PhD Program in “Systems Science”
Track in “Economics, Networks and Business Analytics” (ENBA)

Course List - A.Y. 2020/21
ENBA PhD students are required to take all the following **COMPULSORY COURSES**

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<tr>
<th>Course</th>
<th>Lecturer(s)</th>
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<tr>
<td>Advanced Topics in Network Theory: Algebraic Concepts in Network Theory</td>
<td>Guido Caldarelli</td>
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<tr>
<td>Analytics in Economics and Management</td>
<td>Massimo Riccaboni</td>
<td>20</td>
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<tr>
<td>Econometrics 1</td>
<td>Paolo Zacchia</td>
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<td>Econometrics 2</td>
<td>Armando Rungi</td>
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<td>Firms, Business Analytics and Managerial Behavior</td>
<td>Nicola Lattanzi</td>
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<tr>
<td>Game Theory</td>
<td>Ennio Bilancini</td>
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<tr>
<td>Introduction to Network Theory</td>
<td>Guido Caldarelli</td>
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<tr>
<td>Microeconomics</td>
<td>Kenan Huremovic, Andrea Canidio</td>
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and at least 3 of the following **SPECIALIZING COURSES**

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<th>Course</th>
<th>Lecturer(s)</th>
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<tr>
<td>Advanced Methods for Complex Systems I</td>
<td>Diego Garlaschelli</td>
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<td>Advanced Methods for Complex Systems II</td>
<td>Diego Garlaschelli</td>
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<td>Advanced Methods for Complex Systems III</td>
<td>Tiziano Squartini</td>
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<tr>
<td>Advanced Topics in Econometrics</td>
<td>Francesco Serti</td>
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<tr>
<td>Advanced Topics in Network Theory: Brain Networks</td>
<td>Guido Caldarelli</td>
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<tr>
<td>Advanced Topics in Network Theory: Dynamical Models in Network Theory</td>
<td>Guido Caldarelli</td>
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<tr>
<td>Advanced Topics in Network Theory: Research Topics in Network Theory</td>
<td>Guido Caldarelli</td>
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<tr>
<td>Advanced Topics in Network Theory: Topological Concepts in Network Theory</td>
<td>Guido Caldarelli</td>
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<tr>
<td>Applications of Stochastic Processes</td>
<td>Mirco Tribastone</td>
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<tr>
<td>Behavioral Economics</td>
<td>Ennio Bilancini</td>
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<tr>
<td>Business Model for Emerging Markets</td>
<td>Nicola Lattanzi</td>
<td>20</td>
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<tr>
<td>Evolutionary Game Theory</td>
<td>Ennio Bilancini</td>
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<tr>
<td>Foundations of Probability and Statistical Inference</td>
<td>Irene Crimaldi</td>
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<tr>
<td>Industrial Organization</td>
<td>Massimo Riccaboni</td>
<td>20</td>
</tr>
<tr>
<td>Machine Learning</td>
<td>Giorgio Gnecco</td>
<td>20</td>
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<tr>
<td>Political Economy</td>
<td>Alessandro Belmonte</td>
<td>20</td>
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<tr>
<td>Socio-Economic Networks</td>
<td>Massimo Riccaboni</td>
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<tr>
<td>Stochastic Processes and Stochastic Calculus</td>
<td>Irene Crimaldi</td>
<td>20</td>
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<tr>
<td>Strategies and Business Behavior</td>
<td>Nicola Lattanzi</td>
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The following **ELECTIVE COURSES** are also available for ENBA PhD students:

<table>
<thead>
<tr>
<th>Course</th>
<th>Instructor(s)</th>
<th>Credits</th>
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</thead>
<tbody>
<tr>
<td>Applied Data Science (no exam)</td>
<td>Francesco Serti, Giorgio Gnecco</td>
<td>40</td>
</tr>
<tr>
<td>Basic Elements of Cybersecurity</td>
<td>Rocco De Nicola</td>
<td>10</td>
</tr>
<tr>
<td>Computer Programming and Methodology</td>
<td>Mirco Tribastone</td>
<td>30</td>
</tr>
<tr>
<td>Critical Thinking (no exam)</td>
<td>Gustavo Cevolani</td>
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<tr>
<td>Decision-Making in Economics &amp; Management</td>
<td>Massimo Riccaboni</td>
<td>10</td>
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<tr>
<td>Funding and Management of Research and Intellectual Property (no exam)</td>
<td>Marco Paggi</td>
<td>10</td>
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<tr>
<td>Identification, Analysis and Control of Dynamical Systems</td>
<td>Alberto Bemporad</td>
<td>20</td>
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<tr>
<td>Introduction to Macroeconomics (c/o Scuola Sant'Anna)</td>
<td>Andrea Roventini</td>
<td>20</td>
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<tr>
<td>Markov Processes (c/o Scuola Sant'Anna)</td>
<td>Irene Crimaldi</td>
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<tr>
<td>Matrix Algebra</td>
<td>Giorgio Gnecco</td>
<td>10</td>
</tr>
<tr>
<td>Numerical Methods for Optimal Control</td>
<td>Mario Zanon</td>
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<tr>
<td>Numerical Methods for the Solution of Partial Differential Equations</td>
<td>Marco Paggi</td>
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<tr>
<td>Numerical Optimization</td>
<td>Alberto Bemporad</td>
<td>20</td>
</tr>
<tr>
<td>Optimal Control</td>
<td>Giorgio Gnecco</td>
<td>20</td>
</tr>
<tr>
<td>Philosophy of Science (no exam)</td>
<td>Gustavo Cevolani</td>
<td>20</td>
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</table>
Compulsory Courses
Advanced Topics in Network Theory: Algebraic Concepts in Network Theory
Guido Caldarelli
10 Hours

Learning Outcomes:
THE STUDENT WILL ACQUIRE THE ALGEBRAIC SKILLS TO OPERATE WITH NETWORKS

Abstract:
we shall provide the definitions of the algebraic concepts lying at the core of network theory and shall introduce the principles of network analysis with Python. This module is propedeutic for modules 3, 4, 5.

Lecture Contents:
LECTURE 11  Graph Representation
LECTURE 12  Graph Representation
LECTURE 13  Exercises in Python
LECTURE 14  Graph Laplacian
LECTURE 15  Graph Spectral properties
LECTURE 16  Exercises in Python
LECTURE 17  Exercises in Python
LECTURE 18 Exercises in Python
LECTURE 19 Exercises in Python
LECTURE 20  Exercises in Python

Teaching Method:
Powerpoint lectures

Bibliography:
Scale-Free Networks G. Caldarelli

Final Exam:
The candidate will work in the classroom and we shall assign a "pass" or "retake" vote at The end of course.

Prerequisites:
None
Learning Outcomes:
The aim of this course is to teach students how to produce a research paper in economics and management using hands-on empirical tools for different data structures.

Abstract:
The aim of this course is to teach students how to produce a research paper in economics and management using hands-on empirical tools for different data structures. We will bridge the gap between applications of methods in published papers and practical lessons for producing your own research. After introductions to up-to-date illustrative contributions to literature, students will be asked to perform their own analyses and comment results after applications to microdata provided during the course. How productive is a firm, an industry or a country? Why? Where is it more profitable to locate an economic activity? Who buys what products? How long can we expect a company to outlive its competitors? What is the relationship between economic welfare and size of a city? How do economic agents interact socially in a geographic space or in a workplace? The objective is to develop a critical understanding of the iterative research process leading from real economic data to the choice of the best tools available from the analyst kit. Students are expected to be familiar with microeconomics and econometrics from the first-year sequence.

Lecture Contents:
Class 1: Introduction
Class 2: Challenges of Big Data Analysis
Class 3: New Tricks for Econometrics and Artificial Intelligence
Class 4: Statistical Learning with Sparsity: The Lasso and Generalizations
Class 5: Classification and Regression Trees
Class 6: Bayesian statistical learning
Class 7: Using Big Data for Measurement and Research
Class 8: Matrix Completion and Networks
Class 9: Big Data, Big Cities, Global Studies
Class 10: Mining Text

Teaching Method:
Lecture-cum-Demonstration

Bibliography:
Main readings:
- Bajari P., Nekipelov D., Ryan S.P., Yang M. (2015) Demand Estimation with Machine Learning and
Model Combination, NBER 20955.
28(2), 3-28.

**Final Exam:**
Final scores will be based 50% on individual presentations of a selected supplemental reading and 50% on an individual homework.

**Prerequisites:**
Microeconomics, Econometrics
Learning Outcomes:
The objective of the course is to provide a firm understanding of the core theory of Econometrics at the graduate level.

Abstract:
This course provides a general introduction to modern econometrics. Following a review of fundamental concepts of probability theory, the course illustrates the fundamental linear and non-linear models at the core of econometrics, under the unifying framework of Maximum Estimation. Emphasis is placed upon the concepts of structure, identification, causality; their mutual relationships; as well as their connection to the actual econometric practice.

Lecture Contents:
1) Probability Review
2) Asymptotics Review
3) Structure, Identification and Causality
4) The Linear Regression Model
5) Least Squares Estimation
6) Endogeneity and Instrumental Variables
7) Simultaneous Equations Model
8) Introduction to Maximum Estimation
9) Maximum Likelihood Estimation
10) Generalized Method of Moments

Teaching Method:
Traditional frontal instruction accompanied by optional practice hours

Bibliography:
A. Colin Cameron and Pravin K. Trivedi (2005), Microeconometrics: Methods and Applications, Cambridge University Press
William H. Greene (2012), Econometric Analysis, Pearson
Other notes and scientific articles will be distributed in class

Final Exam:
The assessment is based upon a final written exam (for about 70% of the final grade) as well as on two extensive problem sets (for about the remaining 30%).

Prerequisites:
Multivariate calculus, linear algebra, graduate-level probability and statistical inference.
Econometrics II
Armando Rungi
20 Hours

Learning Outcomes:
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.

Abstract:
This course 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%).

Lecture Contents:
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 with 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)

9) Special seminar: Econometrics and Machine learning

Teaching Method:
Hands-on-tool approach combining theory and practice.

Bibliography:
Cameron and Trivedi (2005), Microeconometrics: Methods and Applications, Cambridge University Press.
Cameron and Trivedi (2010), Microeconometrics using Stata, Stata Press.
Angrist and Pischke (2009), Mostly Harmless Econometrics, Princeton University Press

Final Exam:
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%).

**Prerequisites:**
Foundations of Probability and Statistics; Econometrics I.
Firms, Business Analytics and Managerial Behavior
Nicola Lattanzi
20 Hours

Learning Outcomes:
Students will learn how to observe and evaluate business behavior, as well as how to locate sources of potential competitive advantage. They will also learn the base to identify organizational barriers and corporate behaviors that sustain or challenge manager decisions and execution of strategies.

Abstract:
The course is based on key business concepts that will support students develop the expertise required to understand and evaluate business behaviors, firms’ strategies and financial results. The goal of this course is to give you a solid understanding of the opportunities, techniques, and critical challenges in analyzing firms, business analytics and managerial behavior.
In our lectures we will cover the major issues involved in understanding businesses and decision making, based on fundamental concepts ranging from the theory of the firm, business performances, financial statements, strategy and entrepreneurship.

Lecture Contents:
1. Firm as a system of choices and decisions in progress: theory.
2. The system of forces in a business organization: efficiency in production and effectiveness in results
3. Business performance and ways to represent: quantitative and qualitative languages in accounting. The Financial conditions and the Profit and Loss prospect
4. The fundamental role of Human Being. Human capital and intellectual capital: evolution and analysis
5. Technological progress, occupations and skills in a business combination: the analysis
6. The financial statement. How to read and comprehend performances and results in a business organization: methodology and tools
7. The financial statement. How to read and comprehend performances and results in a business organization: methodology and tools
8. Strategy, forecast simulation versus predictive simulation, Business analytics
9. Entrepreneurship and management in a complex scenario
10. Neuroscience, brain and business

Teaching Method:
Lectures, discussions, business cases, presentations.

Bibliography:
Suggested readings will be provided for each topic.

Final Exam:
Critical paper presentations in groups.

Prerequisites:
Basic knowledge of business economics.
Learning Outcomes:
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 related to strategic behavior.

Abstract:
The course begins by providing a detailed discussion of the state of the art approach to the modeling of strategic situations as games. Then, basic solution concepts and their main refinements will be reviewed. Finally, prominent applications concerning incomplete and asymmetric information will be presented.

Lecture Contents:
Game concepts covered:
Dominance and iterative dominance, rationalizability, Nash equilibrium, subgame perfect Nash equilibrium, trembling hand perfect Nash equilibrium, weak perfect Bayes-Nash equilibrium, sequential equilibrium, perfect Bayes-Nash equilibrium, out-of-equilibrium beliefs refinements.
The discussion of all theoretical concepts will be accompanied by representative applications from economics and the social and behavioral sciences.

Teaching Method:
Frontal lectures

Bibliography:

Final Exam:
1/3 assignments, 1/3 final written exam, 1/3 essay

Prerequisites:
The course is self-contained, but being familiar with basic concepts from calculus, linear algebra, and probability theory is quite helpful.
Introduction to Network Theory
Guido Caldarelli
10 Hours

Learning Outcomes:
Basic Knowledge of Graph Theory and main results in the application of the methodology to various cases of study

Abstract:
we shall provide a broad overview of the concepts and the methods constituting modern network theory.

Lecture Contents:
LECTURE 01 Introduction
LECTURE 02 Graph Theory Introduction
LECTURE 03 Properties of Complex Networks I
LECTURE 04 Communities
LECTURE 05 Different kind of Graphs
LECTURE 06 Ranking
LECTURE 07 Static Models of Graphs
LECTURE 08 Dynamical Models of Graphs
LECTURE 09 Fitness Models
LECTURE 10 Financial Networks
AVAILABLE AT http://guidocaldarelli.com/index.php/lectures

Teaching Method:
Power point Lectures (DOWNLOAD AT http://guidocaldarelli.com/index.php/lectures)

Bibliography:
Scale-Free Networks G. Caldarelli
Networks, Crowds and Markets by David Easley and Jon Kleinberg

Final Exam:
essay/discussion with teacher

Prerequisites:
None
Learning Outcomes:
Acquire a solid understanding of classical microeconomic theory; learn how to read and write mathematical proofs; learn to apply the concepts discussed in class to solve specific exercises

Abstract:
The course aims at introducing students to graduate-level microeconomic theory. The course will give emphasis to problem solving. For this reason problem sets will be assigned during the course at dates to be communicated in class. Students will then rotate on the board in the following lecture to discuss the problems.

Lecture Contents:
Consumer Theory; Producer Theory; Choice under uncertainty; Partial equilibrium and market structure; General Equilibrium; Externalities and Public Goods; Elements of Social Choice Theory (time permitting)

Teaching Method:
Lectures

Bibliography:
There is no required textbook for the course. However, the material presented in class will be taken from Mas-Colell, Whinston, and Green "Microeconomic Theory", which you are encouraged to consult

Final Exam:
Yes.

Prerequisites:
Knowledge of intermediate-level microeconomics is helpful but not necessary.
Learning Outcomes:
Acquire a solid understanding of classical microeconomic theory; learn how to read and write mathematical proofs; learn to apply the concepts discussed in class to solve specific exercises.

Abstract:
The course aims at introducing students to graduate-level microeconomic theory. The course will give emphasis to problem solving. For this reason problem sets will be assigned during the course at dates to be communicated in class. Students will then rotate on the board in the following lecture to discuss the problems.

Lecture Contents:
Consumer Theory; Producer Theory; Choice under uncertainty; Partial equilibrium and market structure; General Equilibrium; Externalities and Public Goods; Elements of Social Choice Theory (time permitting)

Teaching Method:
Lectures

Bibliography:

Final Exam:
Yes.

Prerequisites:
Knowledge of intermediate-level microeconomics is helpful but not necessary. Students should have a working knowledge of calculus and linear algebra on the undergraduate level.
Specializing Courses
Advanced Methods for Complex Systems I
Diego Garlaschelli
20 hours

Learning Outcomes:
Students will learn how to: identify the properties of real-world complex systems that defeat traditional tools of analysis across different disciplines and research fields; design advanced methods to empirically characterise, mathematically model and computationally simulate those properties.

Abstract:
This interdisciplinary course aims at introducing rigorous tools from statistical physics, information theory and probability theory for investigating 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 systems. Special cases of interest for this first part of the course include statistical ensembles of time series and correlation matrices with given properties. Applications to pattern detection in econophysics and neuroscience will be discussed. Full mathematical derivations of the models, as well as methods of statistical inference and model selection for data analysis will be provided.

Lecture Contents:
- Introduction
- From Complexity to Thermodynamics
- From Thermodynamics to Statistical Physics
- Entropy in Probability Theory
- Entropy in Information Theory
- Empirical patterns in univariate time series
- Empirical patterns in multivariate time series- Community detection for correlation matrices

Teaching Method: Combination of frontal lectures, blackboard discussions and students' presentations.

Bibliography: References to relevant research papers are gradually provided during the lectures. Lecture slides and other course materials are regularly distributed to the students.

Final Exam:
Consists of students’ presentations of research papers, around which the professor organises a critical discussion with the rest of the class, towards the end of the course. No additional time slot for the exam is therefore scheduled.

Prerequisites: Solid mathematical background, scientific curiosity, logical rigor, interest in multidisciplinarity, passion for theory.
Learning Outcomes:
Students will learn how to: identify the properties of real-world complex systems that defeat traditional tools of analysis across different disciplines and research fields; design advanced methods to empirically characterise, mathematically model and computationally simulate those properties.

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 modelling. Network pattern detection is the identification of robust empirical patterns (like scale-invariance, clustering, assortativity, 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 1 will then be used here for pattern detection purposes. Similarly, they will be used for modelling the properties of real networks in terms of explanatory factors. 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.

Lecture Contents:
- Complex networks: robust empirical properties
- Maximum-entropy network ensembles
- Networks with given degree sequence
- Maximum likelihood parameter estimation in network ensembles
- Pattern detection in networks
- Reciprocity and the Reciprocal Configuration Model
- The International Trade Network (econometric vs network modelling)

Teaching Method: Combination of frontal lectures, blackboard discussions and students' presentations.

Bibliography:
References to relevant research papers are gradually provided during the lectures. Lecture slides and other course materials are regularly distributed to the students.

Final Exam:
The final consists of students’ presentations of research papers, around which the professor organises a critical discussion with the rest of the class, towards the end of the course. No additional time slot for the exam is therefore scheduled.

Prerequisites: Solid mathematical background, scientific curiosity, logical rigor, interest in multidisciplinarity, passion for theory. Successful completion of the course "Advanced Methods for
Complex Systems I"
Advanced Methods for Complex Systems III
Tiziano Squartini
20 hours

Learning Outcomes:
Students will learn how to: identify the properties of real-world complex systems that defeat traditional tools of analysis across different disciplines and research fields; design advanced methods to empirically characterise, mathematically model and computationally simulate those properties.

Abstract:
The course focuses on the problem of network reconstruction from partial topological information and on the different physical and mathematical properties found when the input information is treated as a “soft” or a “hard” constraint.
On the side of applications, emphasis will be put 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 methods recently found by central banks to be the best-performing reconstruction techniques will be reviewed in detail.
On the side of theory, the surprising breakdown of the equivalence of statistical ensembles constructed from soft and hard constraints will be discussed. We will show how this breakdown affects all models of complex systems encountered throughout the three parts of the course. Finally, we discuss deep implications for data compression, information theory and combinatorial enumeration.

Lecture Contents:
- From binary networks to weighted networks: the Weighted Random Graph
- The Weighted Configuration Model
- The Enhanced Configuration Model
- The Enhanced Gravity Model
- Network reconstruction in various settings
- Adaptive Networks
- Breaking of ensemble equivalence
- Relative entropy between ensembles
- Weak and strong ensemble nonequivalence
- Applications to combinatorial enumeration and data compression

Teaching Method:
Combination of frontal lectures, blackboard discussions and students' presentations.

Bibliography:
References to relevant research papers are gradually provided during the lectures. Lecture slides and other course materials are regularly distributed to the students.

Final Exam:
The final consists of students’ presentations of research papers, around which the professor organises a
critical discussion with the rest of the class, towards the end of the course. No additional time slot for the exam is therefore scheduled.

**Prerequisites:**
Solid mathematical background, scientific curiosity, logical rigor, interest in multidisciplinarity, unlimited passion for theory. Successful completion of the courses “Advanced Methods for Complex Systems I” and “Advanced Methods for Complex Systems II”
Advanced Topics in Econometrics
Lecturer: Francesco Serti
Hours: 20

Learning Outcomes:
The aim of the module is to bridge the step from a technical econometrics course to doing applied research. The emphasis will be on the application of the methods, rather than the technical details about them. As such, the goal is to provide students with enough knowledge to understand when these techniques are useful and how to implement each method in their empirical research.

Abstract:
This module covers some of the most important methodological issues arising in any field of applied economics when the main scope of the analysis is to estimate causal effects. A variety of methods will be illustrated using theory and papers drawn from the recent applied literature.

Lecture Contents:
1 Causality and Randomized Experiments
   a) Structural and Treatment Effects approaches
   b) Basic questions in empirical research
   c) Rubin Causal model
   d) Social Experiments
   e) Application I: Krueger (1999) on class size and educational test scores
   f) Application II: Atkin et al. (2017) on exporting and firm performance: evidence from a randomized experiment

2 Regression and Causality
   a) Properties of the Conditional Expectation Function
   b) Bad controls
   c) Sources of bias
   d) Conditional Independence Assumption

3 Instrumental variables
   a) Basics/recap
   b) IV and causality
   c) IV with heterogeneous treatment effects – LATE
   d) Weak instruments
   e) The bias of 2SLS
   g) Application IV: Nunn (2009) on slave trades and economic performances

4 Matching
   a) Covariate Matching
   b) Propensity Score Matching
   c) Inverse Probability Weighting
d) Entropy balancing  
e) Regression adjustment  
f) Application V: Angrist (1998) on the labor market impact of voluntary military service (matching meets regression)  

5 Differences-in-Differences  
a) Basics  
b) Regression Differences-in-Differences  
c) Robustness checks and picking a good control group  
Application VII: Card & Krueger (1994) on minimum wage and unemployment

6 Regression Discontinuity Design  
a) Sharp RD  
b) Fuzzy RD  
c) Running RD Models  
e) Application IX: Angrist & Lavy (1999) on scholastic achievement

7 The Synthetic Control Method  
a) Basics  
b) Multiple treated units  
c) Robustness checks and inference  
d) Application X: Abadie et al. (2010) on the Effect of California’s Tobacco Control Program  

**Teaching Method:**
The emphasis will be on the application of the methods, rather than the technical details about them. After a review of the theory behind each empirical method, we will focus on their practical implementation and on some examples from the applied economic literature.

**Bibliography:**

**Final Exam:**
The assessment is based on the production of a short empirical essay. To do the project students will need to provide a clear research question and a feasible empirical strategy; collect relevant data; implement an appropriate method chosen among one of those explored in the module; draw conclusions and write up the results in a standard academic style in less than 3,000 words.

**Prerequisites:**
None
Learning Outcomes:
knowledge of the basis of Brain Networks

Abstract:
we shall provide the tools to measure and analyze the different kinds of networks that can be defined when studying the human brain (e.g. the functional and the structural one).

Lecture Contents:
Physics of Brain measurements. Networks from Functional Magnetic Resonance Imaging, applications to cohorts of patients

Teaching Method:
Powerpoint slides

Bibliography:
Scale-Free Networks G. Caldarelli

Final Exam:
the candidate will work in the classroom and we shall assign a “pass” or “retake” vote at the end of course.

Prerequisites:
None
Learning Outcomes:
Being able to use models for network theory

Abstract:
we shall review the most popular growth models for networks, the details of the most studied dynamical processes on networks and their implementation in Python. This module requires module 2.

Lecture Contents:
LECTURE 31 Models I
LECTURE 32 Models II
LECTURE 33 Models III
LECTURE 34-37 Epidemics
LECTURE 37-40 Exercises in Python

Teaching Method:
Powerpoint lectures

Bibliography:
Scale-Free Networks G. Caldarelli

Final Exam:
The candidate will work in the classroom and we shall assign a “pass” or “retake” vote at the end of course.

Prerequisites:
None
Advanced Topics in Network Theory: Research Topics in Network Theory  
Guido Caldarelli  
10 Hours

**Learning Outcomes:**
Being aware of the state of the art

**Abstract:**
We shall review the latest developments in research concerning the field of network theory. This module requires module 2. The course “Advanced Methods for Complex Systems I” is suggested as a prerequisite.

**Lecture Contents:**
The Exponential Random Graph Model: constrained entropy maximization; parameter estimation; computing expectations and errors; a quick look at perturbation theory for networks (2h)  
Hypothesis testing on networks: projecting and filtering bipartite networks; early-warning signals detection; community detection techniques for correlation matrices (asset graph, MSF, dendrogram-cutting, the Masuda approach, random matrix theory-based techniques) (3h)  
Network reconstruction; applications to the World Trade Web; comparison between network models and econometric models; applications to financial networks; link prediction (3h)  
An overview of infrastructural networks (2h)

**Teaching Method:**
Powerpoint lecture

**Bibliography:**
Scale-Free Networks G. Caldarelli

**Final Exam:**
The candidate will work in the classroom and we shall assign a “pass” or “retake” vote at The end of course.

**Prerequisites:**
None
Advanced Topics in Network Theory: Topological Concepts in Network Theory
Guido Caldarelli
10 Hours

Learning Outcomes:
knowledge of the topology associated to graphs

Abstract:
we shall introduce the definitions of the main topological quantities of interest in network theory and their implementation in Python. This module requires module 2 and is propedeutic for module 5.

Lecture Contents:
LECTURE 21  Centrality measures II
LECTURE 22  Centrality measures
LECTURE 23  Bipartite Networks
LECTURE 24  Ranking and Reputation
LECTURE 25  Mesoscale Properties
LECTURE 26  Exercises in Python
LECTURE 27  Exercises in Python
LECTURE 28  Trade Network data
LECTURE 29  Exercises in Python
LECTURE 30  Exercises in Python

Teaching Method:
Powerpoint lectures

Bibliography:
Scale-Free Networks G. Caldarelli

Final Exam:
The candidate will work in the classroom and we shall assign a “pass” or “retake” vote at The end of course.

Prerequisites:
None
Applications of Stochastic Processes
Mirco Tribastone
20 Hours

Learning Outcomes:
To provide students with basic tools for the modeling and analysis of systems using 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.

Lecture Contents:
Introductions to discrete- and continuous-Markov chains; examples (Page Rank, reaction networks, queuing networks); Markov population processes; stochastic simulation algorithms; fluid approximations of Markov population processes; software tools for analysing Markov chains.

Teaching Method:
Blackboard and slides.

Bibliography:
Bibliographic material will consist of research articles distributed throughout the course.

Final Exam:
Student may choose between the presentation of a research paper or the development of project

Prerequisites:
None
Behavioral Economics
Ennio Bilancini
20 Hours

Learning Outcomes:
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 concerning bounded rationality and prosocial behavior.

Abstract:
The course is a self-contained presentation and discussion of 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.

Lecture Contents:
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: Cognitive 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

Teaching Method:
Frontal lectures

Bibliography:

Final Exam:
A 10-page essay applying behavioral economics to a phenomenon decided by the student

Prerequisites:
The course is self-contained, but basic knowledge of microeconomics and choice theory are welcome.
Learning Outcomes:
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.

Abstract:
The course is based on key business concepts that will support students develop the expertise required to understand and evaluate business models in competitive and emerging markets. The course will describe the decision-making in competitive markets as well as in emerging 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 strategies, businesses and market dynamics and the new challenges of businesses in today’s world.

Lecture Contents:
1. What makes the economy emerging and the market new?
2. Fintech challenge: centralized economy versus decentralized economy? Decentralized organizations and business models? DAO, DAC and others
3. Digital Economy: effects and implications on business modeling, business plan and business reporting
4. Family business and Italian SMSB: “Made in a recognizable place”
5. A business model for a global value chain approach in a Digital Economy. The smile curve: where value is added along supply chains
6. The new Silk Road - Belt and Road: Avoiding Errors, Discovering Opportunities
7. Creation of needs, emerging behaviors and business dynamics: the interaction of neuroscience and technology for business and strategy
8. Zombie Economy and Zombie Firms: The Emerging Phenomena
9. Network approach for Business modeling and decision making process
10. The role and function of studies in management science and business strategy. The emerging scenario.

Teaching Method:
Lectures, discussions, business cases, presentations.

Bibliography:
Suggested readings will be provided for each topic.
**Final Exam:**
Critical paper presentations in groups.

**Prerequisites:**
None
Evolutionary Game Theory
Ennio Bilancini
20 Hours

Learning Outcomes:
To provide students with a state of the art overview of evolutionary game theory which can be useful to the potential researcher in the area as well as the interested scholar who works in a related field (behavioral sciences, social sciences, complexity studies).

Abstract:
Evolutionary methods allow to study how behaviors and traits evolve in a population of interacting agents. The object of evolution can be a biological or cultural trait or a profile of strategies in a game. The process by which it changes can depend on fitness, imitation or optimization, possibly as the outcome of a deliberative process.

Lecture Contents:
1. Overview of Evolutionary Game Theory
   Basic concepts, techniques and findings, from ESS strategies to evolutionary stability.
2. Deterministic evolutionary dynamics
   Models of deterministic evolution, mostly based on replicator dynamics and imitation.
3. Stochastic evolutionary models
   Models of stochastic evolution, mostly based on markov chains. Equilibrium selection based on stochastic stability techniques.

Teaching Method:
Frontal lectures

Bibliography:

Final Exam:
A 10-page essay applying evolutionary game theory to a phenomenon decided by the student

Prerequisites:
The course is self-contained, but basic knowledge of game theory and markov chains is welcome.
Learning Outcomes:
By the end of this course, students will:
- have the ability to employ the fundamental tools of Probability Theory in order to solve different kinds of problems,
- have the fundamental concepts of Statistical Inference in order to perform various kinds of statistical analysis,
- appreciate the importance of mathematical formalization in solving probabilistic problems and in performing statistical analysis,
- be able to independently read mathematical and statistical literature of various types and be life-long learners who are able to independently expand their probabilistic and statistical expertise when needed.

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.

Lecture Contents:
This 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,
- Mathematical Statistics (point estimation, interval estimation, hypothesis testing, linear regression, introduction to Bayesian statistics).

Teaching Method:
Frontal teaching

Bibliography:
- Slides and other material provided by the lecturer
Final Exam:
Written test

Prerequisites:
None
Learning Outcomes:
To master the concepts developed in the course material in such a way that independent research can be carried out. Demonstrate knowledge and understanding that provide a basis for originality in developing ideas, often related to a research context. Students should possess the learning outcomes that enable them to continue studying in a way that will be largely self-directed or autonomous.

Abstract:
This course will survey recent developments in theory and empirics of firm dynamics and its importance for aggregate outcomes such as innovation, growth and international trade. In particular, this class will center around the following questions: a) what are the key empirical regularities on firm dynamics and what are the principal measurement issues? b) what drives firms’ size and growth dynamics? c) what determines the dynamics of entrepreneurial growth and innovation by firms? d) how do different sources of firm-level heterogeneity influence aggregate outcomes? e) what drives the rise and fall of inter-firm collaboration and trade networks? Students are expected to be familiar with microeconomics and econometrics from the first-year sequence.

Lecture Contents:
Class 1: Gibrat Legacy
Class 2: Size distribution of business firms, theory
Class 3: Size distribution of business firms, empirics
Class 4: Growth-of-firm, theory
Class 5: Growth-of-firm, empirics 1 (econometrics)
Class 6: Size-Growth Relationship, theory
Class 7: Market Structure: The Bounds Approach
Class 8: Industry Dynamics
Class 9: Machine Learning Firm Dynamics
Class 10: Microfoundations of Aggregate Fluctuations

Teaching Method:
Lecture-cum-Demonstration

Bibliography:
Main reference:
- Other references:
Final Exam:
- Final presentation of student research proposal: 70%
- Class participation and constructive discussion of other students’ research ideas: 30%

Prerequisites:
Microeconomics, Econometrics I & II
Learning Outcomes:
At the end of the course, the student will be able to implement in MATLAB some machine learning
techniques, including ones studied during the course “Machine Learning”.

Abstract:
The course provides MATLAB implementations of some machine learning techniques, including ones
studied during the course “Machine Learning”.

Lecture Contents:
MATLAB code will be presented and discussed for the following studies:
- bias/variance trade-off;
- batch gradient descent and stochastic gradient descent for training perceptrons and multilayer
  neural networks;
- perceptrons and multilayer neural networks applied to the XOR problem;
- multiclass classification via neural networks;
- LQG online learning;
- trade-off between number of examples and precision of supervision in ordinary least squares,
  weighed least squares, and fixed effects panel data models;
- spectral clustering;
- surrogate optimization for optimal material design;
- box identification via the Monte Carlo method;
- curve identification.

Teaching Method:
The teacher will present to the students and discuss with them the MATLAB code developed for the
applications above. Students will have the possibility to run the code and modify it.

Bibliography:
The following reference reports commented MATLAB code for some of the machine-learning applications
presented in the course:
P. Kim, "MATLAB Deep Learning With Machine Learning, Neural Networks and Artificial Intelligence,”

The MATLAB code for most of the other applications is related to the following articles:
A. Bacigalupo, G. Gnecco, M. Lepidi, L. Gambarotta, “Machine-learning techniques for the optimal design
of acoustic metamaterials,” Journal of Optimization Theory and Applications, 2019, DOI: 10.1007/s10957-
019-01614-8.
G. Gnecco, F. Nutarelli, "On the trade-off between number of examples and precision of supervision in


**Final Exam:**
There is no final exam.

**Prerequisites:**
None
Learning Outcomes:
Students will learn the principal methods and some major empirical applications of modern political economy, including how to apply games to political economic situations and how to apply empirical methods to test political economy theories.

Abstract:
The course is a relatively advanced (i.e. at the beginning graduate level) but essentially self-contained introduction to the methods and some major applications of modern political economy.

Lecture Contents:
Topics:
- Institutions and “exogenous” differences in institutions
- At the origin of institutions: From Social Choice to Political Economics
- Median voter models and redistributive politics
- Probabilistic voting models
- Agency models of politics: Electoral accountability and career concerns
- Endogenous Institutions: Institutional transitions and conflicts.

Teaching Method:
Direct instruction complemented by active participation of students. Students will also be asked to present and discuss some relevant empirical works.

Bibliography:
Textbooks:
2) Daron Acemoglu, Political Economy Lecture Notes.

Additional Readings:
2) James Feyrer and Bruce Sacerdote, Colonialism and Modern Income: Islands as Natural Experiments, RESTAT 2009
3) Toke S. Aidt, Raphaël Franck, Democratization Under the Threat of Revolution: Evidence From the Great Reform Act of 1832, ECMA 2015
5) Sascha O. Becker and Luigi Pascali, Religion, Division of Labor and Conflict: Anti-Semitism in German Regions over 600 Years, AER 2019
6) Alesina Alberto and Fuchs-Schündeln Nicola, Goodbye Lenin (or Not?): The Effect of Communism on People's Preferences, AER 2007
7) Fernanda Brollo, Tommaso Nannicini, Roberto Perotti, and Guido Tabellini, The Political Resource Curse, AER 2013

Final Exam:
The exam develops in two parts: 1) students' presentation of an empirical article and 2) a summary of an article

Prerequisites:
The course assumes a good knowledge of macro and microeconomics (especially some growth theory, elementary taxation theory and game theory, including games with asymmetric/incomplete information and the theory of repeated games), of mathematical and statistical methods (especially static and dynamic optimization), and some introductory knowledge of econometric tools (especially familiarity with the issue of causality in econometrics and IV estimation), at the level of the relevant courses offered at IMT.
Learning Outcomes:
To master the concepts developed in the course material in such a way that independent research can be carried out. Learn the socio-economic approach to the analysis of networks.

Abstract:
The main topic of the course is the analysis of socio-economic networks. The course will consist of three parts: (1) basic notions of graph theory and social network analysis; (2) micro level networks of individuals and firms; (3) meso and macro-level networks of sectors and countries. The first part will focus on some basic notions of social network analysis. Individual and inter-organizational networks will be analyzed. In the second part, with a special focus on the division of (innovative) labor within and across firm boundaries. The third part on the empirics of meso and macro networks in economics will have a strong focus on international trade, human mobility and finance. All parts will give you a brief overview on the literature, which predominantly adopted an econometric approach to the analysis of networks.

Lecture Contents:
Section I: Graph theory and social network analysis
- Class 1: Graph Theory and Social networks: basic concepts; embeddedness, reflection problem; diffusion & homophily
- Class 2: Small world, cascading behavior and information cascades
- Class 3: Power laws, preferential attachment
- Class 4: Network effects, epidemics

Section II: Socio-economic networks: Individuals and Organizations
- Class 5: Interorganizational networks: Firms’ collaborative agreements; networks of innovators
- Class 6: Influence and peer effects in social networks

Section III: Empirics of Meso and Macro-Economic Networks
- Class 7: Networks of trade and production
- Class 8: Migration and human mobility
- Class 9: Input-Output networks
- Class 10: Financial networks and systemic risk

Teaching Method:
Lecture-cum-Demonstration

Bibliography:
Main text:
Other readings:

Other reading materials:


Bureau of Economic Research, working paper n. w19466.

Final Exam:
- Referee Reports: 40% Select a recent working paper or a classical paper not covered in the class and
write a referee report on it. The paper selected has to be approved by the instructors.
- Term Paper: 60% A research proposal, with clearly stated questions, adequate literature survey, and
proposed approaches.

Prerequisites:
Introduction to Network Theory
Stochastic Processes and Stochastic Calculus
Irene Crimaldi
20 Hours

Learning Outcomes:
By the end of this course, students will:
- be familiar with some important stochastic processes,
- be familiar with Ito stochastic calculus,
- be able to identify appropriate stochastic process model(s) for a given research problem,
- appreciate the importance of mathematical formalization in solving probabilistic and statistical problems,
- be able to independently read mathematical and statistical literature of various types and be life-long learners who are able to independently expand their probabilistic and statistical expertise when needed.

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.

Lecture Contents:
This course deals with the following topics:
- Markov chains (definitions and basic properties, classification of states, invariant measure, stationary distribution, ergodic limit theorem, cyclic classes, passage problems);
- 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);
- Wiener process (definitions, some properties, Donsker theorem, Kolmogorov-Smirnov test)
- Ito calculus (Ito stochastic integral, Ito processes and stochastic differential, Ito formula, stochastic differential equations, Ornstein-Uhlenbeck process, Geometric Brownian motion, Feynman-Kac Representation formula).

Teaching Method:
Frontal teaching

Bibliography:
- Slides and other material provided by the lecturer
- D. Williams, Probability with martingales, Cambridge Univ. Press (1991)

**Final Exam:**
Seminar with a short written report on the topic of the seminar

**Prerequisites:**
None
Learning Outcomes:
Students will learn how to analyze business behaviour and 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.

Abstract:
The course is based on key business concepts that will support students develop the expertise required to understand business behaviour and evaluate strategies. The course will describe strategy and decision-making in today's world, how to identify organizational barriers and advantages for the development of firms’ strategies, also following the behavioral perspective. The essential “tool-kit” that combines a broad understanding of strategies, businesses and behavioral strategies and the new challenges of businesses in today’s world.

Lecture Contents:
1. Fundamentals of Business Behavior
2. Fundamentals of Strategy
3. Market and strategy: volatility and development
4. The strategic management
5. A focus on specific firms and competitive advantage
6. Business behavior and patterns of innovation
7. Behavioral strategy: rational approach, heuristic system and cognitive biases
8. Cyber-time and cyber-space for humans and virtual humans: business dynamics and organizations
10. Data Science for business: network theory for strategy and management
11. The extra-ordinary life of patterns and trends: how to learn for a business organization?

Teaching Method:
Lectures, discussions, business cases, presentations.

Bibliography:
Suggested readings will be provided for each topic.

Final Exam:
At the end of the course students will be required to prepare and discuss a conceptual framework after reading three selected papers.

Prerequisites:
None
Elective Courses
Applied Data Science
Francesco Serti, Giorgio Gnecco
Hours: 40

(Econometrics part - Francesco Serti - 20 Hours)

Learning Outcomes:
(1) Knowledge of the most relevant functionalities in Stata to carry out data management and exploratory analysis
(2) To achieve autonomy in application of econometric techniques to real data

Abstract:
The aim of this course is to provide students with fundamentals of Stata language to conduct data management and exploratory analysis, and implement a variety of econometric techniques to address typical research questions in Economics.

Lecture Contents:
Lectures will cover the following topics:
– Introduction to Stata, descriptive statistics, fundamentals of inference
– OLS regression
– Panel methods (pooled OLS, Fixed Effects, Random Effects, First Difference, Generalized Least Squares)
– Impact Evaluation (Randomized experiments, Matching, Difference-in-differences, Instrumental Variables, Regression Discontinuity Design, Synthetic Control Methods)
– Total Factor Productivity estimation

Teaching Method:
Computer-based

Bibliography:

Final Exam:
There will be no exam

Prerequisites:
None
Applied Data Science
Francesco Serti, Giorgio Gnecco
Hours: 40

(Machine Learning part - Giorgio Gnecco - 20 Hours)

Learning Outcomes:
At the end of the course, the student will be able to implement in MATLAB some machine learning techniques, including ones studied during the course "Machine Learning".

Abstract:
The course provides MATLAB implementations of some machine learning techniques, including ones studied during the course "Machine Learning".

Lecture Contents:
MATLAB code will be presented and discussed for the following studies:
- bias/variance trade-off;
- batch gradient descent and stochastic gradient descent for training perceptrons and multilayer neural networks;
- perceptrons and multilayer neural networks applied to the XOR problem;
- multiclass classification via neural networks;
- LQG online learning;
- trade-off between number of examples and precision of supervision in ordinary least squares, weighed least squares, and fixed effects panel data models;
- spectral clustering;
- surrogate optimization for optimal material design;
- box identification via the Monte Carlo method;
- curve identification.

Teaching Method:
The teacher will present to the students and discuss with them the MATLAB code developed for the applications above. Students will have the possibility to run the code and modify it.

Bibliography:
The following reference reports commented MATLAB code for some of the machine-learning applications presented in the course:

The MATLAB code for most of the other applications is related to the following articles:

**Final Exam:**
The there is no final exam.

**Prerequisites:**
None
Basic Elements of Cybersecurity
Rocco De Nicola
10 Hours

Learning Outcomes:
Basic knowledge of the risks when surfing the web and of the main tools for defending assets and privacy.

Abstract:
This introductory course would be beneficial for any student and does not assume any prior technical knowledge. We will discuss cybersecurity in general and present techniques and tools for navigating securely and for defending assets and privacy.

Lecture Contents:

Teaching Method:
Blackboard; slides.

Bibliography:
Handouts with the slides, introductory books,

Final Exam:
Final collective discussion about the importance of cybersecurity with short presentations by all students.

Prerequisites:
None
Computer Programming and Methodology  
Mirco Tribastone  
30 Hours

Learning Outcomes:  
This course aims to provide students with basic principles and methodologies of computer programming using Python. It is aimed particularly to students without a computer science background. The main objective is to develop the necessary skills to effectively read, write, and maintain computer programs. It provides background for facilitating the understanding of advanced programming classes as well as the proficiency with domain-specific software libraries and tools.

Abstract:  
The course will cover the basic principles of programming, starting from the interaction between programs and the environment (memory, input/output) in which they execute. It will discuss: fundamental programming constructs (conditional statements, loops); how to effectively structure code using functions; recursion; object-oriented programming; basics of functional programming; memory management for programs (garbage collection). The Python programming language will be used to demonstrate these concepts and to develop simple illustrative programs that will be presented throughout the course.

Lecture Contents:  
Introduction to computer architectures; programming; variables; data structures and Python sequences; memory management; conditional statements; for and while loops; functions; basics of object-oriented programming; basics of functional programming.

Teaching Method:  
Blackboard; slides; programming tutorials

Bibliography:  
M. Lutz. Learning Python, O'Reilly.

Final Exam:  
Group project

Prerequisites:  
None
Learning Outcomes:
The course aims at improving the students’ skills in understanding, presenting and evaluating problem statements and arguments. After following the course, students will be able to rigorously distinguish between “strong” and “weak” arguments; they can formulate and analyze theses and hypotheses and evaluate the impact that evidence and information has on them; and they can better draw logical and effective conclusions from both hypotheses or evidence.

Abstract:
Constructing and evaluating arguments is fundamental in all branches of science, as well as in everyday life. The course provides the basic tools to recognize and analyze correct forms of inference and reasoning, detect the unsound or fallacious ones, and assess the strength of various kinds of argument. The toolbox includes elementary deductive logic, naïve set theory, patterns of inductive and abductive inference, and elements of statistical and probabilistic reasoning. By engaging in real-world exercises of correct and incorrect reasoning, students will familiarize with basic epistemological notions (truth vs. certainty, knowledge vs. belief, theory vs. evidence, etc.), with the analysis of relevant informal concepts (like truth, falsity, lies, misinformation, disinformation, post-truth, fake news, rumors, etc.) and with common reasoning pitfalls, heuristics and biases as investigated in cognitive psychology and behavioral economics.

Lecture Contents:
Lecture 1. Presentation, discussion and choice of specific topics. Arguments and statements.
Lecture 2. Evaluating statements: Truth, certainty, informativeness, truthlikeness, etc. Relativism and post-truth.
Lecture 8. Recap, verification and general discussion.

Teaching Method:
Mixture of lectures and discussion seminar.

Bibliography:
We won’t have a textbook or a proper reading list. Relevant readings will be shared on the IMT Google Drive. The following are useful general texts on the main topics of the course (all of them are owned by the IMT Library).

Final Exam:
Active contribution from the participants is a prerequisite for passing the course.

Prerequisites:
None
Learning Outcomes:
The main goals of the course are: (1) to take marketing theories and methodologies out into the world, applying them to interesting questions of individual behavior and societal outcomes; (2) to develop a basic understanding of human psychology and social dynamics as they apply to marketing contexts; (3) to become familiar with the major theory and research methods for analyzing consumer behavior; (4) to develop market analytics insight into consumer actions.

Abstract:
This class is structured into two parts: 1) general knowledge relating to basic conceptual notions of marketing and consumer behavior; and 2) heritage marketing. Most of time will be devoted to close reading of textbook and research papers, including discussion of the relative merits of particular methodologies. Students will participate actively in class discussion, engage with cutting-edge research, evaluate empirical data, and write an analytical paper. The course aims at enabling students to develop and enhance their own skills and research interests.

Lecture Contents:
1. Course overview, consumer behavior; Chapters 1-4, Principles of Marketing
2. Marketing to create value, theory and practice; Chapters 5-9, Principles of Marketing
3. The Marketing Plan; Chapters 14-16, Principles of Marketing
4. Heritage marketing
5. Behavioral economics insights, guidelines for final paper

Teaching Method:
Lecturing

Bibliography:
The main textbook for this course is entitled “Principles of Marketing” and is freely available online https://open.lib.umn.edu/principlesmarketing/.


Additional readings will be provided by the instructor based on students’ research interests (see Google Drive)

Final Exam:
50% Participation. Attendance is required and will be recorded. The teaching format is interactive, i.e. active discussion is expected between students and instructor and will be part of the student evaluation. Abstract concepts will be understood through real life examples and observations.
50% Final Paper. You will select a topic related to marketing and consumer decision making and write a paper.

**Prerequisites:**
None
Funding and Management of Research and Intellectual Property
Marco Paggi
10 Hours

Learning Outcomes:
How to write a research/mobility project proposal; fundamentals on the management of intellectual property rights.

Abstract:
The long seminar aims at providing an overview of funding opportunities for PhD students' mobility, post-docs, and researchers (Erasmus+ scheme; 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. In the second part of the long seminar, fundamentals on the management of intellectual property rights (copyright transfer agreements, open access, patents, etc.) are provided.

Lecture Contents:
- Overview of funding schemes to support research mobility;
- Fundamentals of Intellectual Property Rights (patents, copyrights, etc.)

Teaching Method:
Powerpoint slides

Bibliography:
Handouts are provided to the participants.

Final Exam:
This long seminar has no final exam.

Prerequisites:
None
Learning Outcomes:
Getting familiar with analyzing, controlling, estimating, and identifying dynamical systems, with emphasis on linear dynamical systems in state-space form.

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.

Lecture Contents:

Teaching Method:
Lecture slides and blackboard

Bibliography:
Lecture slides available on http://cse.lab.imtlucca.it/~bemporad/intro_control_course.html

Final Exam:
Typically a small research project, or discussion about a paper on a subject related to the course, or oral exam.

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

Syllabus is included in “Macroeconomics” (Sant'Anna School for Advanced Studies - Pisa)
Markov Processes
(Sant'Anna School for Advanced Studies - Pisa)
Irene Crimaldi
12 Hours

Learning Outcomes:
By the end of this course, students will:
- be familiar with Markov processes in discrete and continuous time,
- be able to employ the fundamental tools of Markov Processes Theory in order to solve different kinds of problems,
- appreciate the importance of mathematical formalization in solving probabilistic problems,
- be able to independently read mathematical and statistical literature of various types.

Abstract:
This course covers the fundamental results regarding Markov processes. Some proofs are sketched or omitted in order to have more time for examples, applications and exercises.

Lecture Contents:
This course deals with the following topics:
- Markov chains (definitions and basic properties, classification of states, invariant measure, stationary distribution, ergodic limit theorem, random walk and Gambler’s ruin problem);
- Poisson process (definition, properties and applications);
- Markov processes with continuous time (definitions, Markov property, generator, forward Kolmogorov equations, stationary probability distribution);
- Birth-Death processes and queues.

Teaching Method:
Frontal teaching

Bibliography:
- Slides and other material provided by the lecturer

Final Exam:
TBD

Prerequisites:
None
Learning Outcomes:
The course is aimed to review basic concepts of matrix algebra at an intermediate/advanced level.

Abstract:
The course is aimed to review the following basic concepts of linear algebra:
- systems of linear equations: solution by Gaussian elimination, PA=LU factorization, Gauss-Jordan method;
- vector spaces and subspaces, the four fundamental subspaces, and the fundamental theorem of linear algebra;
- determinants and eigenvalues, symmetric matrices, spectral theorem, quadratic forms;
- Cayley-Hamilton theorem, functions of matrices, and application of linear algebra to dynamical linear systems;
- iterative methods for systems of linear equations;
- ordinary least squares problem, normal equations, A=QR factorization, condition number, Tikhonov regularization;
- singular-value decomposition, Moore-Penrose pseudoinverse;
The course also shows how to apply the methods above using MATLAB. Finally, an economic application of matrix algebra (the Leontief input-output model) is also detailed.

Lecture Contents:
- Systems of linear equations;
- Properties of systems of linear equations;
- Determinant and eigenvalues;
- Applications of eigenvalues;
- QR factorization, ordinary least squares problem, and variations;
- An economic application of linear algebra: the Leontief input-output model.

Teaching Method:
The teacher will project slides on the screen (a copy of the slides and of the MATLAB code will be provided to the students). He will also solve some exercises on the blackboard.

Bibliography:
MATLAB teaching codes based on Prof. Strang’s books:
http://web.mit.edu/18.06/www/Course-Info/Tcodes.html

Students having already a good background in matrix algebra are encouraged to read the following more advanced topics from the second book by Prof. Strang:
- application of linear algebra to graphs (Section 2.5),
- application of Gram-Schmidt orthogonalization process to function spaces (Section 3.4),
- Fast Fourier transform (Section 3.5),
- complex matrices (Section 5.5),
- minimum principles (Section 6.4),
- finite element method (Section 6.5),
- linear programming, the simplex method, and duality (Sections 8.1-8.4),
- Jordan’s canonical decomposition (Appendix B).

**Final Exam:**
Final written examination (optional, 2 hours)

**Prerequisites:**
None
Learning Outcomes:
The students will learn how to properly formulate and solve an optimal control problem using state-of-the-art techniques.

Abstract:
Many control and estimation tasks seek at minimizing a given cost while respecting a set of constraints, which belongs to the class of problems denoted as Optimal Control (OC). The most practical approach to solve OC problems is via direct methods, which consists in discretizing the problem to obtain a Nonlinear Program (NLP) which is then solved using one of the many available approaches. The course will be introduced by an overview of the available classes of algorithms for OC and place direct methods in this context. The core of the course is structured around the following two main parts.

NLP solvers:
This part of the course first establishes a sound theoretical background on the characterization of local minima (maxima) by introducing geometric optimality concepts and relating them to the first- and second-order conditions for optimality, i.e. the Karush-Kuhn-Tucker conditions, constraint qualifications and curvature conditions. Second, the theoretical concepts will be used to analyze the most successful algorithms for derivative-based nonconvex optimization, i.e. Sequential Quadratic Programming and Interior Point Methods, both based on Newton’s method. Since there does not exist a plug-and-play NLP solver, attention will be devoted to giving the students a solid understanding of the mechanisms underlying the algorithms so as to endow them with the ability to formulate the problem appropriately and choose the adequate algorithm for each situation.

Discretization techniques:
This second part of the course covers the most successful discretization approaches, i.e. single-shooting, multiple-shooting and collocation. All mentioned approaches rely on the simulation of dynamical systems, for which a plethora of algorithms have been developed. The students will be explained the features of the different classes of algorithms, with particular attention on the numerical efficiency, simulation accuracy and sensitivity computation. Finally, the structure underlying the NLP obtained via direct methods for OC will be analyzed in order to understand the immense benefits derived from developing dedicated structure-exploiting OC solvers.

Advanced Topics:
The course will be concluded by two lectures on parametric sensitivities, path-following methods and Nonlinear Model Predictive Control (NMPC) with considerations on stability, tuning and real-time solvers.

Lecture Contents:
The following lectures are divided by topic in the order in which they will be presented. Some lecture
requires more than 2 hours and some other requires less. Altogether, the 9 lectures require 20 hours of teaching, which will be supported by 10 hours of supervision for the solution of the assignments.

1. Introduction to optimal control
2. Nonlinear Programming: optimality characterization
3. Newton's method and algorithms for nonconvex optimization
4. Shooting methods
5. Numerical integration with sensitivities
6. Collocation methods
7. Structure of discretized optimal control problems
8. Parametric sensitivity and path-following
9. Nonlinear Model Predictive Control

**Teaching Method:**
Lectures and exercise sessions

**Bibliography:**
L. Biegler. Nonlinear Programming, MOS-SIAM Series on Optimization 2010
J. C. Butcher Numerical Methods for Ordinary Differential Equations, Wiley 2016

**Final Exam:**
Solution of all the assignments

**Prerequisites:**
Basic knowledge in dynamical systems and linear algebra. Some knowledge on numerical optimization and simulation can be helpful but is not required.
Learning Outcomes:
Ability to solve numerically a problem related to a physical system and predict its response. The physical system can be embedded within an optimization problem, for instance, or it can be part of a complex system (biological, mechanical, thermo-mechanical, chemical, or even financial) you are interested in predicting its behaviour and evolution over time.

Abstract:
The course introduces numerical methods for the approximate solution of initial and boundary value problems governed by linear and nonlinear partial differential equations (PDEs) used to describe physical systems. The fundamentals of the finite difference method and of the finite element method are introduced step-by-step in reference to exemplary model problems taken from 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 finite element analysis programmes for fast intensive computations.

Lecture Contents:
- Numerical differentiation schemes
- Numerical interpolation schemes
- Numerical integration schemes
- Time integration algorithms
- Newton-Raphson incremental-iterative schemes for nonlinear problems
- Finite difference method
- Finite element method

Teaching Method:
Blackboard. Handouts are also provided.

Bibliography:

Final Exam:
An application of the taught methodologies to one case study of relevance for the PhD student’s research is recommended. Alternatively, a topic to investigate can be suggested by the lecturer.

Prerequisites:
The course is self-contained. Fundamentals of algebra are required.
Learning Outcomes:
Learn how to model optimal decision problems as optimization problems and how to solve them using numerical optimization packages. By learning the basic theory behind the most used numerical optimization methods (optimality conditions, sensitivity, duality) and understanding how the algorithms work, the student will be able to formulate real-life optimization problems and to choose the most appropriate algorithms to solve them, or to develop new optimization algorithms or adapt existing ones to solve them.

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, including active-set methods for linear and quadratic programming, proximal methods and ADMM, stochastic gradient, interior-point methods, line-search methods for unconstrained nonlinear programming.

Lecture Contents:

Teaching Method:
Lecture slides and blackboard.

Bibliography:
Lecture slides available on http://cse.lab.imtlucca.it/~bemporad/optimization_course.html

**Final Exam:**
Typically a small research project, or discussion about a paper on a subject related to the course, or oral exam.

**Prerequisites:**
Linear algebra and matrix computation, calculus and mathematical analysis.
Learning Outcomes:
At the end of the course, the student will be able to formulate optimal control problems and will know a wide range of techniques that can be applied for solving such problems. By attending the course, the student will learn mathematical methods useful for applications of optimal control in differential game theory, machine learning, and macroeconomics.

Abstract:
The course provides an overview of optimal control theory for the deterministic and stochastic cases. Both discrete-time and continuous-time problems are considered, together with some applications to economics.

Lecture Contents:
- An overview of optimal control problems.
- An economic example of an optimal control problem: the cake-eating problem.
- Dynamic programming and Bellman’s equations for the deterministic discrete-time case.
- Reachability/controllability and observability/reconstructability for time-invariant linear dynamical systems.
- The Hamilton-Jacobi-Bellman equation for continuous-time deterministic optimal control problems.
- Pontryagin’s principle for continuous-time deterministic optimal control problems.
- LQ optimal control in discrete time for deterministic problems.
- Application of dynamic programming to stochastic and infinite-horizon optimal control problems in discrete time.
- LQ optimal control in discrete time for stochastic problems and Kalman filter.
- Introduction to approximate dynamic programming and reinforcement learning.
- An economic application of optimal control: a dynamic limit pricing model of the firm.

Teaching Method:
The teacher will project slides on the screen (a copy of the slides will be provided to the students).

Bibliography:
The following books are related to the course. They can be useful as an optional supplementary material.
D. P. Bertsekas and S. E. Shrieve: Stochastic optimal control: the discrete-time case, Academic Press,
1978.

The following are slides/lectures notes from related courses.

**Final Exam:**
The student will prepare slides for a short seminar (20-30 minutes) on a topic related to optimal control. The topic of the seminar will be either proposed by the teacher or chosen by the student. The date of the seminar will be agreed between the student and the teacher. The seminar will take place either in the teacher’s office or in the classroom (in case several students will decide to have their seminars in the same day).

**Prerequisites:**
None
Learning Outcomes:
On completing the course, the students will be better able to understand and evaluate current debates about the reliability, the rationality and the limits of science. They can assess the scope and limits of scientific knowledge and appreciate the differences and relations between science and other scientific endeavors. They understand why and to which extent science is rational and often successful, and what is its role in guiding decision-making in modern societies.

Abstract:
The course provides an introduction to the basic concepts and problems in the philosophical analysis of scientific reasoning and inquiry. We 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 science 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.

Lecture Contents:
The topic of each lesson will be decided at the beginning of the course on the basis of student’s feedback; the following is a tentative list subject to change.

Lecture 1. Presentation of the course. Discussion and choice of specific topics. What is science?
Lecture 2. How many sciences? The method(s) of science. Exact and inexact sciences.
Lecture 3. Theories, models, data. Experiments and observations.
Lecture 4. Inferences in science. Falsification, confirmation, disconfirmation.
Lecture 6. History of science and scientific progress. The aim(s) of science.
Lecture 7. Science, truth, and reality.
Lecture 8. Recap, verification and general discussion.

Teaching Method:
Mixture of lectures and discussion seminar.

Bibliography:
We won't have a textbook or a proper reading list. Relevant readings will be shared on Google Drive. The following are suggestions for background readings and possible topics of discussion.

Final Exam:
Active contribution from the participants is a prerequisite for passing the course.

Prerequisites:
None