LABEX MS2T
“Management of Technological Systems of Systems”

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SoSE 2018 workshop
Paris, June 22, 2018

Compiègne University of Technology

- Founded in 1972, has played a pioneering role for bridging industry and education
- 4 500 engineering students, 300 PhD students
- 9 research laboratories (4 joint with CNRS)
- 120 start-ups

Sorbonne University Association

- Six academic institutions

- Four national research organisations

- 7,700 academic staff (2,900 tenured professors)
- 57,800 students including 23,000 undergraduates

Investing for the future

- Investments for the Future: strategic initiatives launched in 2009 by the French Government, to boost French competitiveness by investing in
  - Research, higher education and vocational training
  - Industry and SMEs
  - Sustainable development
  - Digital technology, biotechnology and nuclear energy, etc.
- Two programmes launched so far: €22.6 bn in 2010 and €4 bn in 2014.

- 3 types of action:
  1. Centres of excellence
  2. Health and biotechnology
  3. Technology transfer and valorisation

Laboratories of Excellence

The Laboratories of Excellence program, launched in 2010, is coordinated by the French National research Agency (ANR). It aims to provide the best national laboratories with international visibility and significant resources in order to enable them to:

- Compete with their foreign counterparts
- Attract internationally renowned researchers and academics, and
- Create a high-level and integrated policy for research, education and valorization/partnership with industry

Consortium

Consortium of 3 joint research units at UTC, affiliated with CNRS and grouped in a research federation:

Heudiasyc: Information & Communication Technologies

BMBI: Biomechanics, Health Engineering

Roberval: Mechanics, Materials, Acoustics

Vision: from Systems to Systems of Systems

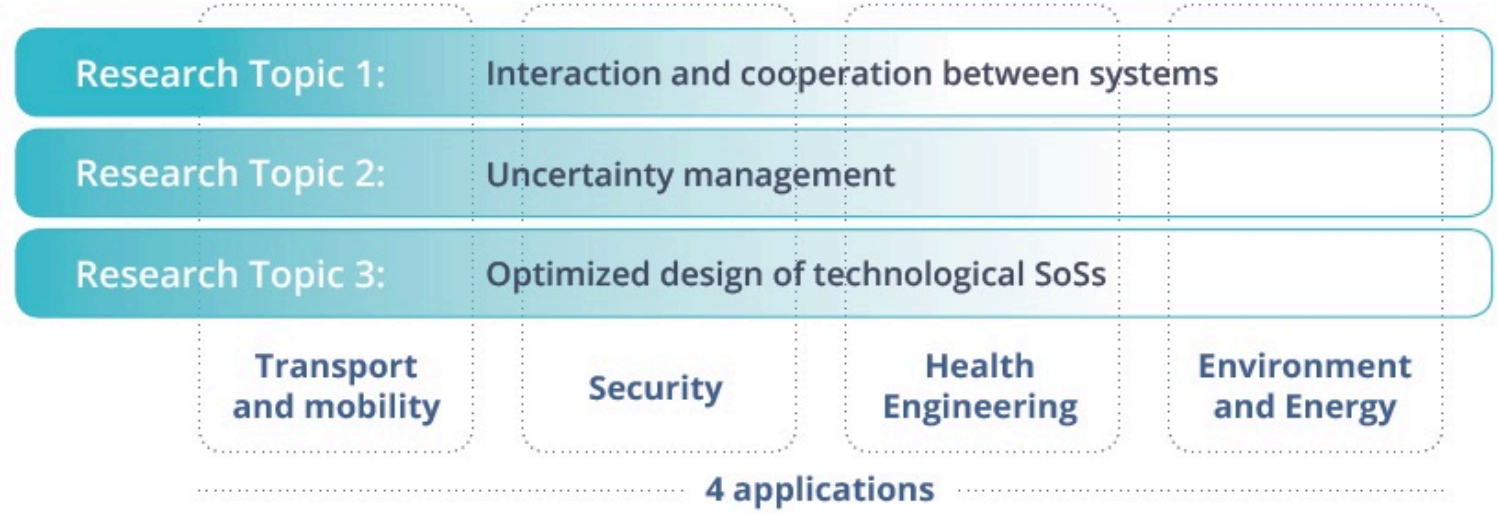
Systems	Systems of Systems
Drone	Fleets of drones
Car with driving assistance	Autonomous cars + V2V/V2I communication + humans
Numerical models	Multi-physics (e.g., fluid-solid-thermal) and multi-scale models
Biohybrid tissues	Biohybrids constructs (e.g., bone-tendon-muscle) and artificial organs
Rehabilitation devices	Connected biomedical objects + patient + healthcare professionals + biomechanical models, etc.

Technological Systems of Systems (TSoS) = highly-organized meta-system whose components are, themselves, systems

Scientific Objectives

- Contribute to the development of a scientific approach to TSoS by drawing from a variety of
  - Disciplines (e.g., automatic control, machine learning, operational research, numerical analysis, etc.)
  - Application areas (transportation systems, mechanics, biomedical engineering)
- Apply the developed methods to challenging real-world problems in order to address major socioeconomic issues (mobility, energy, security, health, etc.)
- Conditions
  1. Development of integrative and interdisciplinary research
  2. Availability of realistic technological platforms allowing for an experimental/inductive approach

Research programme



Topic 1: (a) Management of information flows within communication networks, (b) Distributed information processing, (c) Autonomy of interacting systems

Topic 2: (a) Uncertainty management: Modeling uncertainties, (b) Uncertainty-robustness and integrity, (c) Uncertainties in numerical modeling

Topic 3: (a) Optimized design of TSoS: Multi-level and multi-physical optimization, (b) Scheduling and synchronizing mobile subsystems, (c) Operational safety of TSoSs

Roadmap (4 years ahead)

Table 1: **4-year goals**

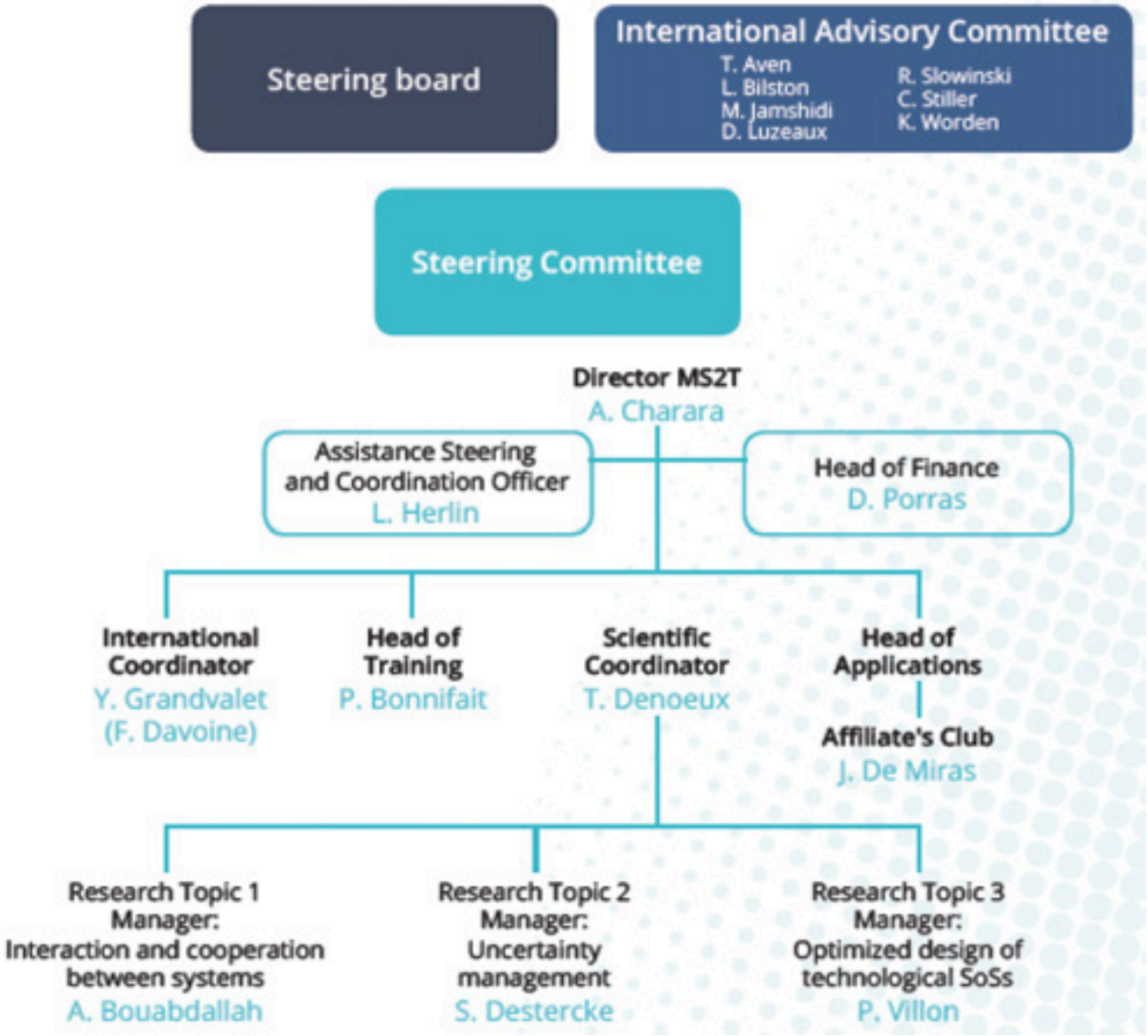
Research topics	Scientific goals	Application goals
	Field 1: Interaction and cooperation	
1.1 Managing information flows	- Security and heterogeneity of sub-systems - Taking into account network dynamics in the distributed algorithm - Detecting attacks within networks (modelling and confinement) - Learning from data streams: building the data representation with limited memory and computational resources (selecting informative examples, interruptible algorithms).	- Networks of sensors for health (SUPGEST, ICARE-U) and the environment - Inter-vehicle communication: up-scaling (2MI, ROBOTEX)
1.2 Distributed processing	- Study decentralized collaborative control and observation methods - Learning from uncertain and partial labels inferred by other modules - Aligning and fusing ontologies	- Guiding a fleet of robots through an unknown and restrictive environment (ROBOTEX) - Bringing multi-physical measurement systems into cooperation with their processing (medical imaging, electro-physiological signals, motion sensors, etc.) for bio-faithful real-time modelling (SUPGEST, ICARE-U) - Distributed information fusion in vehicle ad-hoc networks (ROBOTEX)
1.3 Autonomy of interacting systems	- Detecting context evolution in machine learning. - Studying methods for observing and controlling dynamic systems that have multiple modes of operation, particularly due to the fact that their structure is evolving. - Developing innovative actuators and sensors for integrated systems of systems	- Automatic control of aerial drones for the transition from a vertical takeoff phase to airplane mode - Robust behaviour of mechatronics systems - New devices and technology for characterizing and analyzing complex systems

Roadmap (10 years ahead)

Table 2: **10-year goals**

Research topics	Scientific goals	Application goals
Field 1: Interaction and cooperation		
1.1 Managing information flows	- Guaranteeing quality of service in heterogeneous networks - Masking the dynamics of opportunistic networks	- Spontaneous networks for crisis management (floods, etc.) - Developing social networks via technological SoSs (incorporating relationships between Humans, Technology, and Society)
1.2 Distributed processing	- Automatic quantification of each module's goals and performances for carrying out the SoS's tasks - Learning using implicit supervision (disagreement between the system's recommendations and the supervisor's decisions, operator's actions and reaction time, etc.). - Evolution of ontologies	- Handling the reconfiguration problems of a fleet of robots (such as adding new members) and developing solutions for risk management (ROBOTEX) - Autonomy through learning in TSoSs for Health (SUPGEST, ICARE-U)
1.3 Autonomy of interacting systems	- Continuous autonomous learning: updating the representation of information subsequent to a change in the environment. - Assessing and optimizing *guaranteed* performance on large state spaces, over distant periods of time. - Innovative material in actuators and sensors development	- Controlling aerial drones, road vehicles (ROBOTEX) and barge convoys (NavCenter) - Giving vehicles abilities that make them smarter in their interactions (cooperation with drivers and other vehicles). (ROBOTEX) - Next generation of technology for characterizing and analysing complex systems

Governance

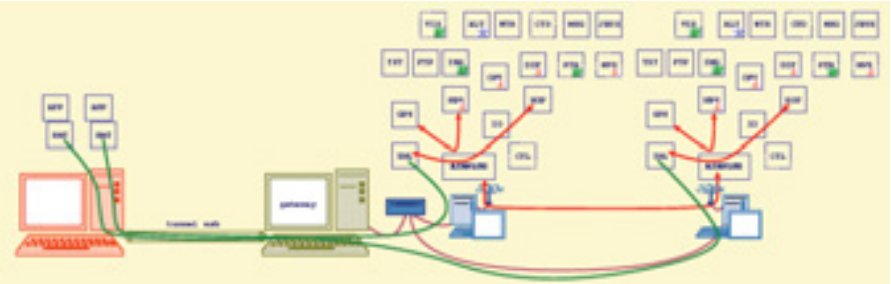

Steering board
International Advisory Committee
T. Aven
L. Bilston
M. Jamshidi
D. Luzeaux
R. Slowinski
C. Stiller
K. Worden
Steering Committee
Director MS2T
A. Charara
Assistance Steering and Coordination Officer
L. Herlin
Head of Finance
D. Porras
International Coordinator
Y. Grandvalet
(F. Davoine)
Head of Training
P. Bonnifait
Scientific Coordinator
T. Denoeux
Head of Applications
Affiliate's Club
J. De Miras
Research Topic 1 Manager: Interaction and cooperation between systems
A. Bouabdallah
Research Topic 2 Manager: Uncertainty management
S. Destercke
Research Topic 3 Manager: Optimized design of technological SoSs
P. Villon

Experimental platforms: ROBOTEX

Experimental platforms funded as part of the ROBOTEX programme (€ 1m):

- Autonomous road intelligent vehicles (3 robotized electric cars)
- Fleet of mini UAVs (octo-rotors with embedded sensors)
- Experimental support: protected outdoor UAVs flight area, “mobile laboratory” (equipped van for outdoor experiments), test track

Other experimental platforms



- Spicarail: Railway supervision system
- SUPGEST: wireless sensor network architecture for functional rehabilitation
- Fully equipped cell biology platform to perform tissue reconstruction and characterization
- PILCAM 2: high-performance parallel computing platform

Funded and co-funded projects (examples)

Position	Start date	End date	Subject
PhD	Nov-2011	Nov-2014	Reliable design methodology of Systems of Systems in the presence of uncertainty: Application to transport systems
PhD	Dec-2011	Nov-2014	Biomechanical data uncertainty: modelling and propagation in musculoskeletal system pathology diagnosis models
Post-doc	April-2012	June-2012	Wavelength coding of digital information transmitted between systems in free space
PhD	Oct-2012	Aug-2015	Energy saving in wireless sensor and actuator networks
PhD	Oct-2012	Sept-2015	Modeling of the flow of capsules through a complex capillary network
PhD	Sept-2012	Sept-2015	Reactive navigation of a fleet of drones in interaction
Post-doc	March-2013	Nov-2013	Sensitivity analysis and uncertainty modelling: application to electromyographical models
Post-doc	April-2013	April-2015	Wavelength coding of digital information transmitted between systems in free space
Post-doc	April-2013	April-2015	Distributed Algorithms and Theory of Belief Functions
Post-doc	July-2013	July-2014	Grammar-based driving scene understanding with uncertainties post-doc in the framework of a joint project with LIAMA – China

Funded and co-funded projects (examples)

Position	Start date	End date	Subject
PhD	Oct-2013	Oct-2016	Internet of Things security: towards a robust interaction of Systems of Systems
PhD	Oct-2013	Oct-2016	The project scheduling problems with storage resources, optimisation and robustness
PhD	Oct-2013	Oct-2016	Modelling of the Surface EMG/Force relationship by data analysis of a high-resolution sensor network
Post doc	Dec-2013	Oct-2014	Robust control-command strategies in a contract-based collaboration framework (co-funded by Labex MS2T/ ALSTOM)
PhD	Dec-2013	Dec-2016	New methods for multi-objective learning (co-funded by Labex MS2T/ Regional Council of Hauts-de-France)
PhD	Oct-2015	Sept-2018	Robust Multi-robots Visual SLAM using Heterogeneous Mobile Cameras Network
PhD	Oct-2015	Sept-2018	Control of Systems of Systems: Case of several autonomous vehicles in interaction
Post doc	Sept-2015	Sept-2016	Control and communication of multi-robot system for visual navigation
Post doc	Oct-2015	Oct-2016	Cyber-Physical Modelling for Smart Systems-of-systems
Post doc	Oct-2016	Oct-2017	Towards System of Information Systems: a proactive Product Lifecycle Management approach
PhD	Nov-2015	Sept-2016	Fault Tolerant Control of an Octorotor Unmanned Aerial Vehicle under Actuators Failures
PhD	April-2016	March-2019	Multi-Robots Exploration Strategies using Active Visual SLAM and Distributed Control Architectures

Challenge teams

- Inductive approach: starting from a set of concrete applications (using experimental platforms) to derive generic concepts and techniques
- From focused research projects to multidisciplinary challenge teams centered on experimental platforms and involving several labs and/or research groups:

  DAPAD: Distributed and augmented vehicle perception to support autonomous driving

  DIVINA: DIstributed cooperative VIsual Navigation for multi-uAv systems

  INTERFACE: Tissues and cell Interfaces in muscle-skeleton system: Application to the design of bioartificial SoS

DAPAD: Objectives

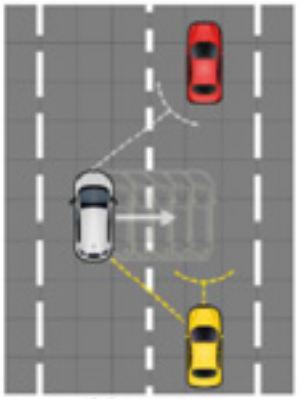
Distributed and augmented vehicle perception to support autonomous driving

Augment the range of perception systems to enhance situational awareness of autonomous vehicles in complex and highly dynamic scenes, by making use of perception data broadcasted by other road users and by the infrastructure through V2V and V2I communication.

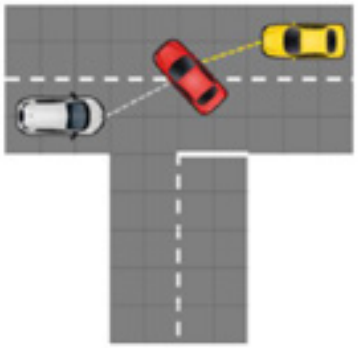
DAPAD: Research actions

Grand Cooperative Driving Challenge 2016, Eindhoven, May 2016

Implementation of state-of-the-art algorithms for localization, perception, control, communication and human-machine interface on our experimental vehicle (a Renault Zoe electric car).



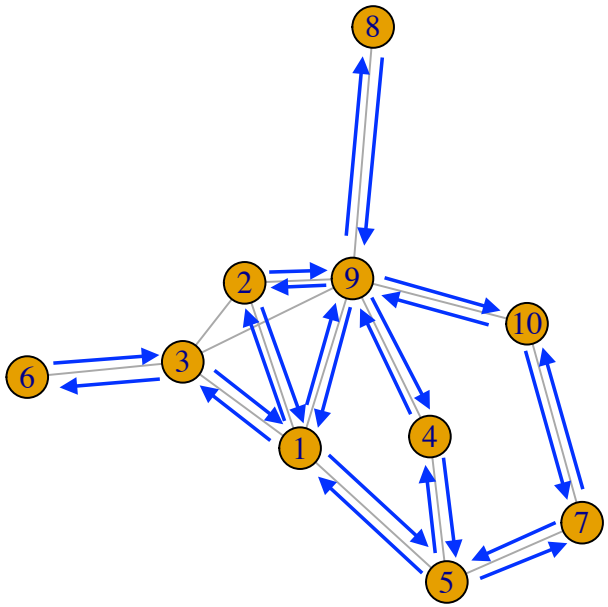
(a) Merging

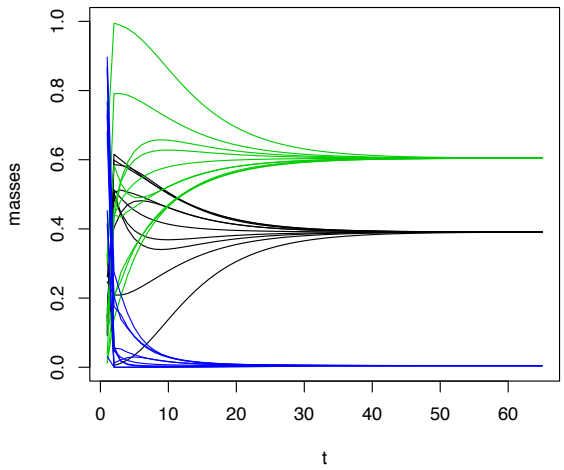


(b) Crossing

(c) Emergency

DAPAD: Ongoing research actions





- Distributed data fusion in the Dempster-Shafer framework
- Collaborative localization and perception (fusion of evidential occupancy grids)
- Cooperative maneuver control for autonomous vehicles
- Data sharing in dynamic networks for cooperative driving
- Etc.

DIVINA: Objectives

DIstributed cooperative VIsual Navigation for multi-uAv systems

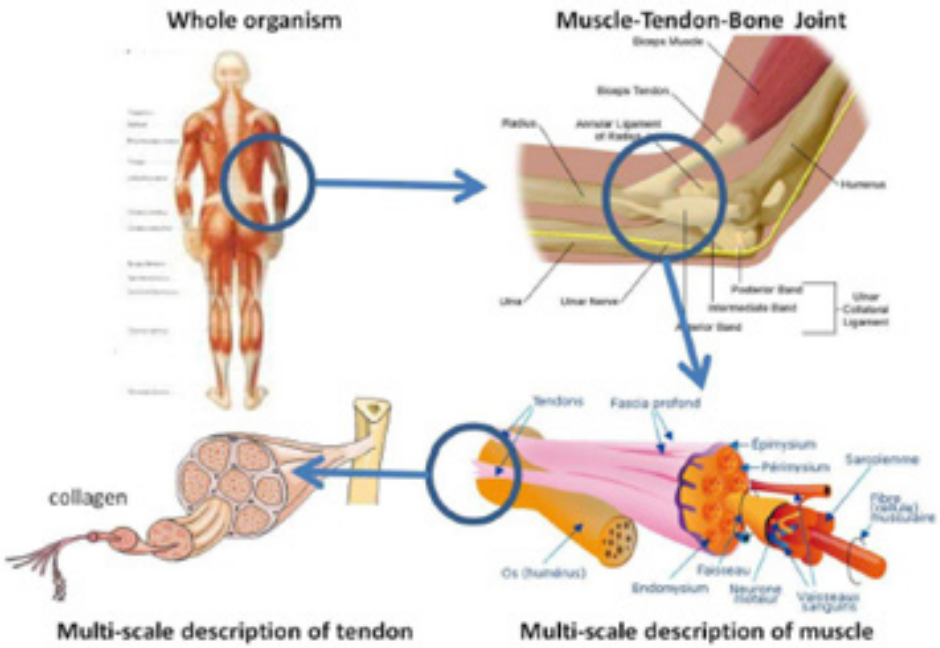
Objective: Efficiently explore a totally or partially unknown geographic area using a multi-UAV system with vision sensors as the main perception modality and bio-inspired communications through distributed control.

DIVINA: Ongoing research actions

- Distributed control: multi-UAV formation, collision-free flocking, loop-closing revisiting strategies.
- Visual Perception: distributed and error-bounded Visual SLAM, heterogeneous camera network, relative pose estimation.
- Bio-inspired Communications: cooperative networking protocols and algorithms, robust and efficient inter-robots communications, evolutionary linguistic models (naming game)

INTERFACE: Objectives

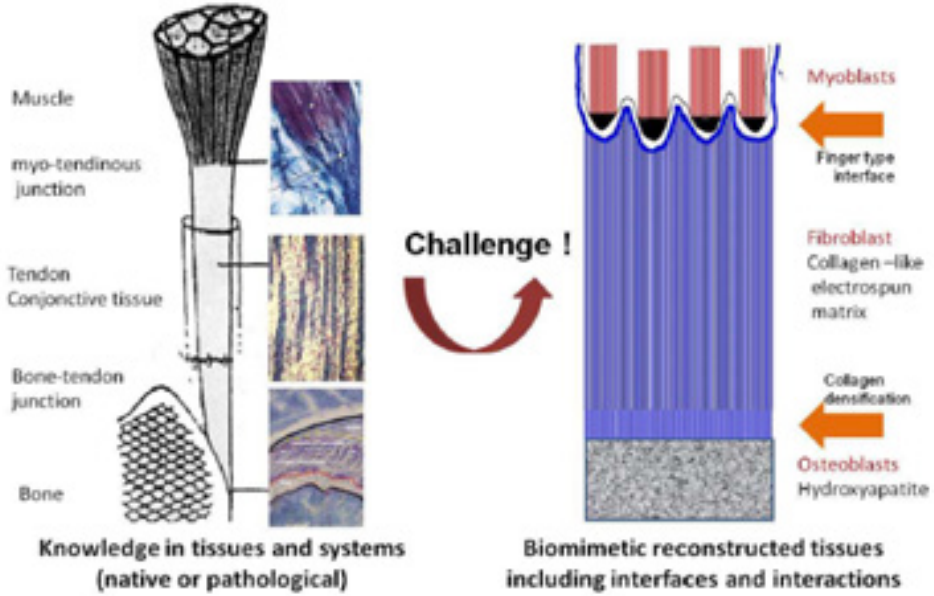
- In the last 15-20 years, the achievements in biotechnology have fostered significant progresses in the field of tissue engineering (bone, skin, muscle, cartilage, liver, etc.)



- Challenge: target global system development in which different multi-layered tissues (muscle-tendon-bone) will be designed together → bioinspired SoS.

INTERFACE: On-going research actions

- Reconstruct the bone-tendon-muscle continuum using smart tissue engineering approaches based on:



- Deep knowledge of the native tissues architecture and composition at different scales
- Design of electrospun materials mimicking the structure
- Relevant cell types
- Culture of the biohybrid constructs under dynamic conditions in bioreactors to exploit mechanical stimulation (as in a body) for enhanced tissue maturation

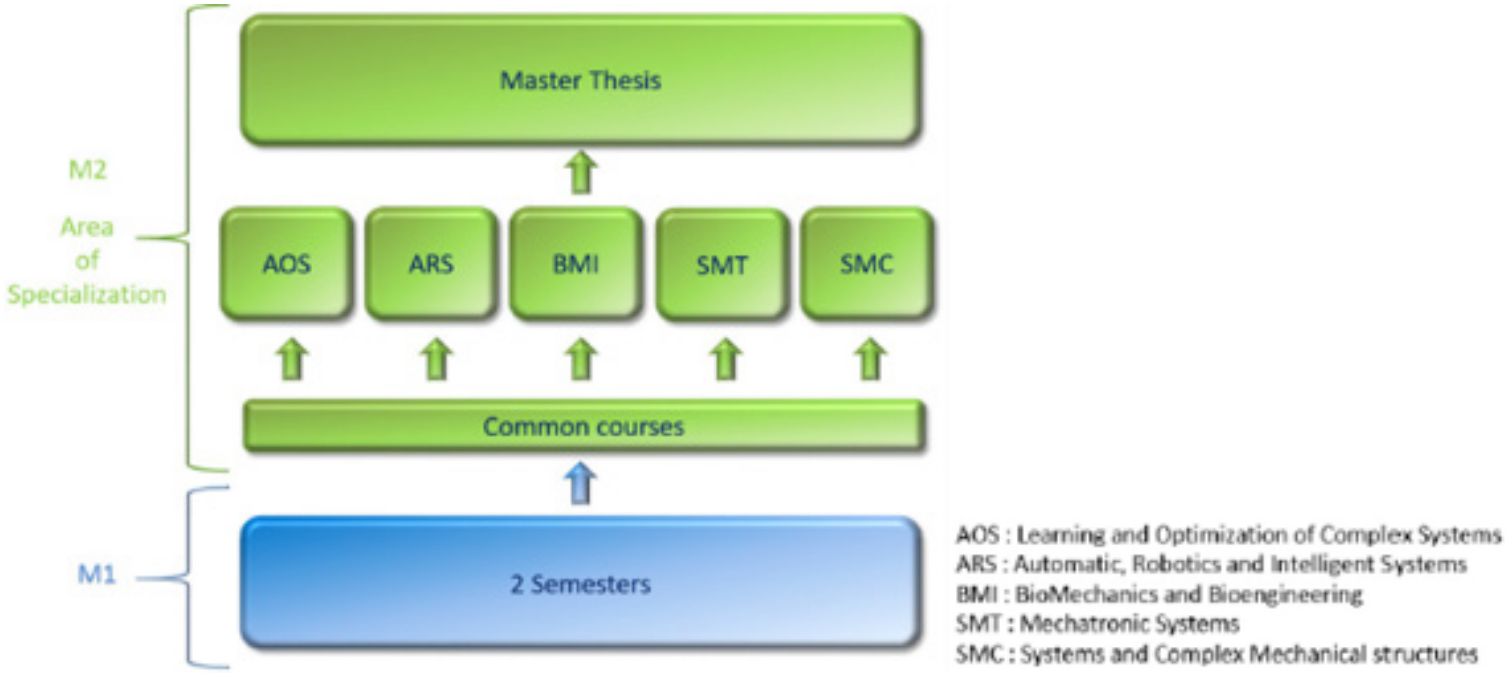
International outreach

- Visiting Scholar Programme (1-3 months): 25 scholarships granted
- Visiting Chair (A. Sekercioglu, Monash U.)
- Hosting and sponsoring of international conferences (e.g., SoSE 2018)
- Participation in strategic groups: Trans-Atlantic Research and Education Agenda on Systems of Systems (T-AREA-SOS), program committee CHIST-ERA (European Coordinated Research on Long-term Challenges in Information and Communication Sciences & Technologies) on Cyber-Physical Systems
- International collaborations

Master's program on "Complex Systems Engineering"

- Two-year Master's program
- Objective: provide skills to analyse and design complex systems using a systemic multidisciplinary approach, over and above a strong, basic engineering qualification
- Course modules correspond to the Labex research program, with hands-on training with the Labex experimental platforms

Master's program on "Complex Systems Engineering"



- Partnership agreement with the University of Genoa: European Master in Engineering for Complex and Interacting Systems, supported by the Erasmus and the Vinci programs for student and faculty mobility.
- Since 2014, 190 M2 graduates, 61 M2 internships (5-6 months), 37 Labex scholarships

Partnership with Industry

- Co-funding: around € 1m since 2012

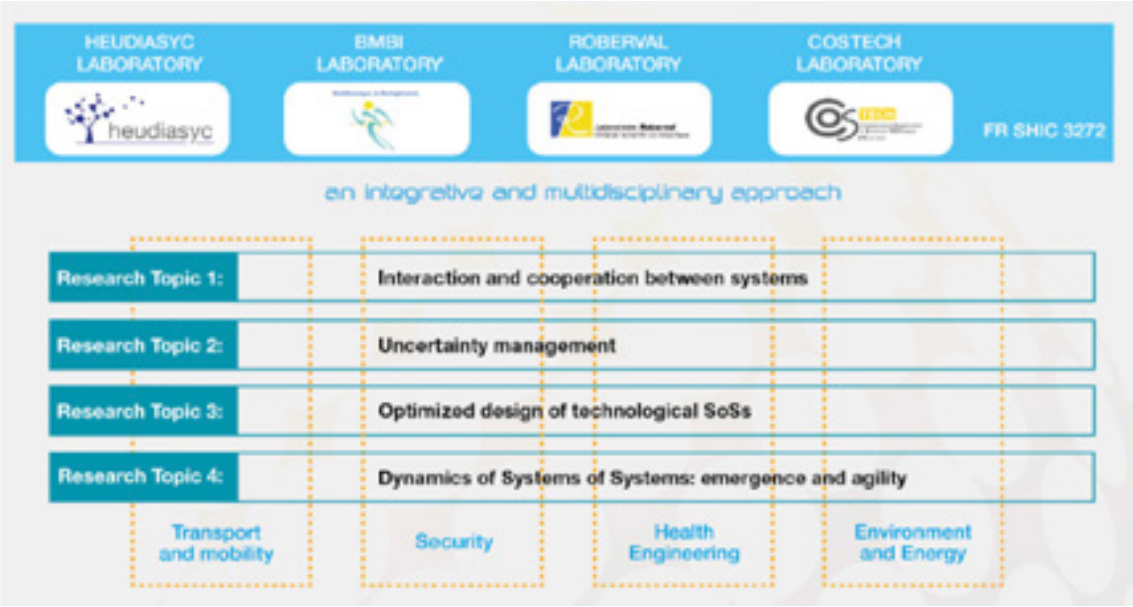
- SIVALab:
  - Joint research laboratory between UTC, CNRS and Renault. Created in 2017
  - Four-year research programme on perception and localization systems supplying reliable navigation data for communicating autonomous vehicles

Mid-term Review (June 2015)

"The overall opinion is definitely positive"
"Analyzing systems of systems is a real research challenge"
"The project overall produced an impressive list of publications and a significant number of them are in top level journals"
"The main added value of the Labex funding consists in establishing a community of scholars from UTC, CNRS and industries on the challenging topics of the project"
"Very good progress in formation and education"
"Tight relations with industries have been established"
"The institutions involved in the project have been able to attract interest from scholars and from industries on the challenges of the project"
"A very good governance and management of the project"

Project evolution

- Integration of a 4th laboratory: CosTech (human and social sciences)
- 4th axis on Dynamics of SoSs: Emergence and agility



- Preparation of a response to the next call of the “Ecole Universitaire de Recherche (EUR)” (multidisciplinary Graduate School) program.

Conclusions

- Positive impact on the three laboratories and the university as a whole, in terms of:
  - Research: interdisciplinary projects, structuring of platforms, etc.
  - Training: dedicated Master program, graduate school, etc.
  - International reach: visiting scholar program, seminar, international student exchange, etc.
  - Value enhancement: increased partnership with industry, startup creations, etc.
- The way ahead:
  - Continue promoting interdisciplinary research, by extending the perimeter of the project to other labs (process/urban engineering, applied mathematics)
  - Further integrating research and training (graduate school project)
  - Enhancing partnership with industry though joint laboratories and industry-funded chairs
  - Continue developing international relations through student exchange programs, joint Master's programs, international laboratories, etc.