MERC Area Courses (2025-2026)

BLOCK 1: from November 10 to December 19, 2025

Course: Introduction to Complex Systems and Networks
Type: Pillar
Hours: 24 (+ 8 optional)
Teaching mode: in presence (Aula 1)
Lecturer: Prof. Marco Coraggio

Course description:
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* 8-h module will follow, focusing on the structure and dynamics of flow networks and oscillator network, and advanced network simulation in Matlab.

Course: Probability Calculus and Elements of Stochastic Modelling
Type: Pillar
Hours: 24
Teaching mode: in presence (Aula 1)
Lecturers: Dr. Nicola Esposito, Dr. Caio César Graciani Rodrigues

Course description:
The objective of the course is to provide the students with the fundamentals of probability calculus and (few) elements of stochastic modelling, as well as with their use in the engineering field and science. Starting from the basics of probability theory, the course will cover elements of statistical theory such as point/interval estimation, confidence intervals, hypothesis testing, p-value, as well as elements of stochastic modelling such as commonly-used random variables models, basics of Markov chains, and Poisson processes. The lectures will be much more focused on the application aspects. For this reason, the students are required to form small teams of 2/3 people and work on assignments that will be given throughout the course. The solutions to the assignments will be discussed during the lectures. The assignments will also require the students to work on Matlab (or R, Python, depending on their preference). On successful completion of the course, the students are

expected to obtain the necessary knowledge in stochastic and probabilistic models to apply them and develop new methods in the applicative domains of their interest.

BLOCK 2: from January 12 to February 20, 2026

Course: Numerical Methods for Data Mining and Machine Learning for Complex Systems
Type: Pillar
Hours: 24
Teaching mode: in presence
Lecturer: Prof. Constantinos Siettos

Course description:
The course of the Numerical methods for Data Mining and Machine Learning aims at giving to the students the necessary theoretical and numerical analysis and scientific computing background on various mathematical and numerical analysis methods for dimensionality reduction, modelling of the dynamics of complex nonlinear large-scale models and the solution of the forward and inverse problem in complex systems with scientific machine learning with a wide range of applications (Fluid Dynamics, socioeconomic, neuroscience, epidemiology, finance, Crowd dynamics).

Course: Stochastic Differential Equations
Type: Pillar
Hours: 24
Teaching mode: in presence
Lecturer: Prof. Tiziano de Angelis

Course description:
Over the past few decades stochastic differential equations and singular stochastic control have become powerful mathematical tools to address practical problems from a broad range of disciplines, including physics, engineering, economics and social sciences. The objective of the course is to provide a self-contained introduction to the subject for non-experts and a selection of tractable problems. On successful completion of the course, the students are expected to acquire the essential skills needed to formalize new stochastic control problems in the applicative domains of their interest.

Course: Introduction to Python
Type: Seminar
Hours: 12
Teaching mode: in presence
Lecturer: Dr. Cinzia Tomaselli

Course description:
This Unit provides an introduction to the fundamentals of Python programming. The course starts with the core concepts of procedural programming and gradually advances toward the use of complex libraries for machine learning. After presenting the basic syntax and structure

of Python as well as the main ideas of procedural programming, students will move to object-oriented programming, gaining a clear understanding of classes, inheritance, and polymorphism. Building on these foundations, the course will introduce essential Python libraries such as NumPy, pandas, and scikit-learn, with practical examples showing their most relevant functions and applications. The unit will conclude with a practical project in which students will integrate the concepts learned throughout the course to solve a case study.

BLOCK 3: from March 2 to April 17, 2026

Course: Fundamentals of Natural Hazards Forecasting
Type: Pillar
Hours: 24
Teaching mode: in presence
Lecturer: Prof. Warner Marzocchi

Course description:
This course offers a thorough foundation in modern natural-hazard forecasting. It frames forecasting as a scientific discipline and introduces core concepts—probabilistic, stochastic, and deterministic modeling. The curriculum covers probabilistic methods and the characterization and quantification of different kinds of uncertainty, including Bayesian approaches. A major emphasis is placed on rigorous statistical test of forecasts: statistical tests for model validation, calibration, consistency, and quantifying the forecasting skill of different models, and methods for constructing (multi-)ensemble forecasts. These principles are illustrated with real-world case studies from seismology, volcanology, geological risks, and meteorology. The course concludes by linking hazard forecasting to risk mitigation, explaining the hazard–risk separation principle and the role of scientific forecasts in informed decision making.

Course: Quantitative Risk Analysis
Type: Pillar
Hours: 24
Teaching mode: in presence
Lecturer: Prof. Pasquale Cito

Course description:
The objective of the course is to provide the students with the fundamentals of quantitative risk analysis of systems exposed to natural and man-made hazards. Starting from seismic risk analysis, other risks will be discussed, such as those related to wind and fire. After recalling the basics of probability theory, the framework for quantifying losses will be introduced. Then, hazard, vulnerability and exposure assessment will be discussed. Lectures will be focused on both theory and applications. Students will be required to work on assignments dealing with risk analysis problems, the solution to which will be discussed during classes. Also, students will be required to work with Matlab (or Excel, depending on their preference). The course consists of twelve lessons of two hours each. On successful

completion of the course, students are expected to acquire the basic knowledge in risk analysis, which can be used in their research field, if needed.

BLOCK 4: from April 27 to June 5, 2026

Course: Introduction to Learning and Data-Driven Methods
Type: Pillar
Hours: 24
Teaching mode: in presence
Lecturers: Prof. Giovanni Russo, Prof. Mirco Musolesi

Course description:
This module introduces students to learning and data-driven methods enabling agents to make decisions. The module starts with motivating the use of these methods across a wide range of application domains that are relevant for risk and complexity. Starting from the motivating examples, the key ingredients of learning and data- driven methods are then introduced. It is then shown how these key ingredients can be *mixed* to obtain classic algorithms enabling agents to make decisions from data. This leads students to familiarize with Dynamic Programming, Gradient Descent and their applications to Reinforcement Learning, focusing on policy-based and value-based resolution methods that require a discretize state/action spaces. Throughout this part of the module, strengths and weaknesses of the methods are discussed and the discussion will smoothly lead to motivate, and introduce, modern data-driven control, deep learning and multi-agent techniques. A key feature of the module is that methodological aspects are complemented with the development of case studies of interest for risk and complexity. By doing so, students will get hands-on-experience in coding their own algorithms, thus leading a computationally-oriented understanding of the methods introduced in the module. Finally, through an interactive discussion, we will outline the open challenges in the fascinating field of data-driven control and reinforcement learning.

Course: Risk assessment in industrial processes
Type: Seminar
Hours: 12
Teaching mode: in presence
Lecturers: Prof. Almerinda di Benedetto, Prof. Ernesto Salzano

Course description:
Risk assessment is defined as the comprehensive and systematic process of identifying, evaluating, and analyzing both internal and external hazards and their potential consequences, with the objective of developing effective risk prevention and mitigation strategies, determining the acceptability of the industrial process, and ensuring compliance with applicable safety standards, regulations, land use planning frameworks, and civil protection requirements.

The course provides a comprehensive introduction to the complex, multidisciplinary methodologies currently employed in advanced industrial countries for systematic risk assessment.