SSM
Scuola Superiore Meridionale

Course title:

Introduction to Complex Systems

Duration [number of hours]**: 24**

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

Name and Contact details of unit organizer(s):

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

This Unit is intended to introduce student to the fundamental concepts behind the modelling, analysis and control of complex systems as large-scale multi-agent systems consisting of many interacting nonlinear dynamical systems communicating over a complex network. After recalling fundamental concepts about the analysis of nonlinear dynamical systems, we will explore the emerging properties and collective behaviour of large ensembles of dynamical systems and introduce analytical and numerical tools to study their convergence, controllability, and observability properties. Applications from Applied Science and Engineering will be used to illustrate the main concepts and complement the theoretical derivations.
This module also includes a series of 10 *additional* hours of seminar lectures, focusing on "Dynamics of Network Systems in Science and Technology". These lectures will present established and emerging frameworks for modelling, analysis, and design of complex network systems. Will survey the available comprehensive theory for linear network dynamical systems and highlight selected nonlinear concepts. Specific topics include: Perron-Frobenious theory, algebraic graph theory (adjacency, Laplacian, and incidence matrices), dynamical phenomena over networks (averaging and flow systems in discrete and continuous time). Example systems and applications will be drawn from science (electric/mechanical networks, sociology, ecology) and technology (network control, robotics, and energy systems).

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

- Introduction and Motivation
- Modeling Complex Dynamical Systems
- Emerging Collective Behaviour in Complex Systems
- Proving stability and convergence
- From static to evolving dynamical networks
- Controllability and control of complex systems
- Applications
- Ongoing research and open challenges

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.

Suggested reading and online resources:

1. F. Bullo, Lectures on Network Systems, Kindle Direct Publishing, 2020
2. K.J. Astrom and R.M. Murray, An introduction to for Scientists and Engineering, Princeton University Press, 2008
3. Y. Liu, JJ Slotine, A Barabasi, Controllability of Complex Networks, Nature, vol 473, pp. 167, 2011
4. S. Strogatz, Exploring Complex Networks, Nature, vol. 410, pp. 268, 2001
5. Y. Liu, A. Barabasi, Control Principles of Complex Systems, Reviews of Modern Physics, vol. 88, 2016
6. M. Newman, The Structure and Function of Complex Networks, SIAM Review, 45, 2, 2003