CAMS/EiR/CPR 2022/2023

Analysis and Control of Multi-Robot Systems

Introduction to the Course

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(Part of the slides by Paolo Robuffo Giordano)

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Organization

Lecturer:

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Course Website:
https://classroom.google.com/c/NjAxOTkxMTIwODI3?cjc=csrnfum

Codice classroom: **csrnfum**

Schedule:
18/04/2022-25/05/2022, Tuesday 14:00-16:00 (A7), Thursday 09:00-13:00 (A4)

Exam:
group project (3 people) or individual report on a research article

Organization

- Goals of the course:
  - Provide some theoretical tools for analyzing and synthetizing cooperative behaviors in multi-robot systems

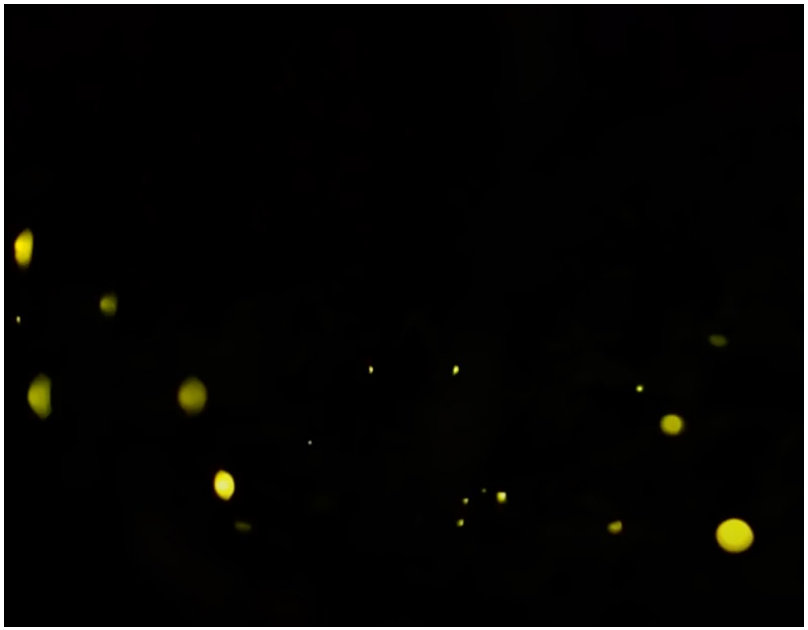
- Topics of the course:
  - Algebraic Graph theory
  - Decentralized Control and Estimation
  - Consensus-like protocols
  - Graph Connectivity and Graph Rigidity
  - Multi-consensus behaviours
  - Passivity Theory
  - Port-Hamiltonian modeling
  - Formation Control

Multi-Robot Systems

Multi-Robot Systems are systems composed of multiple interacting dynamic units.

biologically inspired…

shimmering of giant honeybees
Kastberger G, Schmelzer E, Kranner I (2008) Social Waves in Giant Honeybees Repel Hornets. PLoS ONE 3(9): e3141.



synchronizing fireflies
Buck, J and Buck, E (1968) Mechanism of Rhythmic Synchronous Flashing of Fireflies. Science 22 159(3821):1319-1327.

Multi-Robot Systems

Multi-Robot Systems are systems composed of multiple interacting dynamic units.

Synchronization

An agreement by multiple systems on a common state

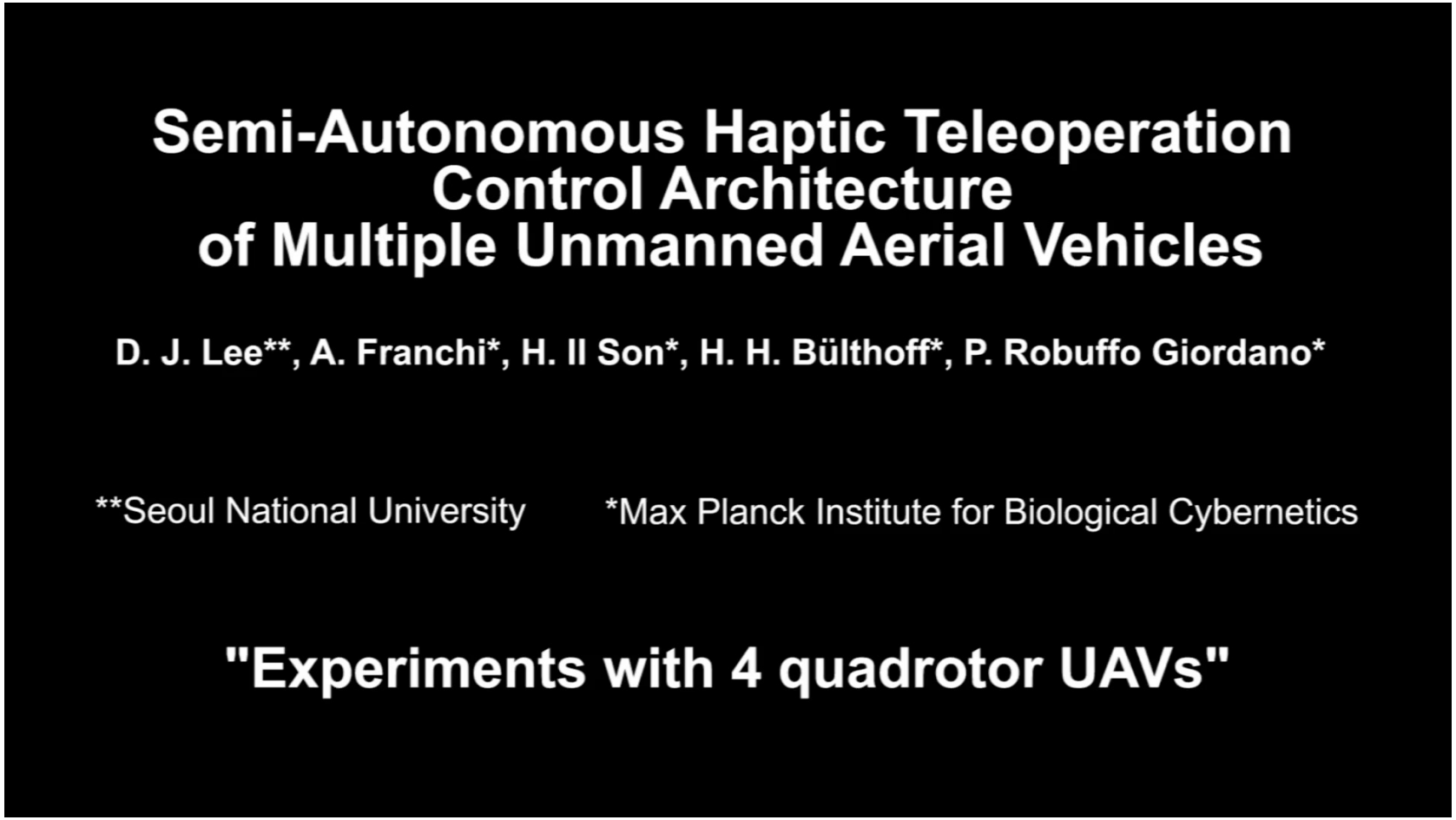
Aldebaran Robotics, Shanghai Expo 2010
https://www.youtube.com/watch?v=uluRc1r_N34

Coordination

Managing of multiple interacting systems to achieve a team objective

Multi-Robot Systems

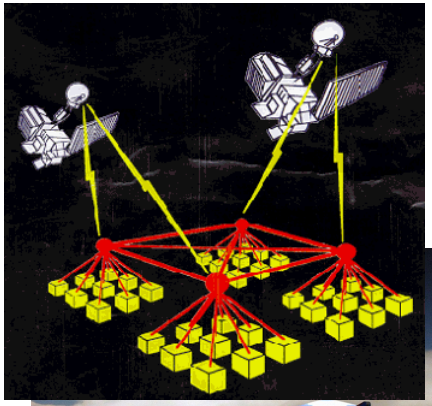
Multi-Robot Systems are systems composed of multiple interacting dynamic units.

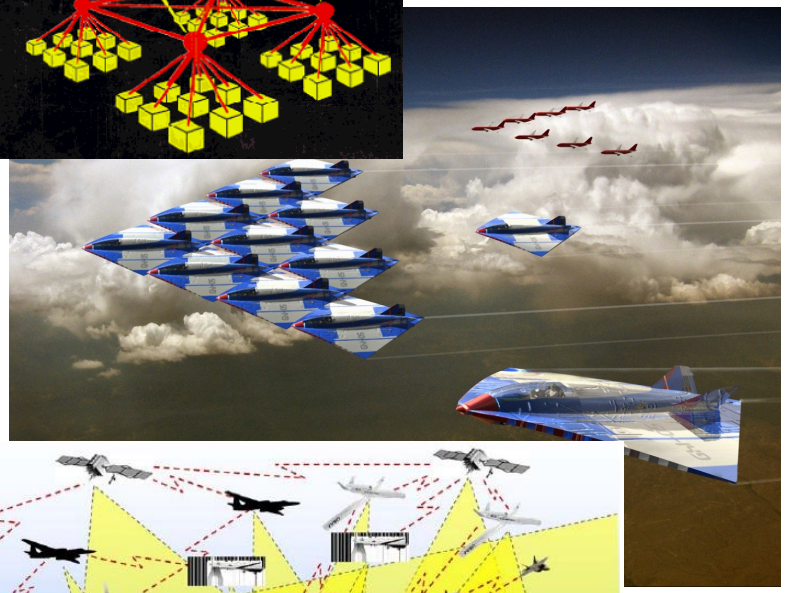


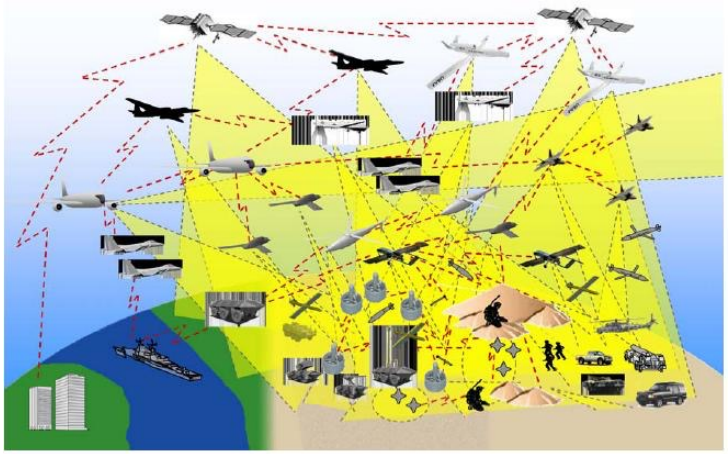
From Nature to Engineered Systems

Course Goals

- Modeling of multi-robot systems
  - Dynamics
  - Interconnections
- Analysis of multi-robot systems
  - Stability and performance
  - Convergence
- Applications of multi-robot systems
  - Formation Control
  - Localization



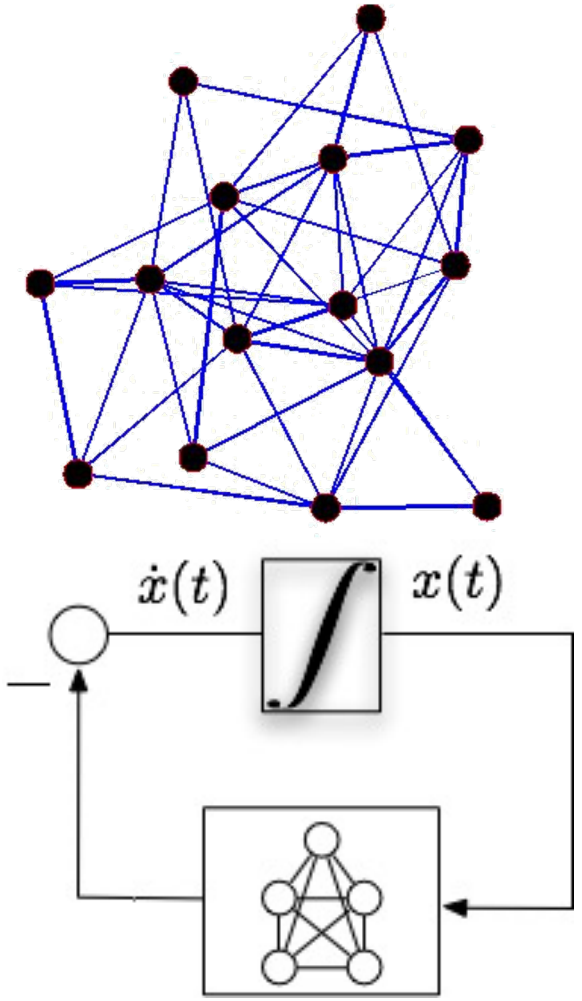




From Nature to Engineered Systems

Course Goals

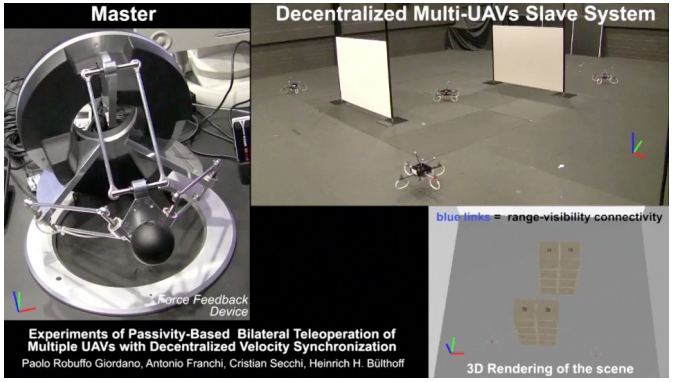
- Graph Theory
  - Algebraic graph theory
- Consensus and Agreement Protocols
  - Undirected/directed communication
- Networks as Systems
  - Graph theory ⇔ System theory

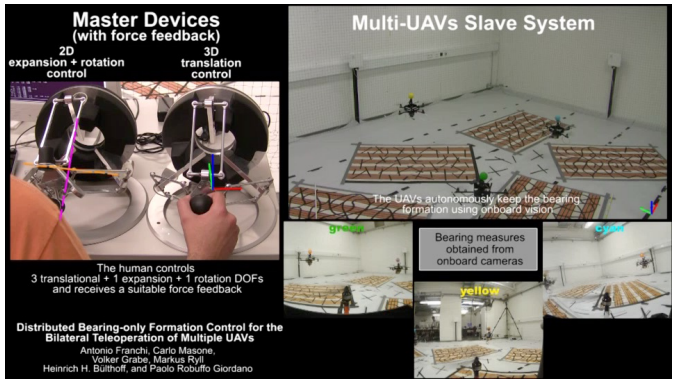


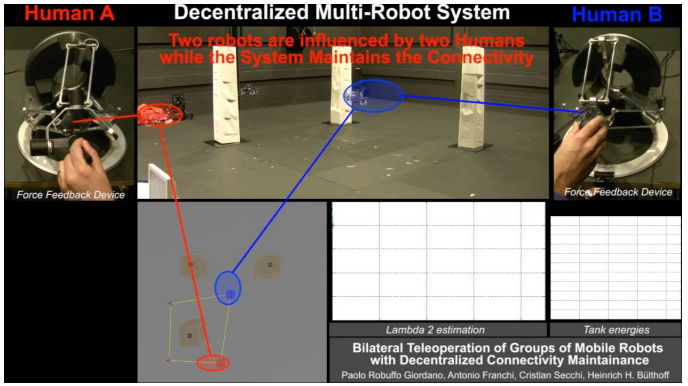
From Nature to Engineered Systems

Course Goals

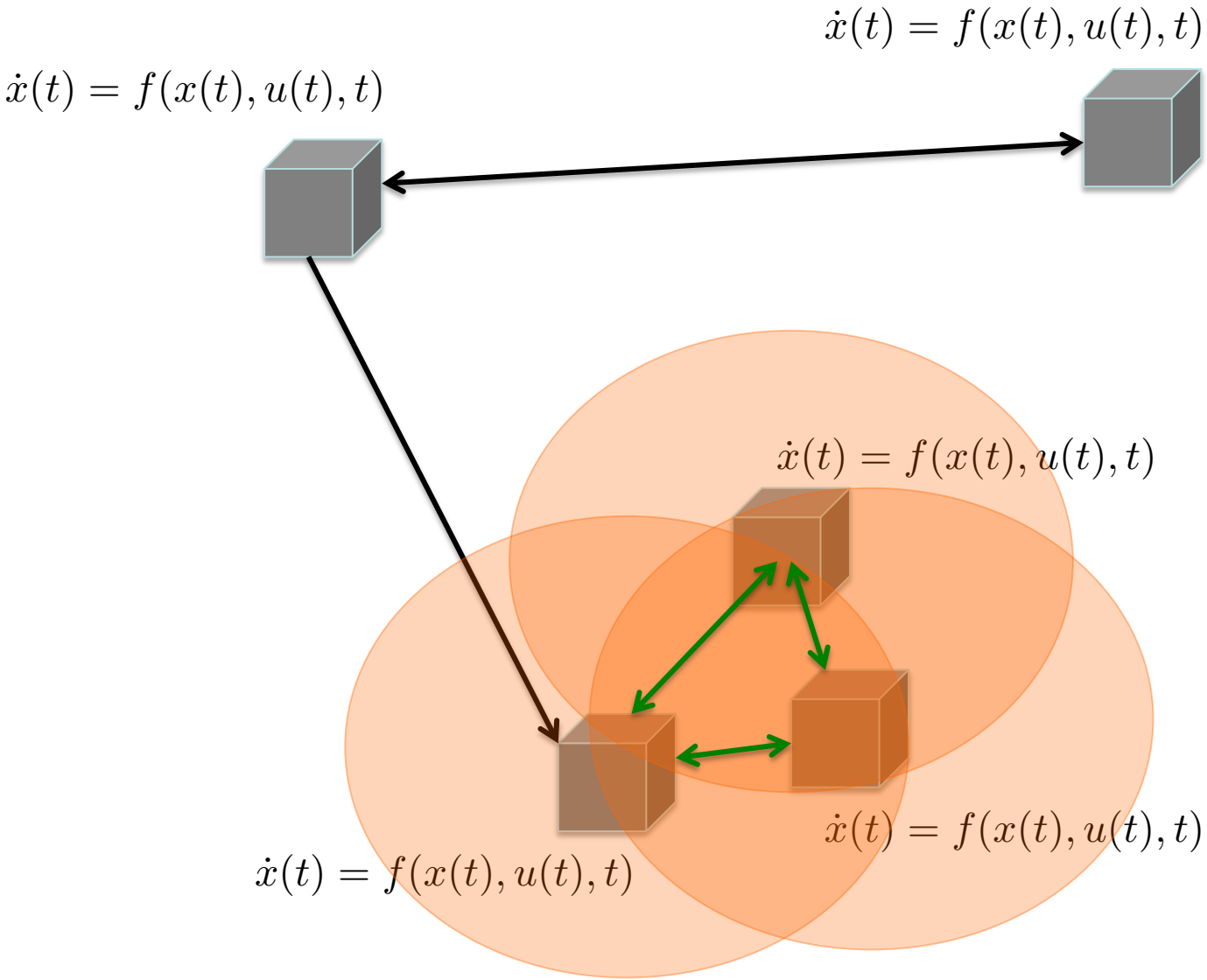
- Exploit energy-based techniques:
  - passivity
  - port-Hamiltonian modeling
- Passivity:
  - general and powerful framework
  - linear/nonlinear setting
  - related to I/O stability
- Port-Hamiltonian modeling
  - approach to model interconnected systems
  - based on the "energy flows"
  - strong link with passivity
- Applications
  - formation control of UAVs
  - connectivity maintenance
  - navigation and exploration







Networked Dynamic Systems

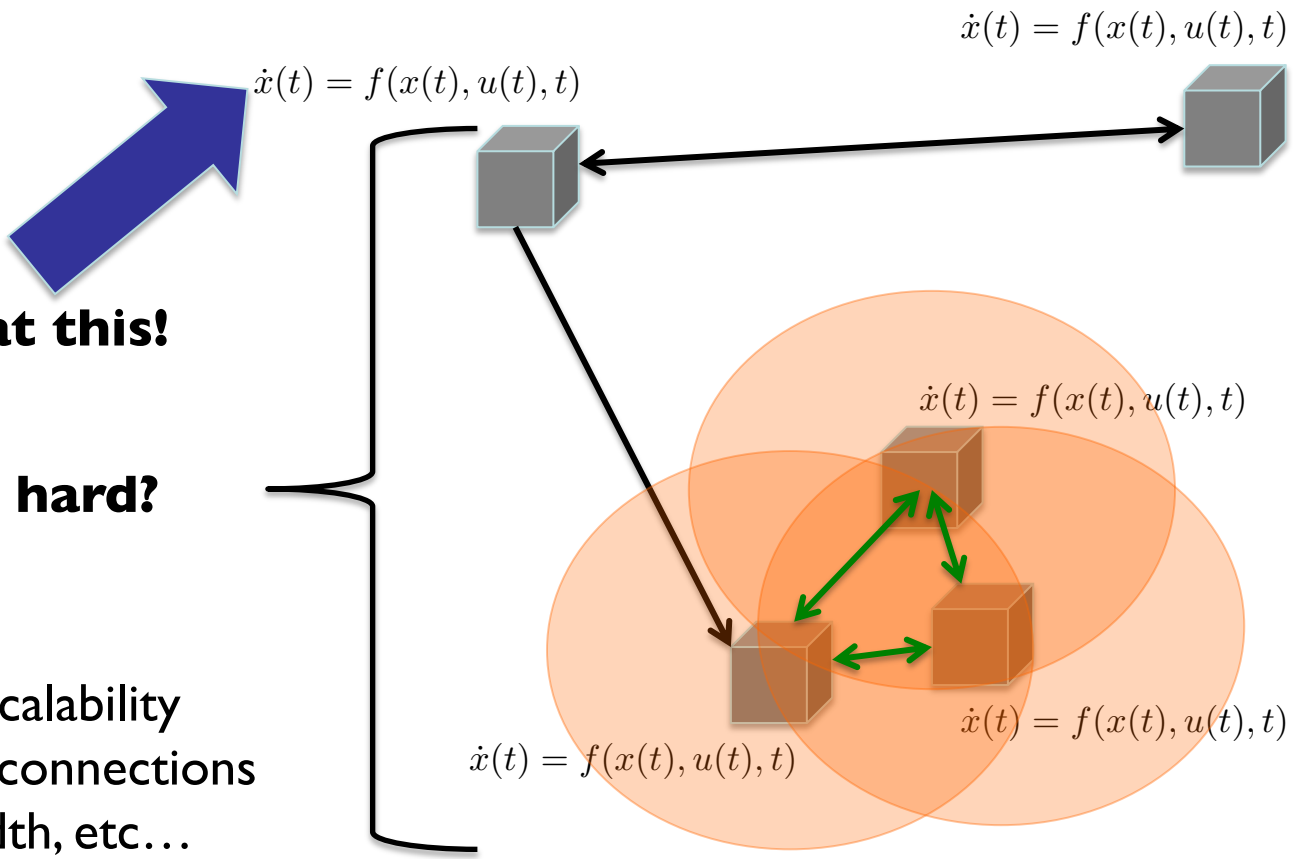


Networked Dynamic Systems

We are good at this!

Why is this hard?

- large-scale
- complexity & scalability
- variety of interconnections
- delays, bandwidth, etc…



Networked Dynamic Systems

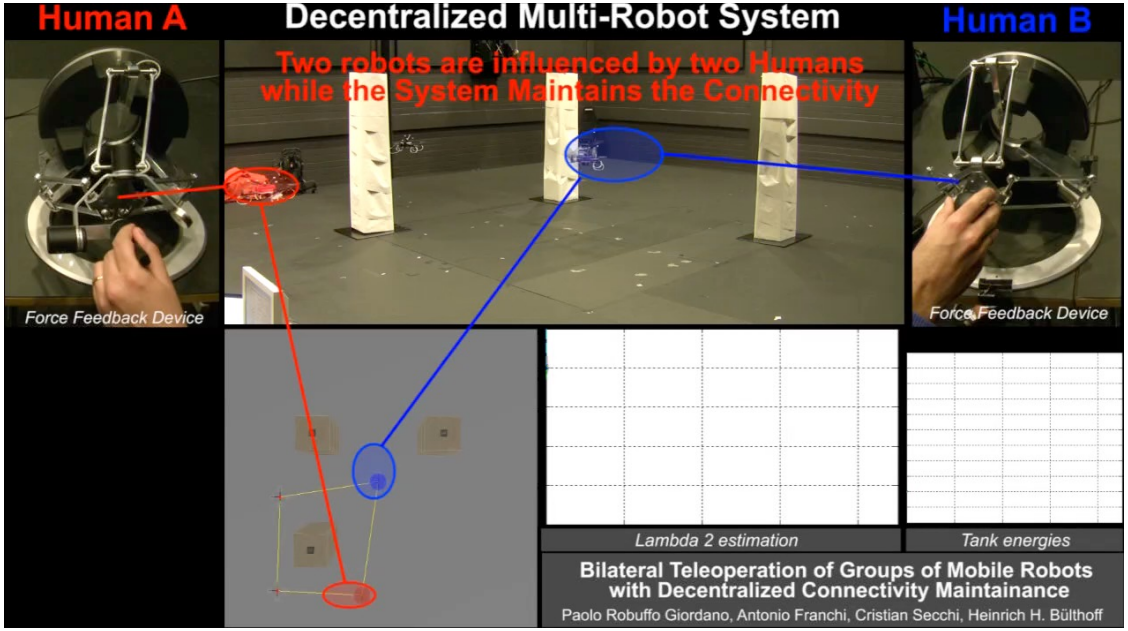
- **Decentralization**: limited sensing/communication and/or computing power
- Every agent must elaborate the gathered information to run its local controller
- The controller complexity is related to the amount of needed information
- If the whole state is needed, the complexity (~ computing power) increases with the number of agents
  - May easily become infeasible

From Nature to Engineered Systems

Course Goals

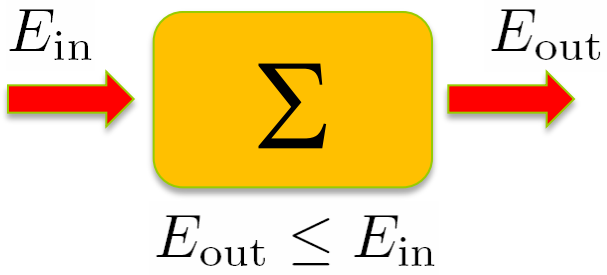
- In this example, no central unit is present
- Every agent has "its own brain"
- Relative communication and sensing depends on the current state
  - within some range
  - in visibility (no occlusions)

- **The complexity of each agent controller doesn't depend on the number of agents**
- Of course:
  - harder to design
  - harder to analyze
  - but closer to how nature works!



Passivity

- **Passivity**: intuitively, something that does not produce internal energy



- A generic nonlinear system $\begin{cases} \dot{x} &= f(x) + g(x)u \\ y &= h(x) \end{cases}$

is said to be passive if there exists a storage function

$$V(x) \in \mathcal{C}^1 : \mathbb{R}^n \rightarrow \mathbb{R}^+$$

such that $\dot{V} \leq y^T u$ or equivalently

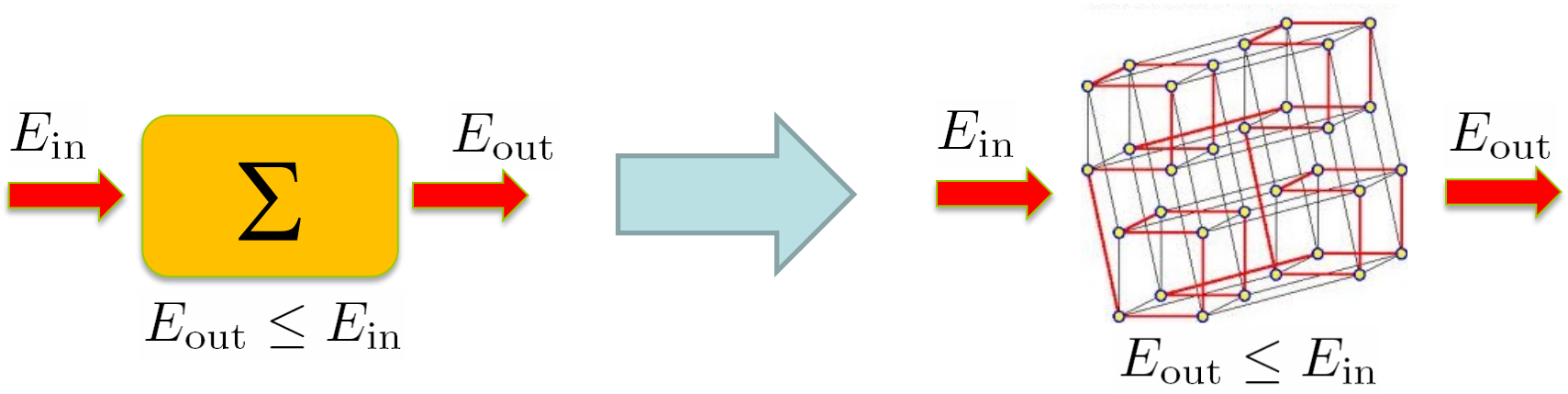
$$V(x(t)) \leq V(x(t_0)) + \int_{t_0}^{t} y^T(s)u(s)\mathrm{d}s$$

Current energy is at most equal to the initial energy + supplied energy from outside

- This condition can be interpreted as "no internal generation of energy"

Passivity: Internal Structure

- An intuition: proper interconnections of passive systems are passive



- Is this a general fact?
- Can we reduce a passive system into the "proper interconnection" of atomic passive sub-systems?

- Is there a network structure behind passivity?
  - … network structure -> multi-robot
  - … network structure + passivity -> port-Hamiltonian Modeling