

Introduction to Open Multi-Agent Systems

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Abstract: Methods for control, optimization, and learning in multi-agent systems are often developed under the assumption that the number of agents is fixed throughout the execution of the algorithms. In many real-world applications, however—including multi-robot systems, swarms, distributed energy systems, and sensor networks—the set of interconnected agents changes over time as agents join or leave the network. The framework of *open multi-agent systems* addresses this challenge by explicitly accounting for such dynamics, with the aim of extending tools from control, optimization, and learning to provide formal guarantees in these more realistic settings.

This course introduces the students to the fundamentals of Multi-Agent Systems and Distributed Optimization to then extend the frameworks to open scenarios.

Day 1 – 3h – Morning – Franceschelli

- Introduction to agents and MAS
- Graphs as network models and Consensus in MAS
- Why openness changes everything

Day 1 – 3h – Afternoon – Franceschelli

- Challenges in OMAS
- Open Average Consensus
- Stability in contractive OMAS

Day 2 – 3h – Morning – Deplano

- Operator theory for open systems
- Gradient descent

Day 2 – 3h – Afternoon – Deplano

- Proximal gradient
- Distributed Gradient Descent (DGD)
- DGD in OMAS

Day 3 – 3h – Morning – Deplano

- Distributed Peaceman–Rachford splitting in OMAS
- Open ADMM
- Open FedPRS

Material for Day 1:

- Lecture slides
- F. Bullo. Lectures on Network Systems. Kindle Direct Publishing, 1.7 edition, 2024. (<https://fbullo.github.io/lns>)
- Mesbahi, Mehran, and Magnus Egerstedt. *Graph Theoretic Methods in Multiagent Networks*. Princeton University Press, 2010. <https://doi.org/10.2307/j.ctt1287k9b>.
- E. Makridis, A. Grammenos, G. Oliva, E. Kalyvianaki, C. N. Hadjicostis, and T. Charalambous, “Average Consensus over Directed Networks in Open Multi-Agent Systems with Acknowledgement Feedback,” IEEE Conference on Decision and Control, 2024.

- G. Oliva, M. Franceschelli, A. Gasparri, and A. Scala. A sum-of-states preservation framework for open multiagent systems with nonlinear heterogeneous coupling. *IEEE Transactions on Automatic Control*, 69(3):1991–1998, 2024
- Z.A.Z.S. Dashti, G. Oliva, C. Seatzu, A. Gasparri, and M. Franceschelli. Distributed mode computation in open multi-agent systems. *IEEE Control Systems Letters*, 6:3481–3486, 2022.
- C.M. De Galland and J.M. Hendrickx. Fundamental performance limitations for average consensus in open multi-agent systems. *IEEE Transactions on Automatic Control*, 68(2):646–659, 2023
- M. Franceschelli and P. Frasca. Stability of open multiagent systems and applications to dynamic consensus. *IEEE Transactions on Automatic Control*, 66(5):2326–2331, 2021.
- R. Olfati-Saber and R. M. Murray, "Consensus problems in networks of agents with switching topology and time-delays," in *IEEE Transactions on Automatic Control*, vol. 49, no. 9, pp. 1520-1533, Sept. 2004,

Material for Day 2/3:

- Lecture slides
- H. H. Bauschke and P. L. Combettes. *Convex Analysis and Monotone Operator Theory in Hilbert Spaces*, 2nd ed. CMS Books in Mathematics, Springer, Cham, 2026.
- D. Deplano, N. Bastianello, M. Franceschelli, and K. H. Johansson. Federated Learning in Open Multi-Agent Systems via Peaceman-Rachford Splitting. *IFAC World Congress* (to appear), 2026
- D. Deplano, N. Bastianello, M. Franceschelli, and K. H. Johansson. Optimization and Learning in Open Multi-Agent Systems. *IEEE Transactions on Automatic Control*, 2026.
- N. Hayashi. Distributed Subgradient Method in Open Multi-Agent Systems. *IEEE Transactions on Automatic Control*, 68(10):6192–6199, 2023.
- M. Hendrickx and M. G. Rabbat. Stability of Decentralized Gradient Descent in Open Multi-Agent Systems. In *Proceedings of the IEEE Conference on Decision and Control*, pp. 4885–4890, 2020.
- Nedić and A. Ozdaglar. Distributed Subgradient Methods for Multi-Agent Optimization. *IEEE Transactions on Automatic Control*, 54(1):48–61, 2009.

Lecturers websites:

Mauro Franceschelli institutional website:

https://web.unica.it/unica/page/en/mauro_franceschelli

Mauro Franceschelli private website:

<https://sites.google.com/site/conetdomesys/>

Diego Deplano private website:

<https://diegodeplano.github.io/>