Università degli Studi di Napoli
Federico II

SINCRO Research Group
Automation and Control of Nonlinear and Complex Systems

Mario di Bernardo
Professor of Automatic Control
Department of Electrical and ICT Engineering

UniNA-Bauman MoU Kick-off meeting – 20th October 2021

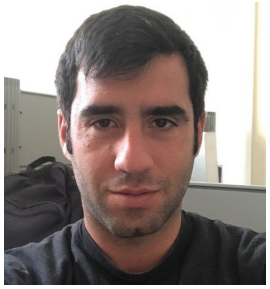
The University and the Department

- Founded in 1224 AD
- Over 90,000 students and 2500 members of academic staff
- The Department of EE and ICT (DIETI) is one of the largest [150 faculty and 7000 students]
- Automation, Biomedical, IT, Electronic, Electrical Telecommunication, and and Computer Engineering, Computer Science

SINCRO Research Group

- 2 Full professors
- 2 Associate Professors
- 1 Assistant Professor
- 3 Postdocs
- 10 PhD students



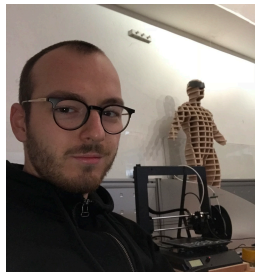











Our Group Mission

Our Group mission is *to develop strategies to control and orchestrate the collective behaviour of large-scale complex multi-agent systems*

- Expertise and know-how:
  - Mathematical Modeling
  - Nonlinear Dynamics and Nonlinear Control
  - System Identification
  - Optimization and Optimal Control
  - Analysis, Synchronization and and ControlComplex Networks
  - Multiagent systems
  - Hybrid and discontinuous Control Systems
  - Control via AI and Reinforcement Learning
  - Applications areas: *smart grids, synthetic and computational biology, human-machine interaction, autonomous systems, mobile and swarm robotics, computational social sciences*

Control of complex systems

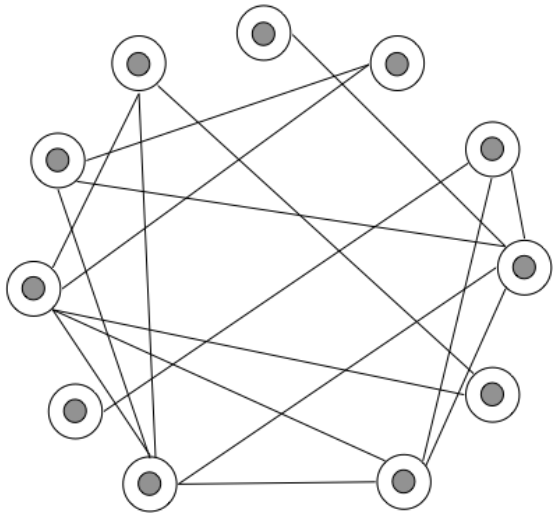
- Traditionally control system design has focussed on automating individual systems and devices
- This paradigm is being constantly challenged by applications
- These are characterized by **not one but many** agents who need to cooperate with each other to perform a desired task

Mathematical Framework

- These problems are all complex network systems

Agent dynamics

$$\dot{x}_i = f_i(x_i) + g_i(x_i)u_i, \quad i = 1, \ldots, N$$



Coupling protocol

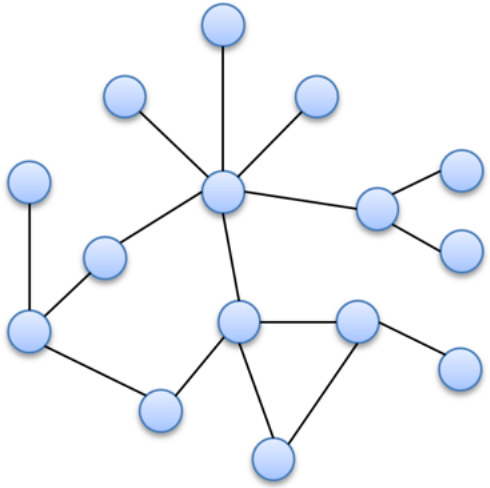
$$u_i = \sigma \sum_{j=1}^{N} a_{ij} \left[h(x_j) - h(x_i) \right]$$

Network structure

$$\mathcal{L} = \mathcal{D} - \mathcal{A}$$

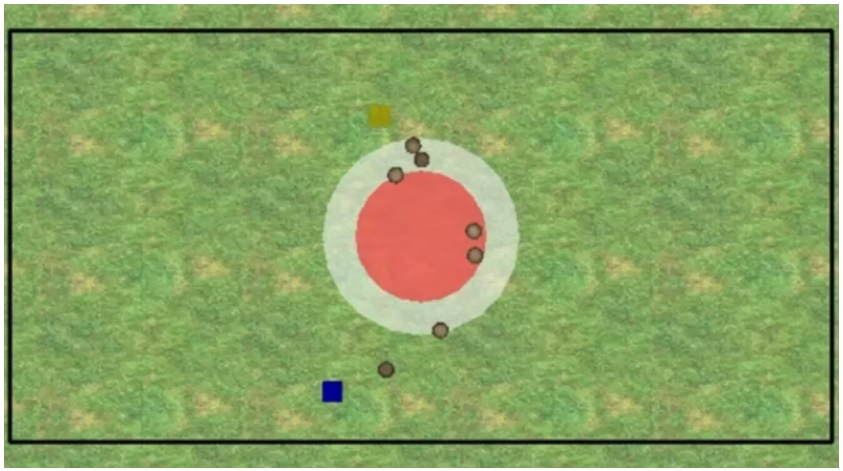
Key open challenge

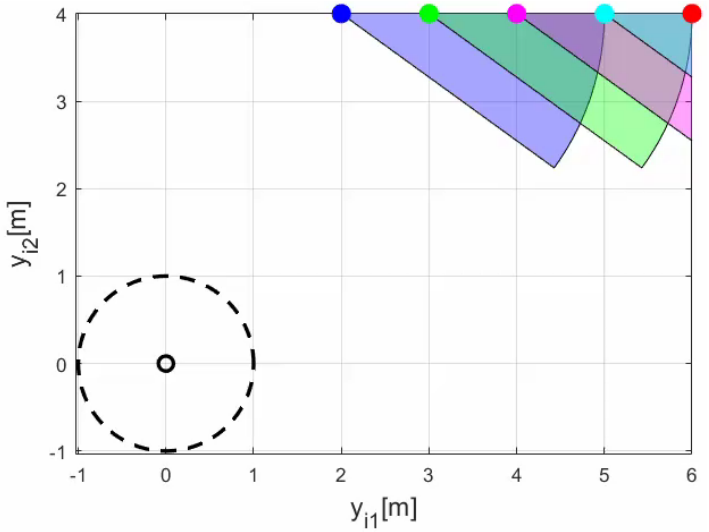
How can we coordinate and orchestrate the behaviour of many interacting agents, to perform a desired task?



Cooperative control

- How do we control flocks, swarms and groups of autonomous agents in a distributed manner?
- Applications: *mobile agents, autonomous vehicles, security and surveillance, Industry 4.0*



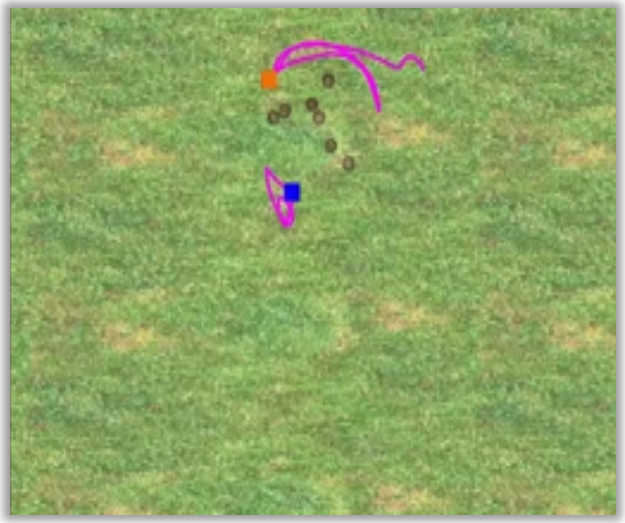


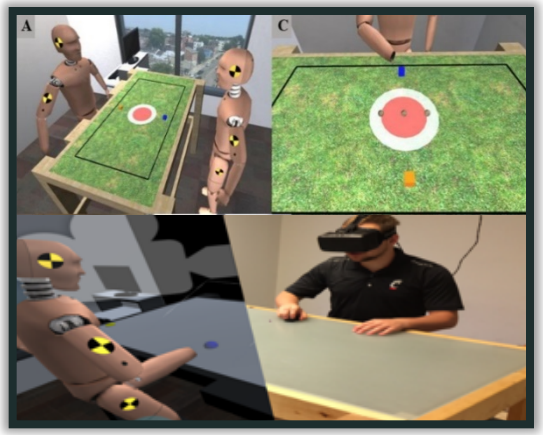
In cooperation with:

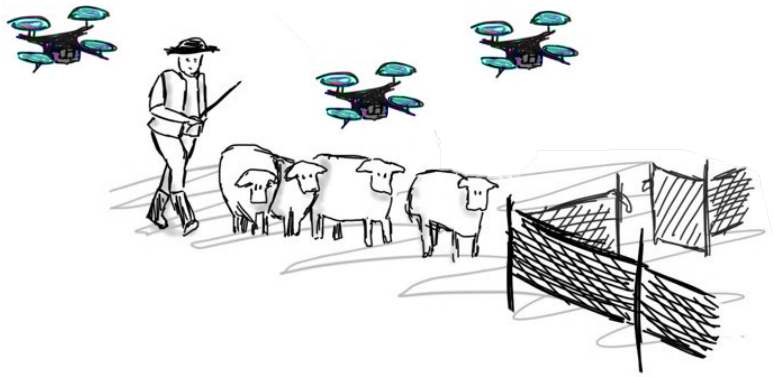
MACQUARIE University
SYDNEY·AUSTRALIA

FUDAN UNIVERSITY 1905

The Herding Control Problem





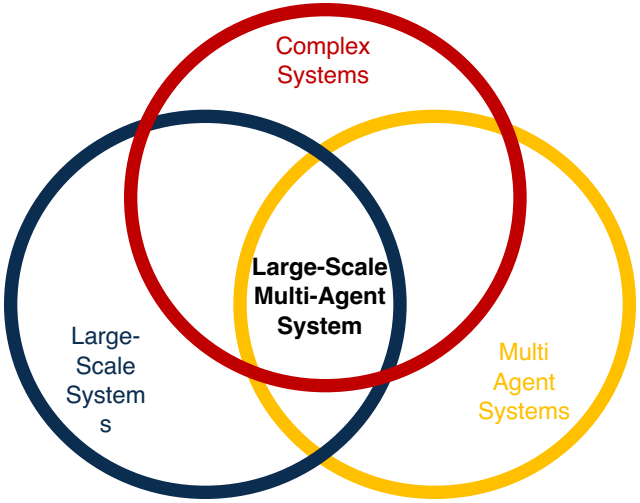


$$\ddot{\mathrm{r}} = -\mathrm{b}_\mathrm{r}\dot{\mathrm{r}} - \epsilon_\mathrm{r}\mathcal{R}(\tilde{\rho}_{\mathrm{i,j}})$$
$$\ddot{\theta} = -\mathrm{b}_\theta\dot{\theta} - \epsilon_\theta\mathcal{T}(\tilde{\phi})$$

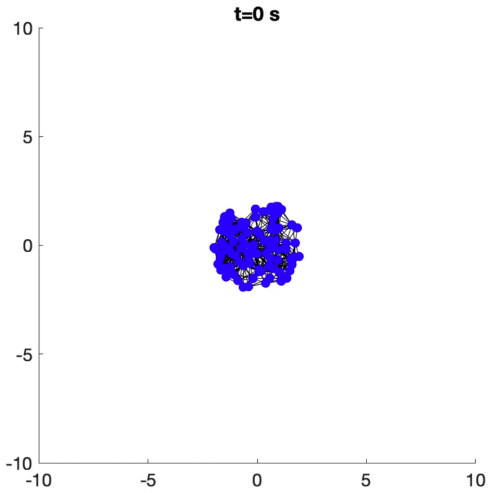
[6] Auletta, Fiore, Richardson, & di Bernardo, (2020). Design of herding autonomous agents via local control rules and target selection strategies. Under review, Autonomous Robots

Large-scale Multi-agent Systems (LS-MAS)

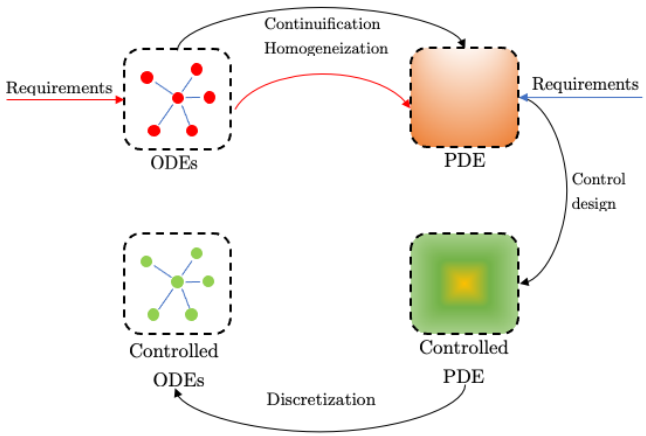
- N grows until emerging properties are invariant to the size of the group.
- Traditional methods may become cumbersome (theoretically and computationally).
- Control is **distributed** and **local**.



Taxonomy



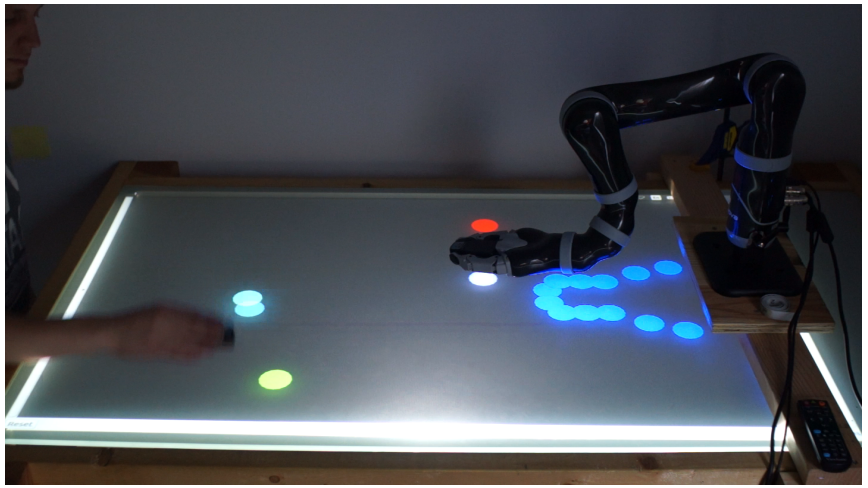
Geometric pattern formation



Macroscopic control of LS-MAS

Human-machine interaction

- Can we control artificial agents (avatars, robots) to interact and coordinate with humans? How?
- Applications: *health, personalized therapies, exergames, healthy aging, Industry 4.0, smart cities*



University of CINCINNATI

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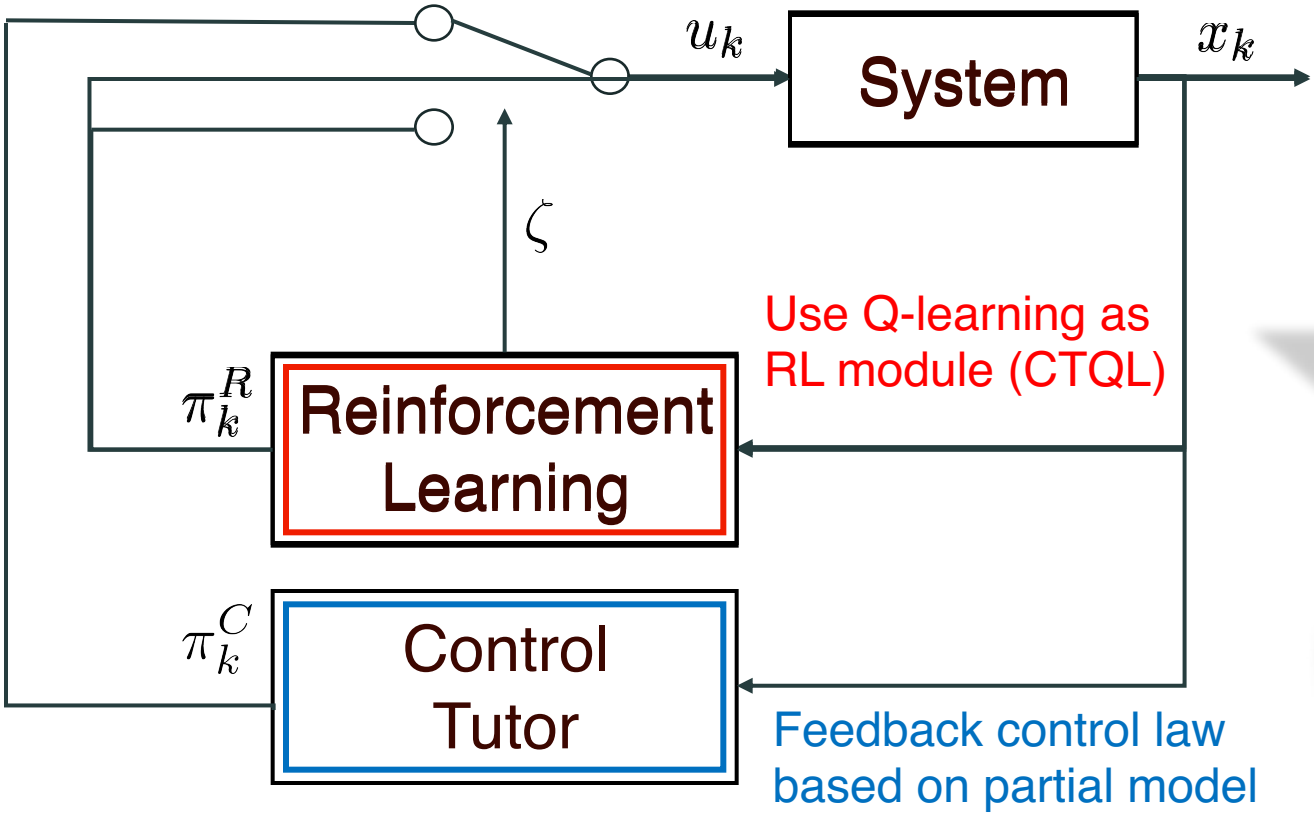
Control Tutored Reinforcement Learning

- The CTRLmakes use of partial/incorrect modeling to:
  - Drive the learning process with partially faulty control laws
  - Improving date efficiency to control dynamical systems



CTQL numerical results:

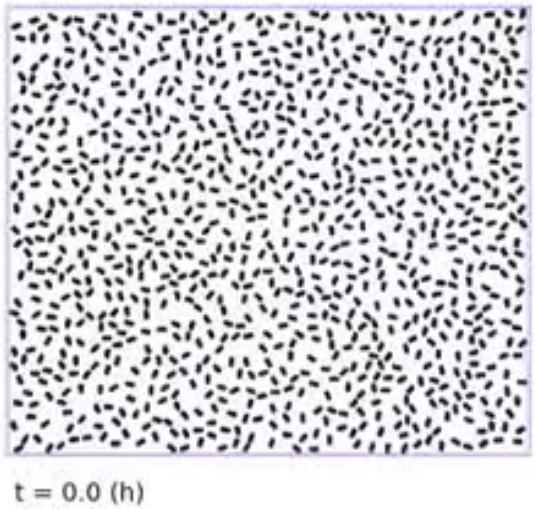
- Inverted Pendulum

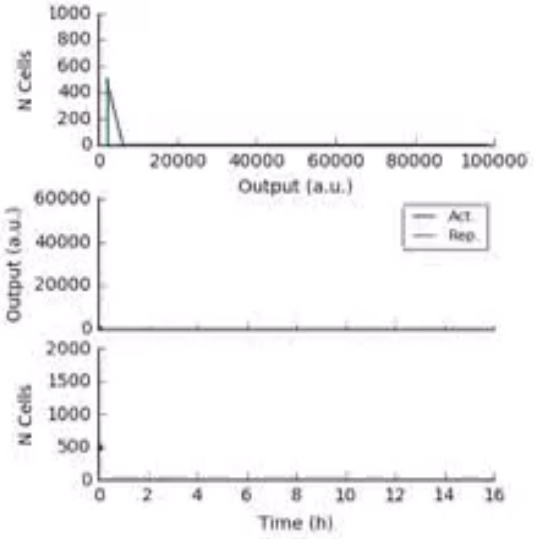
- Herding Problem

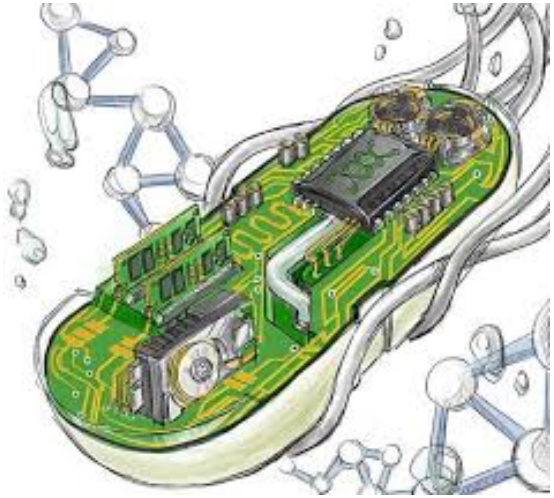
F. De Lellis, G. Russo, M. di Bernardo, "Tutoring Reinforcement Learning via Feedback Control", accepted by European Control Conference (ECC), 2021

Control in synthetic biology

- Can we achieve control of living cell populations to restore healthy behaviour?
- Applications: *Health, Life Sciences, Personalized medicine, process control, biotech industry*







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COSY BIO

ETH zürich

University of BRISTOL

Opportunities for technological transfer

- Solving these problems can be disruptive in many application areas
  - Industry 4.0
  - Health and personalized medicine
  - Biology
  - Human-machine interaction
  - Autonomous vehicles and mobile agents
  - Surveillance and security
  - Interaction in virtual and augmented reality
  - Smart Cities
  - Smart Transportation systems
  - Energy
- Many opportunities in our region (university, competence centres, spin-off incubators etc)

Conclusions

- Our Group mission is to develop strategies to control and orchestrate the collective behaviour of large-scale complex multi-agent systems
- We have expertise on both methodology and applications
- For more info:
- https://sites.google.com/site/dibernardogroup/home
- http://www.ssm.unina.it/en/modeling-and-engineering-risk-eng-and-complexity-merc-eng/