SSM
Scuola Superiore Meridionale

MERC Area Courses (2026-2027)

BLOCK 1: from November 2 to December 18, 2026

Course: Introduction to Complex Systems and Networks
Type: Pillar
Hours: 24
Teaching mode: in presence (Aula 1, SSM San Marcellino)
Lecturer: Prof. Marco Coraggio
Course description: This Unit is intended to introduce student to the fundamental concepts behind the modeling, 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.

Course: Introduction to Python for complex systems
Type: Non-Pillar
Hours: 24
Teaching mode: in presence (Aula 1, SSM San Marcellino)
Lecturer: Prof. Marco Coraggio and 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 2: from January 11 to February 19, 2027

Course: Introduction to Reinforcement Learning and Data-Driven Control for Complex Systems
Type: Pillar
Hours: 24
Teaching mode: in presence
Lecturer: Prof. Mirco Musolesi and Prof. Giovanni Russo
Course description: This module introduces the key concepts of data-driven control and Multi-Agent Reinforcement Learning (MARL). The first part of the module will be devoted to a short overview of Reinforcement Learning (RL) and DDC from the overarching framework of sequential decision making. We will then discuss the extension sof RL to MARL considering different classes of learning, including Online MARL, Co-evolutionary Learning, Swarm Intelligence and Adaptive Mechanism Design. Within the RL framework, the agent learns the task by interacting with an environment. The last part of the module will instead consider situations of practical interest where the task is known but the environment model is not. This leads to formalize the data-driven control problem and, for this problem, we will present a number of resolution methods that allow to solve data-driven control problems in a wide range of applications. Throughout the module, the methodological aspects will be complemented with a discussion on the corresponding computational methods and case studies will be used to illustrate the concepts.

Course: Numerical methods for data mining
Type: Pillar
Hours: 24
Teaching mode: in presence
Lecturer: Prof. Constantinos Siettos
Course description: The course of the Numerical methods for Complex Systems aim sat giving to the students the necessary theoretical and computational background on various mathematical methods and numerical analysis methods for analysis of the dynamics of complex nonlinear large-scale models with a wide range of applications (socioeconomic, neuroscience, epidemiology ,finance).

Course: Probability calculus and elements of stochastic modeling for quantitative risk assessment
Type: Pillar
Hours: 24
Teaching mode: in presence
Lecturer: Prof. Pasquale Cito
Course description: The course provides students with the fundamental concepts of probability calculus and an introduction to stochastic processes, which underpin many engineering applications, including quantitative risk analysis. It begins by reviewing the basic notions of random experiment, event, and probability. The main rules of probability calculus are then introduced, followed by random variables and (some) probability models. The final part provides an introduction to stochastic processes, including the Poisson

process. The course combines theoretical lectures with applications and problem assignments. Students will be required to use MATLAB, Excel, or Python for the practical activities and assignments. Assignment solutions will be discussed in dedicated lessons. The assignments will be assessed together with a final written examination.

Course: Stochastic differential equations
Type: Pillar
Hours: 24
Teaching mode: in presence
Lecturer: Prof. Tiziano De Angelis
Course description: Stochastic differential equations and (singular) stochastic control may occur in problems arising from several research fields outside mathematics. 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.

BLOCK 3: from March 1 to April 16, 2027

Course: Fundamentals of natural hazard forecasting
Type: Non-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: Introduction to Control: Analysis
Type: Pillar
Hours: 24
Teaching mode: in presence
Lecturer: Prof. Mario di Bernardo
Course description: This module introduces the mathematical tools needed to analyse control systems, at the interface between applied mathematics, physics and engineering. After reviewing essential concepts from dynamical systems, the module covers the mathematical modelling of control systems and the analysis of their stability, controllability

and observability. Particular attention is given to linear systems, controllability and observability canonical forms, and the foundations of linear observer theory.

Course: Autonomous Systems, Complex Systems and Risk Laboratory: Module A
Type: Non-Pillar
Hours: 24
Teaching mode: in presence
Lecturer: Prof. Mario di Bernardo and Prof. Pasquale Cito
Course description: This module reviews the theoretical and computational foundations needed for project work on autonomous systems, complex systems and risk. Topics include the modelling and control of autonomous systems, coordination and collective behaviour in multi-agent systems, and quantitative risk assessment, with applications to planning the deployment of mobile robots and drones following natural events. These concepts are complemented by an introduction to the CoRE Lab. Mixed and virtual reality tools and the possibilities and limitations of AI-assisted programming are also introduced. Guided exercises help students connect the theoretical concepts with practical applications and prepare for project development in Module B.

Course: Quantitative risk analysis
Type: Pillar
Hours: 24
Teaching mode: in presence
Lecturer: Prof. Mario di Bernardo and Prof. Pasquale Cito
Course description: The course will provide the fundamentals of infrastructure risk analysis with respect natural and anthropic hazards. The interaction of natural and industrial hazard will also be addressed. The course develops within the performance-based framework where risk assessment is probabilistic and the risk metrics are computed separating the problem in: hazard, vulnerability and loss. The course will address the risk as a time-invariant as well as a time-invariant problem. The most common stochastic models for the representation of the natural and anthropic hazards will be discussed. Similarly, the models for the physical vulnerability of infrastructure components will be addressed. Options for loss and consequence functions will also be part of the course. The course will include applications to natural hazards (i.e., earthquakes and tsunamis of natural origin) and to civil infrastructure (e.g., buildings and lifelines) as well as industrial hazard in the process industry.

BLOCK 4: from April 26 to June 4, 2027

Course: Introduction to Control: Synthesis
Type: Pillar
Hours: 24
Teaching mode: in presence
Lecturer: Prof. Mario di Bernardo
Course description: Building on the analytical foundations introduced in the analysis module, this module presents methods for designing controllers for dynamical systems.

Topics include state feedback and output feedback control, observer design, and optimal control, with particular emphasis on Pontryagin's minimum principle, the linear quadratic regulator and the Riccati equation. The module also introduces elements of nonlinear control and the control of multi-agent systems. Theoretical developments are complemented by worked examples and case studies.

Course: Autonomous Systems, Complex Systems and Risk Laboratory: Module B
Type: Non-Pillar
Hours: 24
Teaching mode: in presence
Lecturer: Prof. Mario di Bernardo and Prof. Pasquale Cito
Course description: This module focuses on developing a collaborative project at the CoRE Lab. Students work in small groups on a topic agreed with the lecturers. Each group translates an open-ended problem into a project with clear objectives, specifications and milestones, progressing towards a working physical or virtual prototype. Projects may address mobile robots and drones, swarm coordination, collective behaviour, mixed and virtual reality, or the quantification and visualisation of natural-event impacts to support the deployment of autonomous systems. The module concludes with a public demonstration and presentation, accompanied by a technical report and a documented project repository.