SSM
Scuola Superiore Meridionale

Course title:

Introduction to Complex Systems and Networks

Duration [number of hours]**: 24** for main module A; **8** for advanced module B (optional)

PhD Program [MERC/MPS/SPACE]**: MERC**

Name and Contact details of unit organizer(s):

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Course Description [max 150 words]**:**

This course introduces the modeling, analysis, and control of complex and network systems, emphasizing how interactions among interconnected units give rise to collective behavior. Starting from graph-theoretic foundations, students learn algebraic tools to describe network structures and study their impact on dynamical processes such as diffusion, consensus, and synchronization. The course develops methods for linear and nonlinear network systems, including stability analysis, Lyapunov methods, and the master stability function. Advanced topics cover network controllability, pinning control, and adaptive coupling design. Practical exercises with Matlab illustrate theoretical concepts and provide hands-on experience with network simulations. By the end, students will be able to analyze and design network systems across physical, biological, and engineered domains.

After the main 24-h module, an *optional* advanced 8-h module will follow, focusing on the structure and dynamics of flow networks and oscillator network, and advanced network simulation in Matlab.

Syllabus [itemized list of course topics]**:**

Main module A (24 h)

- Graphs
- Algebraic graph theory
- Discrete-time and continuous-time averaging systems
- Linear diffusively coupled network systems
- Nonlinear network systems
- Collective behavior and convergence analysis tools
- Control of network systems
- Simulation and analysis in Matlab

Advanced module B (8 h, optional)

- Flow networks
- Oscillator networks

Assessment [form of assessment, e.g., final written/oral exam, solutions of problems during the course, final project to be handed-in, etc.]**:**

Discussion of project work to be handed in at the end of the course, plus oral assessment

Suggested reading and online resources:

F. Bullo, Lectures on Network Systems, Kindle Direct Publishing, 2020

M. Coraggio, D. Salzano, M. di Bernardo, “Controlling complex systems,” Encyclopedia of Systems and Control Engineering. Springer, 2025.