CT SYSME
systèmes mécatroniques

Conception intégrée d'un système de systèmes robotique pour la gestion de la chaîne d'approvisionnement d'une usine 4.0

Gilles TAGNE

Enseignant Chercheur, Responsable du domaine Robotique
Recherche : Laboratoire CRIStAL équipe SoftE
Tél. : 33 (0)3 20 30 40 64
https://www.cristal.univ-lille.fr/
https://www.junia.com/

CRIStAL
Centre de Recherche en Informatique, Signal et Automatique de Lille

JUNIA Grande école d'ingénieurs

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Outline

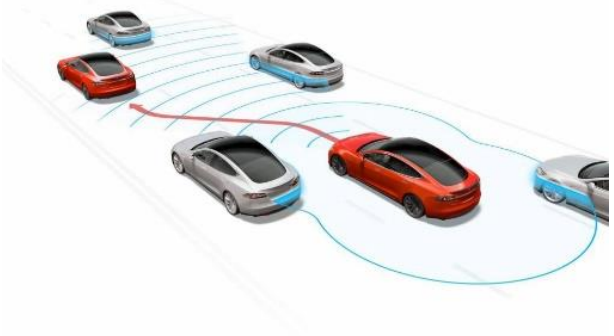
- Definition of System of Systems (SoS)
- Problematic
- Method of designing a SoS
- Preliminary results
- Future work

Large-scale systems

Nowadays, we have more and more Large-Scale Systems (LSS); multimodal transportation systems, financial systems, etc. in various areas of life

Complex systems

- In large-scale systems, there are several classes of systems, among which the **complex systems**, which are part of systems engineering (SE)
- A complex system is a set of a large number of interacting entities whose integration allows to achieve a common goal. Complex systems are characterized by emergent properties that exist only at the system level and cannot be observed at the level of its constituents.



Complex systems - Systems Engineering (SE)

- Systems theory
- Several tools and approaches
- Stability
- Controllability
- Observability
- Passivity
- Robustness

System of systems (SoS)

More and more connected cyber physical systems to achieve a common mission = SoS

SoS definitions [1], [2]

A **system of systems** is a set of many **autonomous systems** or elements of systems that **interact** to provide a **unique capability** that none of the constituent systems (CS) can accomplish alone

To meet the demands of an SoS, Maier [3] proposes five specific characteristics :

- **Operational independence** of the constituent systems (CS): if the SoS is disassembled, the CS must be able to operate autonomously,
- **Managerial independence** of the CS: the constituent systems must maintain a continuous operational existence independent of the SoS,
- **Geographical distribution** of its constituent systems,
- **Presence of emergent and cooperative behaviors** to achieve a common goal,
- **Evolutionary development process:** a system can be added or removed without changing any of the characteristics of the SoS

SoS classification : four categories [4] [5]:

- **Directed SoS**: The system is built for a specific purpose, and centrally managed.

- **Collaborative SoS:** In collaborative SoS, the central management does not have the coersitive power to run the system.

- **Acknowledged SoS:** Which shares attributes from both directed and collaborative SoS. These systems have a central management and resources for the SoS, but the components retain their full independence,

- **Virtual SoS**: It emerges from the interaction between components, whereas the objectives are unknown, and there is no central authority. The system is maintained through invisible mechanisms.

SoS Engineering Applications [6]

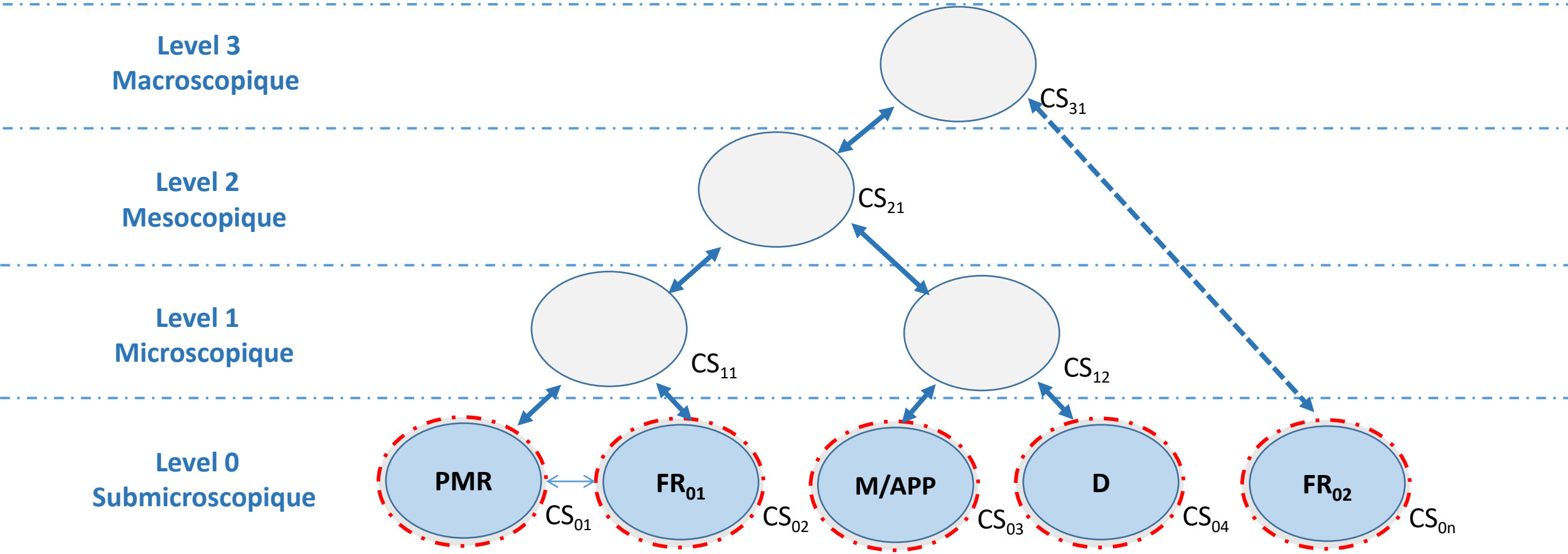
- The ISTAR system (intelligence, surveillance, target acquisition and reconnaissance)
- An SoS in military aeronautics is developed. Its objective is to collect and share information to create the best possible representation of the mission scenario and improve the decision-making process. [7] [8]

SoS Engineering Applications [6]

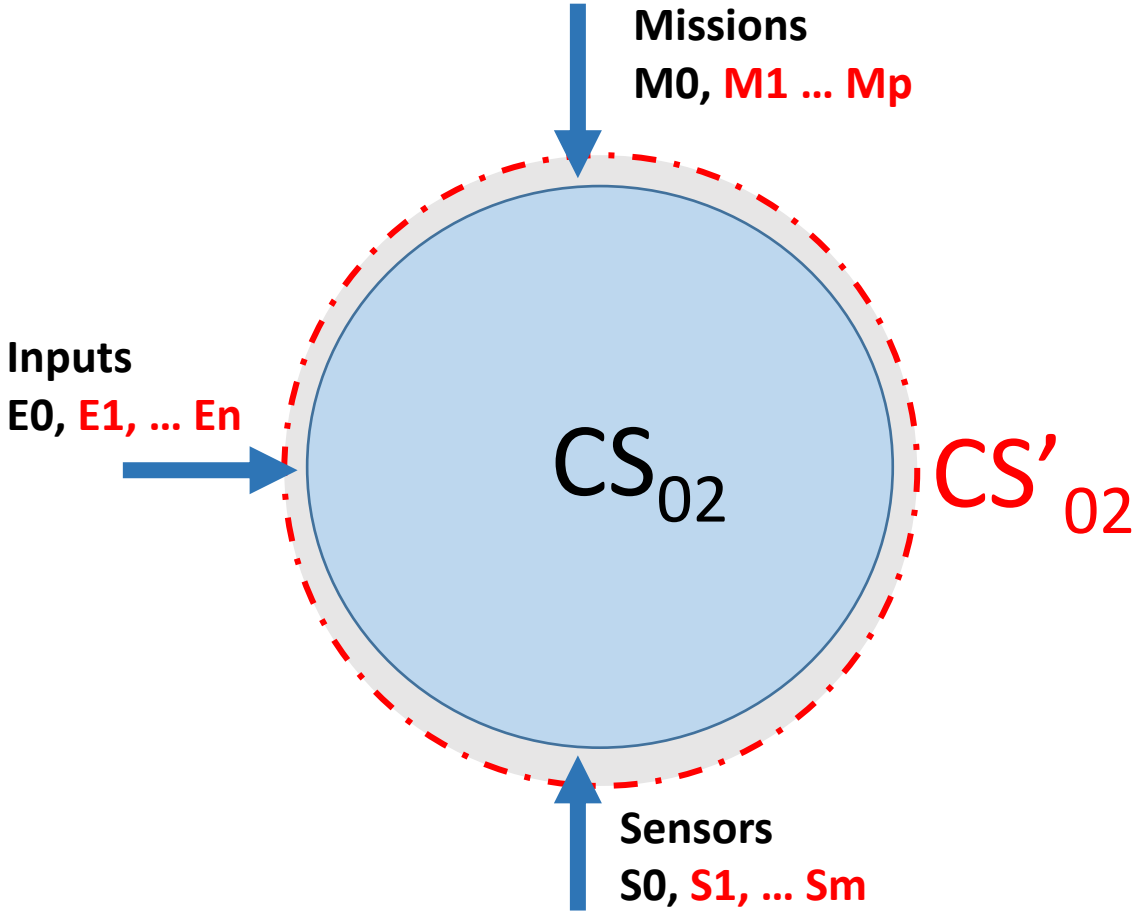
- Military [7] [8]
- Robotics [9] [10]
- Transportation [11] [12] [13]
- Crisis management [14]
- Smart City [15]
- Health care [16]
- Industry 4.0 [17]

System of Systems
Data sharing between components

System of Systems
Several managerial and physical levels



System of Systems – Data exchange



- Level 0
- New models taking into account Mi and S....
- Interoperable models
- Integrated design of robots
- Control
- Non-linear control
- Sensor referenced control

Problematic : System of Systems Engineering (SoSE)

- Systems theory
- Several tools and approaches
- Stability
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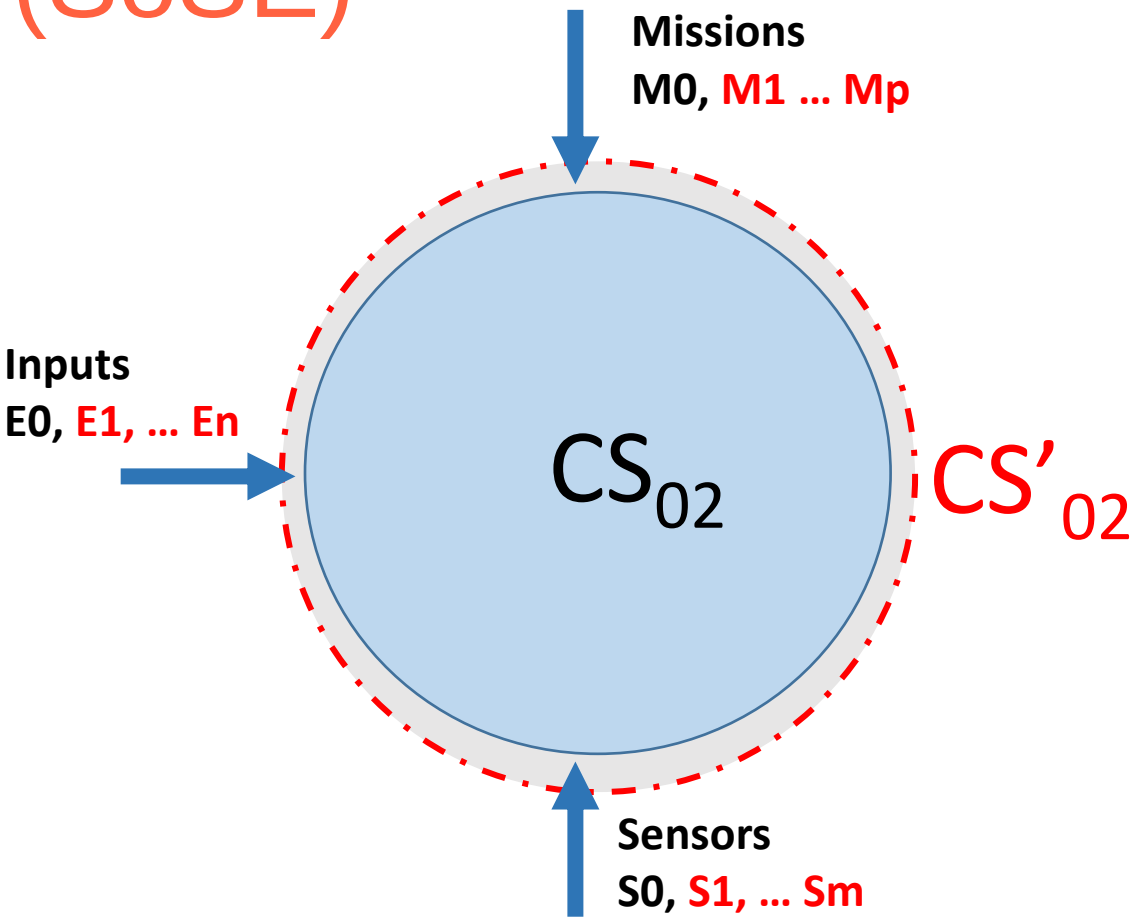
Problematic : System of Systems Engineering (SoSE)



- How to model and control the new CS'0n component for a given mission?
- How to study its new structural properties (observability, stability, controllability, robustness, passivity, etc.)?
- What kind of modeling and control would be appropriate for a given mission?

Problematic : System of Systems Engineering (SoSE)

- Systems Engineering (SE) and SoSE

- The modeling of physical aspects of isolated cyber physical systems and the modeling of organizational aspects (missions and links)
- Interoperate models ?
- Methods to better fit the needs of SoS design (modeling, analyzing, control, optimization)
- Can we extend the tools of SE to SoSE ?
- Developing a unified approach to model different aspects of SoS

We propose an SOS Integrated Design Method

Conceptual analysis

Knowledge of each of the systems that will be involved as well as the management strategy. The knowledge of the physical models and possibilities of interaction is necessary

Architecture definitions

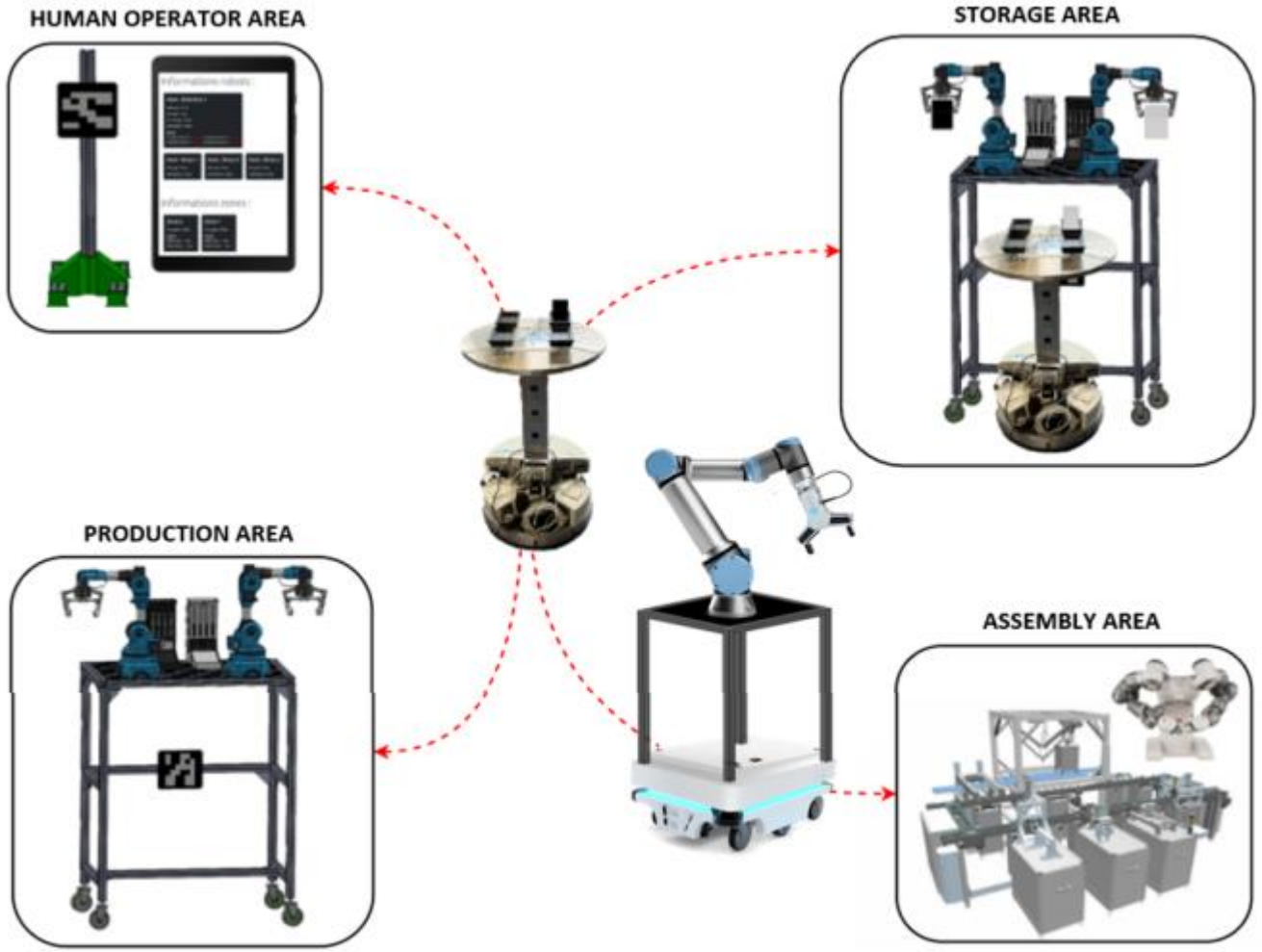
An agile communication architecture capable of exchanging a large amount of information between SoS components must be used depending on the application

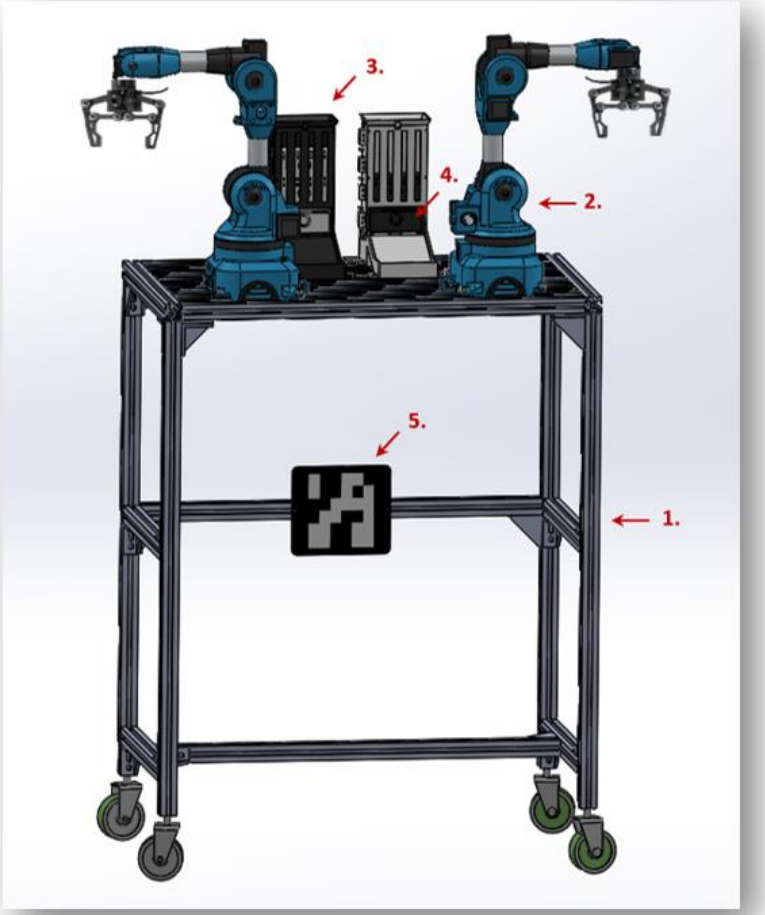
Implementation, integration and testing of the SoS

Optimization and control

Once the collaboration between components is established for a given mission, we will be interested in modeling each of these components by integrating their mission (model interoperability) to have a resilient and optimal SoS.

Example : Integrated Design of a System of Systems for the Management of Supply chain in Industry 4.0





1. Mobile support
2. Nyrio one
3. Rack
4. Boxes
5. Tag ArUco

Example : Integrated Design of a System of Systems for the Management of Supply chain in Industry 4.0

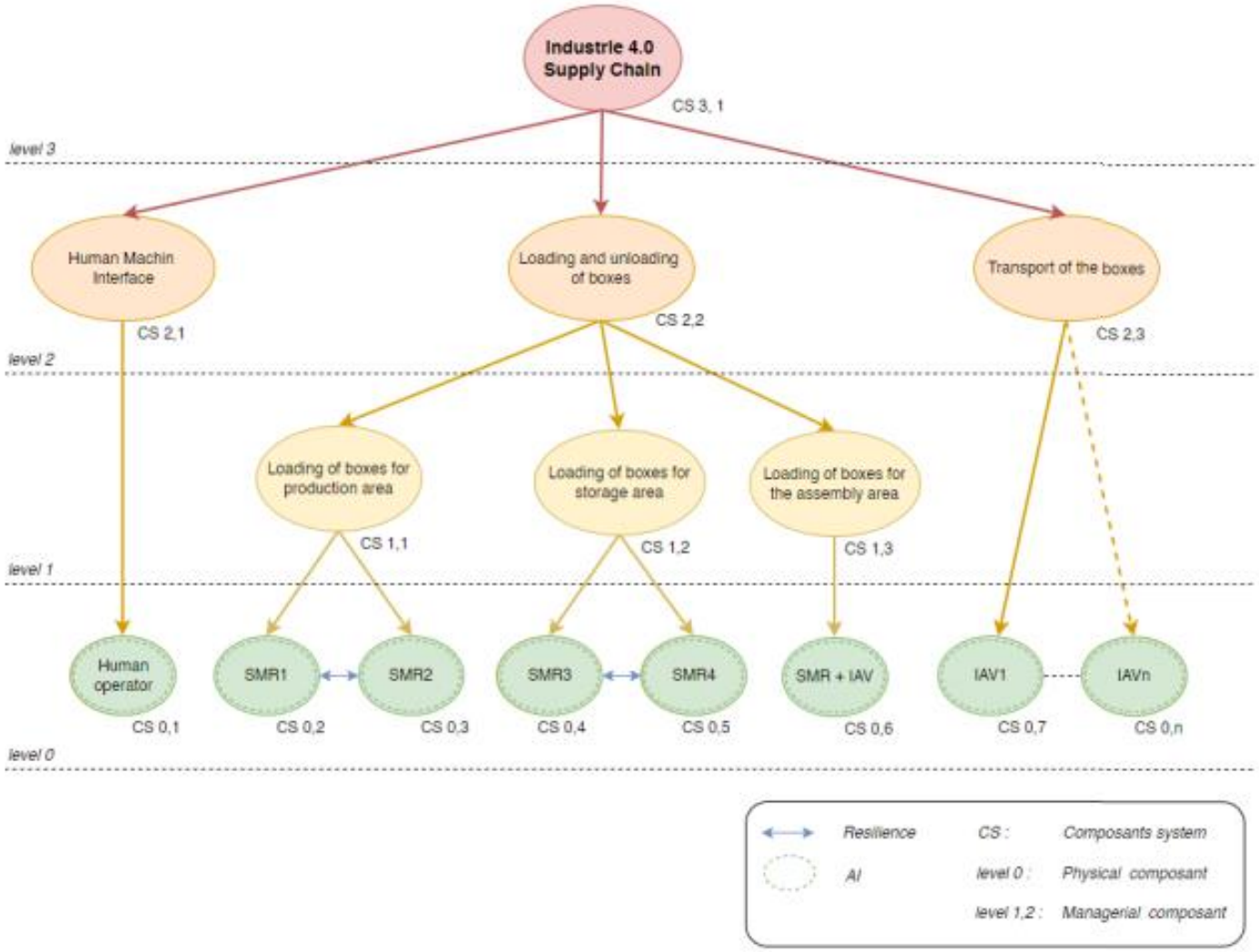
- Storage of boxes in several areas
- Hardware redundancy
- Distributed perception
- Simulation of sensor and robot faults

TABLE I: SoS different robots

Reference	Designation
Niryo one (SMR 1, 2)	Serial Manipulator Robot (SMR)
Niryo Ned (SMR 3, 4)	Serial Manipulator Robot (SMR)
Robotino 4 (IAV1,2..n)	Intelligent Automated Vehicles
MIR+UR5	IAV MIR + Universal Robot UR5

Example : Integrated Design of a System of Systems for the Management of Supply chain in Industry 4.0

- ✓ **Integrated Design**
- ✓ **Collaborative SoS**
- ✓ **MQTT based communication architecture**
- ✓ **Implementation**
- ✓ **Material redundance**
- ✓ **Resilience**
- ✓ **Resilience and emergency**
- ✓ **Distributed perception**
- **Optimal control**



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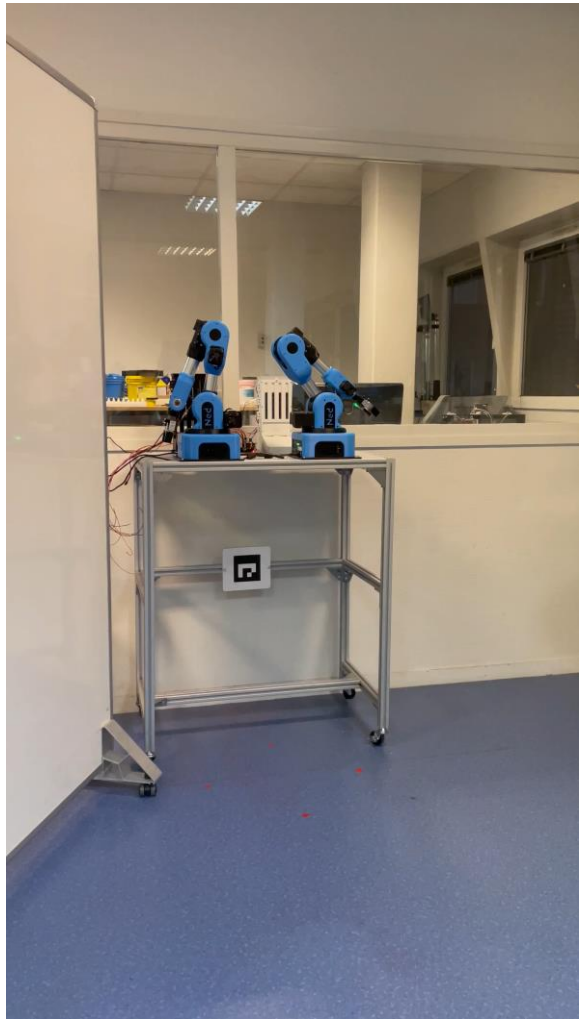

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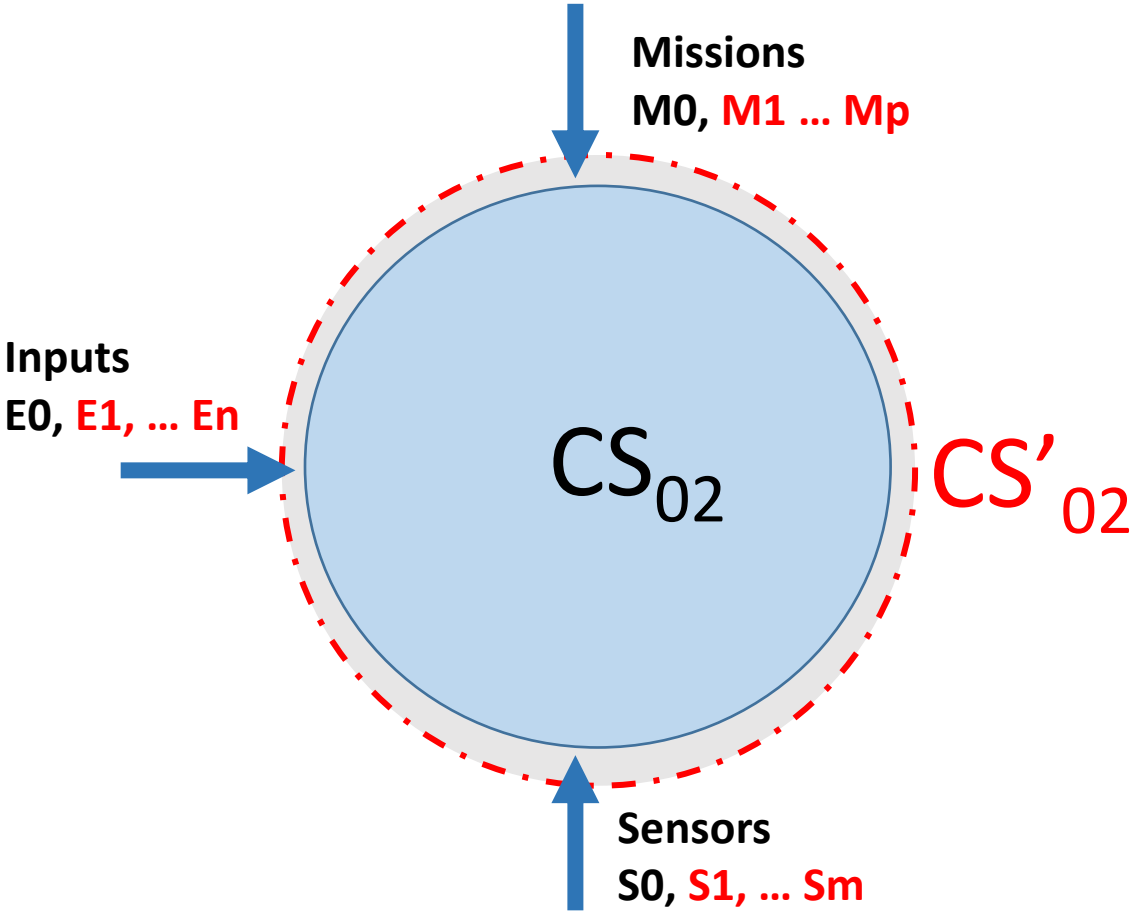

- **Analyze data**
- **Modeling and optimal control**
- How to model and control the new CS'0n component for a given mission?
- How to study its new structural properties (observability, stability, controllability, robustness, passivity, etc.)?
- What kind of modeling and control would be appropriate for a given mission?

Conclusion and Future work

- ✓ SoS definition, challenges
- ✓ Integrated Design Method for SoS based on using SE tools
- ✓ Implementation

- Design interoperability models
- Optimization and control of the SoS
- Application to improve the autonomy of people with reduced mobility

Questions ?

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