Courses

Computer Science and System Engineering

Academic Year 2019 - 2020

Advanced Methods for Complex Systems I

Abstract: This interdisciplinary course aims at introducing rigorous tools from statistical physics, information theory and probability theory to investigate real-world complex systems arising in different fields of research. First, some key aspects of complexity encountered in physical, biological, social, economic and technological systems will be reviewed. Then, emphasis will be put on the construction of theoretical models based on the concept of constrained randomness, i.e. the maximisation of the entropy subject to suitable constraints. This will lead to the introduction of maximum-entropy models that serve as mathematical benchmarks for the properties of highly heterogeneous complex systems. Special cases of interest include statistical ensembles of complex networks and of multivariate time-series with given properties. Comparisons between model outcomes and empirical properties will be presented systematically. Full mathematical derivations of the models, as well as methods of statistical inference, model selection and computer codes for parameter estimation on empirical data will be provided.

The course will include a combination of recent and ongoing research in the NETWORKS unit at IMT Lucca, thereby offering directions for possible PhD projects in this area.

Prerequisites: solid mathematical background, scientific curiosity, interest in multidisciplinarity, passion for theory.

Hours: 20

Professors/Lecturers: Diego Garlaschelli (IMT Lucca)

Available for: Analysis and Management of Cultural Heritage; Cognitive, Computational and Social Neurosciences

Advanced Methods for Complex Systems II

Abstract: The second part of the course “Advanced Methods for Complex Systems” focuses on advanced practical applications of the concepts introduced in the first part. In particular, emphasis will be put on the successful areas of pattern detection and network reconstruction from partial information. Network pattern detection is the identification of robust empirical patterns (like scale invariance, clustering, assortatitvity, reciprocity, motifs, etc.) that are widespread across real-world networks and that deviate systematically from some null hypothesis formalised in terms of a suitable random graph model. The models introduced in part I will then be used here for pattern detection purposes. The problem of community detection will also be covered, with an emphasis on the differences between finding communities in network data and in correlation matrices constructed from (e.g. financial or neural) time series databases. The problem of network reconstruction from partial topological information will be addressed concentrating on the reconstruction of financial and interbank networks from node-specific properties, with the purpose of improving stress tests and systemic risk estimates in real markets and offering better tools to policy makers. The statistical physics methods recently found by central banks to be the best-performing reconstruction techniques will be reviewed in detail.

The course will include a combination of recent and ongoing research in the NETWORKS unit at IMT Lucca, thereby offering directions for possible PhD projects in this area.

Prerequisites: solid mathematical background, scientific curiosity, interest in multidisciplinarity, successful completion of the course “Advanced Methods for Complex Systems I”. Note: completion of this second part of the course is not required in order to move on to the third part (parts II and III can be understood in parallel independently of each other, after part I is completed), although it would surely provide a useful overview of practical motivations for part III.

Hours: 20

Professors/Lecturers: Diego Garlaschelli (IMT Lucca)

Available for: Analysis and Management of Cultural Heritage; Cognitive, Computational and Social Neurosciences

Advanced Methods for Complex Systems III

Abstract: The third part of the course “Advanced Methods for Complex Systems” focuses heavily on deeper theoretical aspects and their consequences. Particular emphasis will be put on the distinction between maximum-entropy models of complex systems with “soft” and “hard” properties. In statistical physics, the resulting models are known as the “canonical” and “microcanonical” ensembles respectively. Many of the results in statistical physics (e.g. the calculation of certain entropies), discrete mathematics (e.g. the combinatorial enumeration of possible configurations of a system with given properties), and information theory (e.g. the calculation of the maximum compressibility of information sequences) rely of the concept of “ensemble equivalence”, i.e. the asymptotic equivalence of soft and hard ensembles in the large size limit. Surprisingly, various complex systems have been found to violate the property of ensemble equivalence. For these systems, the standard approach is not appropriate and new developments are needed. Several intriguing challenges open up, including the uniform sampling of realisations of large complex systems, the combinatorial enumeration of systems with heterogeneous constraints and the recalculation of traditional information-theoretic bounds on communication. Examples of these open challenges will be provided, along with tentative solutions that are underway.

The course will include a combination of recent and ongoing research in the NETWORKS unit at IMT Lucca, thereby offering directions for possible PhD projects in this area.

Prerequisites: unlimited passion for theory and multidisciplinarity, successful completion of the course “Advanced Methods for Complex Systems I”. Note: knowledge of the content of the course “Advanced Methods for Complex Systems II” is not required (parts II and III can be understood in parallel independently of each other, after part I is completed), although it would surely provide a useful overview of practical motivations for this part.

Hours: 20

Professors/Lecturers: Diego Garlaschelli (IMT Lucca)

Available for: Analysis and Management of Cultural Heritage; Cognitive, Computational and Social Neurosciences

Advanced Numerical Analysis

Abstract: 1. General considerations on matrices

Matrices:definitions and properties; norm of matrices
The condition number of a matrix
Sparse matrices and sparse formats (sparsity, structure, functionals)
The role of the PDE discretization (e.g., parameter dependence)

2.a Direct methods for general linear systems

Factorizations: definitions and properties
Factorization algorithms
Cost and numerical stability

2.b Direct methods for sparse linear systems

Factorizations of banded matrices
Ordering strategies to minimize the fill-in of a matrix
Solution of sparse triangular systems
Sparse matrices in Matlab: memorization and handling
Predefined functions for the direct solution of systems

3. Numerical solution of large-scale linear systems

Krylov subspace methods (CG, MINRES, GMRES, IDR family)
Structured problems
Preconditioning
Algebraic multigrid methods (hints)
Numerical experiments with Matlab and the IFISS package

4. Numerical solution of eigenvalue problems

Standard and generalized eigenproblems
Typical numerical methods
Equation of motion in structural dynamics: quadratic eigenproblems
Hours: 20
Professors/Lecturers: Valeria Simoncini (Università di Bologna); Benedetta Morini (Università degli Studi di Firenze)
Available for: Computer Science and System Engineering; Economics, Networks and Business Analytics

Advanced Topics in Network Theory: Algorithms and Applications

Abstract: Centrality metrics and spectral properties of graphs.
Community detection.
Bipartite and multilayer networks.
Applications: Worls Trade Web

Lecture 1: Centrality metrics
Lecture 2: Spectral properties
Lecture 3: Ranklings and reputation on graphs
Lecture 4: Community detection in networks I
Lecture 5: Community detection in networks II
Lecture 6: Bipartite networks
Lecture 7: Multilayer networks
Lecture 8: World Trade Web
Lecture 9: Infrastructural network I
Lecture 10: Infrastructural network II

Hours: 10

Professors/Lecturers: Guido Caldarelli (IMT Lucca)

Specializing course for: Economics, Networks and Business Analytics

Also available for: Computer Science and System Engineering

Advanced Topics in Network Theory: Brain Networks

Abstract: We shall provide the theoretical basis of the measurements and analysis of the various kind of network we can define in the brain.

Hours: 10

Professors/Lecturers: Guido Caldarelli (IMT Lucca)

Specializing course for: Economics, Networks and Business Analytics

Also available for: Computer Science and System Engineering

Advanced Topics in Network Theory: Complex Networks and Python

Abstract: The course must be intended as a laboratory for the theoretical parts explained in the course of Introduction to Complex Networks, It will cover the basic preparation of the pc for the python coding and some example of interest in order to be able to start computational actiity in the field of complex networks.

Hours: 10

Professors/Lecturers: Guido Caldarelli (IMT Lucca)

Compulsory for: Economics, Networks and Business Analytics

Also available for: Computer Science and System Engineering

Advanced Topics in Network Theory: Dynamical Processes of Networks

Abstract: Mean field and master equations.
Percolation and epidemic models.
Contagion: the case of financial networks.
Applications of network theory.

Lecture 1: Master equations for network models
Lecture 2: Fitness and relevance models
Lecture 3: Epidemic processes in mean fiels
Lecture 4: Epidemics on networks
Lecture 5: Scaling and percolation on networks
Lecture 6: Contagion in financial network I
Lecture 7: Contagion in financial network II
Lecture 8: Game theory on networks
Lecture 9: Evolutionary network games
Lecture 10: Networks from time series and visibility graph

Hours: 10

Professors/Lecturers: Guido Caldarelli (IMT Lucca)

Specializing course for: Economics, Networks and Business Analytics

Also available for: Computer Science and System Engineering

Advanced Topics of Computational Mechanics

Abstract: The course is organized as a set of seminars and lectures delivered by IMT Professors and by invited recognized international experts. It covers advanced topics of computational mechanics.

Hours: 20

Professors/Lecturers: Marco Paggi (IMT Lucca); Andrea Bacigalupo (IMT Lucca); Mauro Corrado (Politecnico di Torino)

Available for: Computer Science and System Engineering

Advanced Topics of Computer Science

Abstract: This course will be organized as series of reading groups or specialized seminars by members or collaborators of the research unit on System Modelling and Analisys (SysMA).

Hours:10

Professors/Lecturers: Hugo Torres Vieira (IMT Lucca); Letterio Galletta (IMT Lucca)

Available for: Computer Science and System Engineering

Advanced Topics of Control Systems: Numerical Methods for Optimal Control

Abstract: This course will cover a selected advanced topic in control, identification, or dynamical optimization.

Prerequisites: Linear algebra and matrix computation, calculus and mathematical analysis, control systems, numerical optimization.

Hours: 20

Professors/Lecturers: Mario Zanon (IMT Lucca)

Available for: Computer Science and System Engineering; Economics, Networks and Business Analytics

Applications of Stochastic Processes

Abstract: This course offers an introduction to stochastic processes as a practical modelling tool for the quantitative analysis of systems. It covers the fundamentals of Markov chains, and presents algorithms and state-of-the-art software applications and libraries for their numerical solution and simulation. The class of Markov Population Processes is presented, with its most notable applications to as diverse disciplines as chemistry, ecology, systems biology, health care, computer networking, and electrical engineering. Finally, the course will examine the computational issues arising from the modelling of large-scale systems, reviewing effective approximation methods based ordinary differential equation (fluid)

limits, moment-closure techniques, and hybrid models. Prerequisites: fundamentals of probability theory; knowledge of the topics of “Stochastic Processes and Stochastic Calculus” is useful but not necessary.

Hours: 20

Professors/Lecturers: Mirco Tribastone (IMT Lucca)

Available for: Computer Science and System Engineering; Economics, Networks and Business Analytics

Behavioral Economics

Abstract: The course is a self-contained presentation and discussion of the state-of-the-art research in behavioral economics, an area merging economics and psychology for the purpose of modelling and predicting human decision-making and behavior.

The goal of the course is to provide an all-purpose introduction to behavioral economics as well as to offer hooks and suggestions for cutting-edge research projects.

While a general understanding of game theory is welcome, no prerequisite is strictly necessary.

Specific topics covered:
1. What is Behavioral Economics? An economist’s take on surprising human behaviors, with a reference to why psychologists and neuroscientists are hardly surprised
2. Rationality with cognitive bounds: Searching for predictable mistakes
3. Beyond homo economicus: Searching for predictable other-regarding preferences
4. A case study in behavioral game theory: Foundations of human prosociality
5. A discussion on methods: Experiments by economists in the lab and in the field, with a reference to how psychologists and neuroscientists would disagree

Hours: 20

Professors/Lecturers: Ennio Bilancini (IMT Lucca)

Specializing course for: Economics, Networks and Business Analytics

Also available for: Computer Science and System Engineering

Business Model for Emerging Markets

Abstract: Teaching contents:

1. The economy of the intangibles
2. Manufacturing and robot
3. Strategy and business model
4. How to model a business
5. How to model a business in a complex scenario
6. What make market emerging? Not only new lands.
7. The Blockchain technology and the future
8. Initial Coins Offering (ICO) compressed between Business plan and White paper
9. Possible value of Blockchain technology for Small and medium Italian sized business
10. A global value chain approach to protect and foster strategic identity

Business case

Students will learn how to evaluate strategies, as well as how to locate sources of potential competitive

advantage from a perspective that, for the purpose of this course, encompasses the internal and dynamic fit of a strategy. They will also learn how to identify organizational barriers and corporate behaviors that sustain or challenge the development and execution of strategies, and the competitive advantage of a company.

Hours: 20

Professors/Lecturers: Nicola Lattanzi (IMT Lucca)

Specializing course for: Economics, Networks and Business Analytics

Also available for: Computer Science and System Engineering

Computational Contact and Fracture Mechanics

Abstract: This course provides an overview on the theories of contact and fracture mechanics relevant for a wide range of disciplines ranging from materials science to engineering. Introducing their theoretical foundations, the physical aspects of the resulting nonlinearities induced by such phenomena are emphasized. Numerical methods (FEM, BEM) for their approximate solution are also presented together with a series of applications to real case studies. In detail, the course covers the following topics: Hertzian contact between smooth spheres; the Cattaneo-Mindlin theory for frictional contact; numerical methods for the treatment of the unilateral contact constraints; contact between rough surfaces; fundamentals of linear elastic fracture mechanics; the finite element method for crack propagation; nonlinear fracture mechanics and the cohesive zone model; interface finite elements; applications of fracture mechanics to materials science, retrofitting of civil/architectonic structures, composite materials.

Hours: 20

Professors/Lecturers: Marco Paggi (IMT Lucca)

Available for: Computer Science and System Engineering

Computer Programming and Methodology

Abstract: This course aims at introducing to students principles and methodologies of computer programming. Emphasis is on good programming style, techniques and tools that allow efficient design, development and maintenance of software systems. The course focuses on the design of computer applications drawing attention to modern software engineering principles and programming techniques, like object-oriented design, decomposition, encapsulation, abstraction, and testing. A significative case study is used to allow students to experiment with the principles and techniques considered in this course. Depending on the background of the class, Java, C++, and/or Python are considered in the course.

Hours: 30

Professors/Lecturers: Mirco Tribastone (IMT Lucca)

Available for: Computer Science and System Engineering; Economics, Networks and Business Analytics

Computer-Aided Engineering for Virtual prototyping and Advanced Manufacturing Solutions

Abstract: TBD

Hours: 10

Professors/Lecturers: Marco Paggi (IMT Lucca); Andrea Bacigalupo (IMT Lucca)

Available for: Computer Science and System Engineering

Cybersecurity

Abstract: TBD

Hours: 20

Professors/Lecturers: Rocco De Nicola (IMT Lucca); Gabriele Costa (IMT Lucca)

Available for: Computer Science and System Engineering

Data Science Lab

Abstract: The aim of this class is to provide students with R language fundamentals and basic sintax. In particular, lessons will cover the following topics:

- Overview of R features
- The basics (vectors, matrices, objects, manipulation, basic statements)
- Reading data from files
- Probability distributions
- Basic statistical models
- Graphical procedures
- R packages overview

Hours: 40

Professors/Lecturers: Tbd; Valentina Tortolini (IMT Lucca)

Available for: Computer Science and System Engineering; Economics, Networks and Business Analytics

Econometrics I

Abstract:

- Review of Asymptotic Theory
- Theory and Algebra of OLS
- Inference, non-spherical Errors and Clustering
- Structural Models, Identification and Causality
- Simultaneous Equation Models, 2SLS and 3SLS
- Introduction to M-Estimation
- Generalized Method of Moments
- Maximum Likelihood Estimation

Hours: 20

Professors/Lecturers: Paolo Zacchia (IMT Lucca)

Compulsory for: Economics, Networks and Business Analytics

Also available for: Computer Science and System Engineering

Econometrics II

Abstract: This module covers the most important topics of modern microeconometrics. A variety of methods are illustrated with a hands-on-tool approach, combining theory and practice. The objective is to develop a critical understanding of the iterative research process leading from real economic issues to the choice of the best tools available from the analyst kit. The assessment is based on the production of a short empirical project (50%), a written exam (30%) and the presentation/replication of a published scientific article (20%).

1) Introduction to Microeconometrics
i) Heterogeneity and Microdata
ii) The Potential Outcome Model
iii) Exogeneity and Identification
iv) Parametric, Semiparametric and Non-parametric Models
v) The Local Polynomial Regression Model
vi) The Kernel Density Estimation

2) Survey Design, Sampling and Variance
i) Survey design and Sampling Techniques
ii) The Heckman Correction
iii) One-way and Two-way Analysis of Variance
iv) Analysis of Covariance

3) Linear Panel Models
i) Pooled Models
ii) The Fixed Effects Estimator
iii) The Random Effects Estimator
iv) Mixed Models
v) GMM Estimators for Panel Data
vi) Application: Firms, Productivity and Technical Change (Industrial Organization)

4) The Evaluation Problem
i) Randomized Experiments
ii) Matching Models
iii) The Difference-in-difference Estimators
iv) Instrumental Variables
v) Regression Discontinuity Design
vi) Models with Control Functions
vii) Application: Evaluation of Active Labor Markets Programs (Labor economics)

5) Repeated Measures and Longitudinal Designs
i) Experiments and Quasi-experiments
ii) Longitudinal Designs and Repeated Measures
iii) Between-subjects Hypothesis Testing
iv) Application: Behaviorally Motivated Policies (Behavioral/Experimental Economics)

6) Multinomial Models
i) A Review of Logit and Probit Models
ii) The Multinomial Logit Model
iii) The Conditional Logit Model
iv) The Nested Logit Model
v) The Ordered Probit Model
vi) Application: Location Choices and Agglomeration Economies (Economic Geography)

7) Models for Count Data
i) Poisson Regression Model
ii) Negative Binomial Regression Model

iii) Hurdle Models
iv) Application: Technology Diffusion from Patent Data (Economics of Innovation)

8) Survival/Duration Models
i) On Censoring and Truncation
ii) The Kaplan-Meier Curve
iii) The Cox Regression Model
iv) The Weibull Model
v) Application: Market Access for Pharmaceutical Products (Health Economics)

Hours: 20

Professors/Lecturers: Armando Rungi (IMT Lucca)

Compulsory for: Economics, Networks and Business Analytics

Also available for: Computer Science and System Engineering

Firms, Business Analytics and Managerial Behavior

Abstract: Teaching contents:

1. Theory of the Firm
2. The system of force in a business organization
3. The balance between efficiency of the production and effectiveness in results
4. Business performance and ways to represent
5. The financial statement
6. How to read and comprehend performances and results
7. Methodology and tools for Balance sheet analysis
8. Prevision versus prediction and business analytics
9. Entrepreneurship and management in complex scenario
10. Neuroscience, decision making process and managerial behavior

Business case

Students will learn how to evaluate strategies, as well as how to locate sources of potential competitive advantage from a perspective that, for the purpose of this course, encompasses the internal and dynamic fit of a strategy. They will also learn how to identify organizational barriers and corporate behaviors that sustain or challenge the development and execution of strategies, and the competitive advantage of a company.

Hours: 20

Professors/Lecturers: Nicola Lattanzi (IMT Lucca)

Compulsory for: Economics, Networks and Business Analytics

Also available for: Computer Science and System Engineering

Foundations of Probability and Statistical Inference

Abstract: This course covers the fundamental concepts of probability and statistical inference. Some proofs are sketched or omitted in order to have more time for examples, applications and exercises. In particular, the course deals with the following topics:

- probability space, random variable, expectation, variance, cumulative distribution function, discrete and absolutely continuous distributions,

- random vector, joint and marginal distributions, joint cumulative distribution function, covariance,
- conditional probability, independent events, independent random variables, conditional probability density function, order statistics,
- multivariate Gaussian distribution, copula functions,
- probability
- generating function, Fourier transform/characteristic function,
- types of convergence and some related important results,
- point estimation, interval estimation, hypothesis testing, linear regression, introduction to Bayesian statistics.

Hours: 30

Professors/Lecturers: Irene Crimaldi (IMT Lucca)

Specializing course for: Economics, Networks and Business Analytics

Also available for: Computer Science and System Engineering

Funding and Management of Research and Intellectual Property (long seminar without exam)

Abstract: The long seminar aims at providing an overview on the management of intellectual property rights (copyright transfer agreements, open access, patents, etc.). Funding opportunities for PhD students, post-docs, and researchers are also presented (scholarships by the Alexander von Humboldt Foundation; initiatives by the Deutscher Akademischer Austausch Dienst; scholarships offered by the Royal Society in UK; bilateral Italy-France exchange programmes; Fulbright scholarships; Marie Curie actions; grants for researchers provided by the European Research Council). For each funding scheme, specific hints on how to write a proposal are given.

Hours: 10

Professors/Lecturers: Marco Paggi (IMT Lucca)

Available for: Computer Science and System Engineering; Economics, Networks and Business Analytics

Game Theory

Abstract: The course covers the basics of non-cooperative game theory and information economics. The goal is to equip students with an in-depth understanding of the main concepts and tools of game theory in order to enable them to successfully pursue research in applied areas of economics and related disciplines, and to provide a solid background for students who are planning to concentrate on economic theory.
The course starts with a detailed description of how to model strategic situations as a game. It proceeds by studying basic solution concepts and their main refinements (dominance and iterative dominance, Nash equilibrium, correlated equilibrium, subgame perfect equilibrium, weak perfect Bayesian equilibrium, sequential equilibrium), strategic interaction under incomplete information (Bayesian games, Bayesian Nash equilibrium), and asymmetric information (adverse selection, signaling, screening, moral hazard, and the principal agent problem). The discussion of all theoretical concepts will be accompanied by representative applications from economics.
The course is mostly self-contained, but students should be familiar with basic concepts from calculus, linear algebra, and probability theory.

Hours: 20

Professors/Lecturers: Ennio Bilancini (IMT Lucca)

Compulsory for: Economics, Networks and Business Analytics

Also available for: Computer Science and System Engineering

Identification, Analysis and Control of Dynamical Systems

Abstract: The course provides an introduction to dynamical systems, with emphasis on linear systems in state-space form. After introducing the basic concepts of stability, controllability and observability, the course covers the main techniques for the synthesis of stabilizing controllers (state-feedback controllers and linear quadratic regulators) and of state estimators (Luenberger observer and Kalman filter). The course also briefly covers data-driven approaches of parametric identification to obtain models of dynamical systems from a set of data, with emphasis on the analysis of the robustness of the estimated models w.r.t. noise on data and on the numerical implementation of the algorithms.

Prerequisites: Linear algebra and matrix computation, calculus and mathematical analysis.

Hours: 20

Professors/Lecturers: Alberto Bemporad (IMT Lucca)

Available for: Computer Science and System Engineering; Economics, Networks and Business Analytics

Introduction to Complex Systems and Networks

Abstract: Complexity, self-similarity, scaling, self-organised criticality.
Definition of graphs, real networks and their properties.
Models of static networks, models of network growth.

Lecture 01 Graph Theory Introduction
Lecture 02 Properties of Complex Networks
Lecture 03 Communities
Lecture 04 Different Kind of Graphs
Lecture 05 Ranking
Lecture 06 Static Models of Graphs
Lecture 07 Dynamical Models of Graphs
Lecture 08 Fitness Models
Lecture 09 World Trade Web
Lecture 10 Financial Networks

Hours: 10

Professors/Lecturers: Guido Caldarelli (IMT Lucca)

Compulsory for: Economics, Networks and Business Analytics

Also available for: Computer Science and System Engineering

Machine Learning

Abstract: The course provides an introduction to basic concepts in machine learning. Topics include: learning theory (bias/variance tradeoff; Vapnik-Chervonenkis dimension and Rademacher complexity, cross-validation, feature selection); supervised learning (linear regression, logistic regression, support vector machines); unsupervised learning (clustering, principal and independent component analysis);

semisupervised learning (Laplacian support vector machines); online learning (perceptron algorithm); hidden Markov models.

Hours: 20

Professors/Lecturers: Giorgio Stefano Gnecco (IMT Lucca)

Specializing course for: Economics, Networks and Business Analytics

Also available for: Computer Science and System Engineering

Matrix Algebra

Abstract: This course is aimed to review the basic concepts of linear algebra:

1. Systems of linear equations: solution by Gaussian elimination, PA=LU factorization, Gauss-Jordan method.
2. Vector spaces and subspaces, the four fundamental subspaces, and the fundamental theorem of linear algebra.
3. Determinant and eigenvalues, symmetric matrices, spectral theorem, quadratic forms.
4. Cayley-Hamilton theorem, functions of matrices, and application of linear algebra to dynamical linear systems.
5. Iterative methods for systems of linear equations.
6. Ordinary lest squares problem, normal equations, A=QR factorization, condition number, Tikhonov regularization.
7. Singular-value decomposition, Moonre-Penrose pseudoinverse.
8. An economic application of linear algebra: the Leontief input-outpul model.

Hours: 10

Professors/Lecturers: Giorgio Stefano Gnecco (IMT Lucca)

Available for: Computer Science and System Engineering; Economics, Networks and Business Analytics

Model Predictive Control

Abstract: Model Predictive Control (MPC) is a well-established technique for controlling multivariable systems subject to constraints on manipulated variables and outputs in an optimized way. Following a long history of success in the process industries, in recent years MPC is rapidly expanding in several other domains, such as in the automotive and aerospace industries, smart energy grids, and financial engineering. The course teaches the theory and practice of Model Predictive Control (MPC) of constrained linear, linear time-varying, nonlinear, stochastic, and hybrid dynamical systems, and numerical optimization methods for the implementation of MPC, including the use of the MPC Toolbox for MATLAB for basic linear MPC, and of the Hybrid Toolbox for explicit and hybrid MPC.

Topics covered in the course: General concepts of Model Predictive Control (MPC); MPC based on quadratic programming; General stability properties; MPC based on linear programming; Models of hybrid systems: discrete hybrid automata, mixed logical dynamical systems, piecewise affine systems; MPC for hybrid systems based on on-line mixed-integer optimization; Multiparametric programming and explicit linear MPC, explicit solutions of hybrid MPC; Stochastic MPC based on scenario enumeration; Linear parameter- and time-varying MPC and applications to nonlinear dynamical systems; Selected applications of MPC in various domains, with practical demonstration of the MATLAB toolboxes.

Prerequisites: Linear algebra and matrix computation, linear control systems, numerical optimization.

Hours: 20

Professors/Lecturers: Alberto Bemporad (IMT Lucca)

Available for: Computer Science and System Engineering

Modelling and Verification of Reactive Systems

Abstract: Computing systems are becoming increasingly sophisticated and control key aspects of our lives. In light of the increasing complexity of such computing devices, one of the key scientific challenges in computer science is to design and develop computing systems that do what they were expected to do, and do so reliably. The aim of this course is to introduce models for the formal description of computing systems, with emphasis on parallel, reactive and possibly real-time systems, and the techniques for system verification and validation that accompany them. As an important component of the course, we shall introduce industrial-strength software tools for modelling and analyzing the behaviour of (real-time) reactive systems.

Hours: 20

Professors/Lecturers: Rocco De Nicola (IMT Lucca)

Available for:n Computer Science and System Engineering

Neuroscience in Bio-Engineering and Robotics

Abstract: TBD

Hours: 18

Professors/Lecturers: Andrea Leo (IMT Lucca); Domenico Prattichizzo (Università degli Studi di Siena); Enzo Pasquale Scilingo (Università di Pisa)

Available for: Computer Science and System Engineering

Numerical Methods for the Solution of Partial Differential Equations

Abstract: The course introduces numerical methods for the approximate solution of initial and boundary value problems governed by linear partial differential equations (PDEs) ubiquitous in physics, engineering, and quantitative finance. The fundamentals of the finite difference method and of the finite element method are introduced step-by-step in reference to exemplary model problems related to heat conduction, linear elasticity, and pricing of stock options in finance. Notions on numerical differentiation, numerical integration, interpolation, and time integration schemes are provided. Special attention is given to the implementation of the numerical schemes in Matlab and in the finite element analysis program FEAP fast intensive computations.

Hours: 20

Professors/Lecturers: Marco Paggi (IMT Lucca)

Available for: Computer Science and System Engineering; Economics, Networks and Business Analytics

Numerical Optimization

Abstract: Optimization plays a key role in solving a large variety of decision problems that arise in engineering (design, process operations, embedded systems), data science, machine learning, business analytics, finance, economics, and many others. This course focuses on formulating optimization models and on the most popular numerical methods to solve them.
The topics covered in the course include: modeling (linear programming models, convex optimization models), basic optimization theory (optimality conditions, sensitivity, duality), algorithms for constrained convex optimization (active-set methods for linear and quadratic programming, proximal methods and ADMM, stochastic gradient, interior-point methods), line-search methods for unconstrained nonlinear programming, sequential quadratic programming.

Prerequisites: Linear algebra and matrix computation, calculus and mathematical analysis.

Hours: 20

Professors/Lecturers: Alberto Bemporad (IMT Lucca)

Available for: Computer Science and System Engineering; Economics, Networks and Business Analytics

Optimal Control

Abstract: Discrete-time optimal control: dynamic programming for finite/infinite horizon and deterministic/stochastic optimization problems. LQ and LQG problems, Riccati equations, Kalman filter. Deterministic continuous-time optimal control: the Hamilton-Jacobi-Bellman equation and the Pontryagin's principle. Examples of optimal control problems in economics.
An economic application of optimal control: a dynamic limit pricing model of the firm.

Hours: 20

Professors/Lecturers: Giorgio Stefano Gnecco (IMT Lucca)

Available for: Computer Science and System Engineering; Economics, Networks and Business Analytics

Philosophy of Science (long seminar without exam)

Abstract: This is an introduction to the basic concepts and problems in the analysis of scientific reasoning and inquiry. The seminar will focus on some central patterns of reasoning and argumentation in science and critically discuss their features and limitations. Topics covered include the nature of theory and evidence, the logic of theory testing, and the debate about the aims of science and the trustworthiness of scientific results. We shall discuss classical examples and case studies from the history and practice of scientific inquiry to illustrate the relevant problems and theoretical positions. Students will freely engage in brainstorming on these topics and are welcome to propose examples, problems, and methods from their own disciplines. No previous knowledge of either logic or philosophy is required.

Hours: 10

Professors/Lecturers: Gustavo Cevolani (IMT Lucca)

Available for: Computer Science and System Engineering; Economics, Networks and Business Analytics

Principles of Concurrent and Distributed Programming

Abstract: The objective of the course is to introduce the basics of concurrent and distributed programming through an illustration of the concepts and techniques related to modelling systems in which there are more components that are simultaneously active and need to coordinate and compete for the use of shared resources. At the end of the course, students will have a good understanding of the problems connected to concurrent programming and a good knowledge of the different approaches to modelling communication among distributed components and to safe resource sharing. By means of an hands-on approach, at the end of the course students be able to write and evaluate concurrent programs using different programming languages.

Hours: 30

Professors/Lecturers: Rocco De Nicola (IMT Lucca); Letterio Galletta (IMT Lucca)

Available for: Computer Science and System Engineering

Qualitative and Quantitative Formal Methods for Computer Science

Abstract: This course offers an introduction to core topics in formal methods for the specification and analysis of systems, both for functional and nonfunctional properties. Students will be exposed to basic models of computation such as labelled transition systems and process algebra, formal approaches to specifying the semantics of programming languages (such as operational and denotational semantics), and quantitative analysis methods based on Markov processes.

Hours: 20

Professors/Lecturers: Rocco De Nicola (IMT Lucca); Mirco Tribastone (IMT Lucca)

Available for: Computer Science and System Engineering

Research Topics in Computer Science

Abstract: The goal of this course is to get students acquainted with research methods in computer science, including publication strategies and a classification of its main outlets (workshops, conferences, and journals). Students will receive a broad perspective on the major sub-fields computer science (e.g., programming languages, verification, software engineering, security, …) by means of guest lectures delivered by leading experts in the respective areas.

Hours: 20

Professors/Lecturers: Rocco De Nicola (IMT Lucca); Mirco Tribastone (IMT Lucca)

Available for: Computer Science and System Engineering

Scientific Writing, Dissemination and Evaluation (long seminar without exam)

Abstract: In order to ensure their widest possible dissemination, research results need to be presented in academic publications and in talks. The first goal of this course is to introduce students to basic principles of academic writing and on basic techniques to plan and deliver good academic talks. In addition, the course discusses the key principles of peer review, which is what makes science reliable knowledge. In particular, the course focuses on how to write a professional referee report.

Hours: 8

Professors/Lecturers: Tbd

Available for: Computer Science and System Engineering; Economics, Networks and Business Analytics

Software Verification

Abstract: Software verification is the process by which a computer program is analysed in order to prove its correctness or to discover bugs. This course will introduce students to this topic with an overview of several techniques based on both testing and static verification, such as abstract interpretation, model checking, and satisfiability modulo theories. Students will be exposed to both theory and practice of software verification by means of practical sessions with state-of-the-art software tools.

Hours: 20

Professors/Lecturers: Tbd; Gabriele Costa (IMT Lucca)

Available for: Computer Science and System Engineering

Stochastic Processes and Stochastic Calculus

Abstract: This course aims at introducing some important stochastic processes and Ito stochastic calculus. Some proofs are sketched or omitted in order to have more time for examples, applications and exercises.
In particular, the course deals with the following topics:

- Markov chains (definitions and basic properties, classification of states, invariant measure, stationary distribution, some convergence results and applications, passage problems, random walks, urn models, introduction to the Markov chain Monte Carlo method),
- conditional expectation and conditional variance,
- martingales (definitions and basic properties, Burkholder transform, stopping theorem and some applications, predictable compensator and Doob decomposition, some convergence results, game theory
, random walks, urn models),
- Poisson process, Birth-Death processes,
- Wiener process (definitions, some properties, Donsker theorem, Kolmogorov-Smirnov test) and Ito calculus (Ito stochastic integral, Ito processes and stochastic differential, Ito formula, stochastic differential equations, Ornstein-Uhlenbeck process, Geometric Brownian motion, Fey
nman-Kac representation formula).

Hours: 30

Professors/Lecturers: Irene Crimaldi (IMT Lucca)

Specializing course for: Economics, Networks and Business Analytics

Also available for: Computer Science and System Engineering

Strategies and Business Behavior

Abstract: Teaching contents:

1. Market and strategy
2. Business and behavioral strategy
3. A new dimension for space and time in organization and strategy
4. Optimization and decision modeling on strategic decision making

5. Skills, competence and a new role of the human being
6. Business behavior as managerial evidence
7. Business plan: the role and function
8. Big data & decision-making process
9. Big data, machine learning for Management science
10. A multidisciplinary approach to business behavior

Business and Behavioral Strategy offers an essential view of the corporate decision-making involved in orchestrating the strategy process - the key ideas, concepts, and tools - and answer to questions like why firms adopt different strategies and structures, why heterogeneity persists. The course will describe the decision-making in competitive markets at the business unit level in which many key strategic choices and actions are formulated and undertaken. The essential “tool-kit” that combines a broad understanding of competitive strategy analysis and the decision-making will be taught in a journey through the frameworks of the analytical and behavioral processes.

The course is divided into three parts.
1. The first focuses on the strategy problem. This part of the course starts by proposing vocabulary and models, which help understand how corporate behaviors influence corporate strategy and sustain (or tackle) competitive advantage depending on the size of the company.
Topic points:
- context and principles of strategic management;
- organizational behavior in entrepreneurial and family firms.

2. The second part focuses on how turning the data and judgment into a decision. It tackles the question of how an executive and business unit can locate opportunities to achieve sustained competitive advantage thanks to the contribution of management science framed within the strategy formulation analytical process.
Topic points:
- optimization and decision modeling;
- problem structuring;
- strategic decision making.

3. The third part focuses on how competency and behavior affect the development and execution of a successful strategy. This part of the course concludes with a discussion of why good analysis in the hands of managers who have good judgment won’t naturally yield good decisions. Strategic leaders should be not only competent to read market forces but also competent “practitioner psychologists,” and what developing such competencies entails. This discussion will help surface the biases to which the decision process under review is particularly prone.
Topic points:
- cognitive biases, organization, entrepreneurial and family firm survival;
- the psychology of strategy, rational heuristics and cognitive biases.

Business case

Students will learn how to evaluate strategies, as well as how to locate sources of potential competitive advantage from a perspective that, for the purpose of this course, encompasses the internal and dynamic fit of a strategy. They will also learn how to identify organizational barriers and corporate behaviors that sustain or challenge the development and execution of strategies, and the competitive advantage of a company

Hours: 20

Professors/Lecturers: Nicola Lattanzi (IMT Lucca)

Specializing course for: Economics, Networks and Business Analytics

Also available for: Computer Science and System Engineering