Coordination and Control of Multi-Agent Systems (0860730)
Winter Semester 2025

Instructor: Prof. Daniel Zelazo, Lady Davis 755, Phone: x3196
Course Schedule: Wednesdays 9:30 - 12:30, Ullman 504
Office Hours: TBD or by appointment
Web: Moodle
Grader: Zamir Martinez z.m@campus.technion.ac.il

1 Course Overview

Multi-agent systems, or *networked dynamic systems*, are systems composed of dynamic units that interact with each other over an information exchange network. These systems can be used to perform team objectives with applications ranging from formation flying to distributed computation. Challenges associated with these systems are their analysis and synthesis, arising due to their decoupled, distributed, large-scale nature, and due to limited inter-agent sensing and communication capabilities. This course provides an introduction to these systems via tools from graph theory, dynamic systems theory, and optimization. The course will cover a variety of modeling techniques for different types of networked systems and proceed to show how their properties, such as stability and performance, can be analyzed. The course will also explore techniques for designing these systems, including distributed control strategies, and optimization methods for network design. The course will also cover real-world applications by presenting recent results obtained in the distributed formation control of multi-robot systems.

2 Syllabus

graph theory; algebraic and spectral graph theory; the consensus protocol (undirected, directed, switching, random); relative sensing networks (formation control, distributed estimation); analysis of networked system (stability, rate of convergence and the Fiedler eigenvalue, $\mathcal{H}_2$ and $\mathcal{H}_\infty$ performance, controllability, observability); nonlinear models (Kuramoto model, interconnected passive systems); connectivity maintenance and maximization; rigid formations for control and localization; graph design for networked systems; Applications: formation control of quadrotors, attitude consensus for multiple satellites, autonomous vehicle swarms.

3 Grading Policy

Homeworks: - There will be 4-6 homework assignments to be completed outside the class. This semester the homeworks will not be graded. Solutions will be provided and students are expected to solve them in order to be prepared for the midterm and final projects.

Midterm Project: 40% - A take-home project will be given at approximately the half-way mark of the course. Projects must be completed independently (no team effort, no discussions).

Final Project: 60% - TBD with more details to follow.

4 Lectures

Lectures will be held in English.

5 Course Schedule

This is a (tentative) outline of the course schedule.

Week	Subject
1	Introduction to NDS; fundamentals of graph theory; algebraic graph theory
2	Consensus protocol - undirected, directed
3	Consensus protocol - switching, distributed connectivity maintenance
4	Consensus feedback for Linear Systems
5	Networks as systems - controllability, observability
6	Networks as systems - stability, performance; edge agreement problem
7	Rigidity Theory - application to formation control
8	Formation Control - distance constrained formations
9	Formation Control - bearing constrained formations
10	Synthesis of Networks - consensus design
11	Nonlinear consensus - Kuramoto model, passive systems
12-13	Advanced topics/Projects - network clustering, network games, graph decomposition, Markov chains and NDS, circuit theory and consensus

6 Suggested Text Books

1. M. Mesbahi and M. Egerstedt, *Graph Theoretic Methods in Multiagent Networks*, Princeton University Press, 2010.

2. F. Bullo, *Lectures on Network Systems*, `http://motion.me.ucsb.edu/book-lns`, 2017.

3. J. Lunze, *Networked Control of Multi-Agent Systems*, 2019.

4. C. Godsil and G. Royle, *Algebraic Graph Theory*, Springer, 2009.

5. R. A. Horn and C. R. Johnson, *Matrix Analysis*, Cambridge University Press, 1990.

6. H. Bai, M. Arcak, and J. Wen, *Cooperative Control Design: A Systematic, Passivity-based Approach*, Springer, 2011.

7. W. Ren and R. Beard, *Distributed Consensus in Multi-Vehicle Cooperative Control*, Springer, 2008.

8. F. Bullo, J. Cortes, and S. Martinez, *Distributed Control of Robotic Networks*, Princeton University Press, 2009.

7 Online Resources

- **MATLAB** - Graphs and Network Algorithms (https://www.mathworks.com/help/matlab/graph-and-network-algorithms.html)
- Supplementary material to Mesbahi & Egerstedt book - (https://sites.google.com/site/mesbahiegerstedt/)