Intelligent Distributed Systems

(aka: *Distributed Systems for Measurement and Automation; Distributed Robot Perception; Distributed Estiamtion for Robots and Vehicles)*

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Course presentation

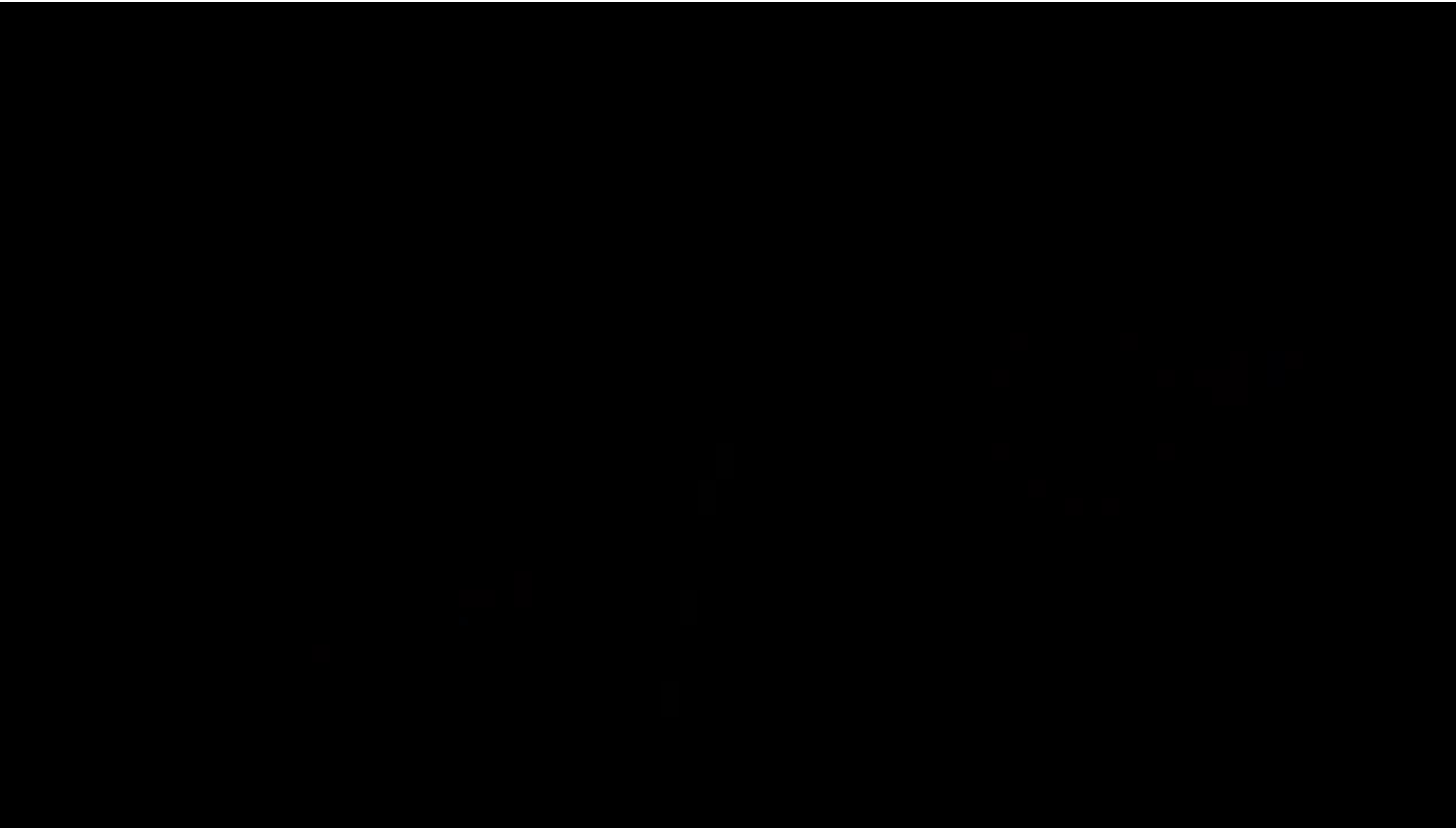
Objective: theory and practice of Intelligent distributed systems and robotic perception

- The course gives an overview of the modern industrial and robotics distributed systems
- In particular:
    - an overview of the most recent technological solutions
    - presents the technical solutions for advanced distributed systems
- These practical and theoretical issues are related to the computing and communication infrastructures of the distributed systems

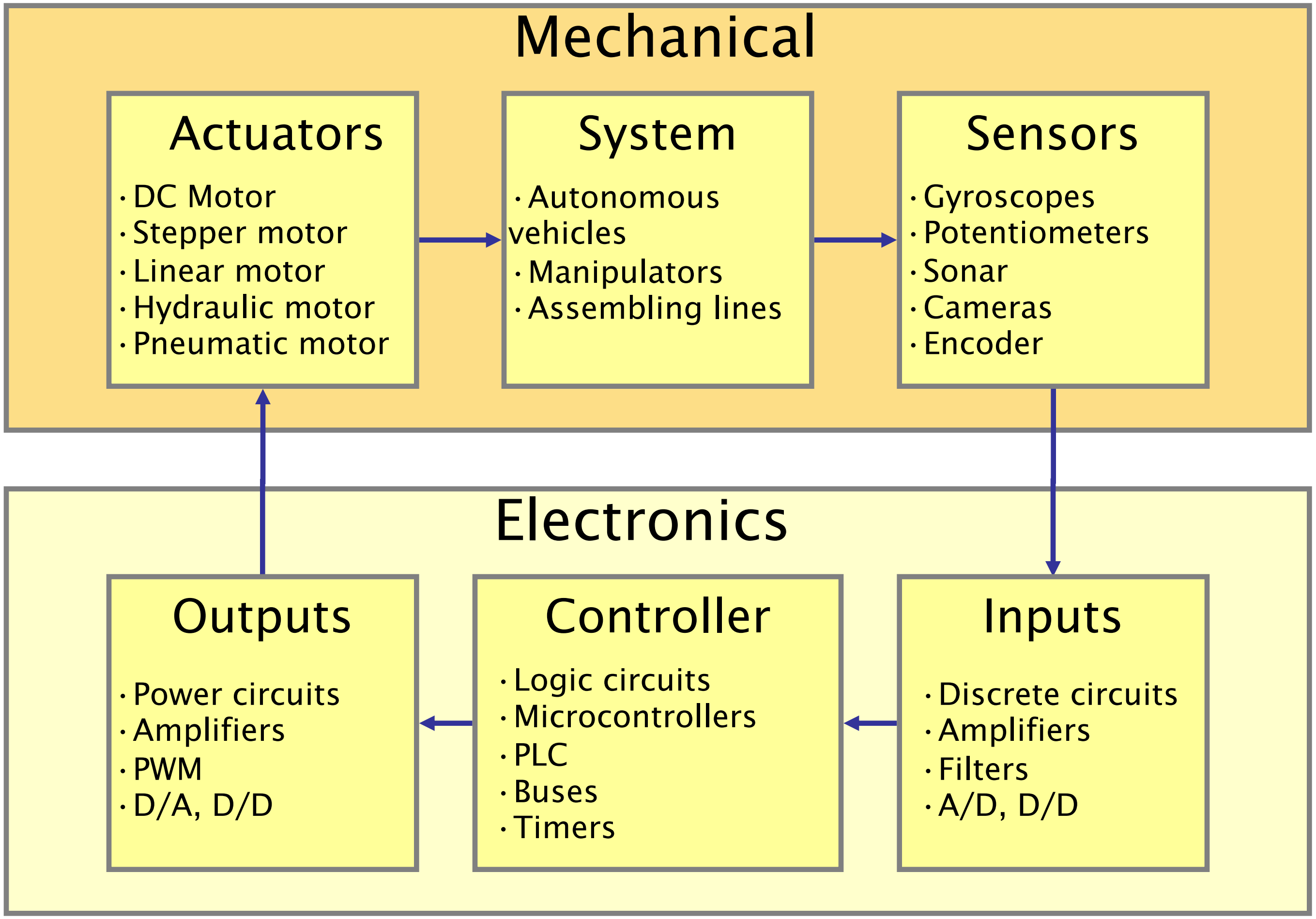
Course objectives

- The main ingredient of a *Distributed Control System* (DCS) is the presence of a communication network
- This fact has two main consequences:
  - *Many control systems* can be deployed in an environment
  - *Many sensors* from which measure the quantities of interest
- Therefore, in this course we have to be familiar with:
  - The bases of *(industrial) communication*
  - The basic notions of *distributed estimation*
  - The fundaments of *distributed consensus algorithms*
  - Some *learning-based solutions* will be presented as well for robotics perception
- *Relevant applications* will be presented throughout the course as running examples

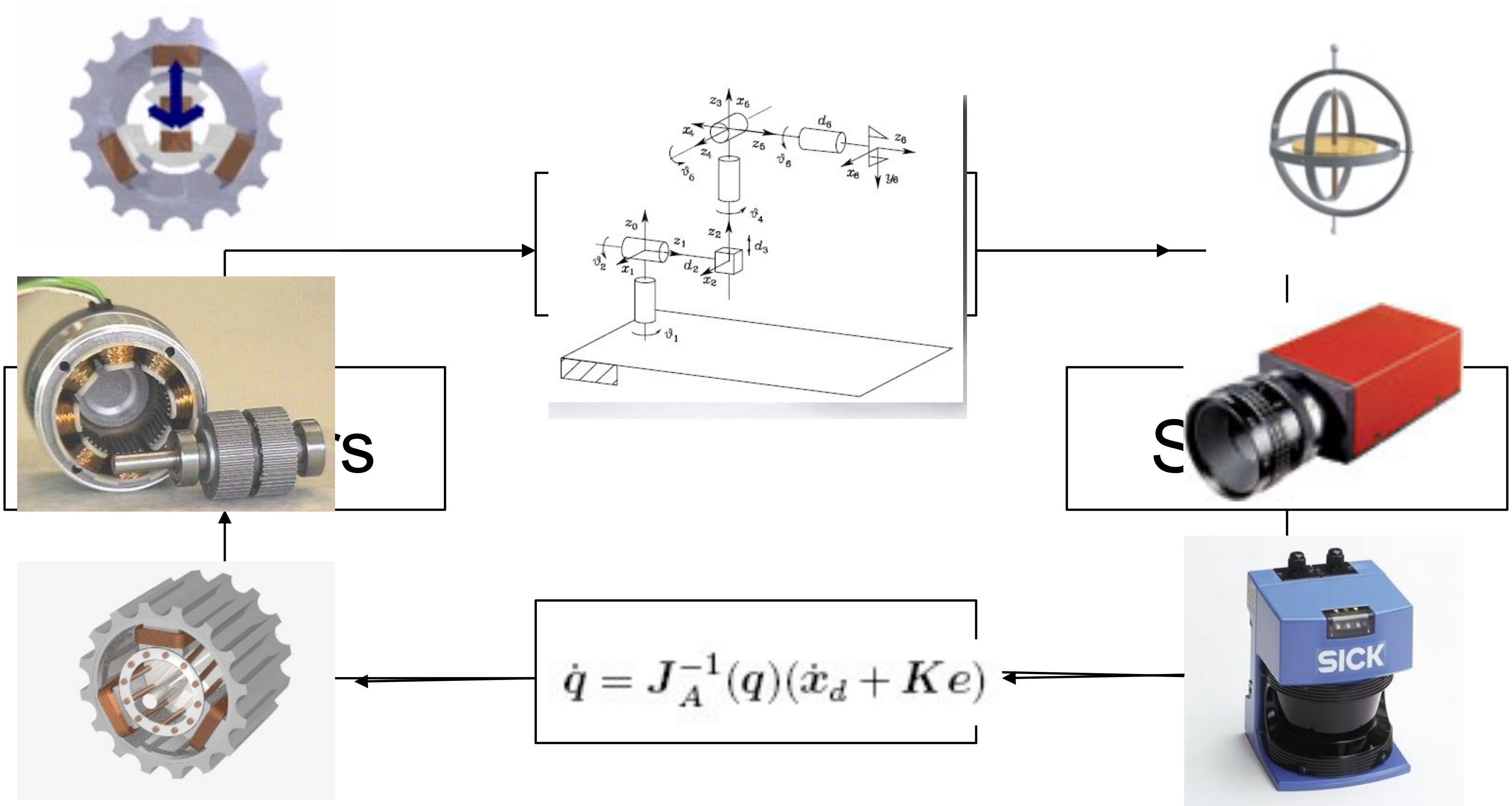
Automation



Starting point: Control System

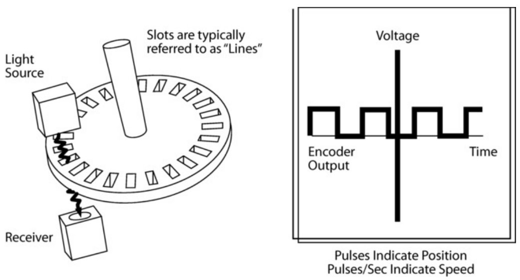


Feedback Control System

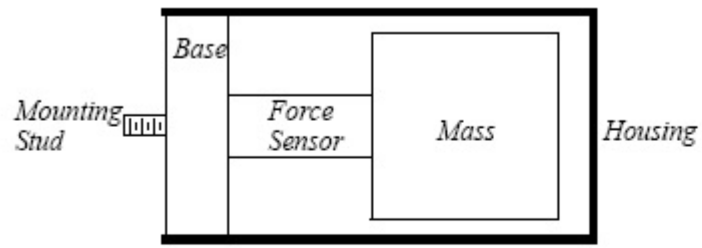


Proprioceptive sensors

Encoders
(relative/absolute posistions)

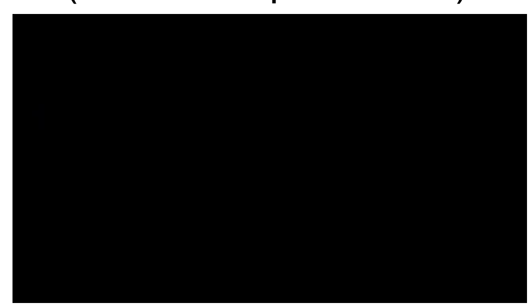


Accelerometer
(accelerations)



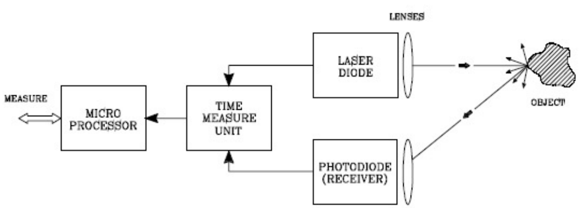
Gyroscope
(angular velocities)

Visual odometry
(relative displacement)

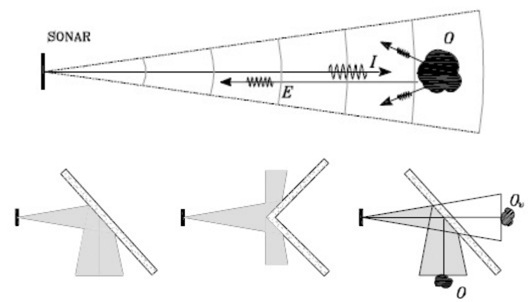


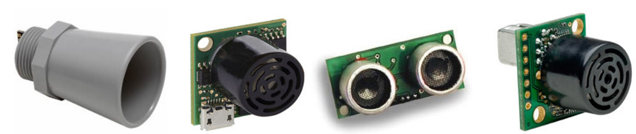
Exteroceptive sensors (I)

Laser
(position & ranging)



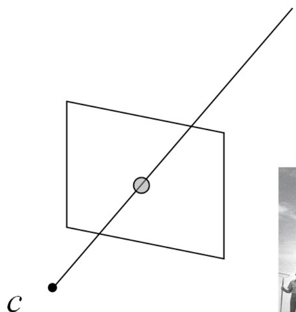
Sonar
(ranging)





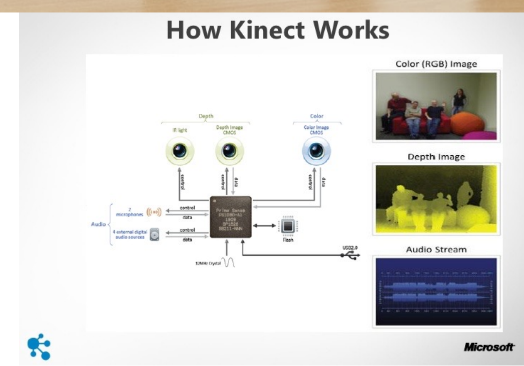
Exteroceptive sensors (II)

Cameras
(projected positions)



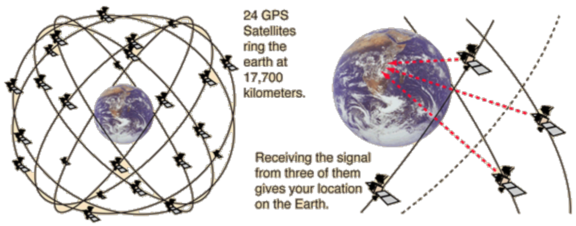
Single-view ambiguity

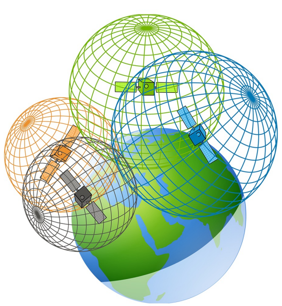
RGB-D cameras
(3D positions)

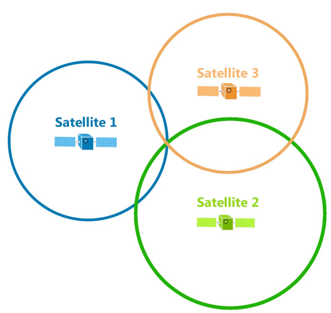


Exteroceptive sensors (III)

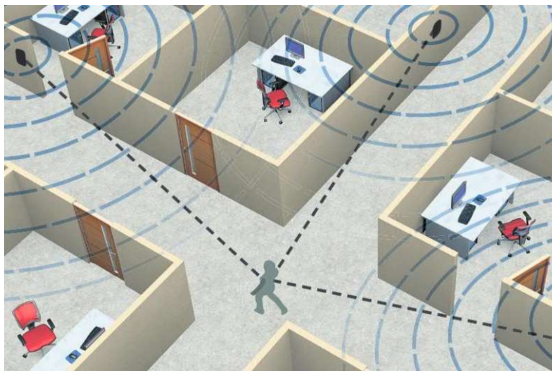
GPS

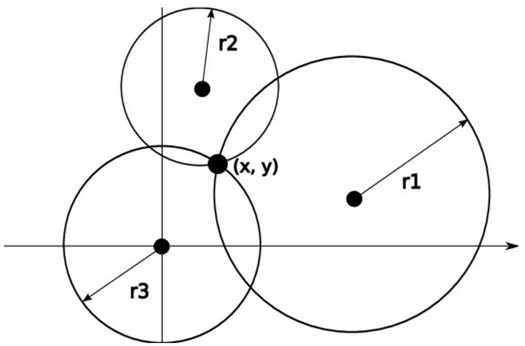






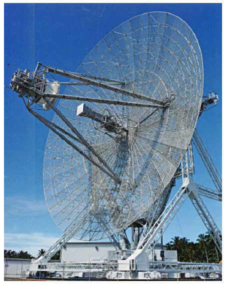
Wireless

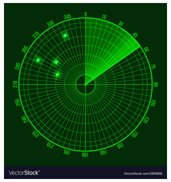


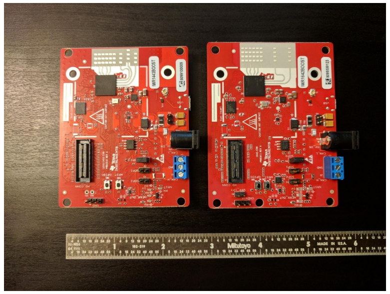


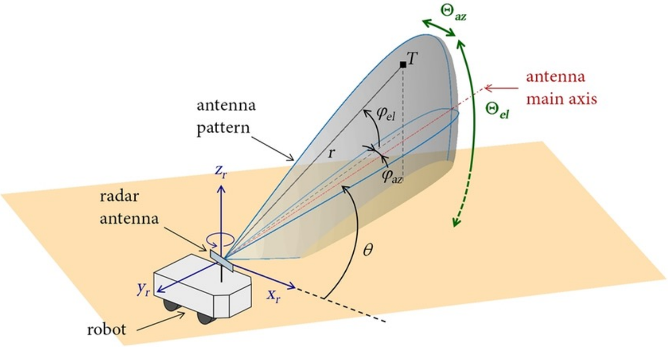
Exteroceptive sensors (IV)

Radar

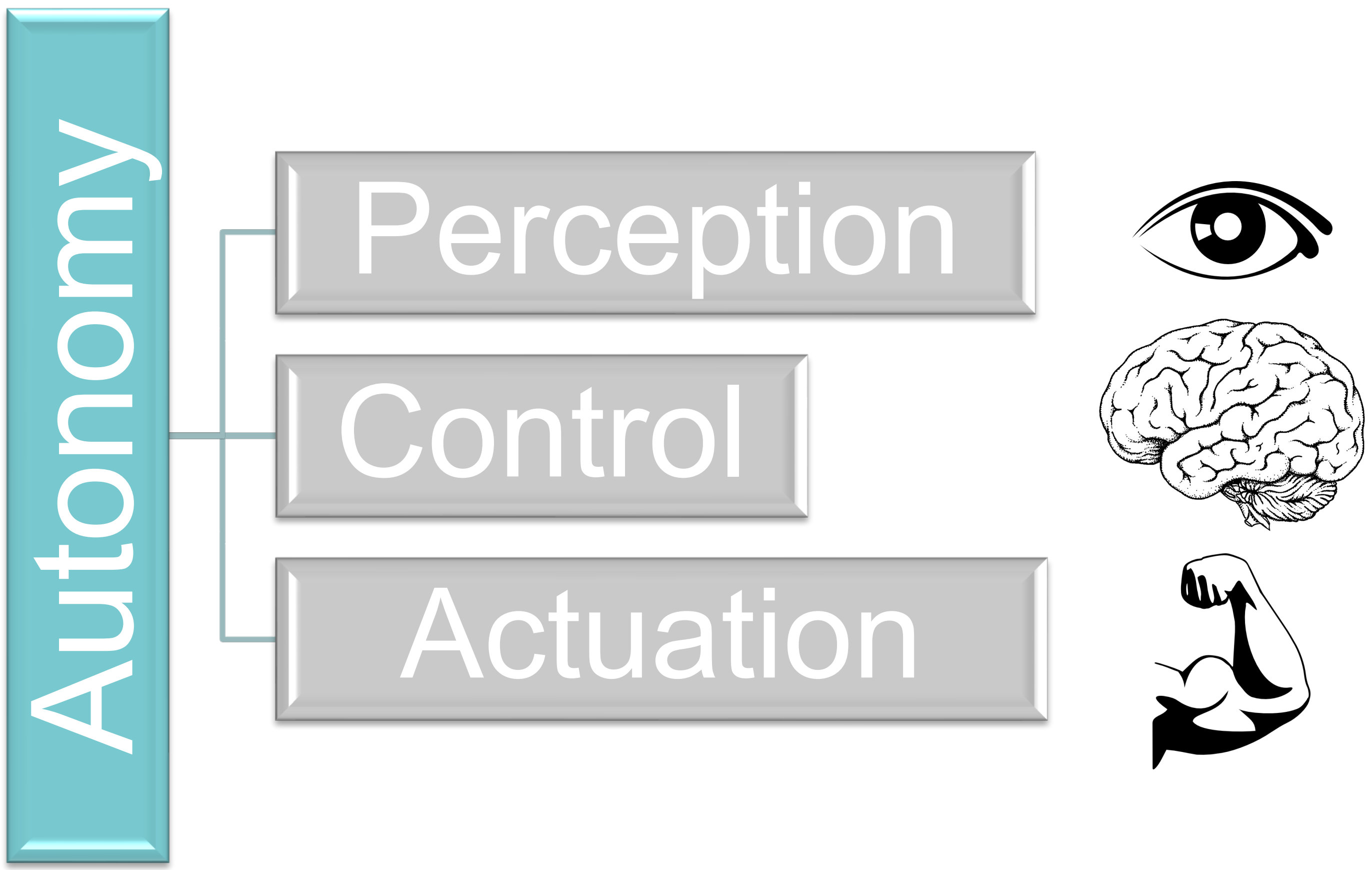








Perception: measurements and estimation



Example: Robot Autonomy

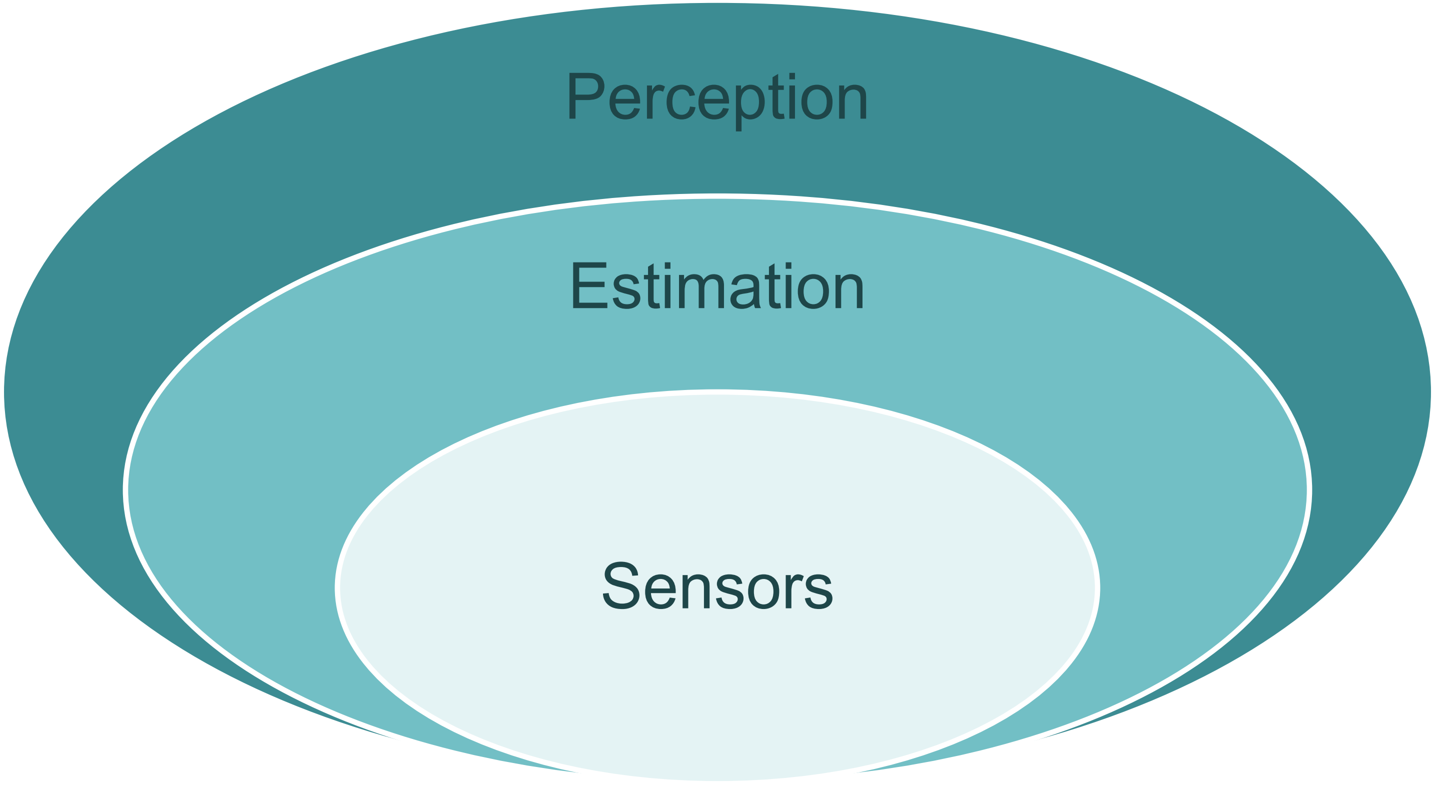
Where am I? → Localization and position tracking

Where am I going? → Mapping and Path planning

How do I get there? → Control and navigation

Perception and estimation problems!

Perception and Estimation



The long road towards autonomy

Two years until self-driving cars are on the road – is Elon Musk right?

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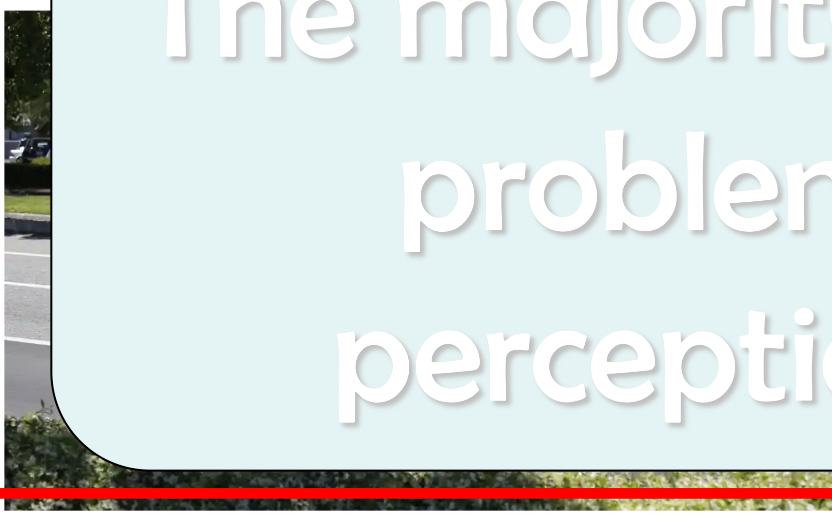


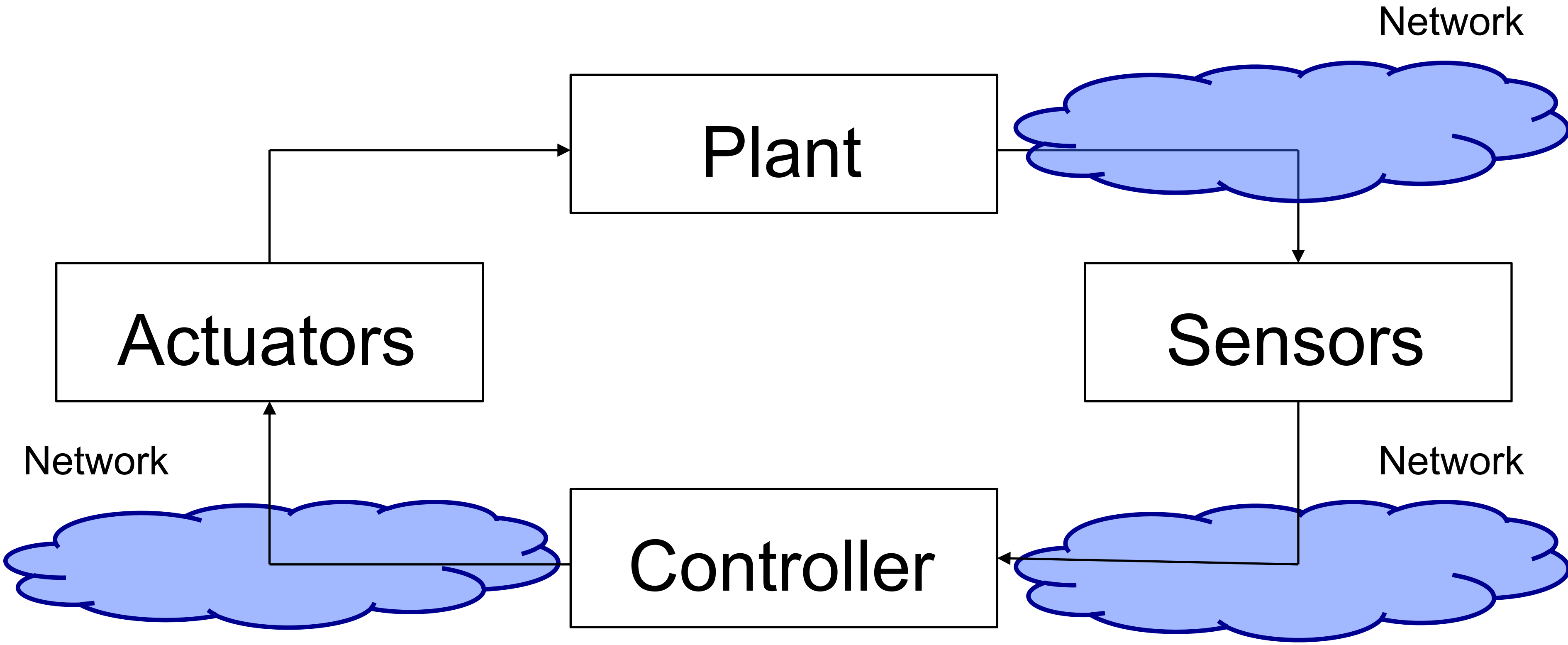
▲ Google's Sergey Brin gave a rosy prediction in 2012: 'You can count on one hand the number of years it will take before ordinary people can experience this.' Photograph: Eric Risberg/AP

- “Tesla’s Musk minimized the challenges necessary

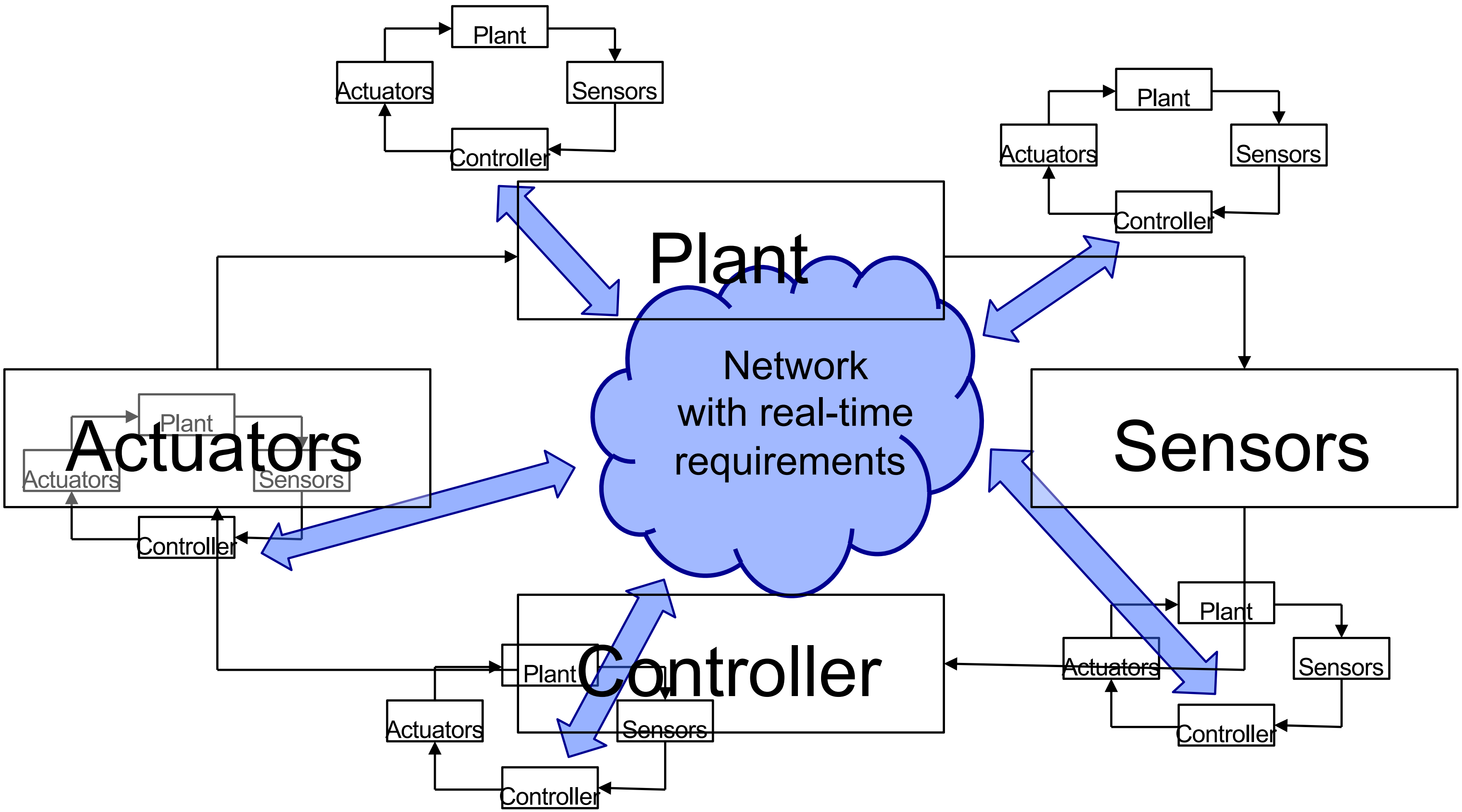
The majority of the open problems are still perception related!

Examples of state estimation

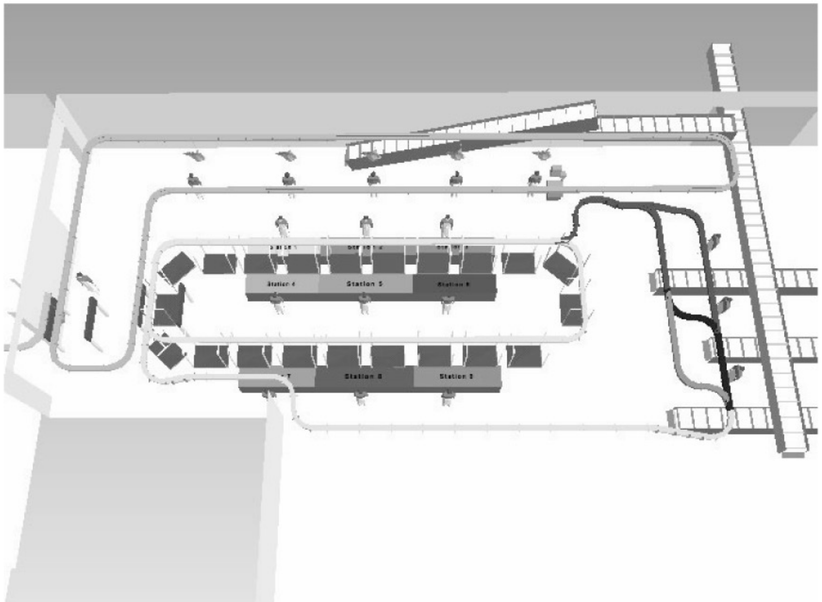
Networked Control System

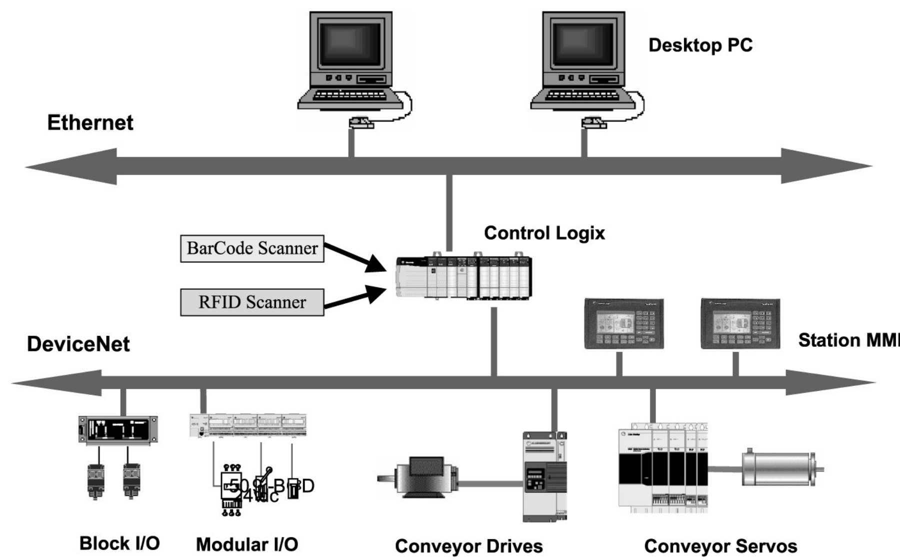


Distributed Control System



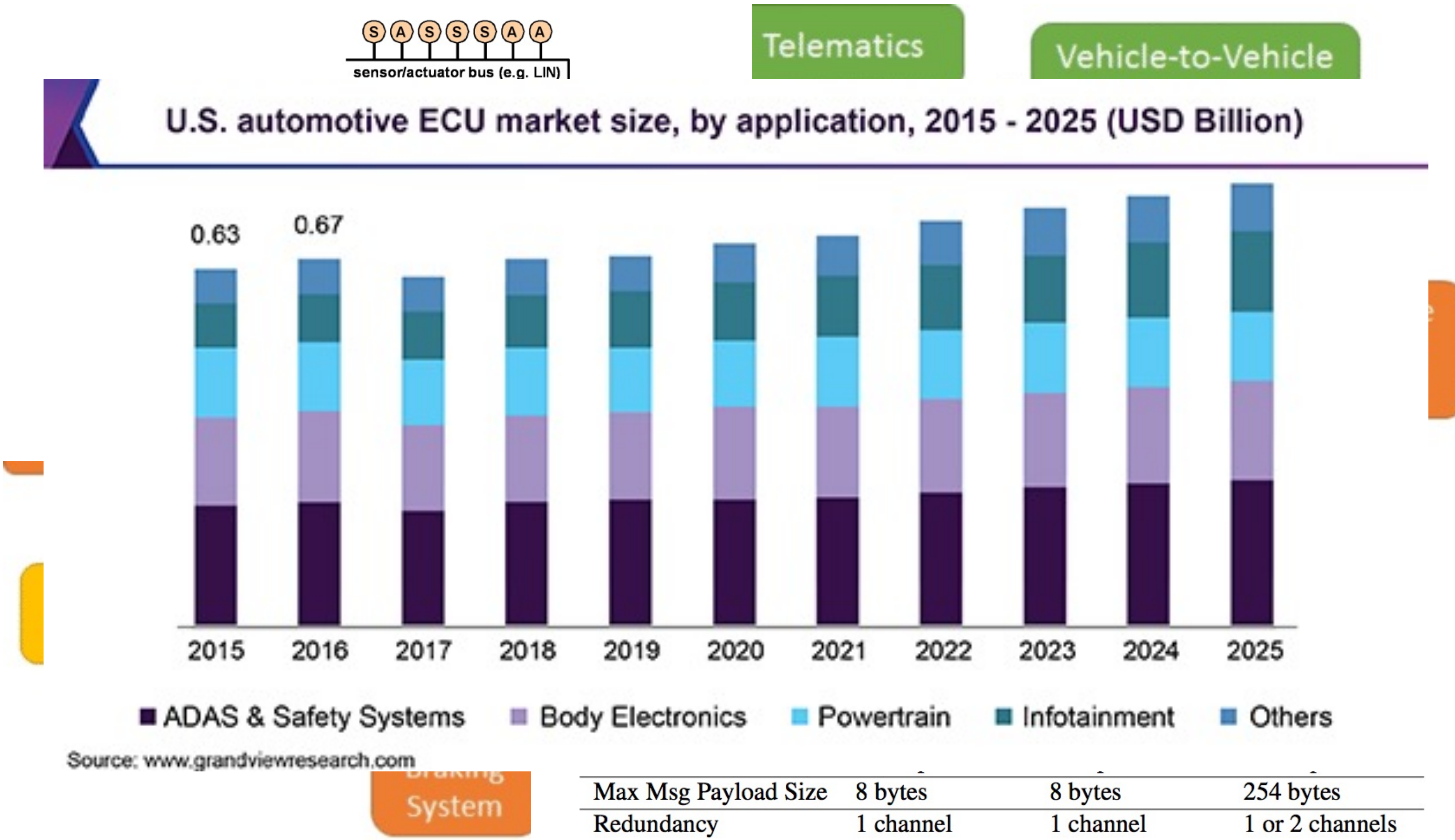
Ex: Monitoring and Control





A. Mousavi, M. Sarhadi, A. Lenk, S. Fawcett, "Tracking and traceability in the meat processing industry: a solution", British Food Journal

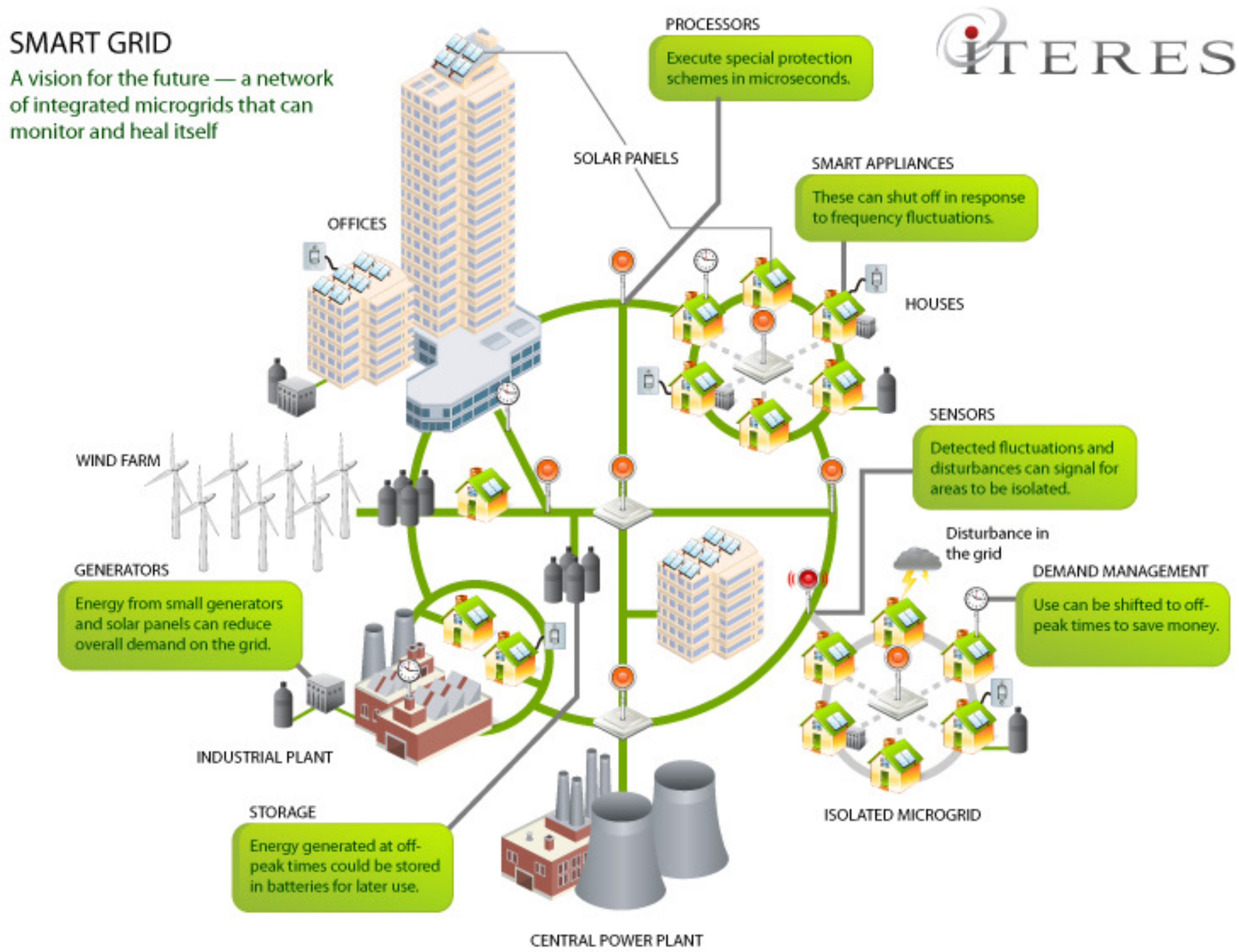
Ex: Automotive



Max Msg Payload Size	8 bytes	8 bytes	254 bytes
Redundancy	1 channel	1 channel	1 or 2 channels

Wörner M, Schuster F, Dölitzscher F, Keller CG, Haueis M, Dietmayer K. Integrity for autonomous driving: A survey. In2016 IEEE/ION Position, Location and Navigation Symposium (PLANS) 2016 Apr 11 (pp. 666-671).

Ex: Smart Grids



Motivations

- Decentralization enhance system *robustness* and *scalability*
- In industrial applications, this added flexibility opens to:
  - *Plug-and-play systems* which use sensors with different capabilities and produced from different vendors
    - Of course, a *common standard* is needed
  - *Optimization* of performance, power consumption and costs

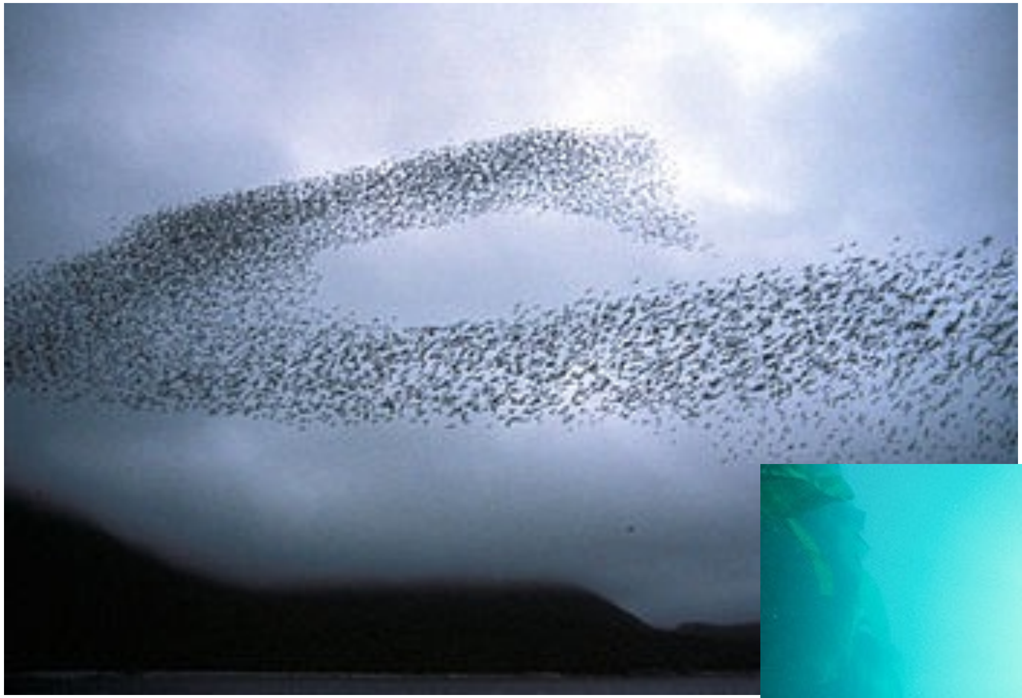
- For an effective decentralization we need to:
  - *Coordinate the controllers* by means of message exchange
  - *Fuse information* and share information between the different systems
  - *Scalability and flexibility* should be always guaranteed

Pushing forward the idea

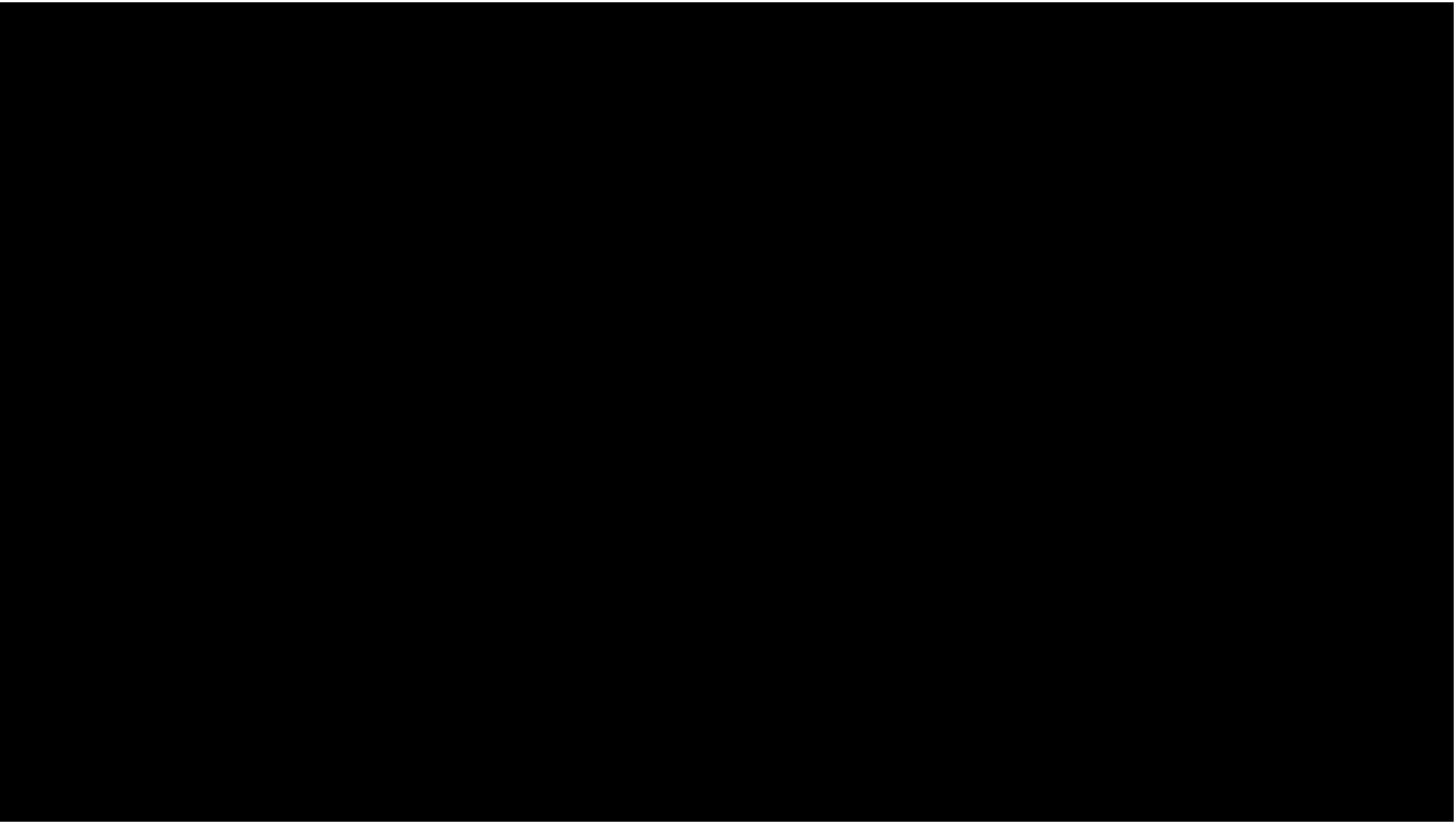
The global behavior of the system is generated by the local behaviors of the various components of the system

- This is, for instance, the idea behind:
  - *Statistical mechanics*: the global behavior is determined by the interaction of billions of particles
  - *Social networking*: there exist common social behaviors emerging from point-to-point social interactions

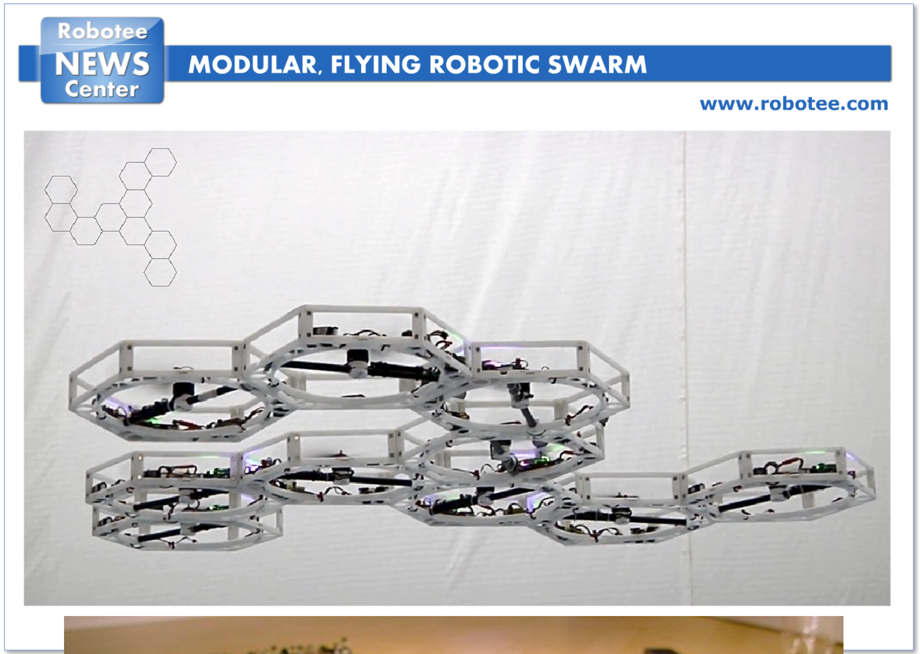
Ex: In nature…

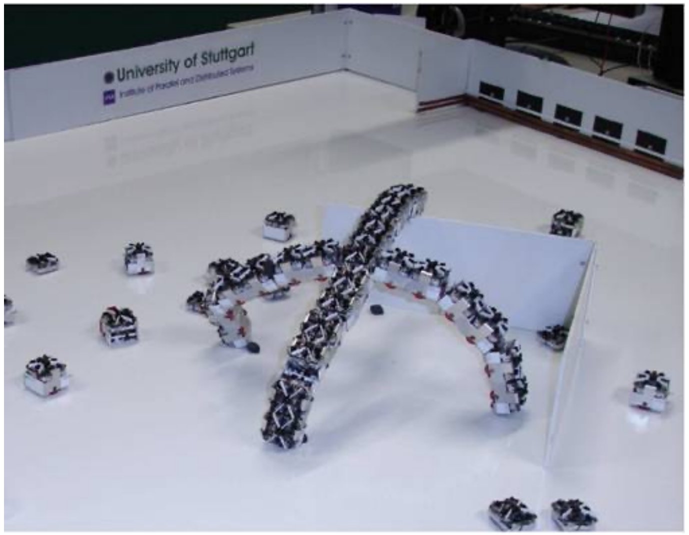


Ex: In nature...

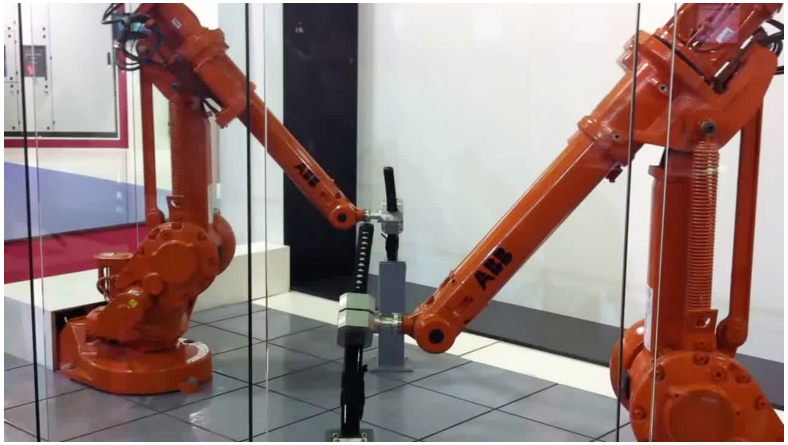


Ex: Robot Coordination

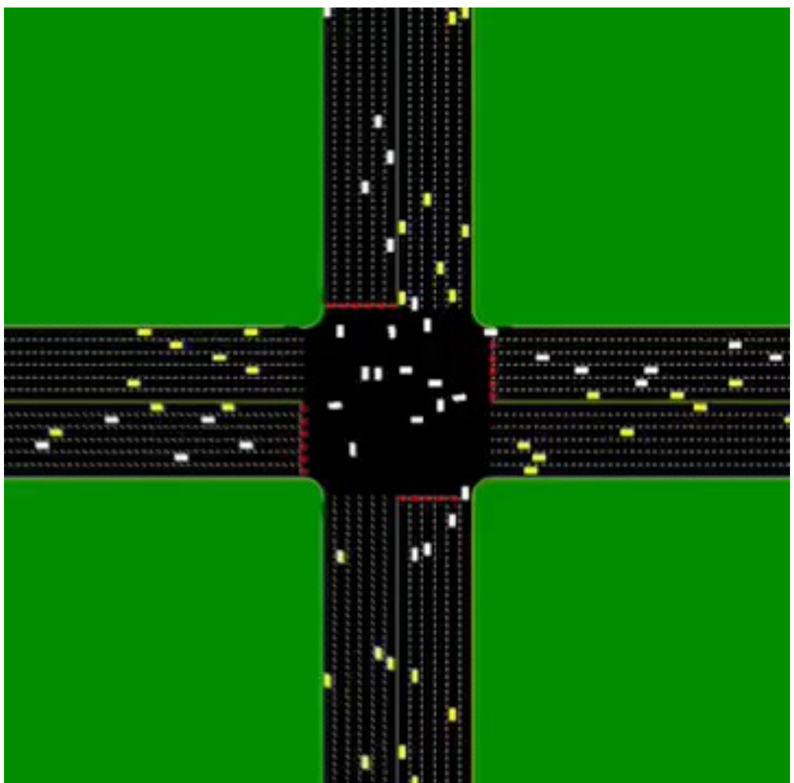




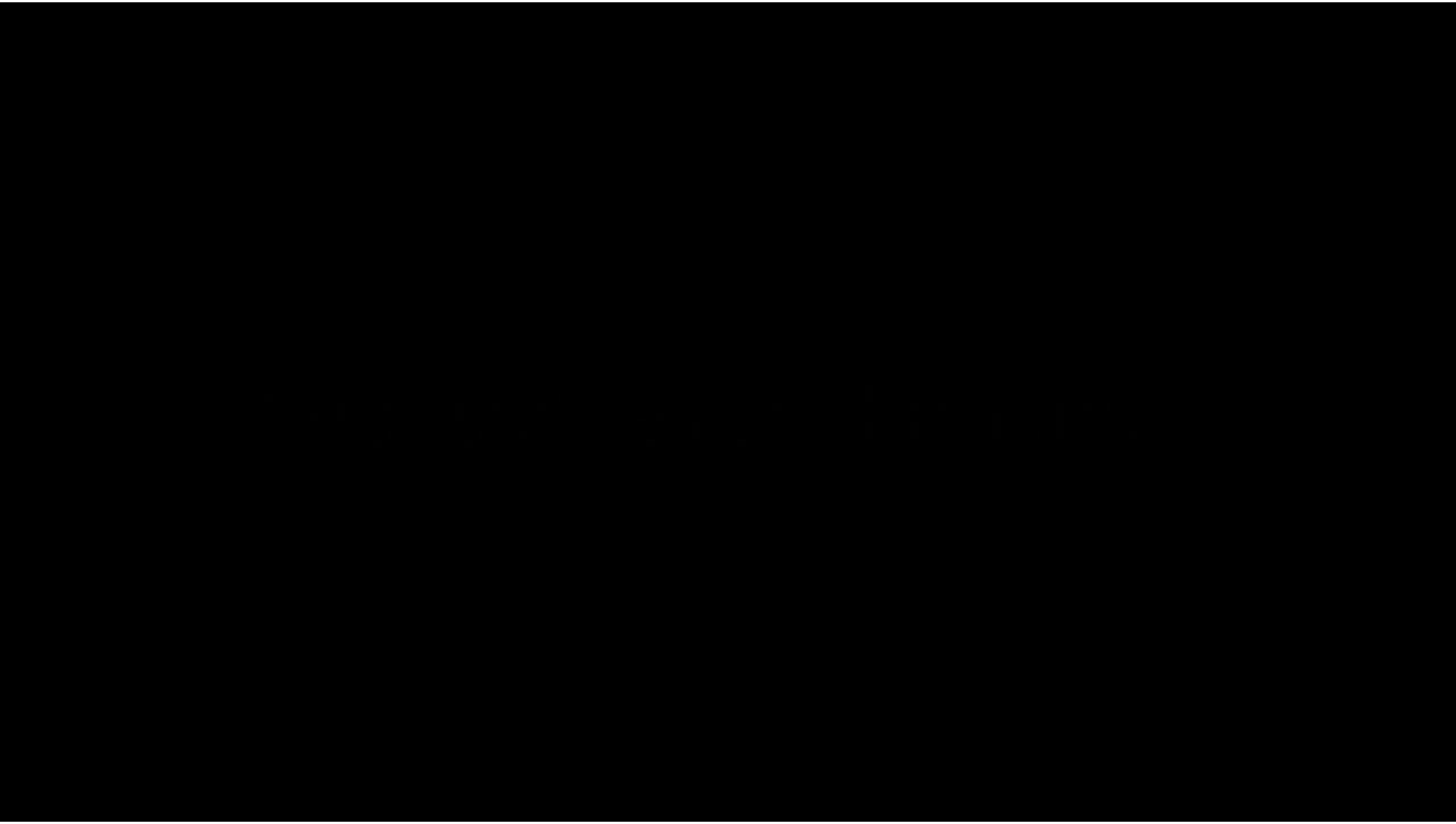
Ex: Industrial Control



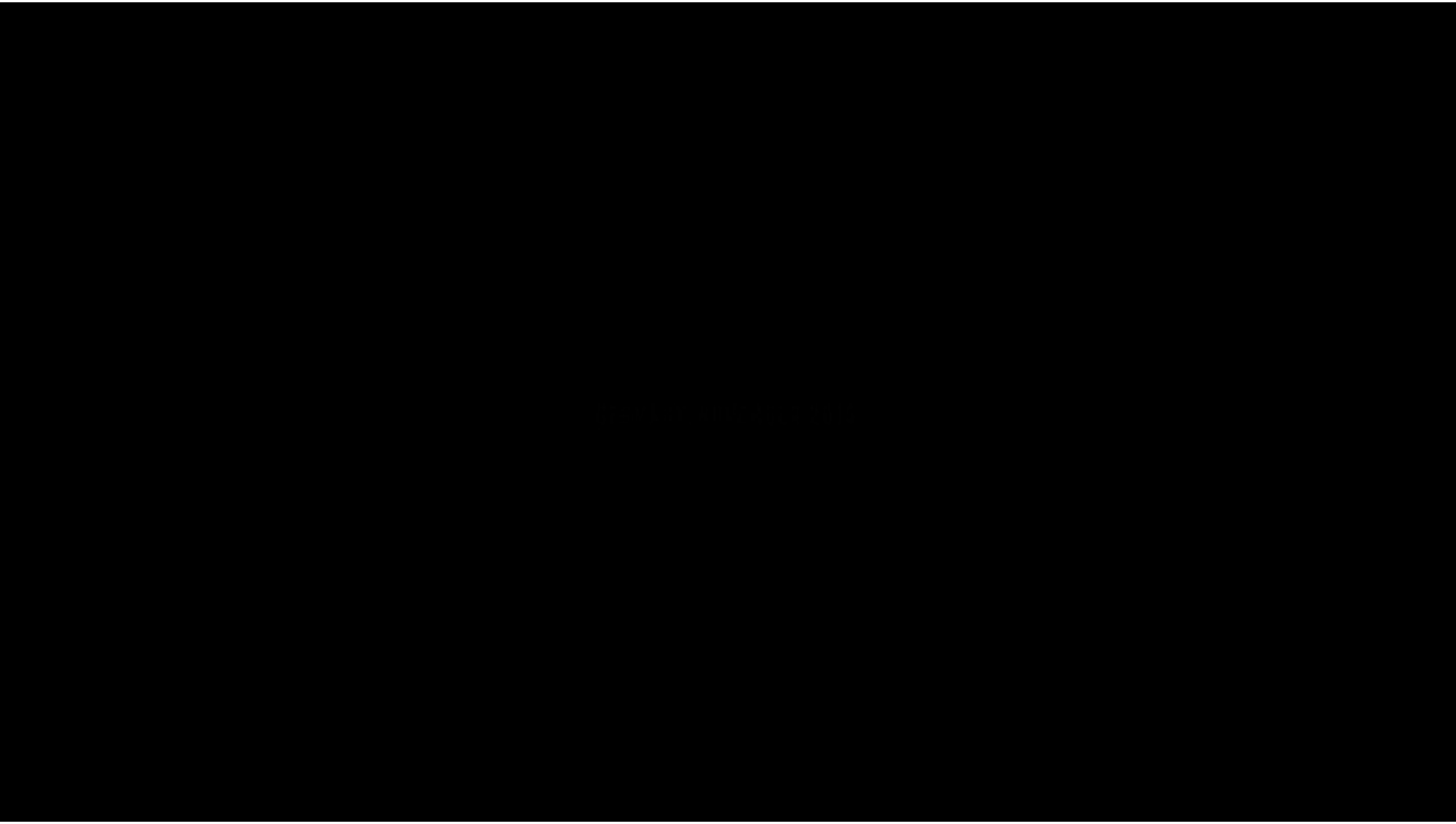
Ex: Traffic Control



Ex: Dancing Flying Robots (I)



Ex: Dancing Flying Robots (II)



Ex: UniTN Examples (I)

Multi-Agent Navigation in Human-Shared Environments: a Safe and Socially-Aware Approach

Manuel Boldrer [+], Alessandro Antonucci[*], Paolo Bevilacqua[*], Luigi Palopoli[*] and Daniele Fontanelli[+]

[+] Dep. of Industrial Engineering – DII

[*] Dep. of Information Engineering and Computer Science – DISI

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Ex: UniTN Examples (II)

Graph Connectivity Control of a Mobile Robot Network with Mixed Dynamic Multi-Tasks

Manuel Boldrer [+], Paolo Bevilacqua[*], Luigi Palopoli[*] and Daniele Fontanelli[+]

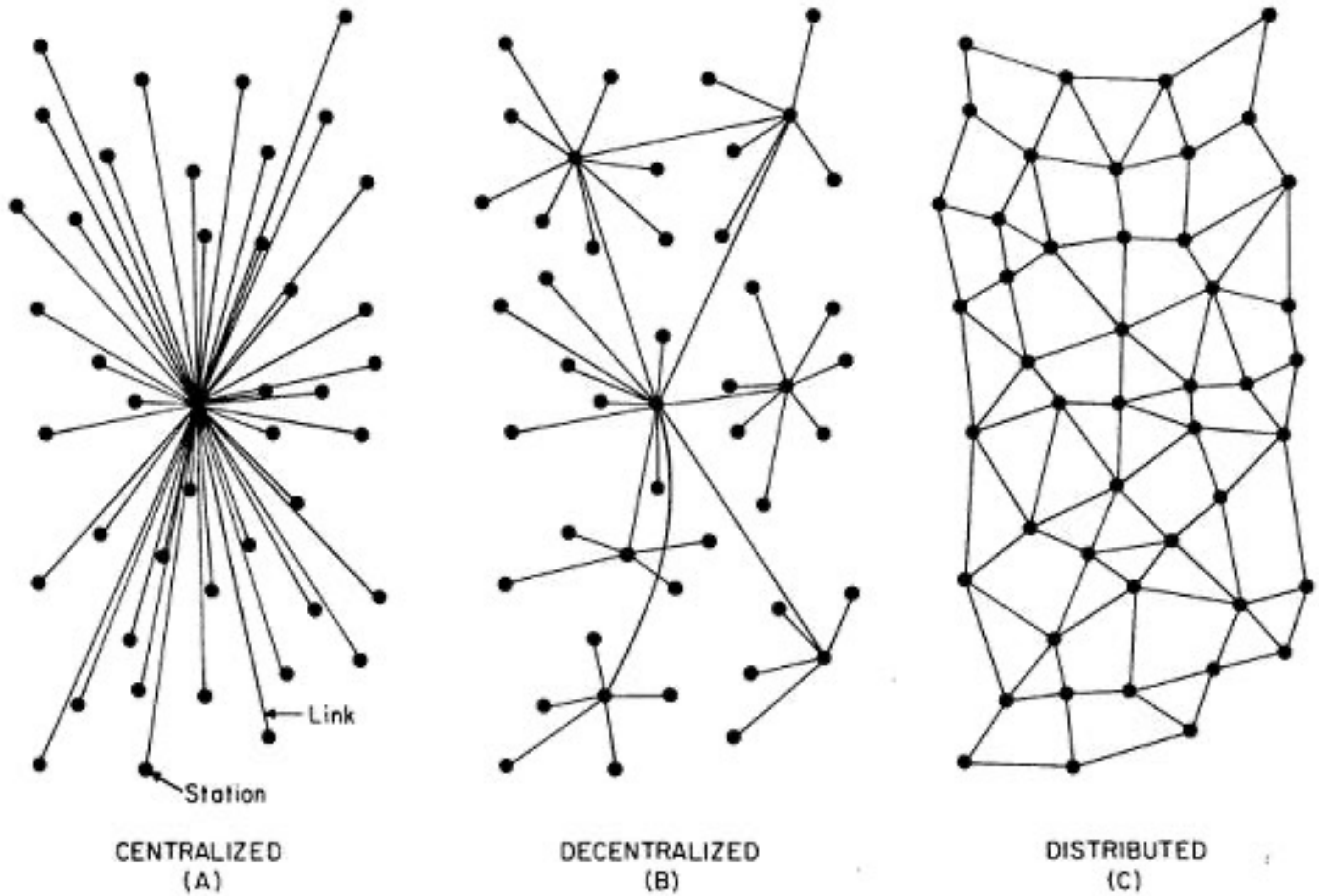
[+] Dep. of Industrial Engineering – DII

[*] Dep. of Information Engineering and Computer Science – DISI

UNIVERSITY OF TRENTO - Italy

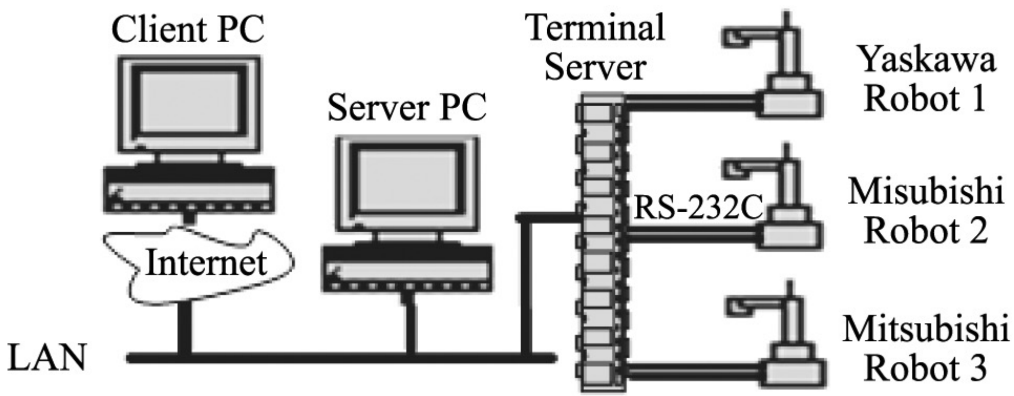
M. Boldrer, P. Bevilacqua, L. Palopoli, and D. Fontanelli, "Graph Connectivity Control of a Mobile Robot Network with Mixed Dynamic Multi-Tasks," IEEE Robotics and Automation Letters, Under Review, 2021.

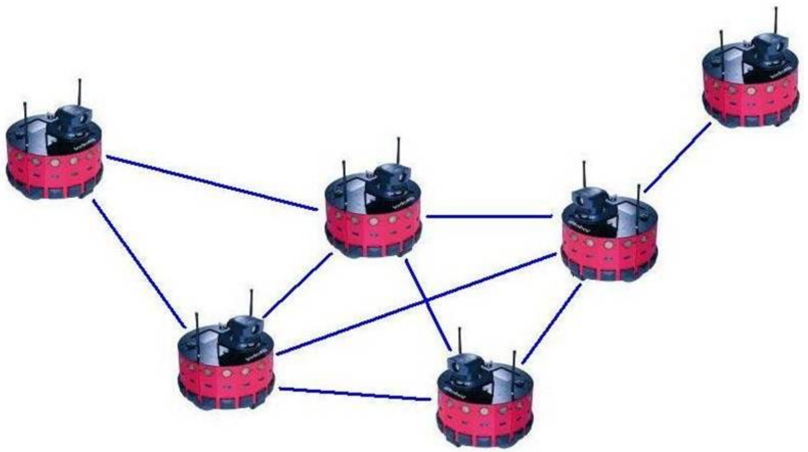
Type of Networks

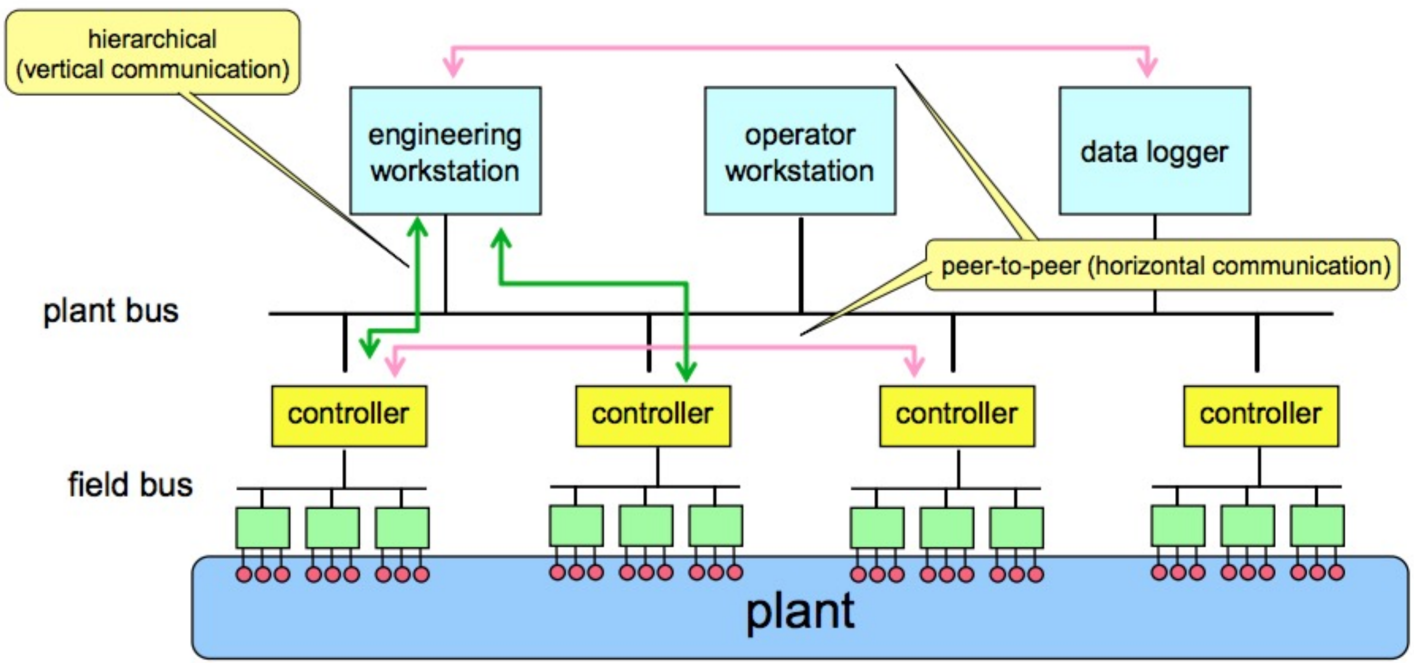


Centralized, Decentralized and Distributed Systems (Paul Baran, 1964)

Industrial Examples







Basic Ingredients

Technological

- The distributed systems rely on the presence of a communication infrastructure
  - Communication basic concepts: digital networks and components
  - IEC standards for automation: IEC61499
  - Fieldbus
  - Control Networks
  - Real-Time Ethernet
  - Wireless and Hybrid networks
  - Industrial systems for smart sensing (SCADA)

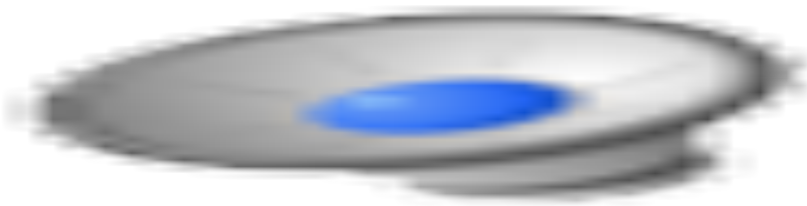
Thechnical

- IEC standards for automation: IEC61131 and Programmable Logic Controllers (PLC)
- The estimation problem: WLS and Kalman filtering
- The sampling problem and systems digitalization
- Network synchronization
- Distributed Systems with consensus
  - Basic communication graph concepts
  - Distributed measurements and estimation: distributed WLS
  - Distributed control: rendezvous and deployment problems
- Model-based learning for robotics perception (IMM, Graphical Models, PF)
- Application: Society of Robots

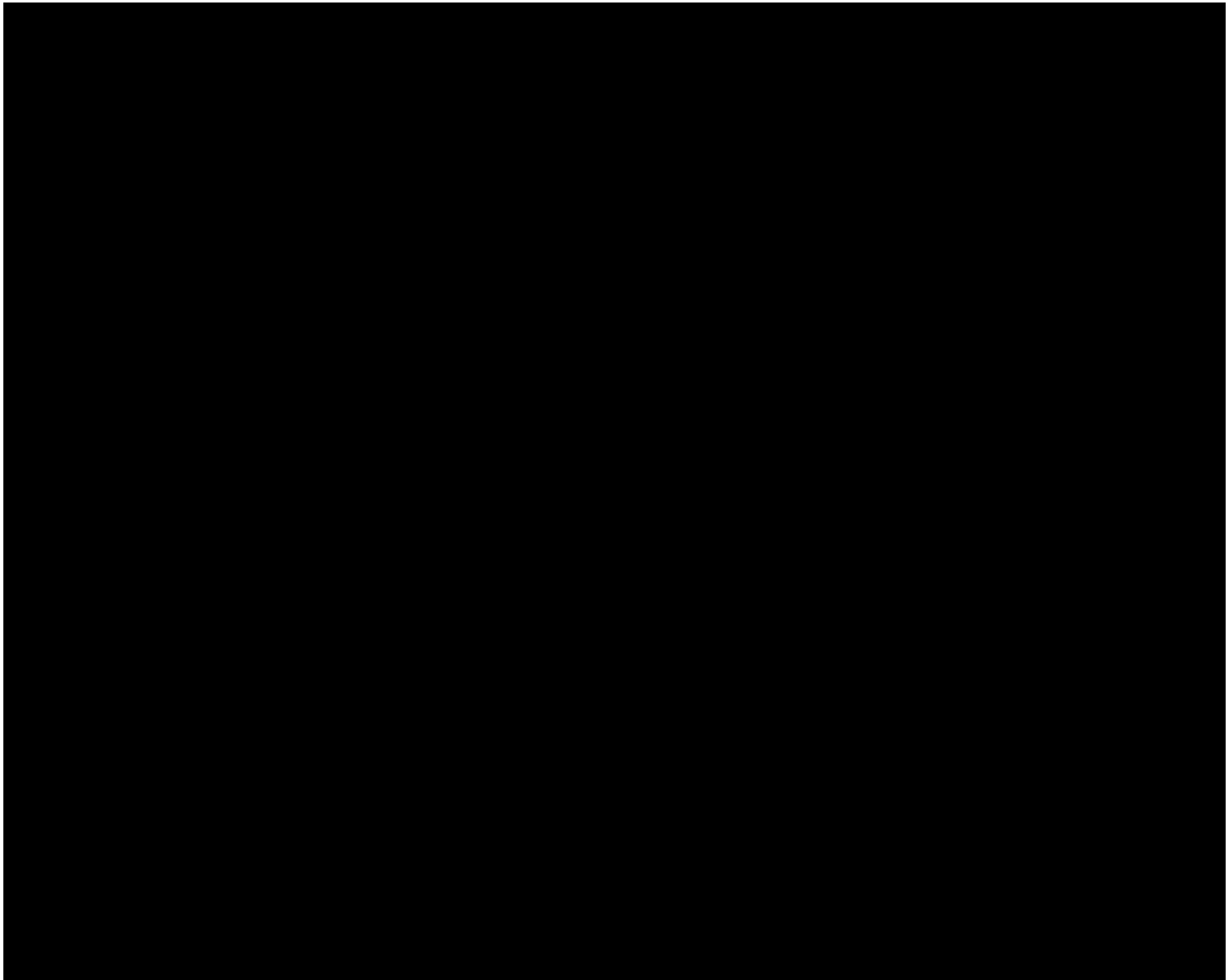
Implementation

- Practice: Parrot Mambo, Shelfy, small-scale racing vehicles, robotic lab

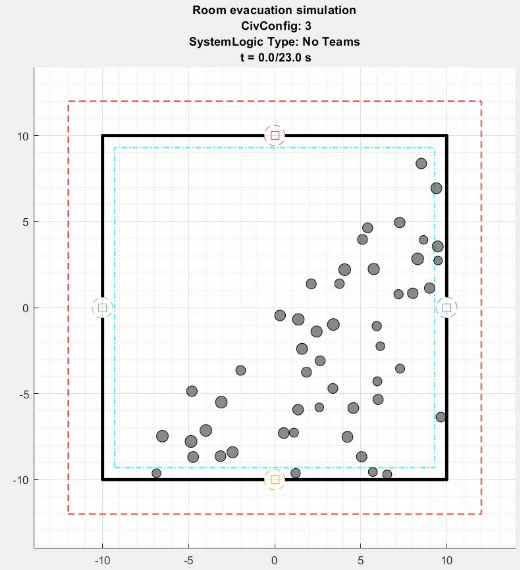
Project examples

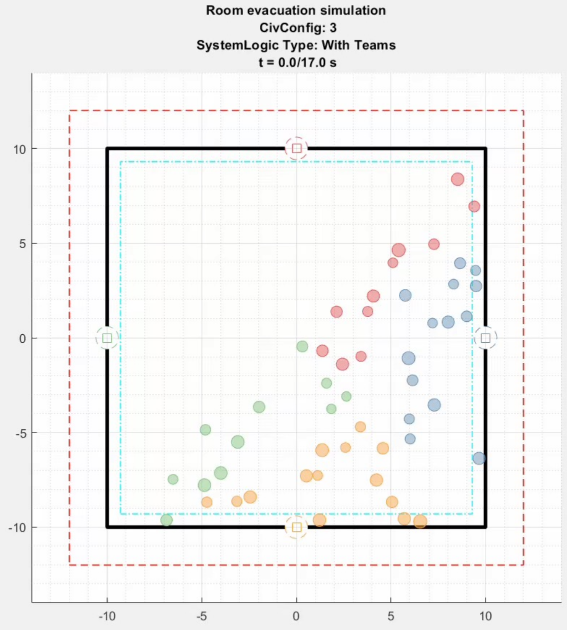


Project examples

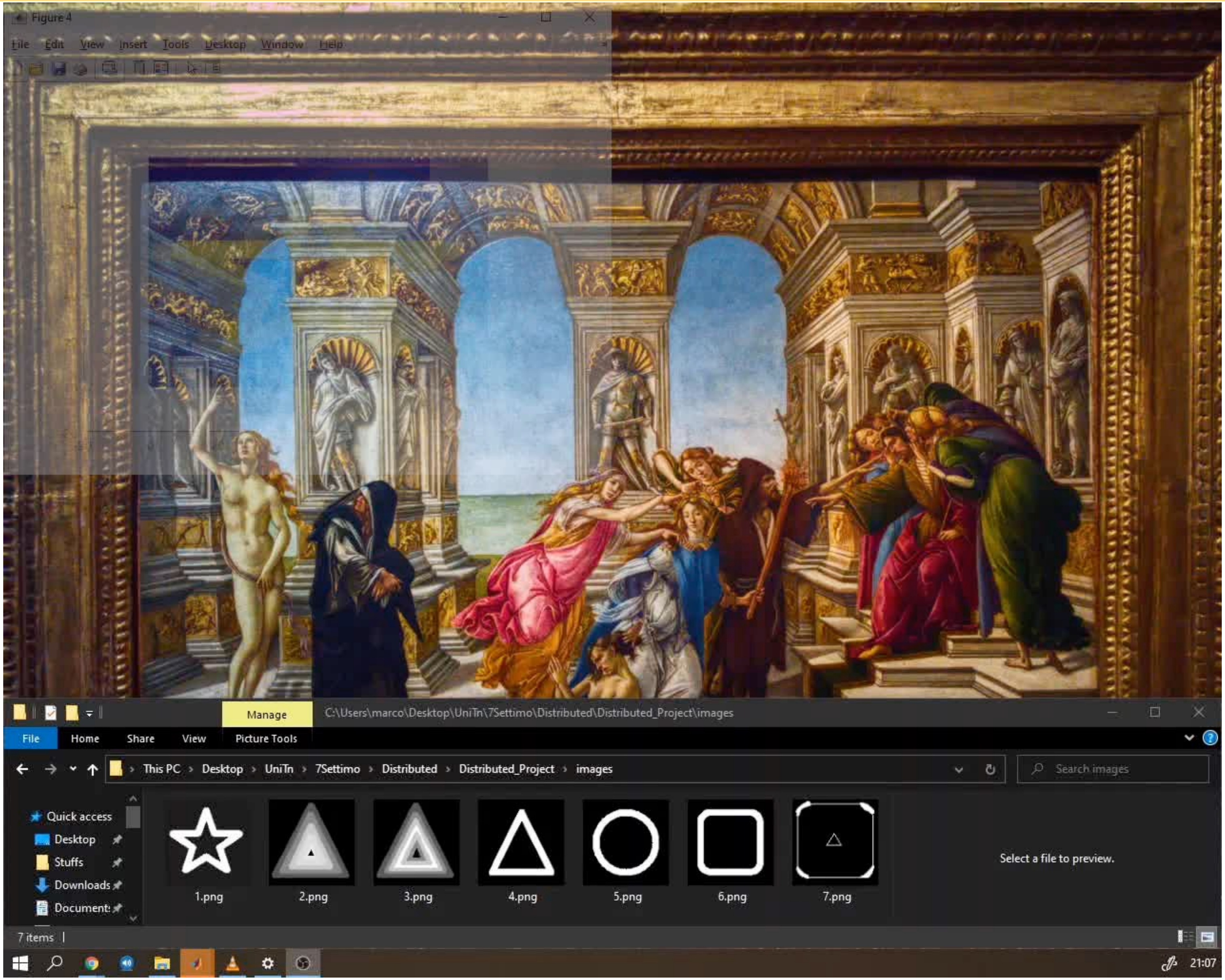


Project examples

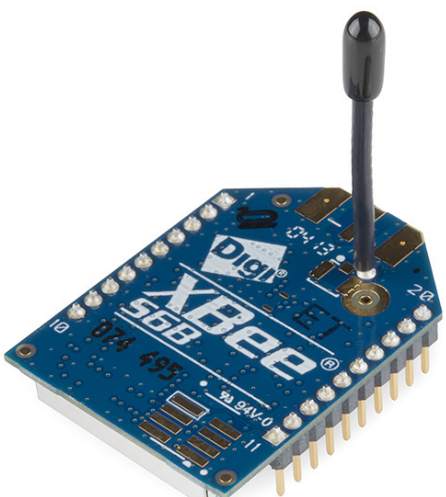


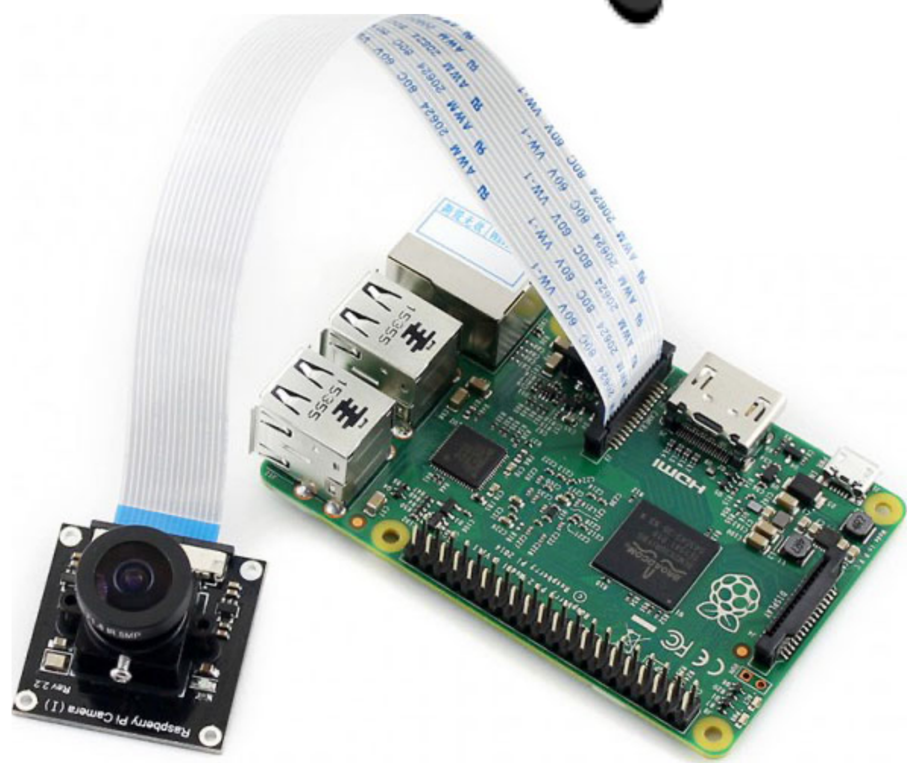


Project examples



Project possibilities





Exam rules

In order to pass the exam the students (individually or in group) are required:

- To complete a practical project on case study of interest regarding a distributed system;
- To present a project report;
- To present the simulative and/or experimental results of the project;
- To answer to **individual** questions regarding the project topics.

The mark will be given by the sum of the results based on the following scheme:

- Thoughtfulness and completeness of the project report: [0 – 10]
- Quality of the results: [0 – 10]
- Correctness of the **individual** question/answer: [0 – 10]

The purpose of the exam is to verify the knowledge gained during the course, the problem-solving ability of the student, the capability for problem analysis and synthesis of results. The final grade comes from a blended opinion of the previous abilities as well as on the originality, scientific soundness and technical validity of the presented project.

The project should be delivered **at least 48h** before the exam discussion

Project report

Project Report (double column, article style)

a) Abstract, introduction and problem formulation

b) Distributed system adopted (SCADA, DCS, robot network, etc.)

c) System model (robot, sensors and actuators)

d) Proposed solution (control laws, estimators, etc.)

e) Implementation (practical and/or developed simulator)

f) Experimental results on the system, to be shown with numeric data evidence and graphs (>= 2 pages)

g) Conclusions and discussions of the benefits and limits of the application and possible future directions

Use the template model available. The report should be of a length between 6 to 8 pages.

Calendar organisation

	Settembre									Ottobre												Novembre															Dicembre								
	12_16			19_23			26_30			3_7			10_14			17_21			24_28			31_4			7_11			14_18			21_25			28_2			5_9			12_16			19_22		
Intelligent Distributed Systems	3	2	2	3	2	2	3	2	2	3	2	2	3	2	2	3	2	2	3	2	2			2	3	2	2	3	2		3	2	2	3	2	2	3	2	2	3	2	2	3		
Distributed systems for measurement and automation										3	2	2	3	2	2	3	2	2	3	2	2			2	3	2	2	3	2		3	2	2	3	2						2	2	3		
Distributed Robot Perception										3	2	2	3	2	2			2	3	2	2			2	3	2	2	3	2		3	2	2	3	2	2	3	2	2	3					
Distributed estimation for robots and vehicles										3	2	2	3	2	2	3	2	2	3	2	2			2	3	2	2	3	2		3	2	2	3	2						2	2	3		