'ouvrage

❑ Pour les entreprises et organismes coopérant :
  - Aligner les projets avec les stratégies
  - Capitaliser sur les métiers et les projets
  - Diminuer le risque d'échec total ou partiel des projets

# Séparation problème / solution

Problème = Besoin = Exploration des situations du cycle de vie

Solution = Résultat de la conception

Besoin en utilisation, exploitation
- Environnement naturel
- Environnement induit
- Scénarios opérationnels
- Menaces
- Efficacité (performance)
- Capacité d'opération
- Systèmes externes, interfaces (contexte)

Besoin en dévelop.ment
- Réutilisation
- Connaissances scientifiq.

Besoin en fabrication
- Capacité d'outillage
- Contrôle

Besoin en support
- Déploiement, formation
- Support utilisateur

Besoin en retrait de service
- Démantèlement, outillage spécifique

Besoins

traduits, raffinés en

Exigences techniques

allouée à

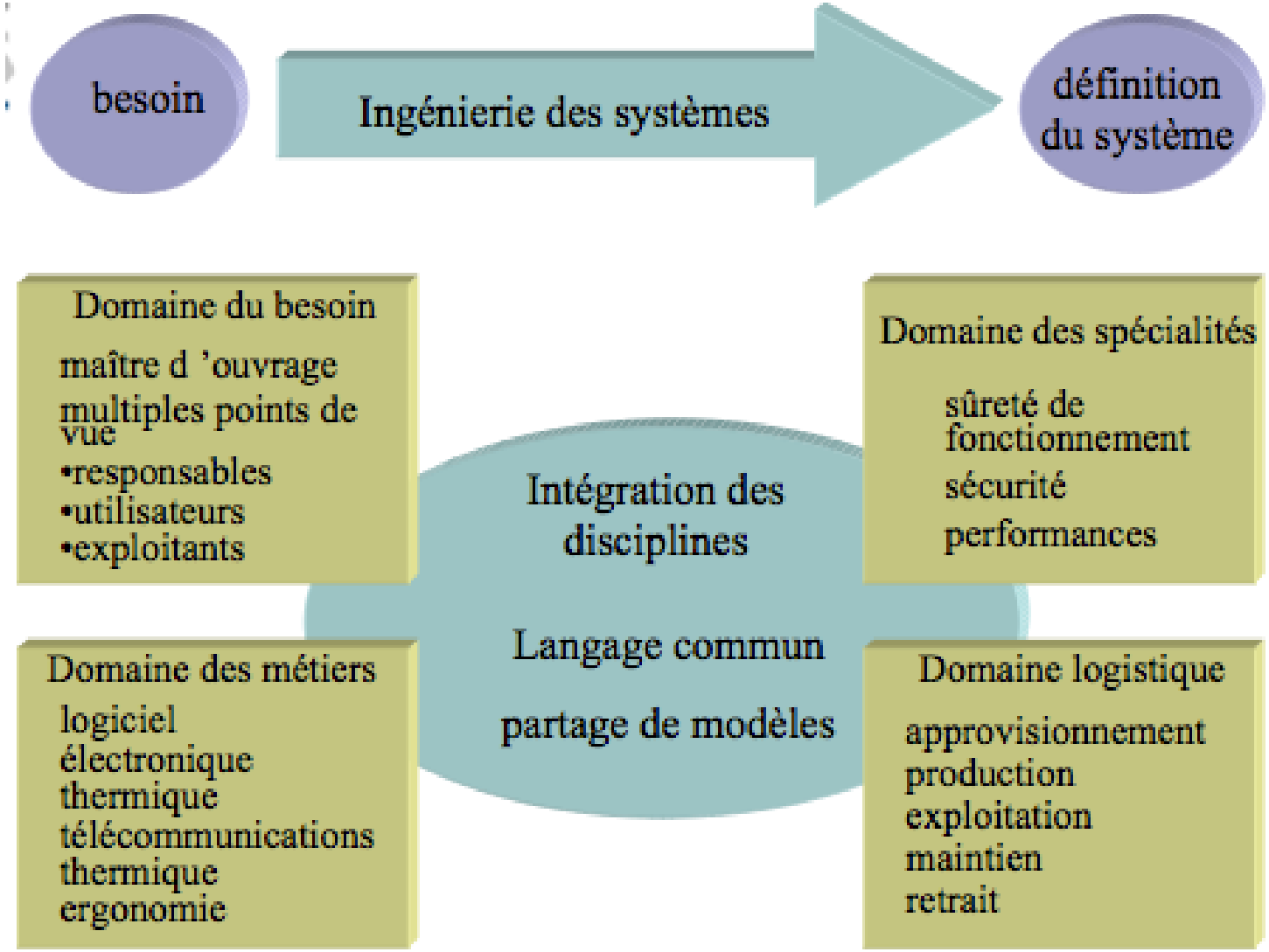
Architecture fonctionnelle

allouée à

Architecture organique

allouée à

# Intégration des disciplines

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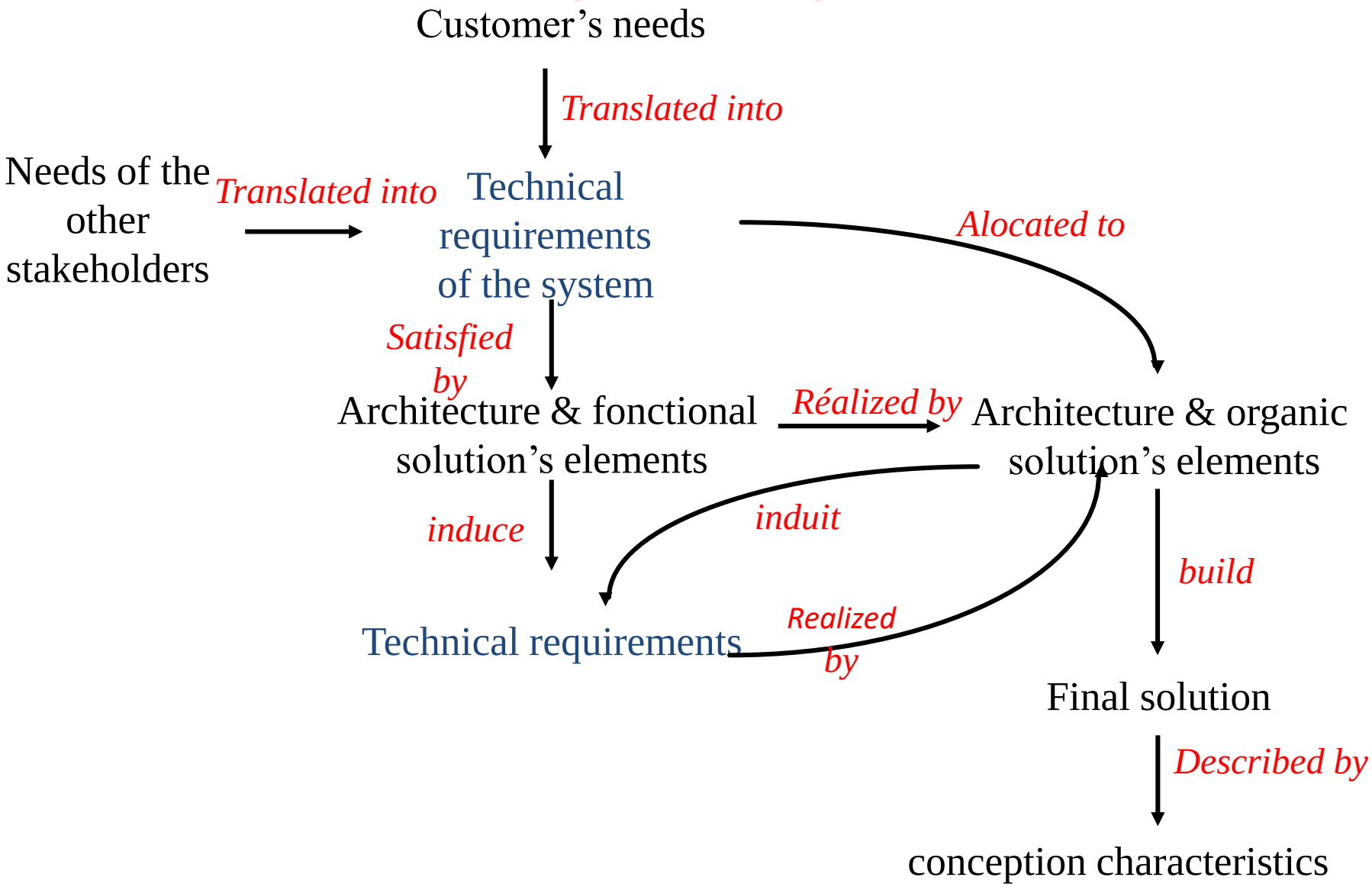
# L’ingénierie des exigences

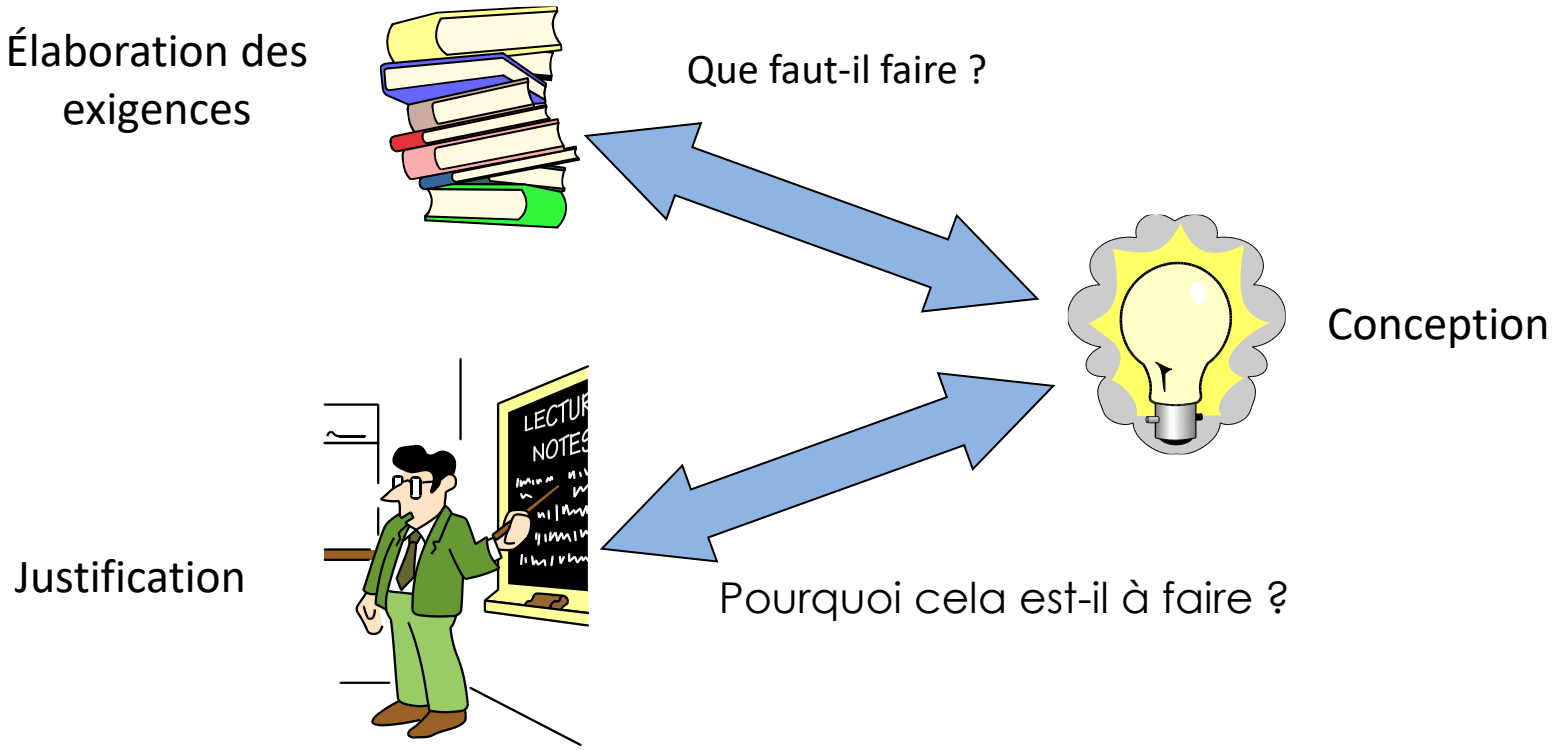
# The place of requirements in system engineering



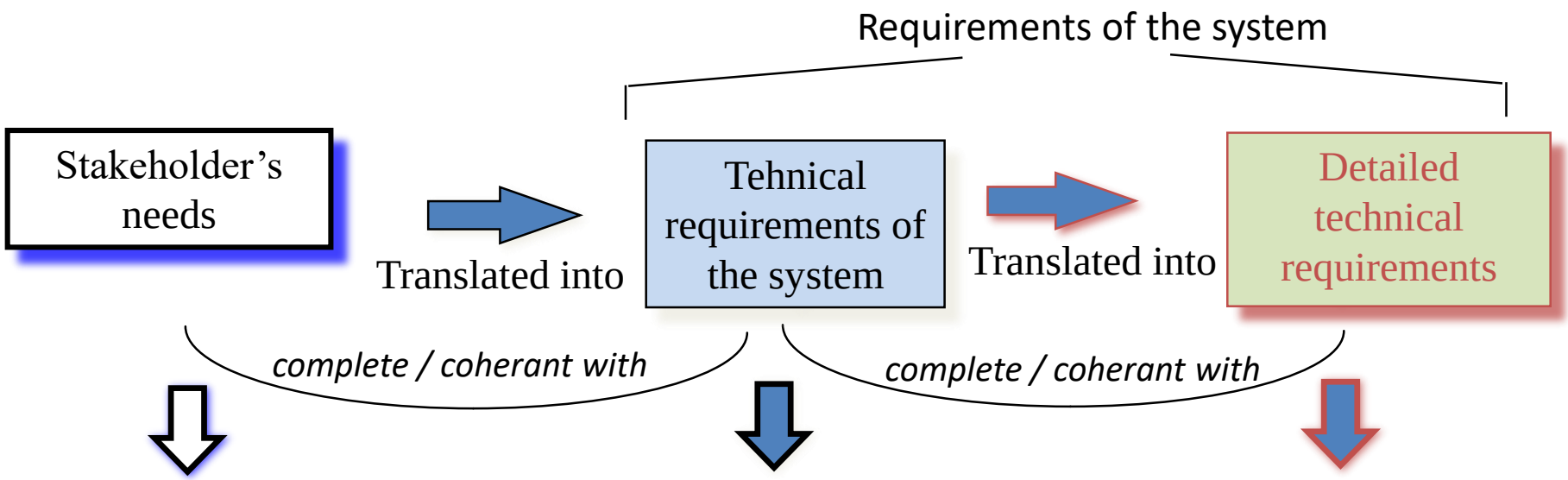
# Rôle des exigences

L'élaboration des exigences joue deux rôles :

1. Identifier le travail de conception à réaliser
2. Servir de référence à la justification et à la validation



# The gradual transformation of needs




needs, desires
expectations, priorities
objectives, capacities ...

Often non technicals words
**Not appropriated to design,**
And for the verification

requires agreement between the customer and the provider

**Technical words**

unambiguous
Not contradictory
**coherant**
complete
**verifiable**

Logical arrangements of requirements,
In order to allocate to final products,
Some manual tasks and processes

# Principaux risques lors de la traduction

Les interlocuteurs ne manipulent pas les mêmes concepts

Les interlocuteurs interprètent les formalismes différemment

Les informations sont perdues ou altérées

Rédacteur d'exigences

Concepteur

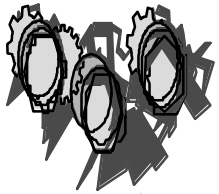
Formaliser → Rédiger → Transmettre → Lire → Comprendre

# Classification of requirements

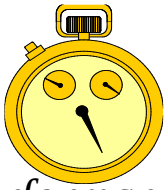
•Requirements represent **simple ideas**.

•To prepare the design and conception, it is necessary to give details on **notions** represented by each type of requirement.

*Scenarios and Operating modes*



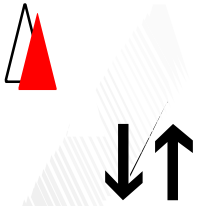
*Functional requirements*



*Performances requirements*

*Constraints*

*Operational requirements*



*Interface requirements*

*Validation requirements*

Caution : requirement's types are defined by the process

# Scenarios and operating modes

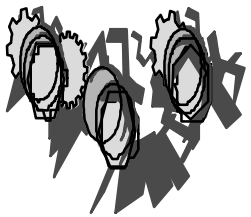
*Scenarios and modes*

Scenarios and operating modes describe the **expected behavior** of the system in its different steps of life

To find the **operational situations**, imagine all the situations to which the future product or service will have to face:

Nominal use – end of life – unexpected use – recycling – braking attempt – counterfeiting attempt – homologation – degraded modes – use of day an night – use by unexpected operators – handling by children – toxicity assessment – stay in water – passing through a washing maxhine – etc ...

# Functional requirements



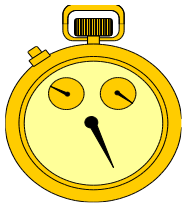
*Functional requirement*

- Functional requirements describe the transformations, the storages or the transports linked to the energy, to hardware and information.
- Functional requirements are expressed by transformation or action.

*Functions express treatments whose execution will be allocated to mechanical, software, human, chemical, organizational, etc…*
*To be complete, the requirement must specify the inputs, outputs, triggers and the sequence of functions*

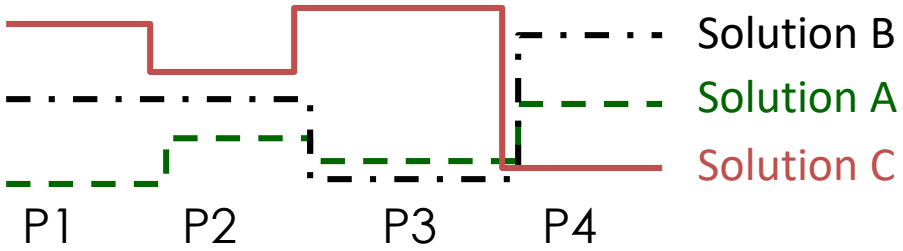
Use glossaries to define specialized words

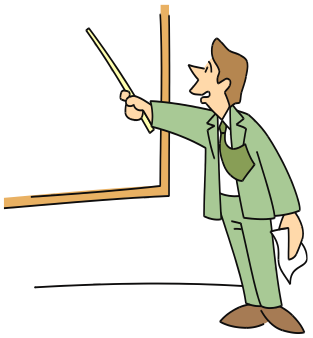
# Performance requirements



*Performances requirements*

•The expected performances quantify the domain of use and the objectives to reach according to the functions of the considered system.



A process of design and conception helps to identify the **multiple technological solutions**, with different organical and functional architectures.

The **performance requirements** are use to make a **choice** between the different solutions.

# Constraints

*Constraints*

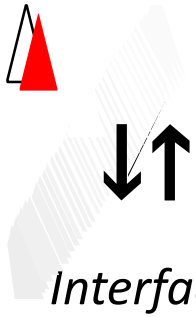
- Constraints are the requirements that are usually applied directlyto the organical architecture and its componets,
- They are often dimensioning : renewal of components, imposed solutions…

Constraints can come from the « upstream », as for instance the geometry or the imposed technology

They can eventually come « downstream » because of the design choices

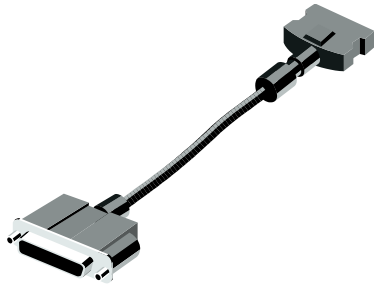
Constraints can also come from non-technical choices related to subcontracting, management choices, etc...

# Interface requirements



*Interface requirements*

•Interface requirements are used to describe the expected contributions attendues to the functional or physic interaction between different systems.

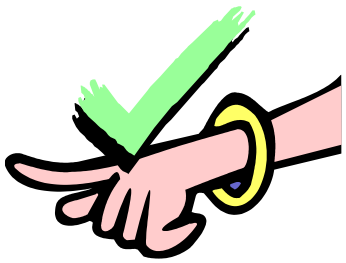


Interfaces are not just energy, material or information transport technologies.

An interface belongs to worlds *functional and physic*.

Interfaces are constituents involving not only sets of components, but also intercations.

# Validation requirements



*Validation requirements*

•These requirements are used to inform the designer of the different validation situations that will be encountered,

*These requirements can help to specify :*

- the validation's scenarios,
- the observable phenomena (vibrations, temperatures, mechanical curvatives, execution speed…),
- The different trial situations (sampling for destructive testing, x-rays, etc…),
- Constraintts on measuring points, reserved volumes for measuring instruments, simulation capabilities, etc...

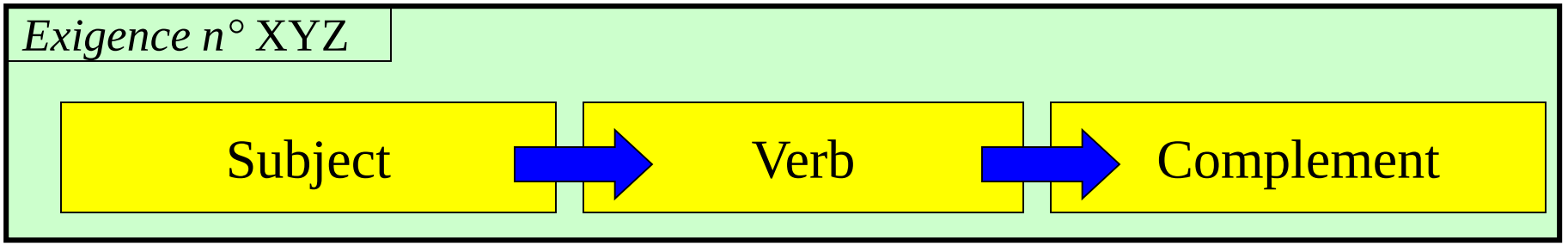
# What is a requirement ?

A requirement is an *element* of engineering

that specify a need

A requirement is an expression which must be

expressed by a simple sentence.

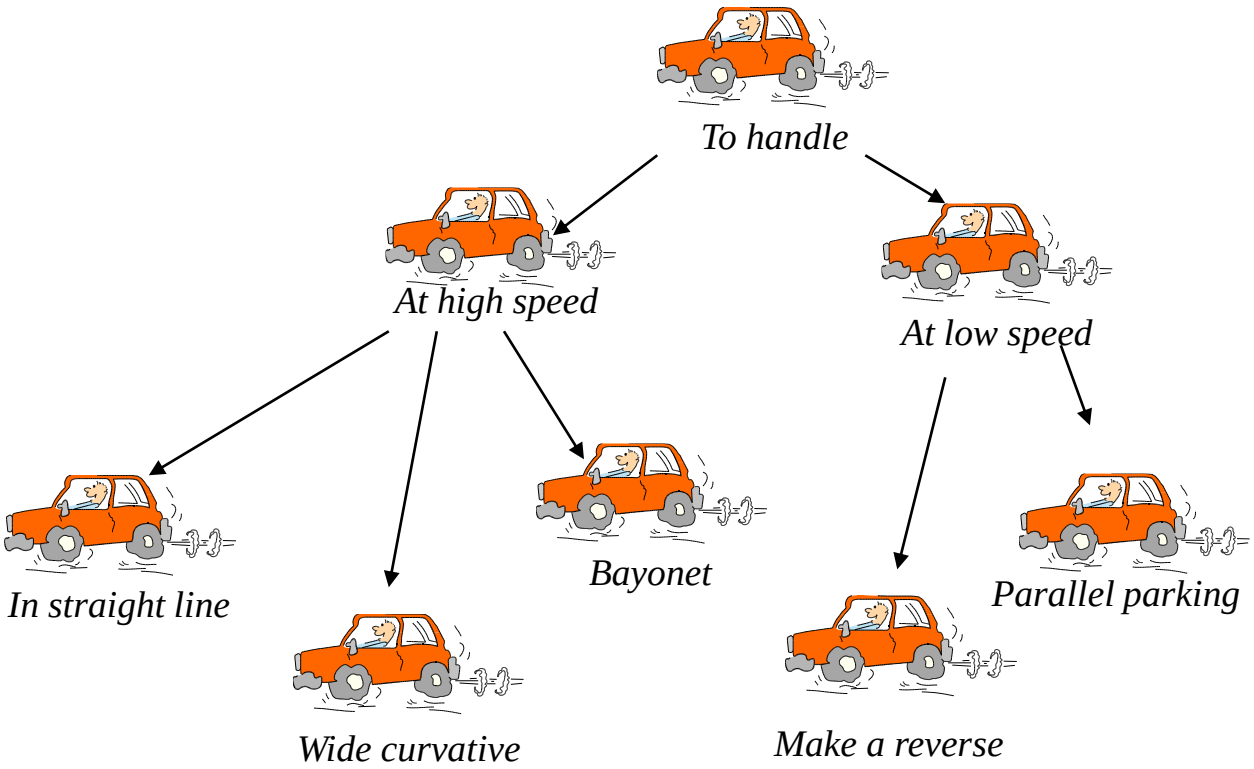


# Examples of requirements

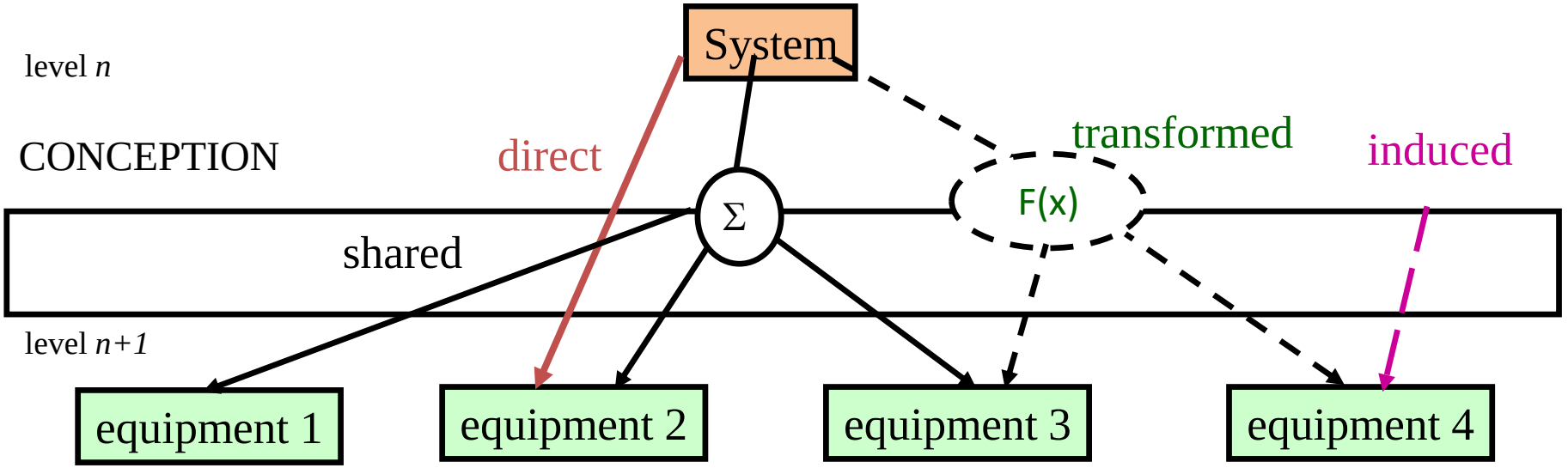
- The vehicule AA reaches the speed of 180 km/h.
- The front projectors can be dismounted in less than15 minutes.
- The painting cost of a structure is less than 100 Euros.
- The system records faults in real time.
- A light informs the driver in case of failiure of one of the computers.
- The power supply is provided by the 28V network of the aircraft.
- the turning radius allows a parallel parking in town.
- The on-board computer displays the position of the vehicle with an accuracy of 10 meters.
- The sound system remains constant.

# Refinement of requirements

- The refinement is done within objects of the same nature.
- Each refinement reformulates the top level and details it without adding any feature



# Declination of requirements




- The requirements of the system's level cannot be allocated directly on the components of the lower level. A need of going through a design phase is important to determine
  - The requirements directly allocated,
  - The requirements spread over several equipments, without transformation,
  - The requirements spread over several equipments, with transformation,
  - The induced requirements (due to the choice of the architecture, to interfaces created …).