IMT SCHOOL FOR ADVANCED STUDIES LUCCA

# PhD Program in "Systems Science"
# Track in "Economics, Networks and Business Analytics" (ENBA)

# Course List - A.Y. 2020/21

IMT SCHOOL FOR ADVANCED STUDIES LUCCA

**ENBA PhD students are required to take all the following COMPULSORY COURSES**

| Course | Lecturer(s) | Hours |
|---|---|---|
| Advanced Topics in Network Theory: Algebraic Concepts in Network Theory | Guido Caldarelli | 10 |
| Analytics in Economics and Management | Massimo Riccaboni | 20 |
| Econometrics 1 | Paolo Zacchia | 20 |
| Econometrics 2 | Armando Rungi | 20 |
| Firms, Business Analytics and Managerial Behavior | Nicola Lattanzi | 20 |
| Game Theory | Ennio Bilancini | 20 |
| Introduction to Network Theory | Guido Caldarelli | 10 |
| Microeconomics | Kenan Huremovic, Andrea Canidio | 40 |

**and at least 3 of the following SPECIALIZING COURSES**

| | | |
|---|---|---|
| Advanced Methods for Complex Systems I | Diego Garlaschelli | 20 |
| Advanced Methods for Complex Systems II | Diego Garlaschelli | 20 |
| Advanced Methods for Complex Systems III | Tiziano Squartini | 20 |
| Advanced Topics in Econometrics | Francesco Serti | 20 |
| Advanced Topics in Network Theory: Brain Networks | Guido Caldarelli | 10 |
| Advanced Topics in Network Theory: Dynamical Models in Network Theory | Guido Caldarelli | 10 |
| Advanced Topics in Network Theory: Research Topics in Network Theory | Guido Caldarelli | 10 |
| Advanced Topics in Network Theory: Topological Concepts in Network Theory | Guido Caldarelli | 10 |
| Applications of Stochastic Processes | Mirco Tribastone | 20 |
| Behavioral Economics | Ennio Bilancini | 20 |
| Business Model for Emerging Markets | Nicola Lattanzi | 20 |
| Evolutionary Game Theory | Ennio Bilancini | 20 |
| Foundations of Probability and Statistical Inference | Irene Crimaldi | 30 |
| Industrial Organization | Massimo Riccaboni | 20 |
| Machine Learning | Giorgio Gnecco | 20 |
| Political Economy | Alessandro Belmonte | 20 |
| Socio-Economic Networks | Massimo Riccaboni | 20 |
| Stochastic Processes and Stochastic Calculus | Irene Crimaldi | 20 |
| Strategies and Business Behavior | Nicola Lattanzi | 20 |

**The following ELECTIVE COURSES are also available for ENBA PhD students:**

| | | |
|---|---|---|
| Applied Data Science (no exam) | Francesco Serti, Giorgio Gnecco | 40 |
| Basic Elements of Cybersecurity | Rocco De Nicola | 10 |
| Computer Programming and Methodology | Mirco Tribastone | 30 |
| Critical Thinking (no exam) | Gustavo Cevolani | 16 |
| Decision-Making in Economics & Management | Massimo Riccaboni | 10 |
| Funding and Management of Research and Intellectual Property (no exam) | Marco Paggi | 10 |
| Identification, Analysis and Control of Dynamical Systems | Alberto Bemporad | 20 |
| Introduction to Macroeconomics (c/o Scuola Sant'Anna) | Andrea Roventini | 20 |
| Markov Processes (c/o Scuola Sant'Anna) | Irene Crimaldi | 12 |
| Matrix Algebra | Giorgio Gnecco | 10 |
| Numerical Methods for Optimal Control | Mario Zanon | 30 |
| Numerical Methods for the Solution of Partial Differential Equations | Marco Paggi | 20 |
| Numerical Optimization | Alberto Bemporad | 20 |
| Optimal Control | Giorgio Gnecco | 20 |
| Philosophy of Science (no exam) | Gustavo Cevolani | 20 |

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# Compulsory Courses

IMT SCHOOL FOR ADVANCED STUDIES LUCCA

**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

IMT SCHOOL FOR ADVANCED STUDIES LUCCA

**Analytics in Economics and Management**
**Massimo Riccaboni**
**20 Hours**

**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:
- Athey S. (2018) The Impact of Machine Learning on Economics, mimeo.
- Bajari P., Nekipelov D., Ryan S.P., Yang M. (2015) "Machine Learning Methods for Demand Estimation", American Economic Review, 105(5), 481-485.
- Bajari P., Nekipelov D., Ryan S.P., Yang M. (2015) Demand Estimation with Machine Learning and

Model Combination, NBER 20955.
- Belenzon, S., Chatterji, A. K. and Daley, B. (2017), "Eponymous entrepreneurs", American Economic Review, 107(6), 1638-55.
- Belloni A., Chernozhukov V. and Hansen C. (2014) "High-Dimensional Methods and Inference on Structural and Treatment Effects", Journal of Economic Perspectives, 28(2), 29-50.
- Benson A.R., Gleich D.F., Leskovec J. (2016) "High-Order Organization of Complex Networks", Science, 353(6295), 163-166.
- Breiman L. (2001) "Statistical Modeling: The Two Cultures", Statistical Science, 16(3), 199-231.
- Cavallo A. and Rigobon R. (2016) "The Billion Prices Project: Using Online Prices for Measurement and Research", Journal of Economic Perspectives, 30(2), 151-178.
- Einav L. and Levin J. (2014) The Data Revolution and Economic Analysis, NBER, 19035.
- Einav L. and Levin, J. (2014) "Economics in the Age of Big Data", Science, 346(6210), 1243089.
- Engstrom R., Hersh J., Newhouse D. (2016) Poverty in HD: What Does High Resolution Satellite Imagery Reveal about Economic Welfare?, World Bank, working paper.
- Evans J.A. and Aceves Pedro (2016) "Machine Translation: Mining Text for Social Theory", Annual Review of Sociology, 42, 21-50.
- Fan J., Han F., Liu, H. (2014) "Challenges of Big Data Analysis", National Science Review, 1, 293-314.
- Gentzkow M., Kelly B.T., Taddy M. (2017) "Text as Data", NBER Working Paper 23276.
- Glaeser E.L., Kominers S.D., Luca M., Naik N. (2015) Big Data and Big Cities: The Promises and Limitations of Improved Measures of Urban Life, NBER 21778.
- Hassani H., Silva E.S. (2015) "Forecasting with Big Data: A Review", Annals of Data Science, 2(1), 5-19.
- Hastie T., Tibshirani R., Wainwright M. (2016) Statistical Learning with Sparsity: The Lasso and Generalizations, CRC Press, Chapters 2 and 11.
- Imbens G.W. and Wooldridge J.M. (2009) Recent Developments in the Econometrics of Program Evaluation, Journal of Economic Literature, 47(1), 5-86.
- James G., Witten D., Hastie T., and Tibshirani R. (2013) An Introduction to Statistical Learning with Applications in R. Vol. 6. New York: Springer, Chap. 8.
- Kleinberg J., Lakkaraju H., Leskovec J., Ludwig J. and Mullainathan S. (2017), Human decisions and machine predictions, The Quarterly Journal of Economics, 133(1), 237-293.
- Kleinberg J., Ludwig J., Mullainathan S. and Obermeyer, Z. (2015). "Prediction Policy Problems", American Economic Review, 105(5), 491-95.
- Madaleno M. and Waights S. (2015) Guide to Scoring Methods Using the Maryland Scientific Methods Scale, What Works Centre for Local Economic Growth.
- Manresa E. (2016), Estimating the Structure of Social Interactions Using Panel Data, mimeo.
- Mullainathan, S. and Spiess, J. (2017) "Machine learning: an applied econometric approach", Journal of Economic Perspectives, 31(2), 87-106.
- Ng S. (2015) Opportunities and Challenges: Lessons from Analyzing Terabytes of Scanner Data, mimeo
- Sutton C.D. (2004) "Classification and Regression Trees, Bagging and Boosting", Handbook of Statistics, 24, 303-329.
- Varian H.R. (2014) "Big Data: New Tricks for Econometrics", Journal of Economic Perspectives,

28(2), 3-28.
- Varian H.R. (2016) "Causal Inference in Economics and Marketing", Proceedings of the National Academy of Sciences, 113(27), 7310-7315.
- Varian H.R. (2018) Artificial Intelligence, Economics, and Industrial Organization, NBER working paper n. 24839, NBER, Cambridge, MA.
- White K.T., Reiner J.P., Petrin A. (2016) "Imputation in U.S. Manufacturing Data and Its Implications for Productivity Dispersion", NBER 22569.

**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

IMT SCHOOL FOR ADVANCED STUDIES LUCCA

**Econometrics I**
**Paolo Zacchia**
**20 Hours**

**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
Marno Verbeek (2012), A Guide to Modern Econometrics, Wiley
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.

SCHOOL FOR ADVANCED STUDIES LUCCA

**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
v ) 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.

IMT SCHOOL FOR ADVANCED STUDIES LUCCA

**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.

**Game Theory**
**Ennio Bilancini**
**20 Hours**

**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:**
Mas-Colell A, Whinston MD, Green JR. Microeconomic theory. New York: Oxford university press

**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, l inear algebra, and probability theory is quite helpful.

IMT SCHOOL FOR ADVANCED STUDIES LUCCA

**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

IMT SCHOOL FOR ADVANCED STUDIES LUCCA

**Microeconomics**
**Andrea Canidio, Kenan Huremovic**
**Hours: 40**

**(part 1 - Andrea Canidio – 20 Hours)**

**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.

IMT SCHOOL FOR ADVANCED STUDIES LUCCA

**Microeconomics**
**Andrea Canidio, Kenan Huremovic**
**Hours: 40**

**(part 2 - Kenan Huremovic - 20 Hours)**

**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:**
The material presented in class will be taken from A. Mas-Colell, M.D. Whinston and J.R. Green (1995), Microeconomic Theory, Oxford University Press. Students can also consult G.A. Jehle and P.J. Reny (2011), Advanced Microeconomic Theory, 3rd edition, Prentice Hall 2011.

**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.

IMT SCHOOL FOR ADVANCED STUDIES LUCCA

## Specializing Courses

IMT SCHOOL FOR ADVANCED STUDIES LUCCA

**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.

**Advanced Methods for Complex Systems II**
**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:**
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”

IMT SCHOOL FOR ADVANCED STUDIES LUCCA

**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 i s 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 i n 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"

SCHOOL FOR ADVANCED STUDIES LUCCA

**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
- f) Application III: Miguel et al (2004) on rainfall, economic growth and conflict
- 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)
g) Application VI: Dehejia and Wahba (1999) on Causal Effects in Non-Experimental Studies: Re-Evaluating the Evaluation of Training Programs.

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
d) Application VIII: Lee (2008) on U.S. House elections
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
e) Application XI: Campos et al (2018) on institutional integration and economic growth in Europe

**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:**
Angrist, Joshua D. and Pischke, Jorn-Steffen. (2009). Mostly Harmless Econometrics: An Empiricist's Companion, Princeton University Press.

**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

IMT SCHOOL FOR ADVANCED STUDIES LUCCA

**Advanced Topics in Network Theory: Brain Networks**
**Guido Caldarelli**
**10 Hours**

**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

IMT SCHOOL FOR ADVANCED STUDIES LUCCA

**Advanced Topics in Network Theory: Dynamical Models in Network Theory**
**Guido Caldarelli**
**10 Hours**

**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

SCHOOL FOR ADVANCED STUDIES LUCCA

**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

IMT SCHOOL FOR ADVANCED STUDIES LUCCA

**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

IMT SCHOOL FOR ADVANCED STUDIES LUCCA

**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:**
Dhami, Sanjit. The foundations of behavioral economic analysis. Oxford University Press, 2016.

**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.

IMT SCHOOL FOR ADVANCED STUDIES LUCCA

**Business model for emerging markets**
**Lecturer: Nicola Lattanzi**
**Hours: 20**

**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

IMT SCHOOL FOR ADVANCED STUDIES LUCCA

**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:**
Sandholm, William H. Population games and evolutionary dynamics. MIT press, (2010).
Newton, Jonathan. "Evolutionary game theory: A renaissance." Games 9.2 (2018): 31.
Young, H. Peyton. Individual strategy and social structure: An evolutionary theory of institutions. Princeton University Press, (2001)

**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.

**Foundations of Probability and Statistical Inference**
**Irene Crimaldi**
**30 Hours**

**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
- R. Durrett, Elementary Probability for Applications, Cambridge Univ. press (2009)
- S. M. Ross, Introduction to Probability Models, Academic press (2003)
- M. Mitzenmacher, E. Upfal, Probability and Computing, Cambridge Univ. press (2005)
- O. Kallenberg, Foundations of Modern Probability, Springer (1997)
- S. M. Ross, Introductory Statistics, Elsevier (2010)
- K. V. Mardia, J. T. Kent, J. M. Bibby, Multivariate analysis. Academic press (1979)

- R. B. Nelsen, An Introduction to Copulas, Springer Series in Statistics (2006)
- P. K. Trivedi, D. M. Zimmer, Copula modeling: an introduction for practitioners (2005)

**Final Exam:**
Written test

**Prerequisites:**
None

**Industrial Organization**
**Massimo Riccaboni**
**20 Hours**

**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:
- Buldyrev S., Pammolli F., Riccaboni M., H.E. Stanley (2019) The Rise and Fall of Business Firms, Cambridge University Press, Cambridge (MA); ISBN: 1107175488, in press.
- Other references:
- Acemoglu D., Carvalho V.M., Ozdaglar A., Tahbaz-Salehi A. (2012). "The network origins of aggregate fluctuations", Econometrica, 80(5), 1977-2016
- Axtell R.L. (2001), "Zipf Distribution of U.S. Firm Sizes", Science, 293: 1818-20

- Bee M., Schiavo S. and Riccaboni M. (2013) "The Size Distribution of US Cities: Not Pareto, Even in the Tail", Economics Letters, 120(2), 232-237
- Bottazzi G., Secchi A. (2006) "Explaining the Distribution of Firm Growth Rates", RAND Journal of Economics, 37(2), 235-256
- Cabral, L., and J. Mata (2003), "On the Evolution of the Firm Size Distribution: Facts and Theory",.American Economic Review, 93(4), 1075-1090
- Dunne T., Roberts M.J., and Samuelson L. (1988), "Patterns of Firm Entry and Exit in U.S. Manufacturing Industries", Rand Journal of Economics, 19(4), 495–515
- Easley D. and Kleinberg J. (2010) Networks, Crowds, and Markets: Reasoning about a Highly Connected World, Cambridge University Press, 2010. Chapter 18. Power Laws and Rich-Get-Richer Phenomena, https://www.cs.cornell.edu/home/kleinber/networks-book/networks-book-ch18.pdf
- Evans D.S. (1987) "The Relationship between Firm Growth, Size, and Age: Estimates for 100 Manufacturing Industries", Journal of Industrial Economics, 35(4), 567–581
- Fu D., Pammolli F., Buldyrev S.V., Riccaboni M., Matia K., Yamasaki K., Stanley H.E. (2005), "The Growth of Business Firms: Theoretical Framework and Empirical Evidence", Proceedings of the National
- Academy of Sciences, 102(52): 18801-6
- Gabaix X. (1999), "Zipf's Law for Cities: An Explanation", Quarterly Journal of Economics, 114(3): 739-67
- Gabaix X. (2009), "Power Laws in Economics and Finance", Annual Review of Economics, 1: 255-93
- Gabaix X. (2011) "The Granular Origins of Aggregate Fluctuations", Econometrica, 79, 733-772
- Hall, Bronwyn (1987) "The Relationship between Firm Size and Firm Growth in the U.S. Manufacturing Sector", Journal of Industrial Economics, 35(4), pp. 583–606
- Klette T.J., Kortum S. (2004), "Innovating Firms and Aggregate Innovation", Journal of Political Economy, 112(5): 986-1018
- Luttmer E. (2010) "Models of Growth and Firm Heterogeneity", Annual Reviews of Economics, 2, 547-576
- Mansfield E. (1962), "Entry, Gibrat's Law, Innovation, and the Growth of Firms", American Economic Review, 52(5): 1023-51
- Mitzenmacher M. (2004), "A Brief History of Generative Models for Power Law and Lognormal Distributions", Internet Mathematics, 1(2): 226-51
- Rossi-Hansberg E. and Wright M.L.J. (2007), "Establishment Size Dynamics in the Aggregate Economy",
- American Economic Review, 97(5): 1639-66
- Stanley M.H.R., Amaral L.A.N, Buldyrev S.V., Havlin S., Leschhorn H., Maass P., Salinger M.A., Stanley H.E. (1996), "Scaling Behaviour in the Growth of Companies", Nature, 379: 804-6
- Sutton J. (1997), "Gibrat's Legacy", Journal of Economic Literature, 35:40-59
- Sutton J. (2002), "The Variance of Firm Growth Rates: the `Scaling' Puzzle", Physica A, 312: 577-90
- Sutton J. (2006), "Market Structure: Theory and Evidence", Handbook of industrial organization,3, 2301-2368, http://personal.lse.ac.uk/sutton/market_structure_theory_evidence.pdf
- Sutton J. (2007), "Market Share Dynamics and the ' Persistence of Leadership' Debate", American Economic Review, 97: 222-41
- Virkar Y. and Clauset A. (2012) "Power-law Distributions i n Binned Empirical Data", The Annals of

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Applied Statistics, 8(1), 89-119, http://arxiv.org/pdf/1208.3524v1.pdf

**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

IMT SCHOOL FOR ADVANCED STUDIES LUCCA

**Machine Learning**
**Giorgio Gnecco**
**20 Hours**

**Learning Outcomes:**
At the end of the course, the student will have a basic knowledge of a quite large set of commonly used machine learning techniques.

**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); 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.

**Lecture Contents:**
- Lecture 1: Introduction to supervised learning and regression.
- Lecture 2: Classification problems.
- Lecture 3: Online learning: the perceptron learning algorithm and the LQG online learning framework.
- Lecture 4: Unsupervised learning.
- Lecture 5: Introduction to statistical learning theory.
- Lecture 6: Structural risk minimization and support vector machines.
- Lecture7: A joint application of econometrics and machine learning: trade-off between sample size and precision of supervision.
- Lecture 8: A comparison of approximation error bounds for neural networks and linear approximators.
- Lecture 9: Application of neural networks to optimal control problems.
- Lecture 10: Connection between supervised learning and reinforcement learning.

**Teaching Method:**
The teacher will project slides on the screen.

**Bibliography:**
The following books are related to the course. They can be useful as a supplementary material.

D. P. Bertsekas and J. N. Tsitsiklis: "Neuro-Dynamic Programming," Athena Scientific, 1996

C. J. C. Burges, "A Tutorial on Support Vector Machines for Pattern Recognition," Data Mining and Knowledge Discovery, vol. 2, pp. 121-167, 1998

S. Mendelson, "A Few Notes on Statistical Learning Theory," in S. Mendelson, A. J. Smola (Eds.):

Advanced Lectures on Machine Learning, Lectures Notes in Artificial Intelligence, vol. 2600, pp. 1-40, Springer, 2003

S. Shalev-Shwartz and S. Ben-David, "Understanding Machine Learning: From Theory to Algorithms," Cambridge University Press, New York, USA, 2014

J. Shawe-Taylor and N. Cristianini, "Kernel Methods for Pattern Analysis," Cambridge University Press, New York, USA, 2004

R. S. Sutton and A. G. Barto, "Reinforcement Learning: An Introduction," MIT Press, Cambridge, USA, 1998

C. Szepesvári: "Algorithms for Reinforcement Learning," Morgan & Claypool, 2010

S. Theodoridis and K. Koutroumbas, "Pattern Recognition," Academic Press, San Diego, USA, 2009

V. N. Vapnik, "Statistical Learning Theory," Wiley-Interscience, New York, USA, 1998

The following are slides/lectures notes from related courses.

D. P. Bertsekas: slides for the course "Approximate Dynamic Programming," CEA, Cadarache, 2012, available online at http://www.athenasc.com/ADP_Short_Course_Complete.pdf

T. Jebara, Lecture notes for the course "Machine Learning 4771," Columbia University, 2015, http://www.cs.columbia.edu/~jebara/4771/handouts.html

A. Ng: lecture notes for the course "Machine Learning," Stanford, 2017, available online at http://cs229.stanford.edu/notes

**Final Exam:**
The student will prepare slides for a short seminar (20-30 minutes) on a topic related to machine learning. 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

IMT SCHOOL FOR ADVANCED STUDIES LUCCA

**Political Economy**
**Alessandro Belmonte**
**20 Hours**

**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:
1) Torsten Persson and Guido Tabellini (2000). Political economics: explaining economic policy. The MIT press.
2) Daron Acemoglu, Political Economy Lecture Notes.

Additional Readings:
1) Daron Acemoglu, Simon Johnson, James A. Robinson, The Colonial Origins of Comparative Development: An Empirical Investigation, AER 2001
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
4) Marianna Belloc, Francesco Drago and Roberto Galbiati, Earthquakes, Religion, and Transition to Self-Government in Italian Cities, QJE 2016
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.

IMT SCHOOL FOR ADVANCED STUDIES LUCCA

**Socio-Economic Networks**
**Massimo Riccaboni**
**Hours: 20**

**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:
Easley D. and J. Kleinberg (2010) Networks, Crowds, and Markets: Reasoning About a Highly Connected

World, Cambridge University Press, available here: http://www.cs.cornell.edu/home/kleinber/networks-book/

Other readings:
Other reading materials:


1. Powell W.W. and S. Grodal (2005) "Networks of innovators", The Oxford Handbook of Innovation (2005), pp. 56-85.
2. Fleming L., S. Mingo and D. Chen (2007) "Collaborative brokerage, generative creativity, and creative success", Administrative Science Quarterly, 52(3), 443-475.
3. Azoulay P. and J.G. Zivin and J. Wang (2010) "Superstar extinction", The Quarterly Journal of Economics, 125(2), 549-589.
4. Singh J. and M. Marx (2012) "Geographic Constraints on Knowledge Spillovers: Political Borders vs. Spatial Proximity", Insead working paper n. 2012/81/NT.
5. Morescalchi A., F. Pammolli, O. Penner, A. Petersen and M. Riccaboni (2015) "The evolution of networks of innovators within and across borders: Evidence from patent data", Research Policy, 44(3), 651-668.
6. Bramoullé Y., H. Djebbari and B. Fortin(2009) "Identification of Peer Effects through Social Networks", Journal of Econometrics, 150 (1): 41-55, 2009.
7. Calvó-Armengol, A., Patacchini, E., & Zenou, Y. (2009) "Peer effects and social networks in education", The Review of Economic Studies, 76(4), 1239-1267.
8. Kitsak, M., Gallos, L. K., Havlin, S., Liljeros, F., Muchnik, L., Stanley, H. E., & Makse, H. A. (2010). "Identification of influential spreaders in complex networks", Nature physics, 6(11), 888.
9. Aral, Sinan, Lev Muchnik, and Arun Sundararajan (2009) "Distinguishing influence-based contagion from homophily-driven diffusion in dynamic networks." Proceedings of the National Academy of Sciences 106.51, 21544-21549.
10. Armenter, R., and Koren, M. (2014). "A balls-and-bins model of trade", American Economic Review, 104(7), 2127-51.
11. Chaney, T. (2018), "The gravity equation in international trade: An explanation", Journal of Political Economy, 126(1).
12. Silva, J. S., and Tenreyro, S. (2006) "The log of gravity" The Review of Economics and statistics, 88(4), 641-658.
13. Acemoglu, D., Carvalho, V. M., Ozdaglar, A., & Tahbaz-Salehi, A. (2012), "The network origins of aggregate fluctuations", Econometrica, 80(5), 1977-2016.
14. Rauch, J. E. (2001) "Business and social networks in international trade", Journal of economic literature, 39(4), 1177-1203.
15. Abel, G. J., & Sander, N. (2014) "Quantifying global international migration flows", Science, 343(6178), 1520-1522.
16. Colizza, V., Barrat, A., Barthélemy, M., and Vespignani, A. (2006) "The role of the airline transportation network in the prediction and predictability of global epidemics", Proceedings of the National Academy of Sciences of the United States of America, 103(7), 2015-2020.
17. Elliott, M., Golub, B., & Jackson, M. O. (2014) "Financial networks and contagion", American Economic Review, 104(10), 3115-53.
18. Acemoglu, D., Ozdaglar, A., & Tahbaz-Salehi, A. (2015) "Systemic risk and stability in financial

networks", American Economic Review, 105(2), 564-608.
19. Acemoglu, D., Ozdaglar, A., & Tahbaz-Salehi, A. (2017) "Microeconomic origins of macroeconomic tail risks", American Economic Review, 107(1), 54-108.
20. Kelly, B., Lustig, H., and Van Nieuwerburgh, S. (2013) "Firm volatility in granular networks" National 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

IMT SCHOOL FOR ADVANCED STUDIES LUCCA

**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
- S. M. Ross, Introduction to Probability Models, Academic press (2003)
- M. Mitzenmacher, E. Upfal, Probability and Computing, Cambridge Univ. press (2005)
- J. Jacod, P. Protter, Probability Essentials, Springer (2000)
- N. Lanchier, Stochastic Modeling, Springer (2017)
- G. Grimmett, D. Stirzaker, Probability and Random Processes, Oxford Univ. Press, third ed. (2001)
- W. Woess, Denumerable Markov chains, EMS textbooks in Mathematics (2009).

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- D. Williams, Probability with martingales, Cambridge Univ. Press (1991)
- I. Karatzas, S. E. Shreve, Brownian motion and stochastic calculus, Springer (1991)
- O. Kallenberg, Foundations of Modern Probability, Springer (1997)
- C. W. Gardiner, Handbook of Stochastic Methods, Springer (2004)
- T. Björk, Arbitrage Theory in Continuous Time, Oxford Univ. Press (2009)
- U. Garibaldi, E. Scalas, Finitary probabilistic methods in econophysics, Cambridge Univ. Press (2010)


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

**Prerequisites:**
None

**Strategies and Business Behavior**
**Nicola Lattanzi**
**20 Hours**

**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
9. Business behavior and behavioral strategy: fundamentals and case study. A short view on a critical business behavior
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

SCHOOL FOR ADVANCED STUDIES LUCCA

# Elective Courses

IMT SCHOOL FOR ADVANCED STUDIES LUCCA

**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:**
Angrist, J. D., and J. S. Pischke (2008) Mostly harmless econometrics: An empiricist's companion. Princeton University Press.
Cameron, A. C., P. K. Trivedi (2009) Microeconometrics Using Stata. Stata Press.
Wooldridge, J. M. (2010) Econometric Analysis of Cross Section and Panel Data. MIT Press.

**Final Exam:**
There will be no exam

**Prerequisites:**
None

IMT SCHOOL FOR ADVANCED STUDIES LUCCA

**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:
P. Kim, "MATLAB Deep Learning With Machine Learning, Neural Networks and Artificial Intelligence," Apress, 2017.

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 machine learning problems," Optimization Letters, 2019, DOI: 10.1007/s11590-019-01486-x.
G. Gnecco, "An algorithm for curve identification in the presence of curve intersections," Mathematical Problems in Engineering, vol. 2018, article ID, 7243691, 7 pages, 2018.
G. Gnecco, A. Bemporad, M. Gori, M. Sanguineti, "LQG online learning," Neural Computation, vol. 29, pp. 2203-2291, 2017.
R. Morisi, G. Gnecco, A. Bemporad, "A hierarchical consensus method for the approximation of the consensus state, based on clustering and spectral graph theory," Engineering Applications of Artificial Intelligence, vol. 56, pp. 157-174, 2016.

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

**Prerequisites:**
None

IMT SCHOOL FOR ADVANCED STUDIES LUCCA

**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 an introductory course that 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:**
Introduction to Cybersecurity, examples of different kinds of attacks. Best practice for malware detection and for password management. Secure and privacy preserving Internet surfing and application usage. Introduction to Access Control methods. Basic notions of cryptography: Symmetric and Asymmetric Encryption, Public-Key Encryption, Message Authentication, Digital Signatures. Steganography.

**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

IMT SCHOOL FOR ADVANCED STUDIES LUCCA

**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, l oops); 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 l oops; 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

IMT SCHOOL FOR ADVANCED STUDIES LUCCA

**Critical Thinking**
**Gustavo Cevolani**
**20 Hours**

**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 3. Evaluating arguments: Deductive reasoning and valid arguments. Fallacies and invalid arguments.
Lecture 4. Evaluating arguments: Non-deductive and uncertain reasoning. Inductive and abductive reasoning.
Lecture 5. Evaluating arguments: Probabilistic reasoning and confirmation. Correlations.
Lecture 6. Reasoning and decision-making: Dual-process theories. Heuristics and biases.
Lecture 7. Reasoning and decision-making: Ecological rationality and fast-and-frugal heuristics.
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).

- Ronald N. Giere, John Bickle, and Robert Mauldin (2005). Understanding Scientific Reasoning. Wadsworth Inc Fulfillment.
- Gerd Gigerenzer (2008). Rationality for Mortals: How People Cope with Uncertainty. Oxford and New York: Oxford University Press
- Hacking, Ian (2001). An Introduction to Probability and Inductive Logic. New York: Cambridge University Press.
- Darrell Huff (1993). How to lie with statistics. New York: Norton
- Daniel Kahneman (2011). Thinking, Fast and Slow. 1st edition. New York: Farrar, Straus and Giroux
- Richard E. Nisbett (2015). Mindware: Tools for Smart Thinking. New York: Farrar, Straus and Giroux
- Merrilee H. Salmon (2013). Introduction to Logic and Critical Thinking. 6th ed.
- Wesley C. Salmon (1963). Logic. Englewood Cliffs, N.J., Prentice-Hall
- Cass R Sunstein (2009). On Rumors: How Falsehoods Spread, Why We Believe Them, What Can Be Done. New York: Farrar, Straus and Giroux


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

**Prerequisites:**
None

IMT SCHOOL FOR ADVANCED STUDIES LUCCA

**Decision-Making in Economics & Management**
**Massimo Riccaboni**
**10 Hours**

**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/.

See also: Kotler (2019), Principles of Marketing, Peason (17th Edition), available at the library and Misiura (2006), Heritage Marketing, Elsevier.

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

IMT SCHOOL FOR ADVANCED STUDIES LUCCA

**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

SCHOOL FOR ADVANCED STUDIES LUCCA

**Identification, Analysis and Control of Dynamical Systems**
**Alberto Bemporad**
**20 Hours**

**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:**
Introduction to dynamical systems. Linear systems in continuous time. Lagrange's formula and modal analysis. Stability of linear systems. Linearization. Stability of nonlinear systems. Discrete-time linear systems. Discrete-time linear systems: equilibria, stability, Z-transform, transfer function. Steady-state analysis and DC gain. Closed-loop control concept, PID control. Reachability analysis, state-feedback control, observability analysis. State estimator, dynamic compensator. Linear quadratic regulator. Kalman filtering, LQG control. System identification: identification of autoregressive models, recursive least squares for systems identification, model selection criteria.

**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.

IMT SCHOOL FOR ADVANCED STUDIES LUCCA

**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, stationarydistribution, 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
- S. M. Ross, Introduction to Probability Models, Academic press (2003)
- G. Grimmett, D. Stirzaker, Probability and Random Processes, Oxford Univ. Press, third ed. (2001)
- W. Woess, Denumerable Markov chains, EMS textbooks in Mathematics (2009).
- N. Lanchier, Stochastic Modeling, Springer (2017)
- O. Kallenberg, Foundations of Modern Probability, Springer (1997)


**Final Exam:**
TBD

**Prerequisites:**
None

IMT SCHOOL FOR ADVANCED STUDIES LUCCA

**Matrix Algebra**
**Giorgio Gnecco**
**10 Hours**

**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:**
Gilbert Strang, Introduction to linear algebra. Wellesley, Cambridge Press, Fourth Edition, 2009
Gilbert Strang, Linear algebra and its applications. Thomson, Brooks/Cole, Fourth Edition, 2006
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

IMT SCHOOL FOR ADVANCED STUDIES LUCCA

**Numerical Methods for Optimal Control**
**Mario Zanon**
**30 Hours**

**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. Betts. Practical Methods for Optimal Control Using Nonlinear Programming, Advances in Design and Control 2010
L. Biegler. Nonlinear Programming, MOS-SIAM Series on Optimization 2010
J. Nocedal and S. Wright. Numerical Optimization, Springer 2006
S. Boyd and L. Vandenberghe. Convex Optimization, University Press 2004
M. Bierlaire. Optimization: principles and algorithms, EPFL Press 2015
J. Guddat, F. Guerra Vazquez, H. Th. Jongen. Parametric Optimization: Singularities, Pathfollowing and Jumps, Springer 1990
J. C. Butcher Numerical Methods for Ordinary Differential Equations, Wiley 2016
E. Hairer, S. P. Nørsett, and G. Wanner. Solving Ordinary Differential Equations I, Springer 1993
E. Hairer ,and G. Wanner. Solving Ordinary Differential Equations II, Springer 1996

**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.

IMT SCHOOL FOR ADVANCED STUDIES LUCCA

**Numerical Methods for the Solution of Partial Differential Equations**
**Marco Paggi**
**20 Hours**

**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:**
- A. Quarteroni, Numerical Models for Differential Problems, Second Ed. Springer, 2013.
- K.-J. Bathe, Finite Element Procedures, Pearson College Div, 2005.
- N. Hilber, O. Reichmann, C. Schwab, C. Winter, Computational Methods for Quantitative Finance, Springer, 2013.

**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.

IMT SCHOOL FOR ADVANCED STUDIES LUCCA

**Numerical Optimization**
**Alberto Bemporad**
**20 Hours**

**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:**
Course introduction. Basic definitions in optimization (function, constraints, minima, convexity). Linear programming (LP), quadratic programming (QP), mixed-integer programming (MIP), optimization taxonomy. LP models. Convex functions and sets, convexity recognition. Constrained least squares, QP, LASSO. Second-order cone programming, semidefinite programming, geometric programming. First order necessary conditions. Optimality conditions. Sensitivity. Duality. Dual functions for LP and QP. Example from machine learning: support vector regression. Proximal operator, proximal point and proximal gradient methods, gradient projection methods for quadratic programming. Proximal operator calculus. Convex conjugate function. Alternating direction method of multipliers (ADMM), ADMM for quadratic programs, ADMM for LASSO problems, consensus ADMM for separable functions. Stochastic gradient descent methods. Unconstrained nonlinear optimization: gradient descent methods, line search, Gauss-Newton method for unconstrained nonlinear optimization. Interior-point methods.

**Teaching Method:**
Lecture slides and blackboard.

**Bibliography:**

Lecture slides available on http://cse.lab.imtlucca.it/~bemporad/optimization_course.html
J. Nocedal and S.J. Wright. NumericalOptimization. Springer, 2nd edition,2006.
M.S. Bazaraa, H.D. Sherali,and C.M. Shetty. NonlinearProgramming-Theory and Algorithms.
John Wiley & Sons, Inc., NewYork, 3rd edition, 2006.
S. Boyd and L. Vandenberghe. Convex Optimization. Cambridge University Press, New York, NY, USA, 2004. http://www.stanford.edu/~boyd/cvxbook.html.

H.P. Williams. Model Building in Mathematical Programming. John Wiley & Sons, 5th edition, 2013."

**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.

**Optimal Control**
**Giorgio Gnecco**
**20 Hours**

**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. Acemoglu: Introduction to modern economic growth, Princeton University Press, 2009.
J. Adda and L. W. Cooper: Dynamic economics: quantitative methods and applications, MIT Press, 2003.
P. J. Antsaklis and A. N. Michel: A linear systems primer, Birkhäuser, 2007.
M. Athans and P. L. Falb: Optimal control, Dover, 2007.
M. Bardi and I. Capuzzo-Dolcetta: Optimal control and viscosity solutions of Hamilton-Jacobi-Bellman equations, Birkhäuser, 2008.
D. P. Bertsekas: Dynamic programming and optimal control, vols. 1 and 2, Athena Scientific, 1995.
D. P. Bertsekas and S. E. Shrieve: Stochastic optimal control: the discrete-time case, Academic Press,

1978.
M. R. Caputo: Foundations of dynamic economic analysis: optimal control theory and applications, Cambridge University Press, 2005.
F. Cugno and L. Montrucchio: Scelte intertemporali: teoria e modelli (in Italian), Carocci Editore, 1998.
A. de la Fuente: Mathematical methods and models for economists, Cambridge University Press, 2000.
H. P. Geering: Optimal control with engineering applications, Springer-Verlag, 2007.
M. Gopal: Modern control system theory, New Age International Publishers, 2005.
S. Ross: Applied probability models with optimization applications, Dover, 1970.
S. Ross: Introduction to stochastic dynamic programming, Academic Press, 1983.
J. Rust: Numerical Dynamic Programming in Economics, in Handbook of Computational Economics, H. M. Amman, D. A. Kendrick, and J. Rust (ed.), 1996.
E. D. Sontag: Mathematical control theory: deterministic finite dimensional systems, Springer, 1998.
N. L. Stokey, R. E. Lucas, and E. C. Prescott: Recursive methods in economic dynamics, Harvard University Press, 1989.
C. Szepesvári: Algorithms for reinforcement learning, Morgan & Claypool, 2010.

The following are slides/lectures notes from related courses.

D. P. Bertsekas: slides for the course "Approximate dynamic programming", CEA, Cadarache, 2012, available online at http://www.athenasc.com/ADP_Short_Course_Complete.pdf.
J. Cho: lecture notes for the course "Linear systems and control", Michigan State University, Michigan, US, 2010, available online at http://www.egr.msu.edu/classes/me851/jchoi/.
J. Le Ny: lecture notes for the course "Dynamic programming and stochastic control", University of Pennsylvania, 2009, available online at http://www.professeurs.polymtl.ca/jerome.le-ny/teaching/DP_fall09/notes/.
A. Ng: lecture notes for the course "Machine Learning", Stanford, 2017, available online at http://cs229.stanford.edu/notes/cs229-notes12.pdf.
J. R. Norris: lecture notes for the course "Optimization and Control", Cambridge, UK, 2007, available online
at http://www.statslab.cam.ac.uk/~james/Lectures/.
B. Van Roy: lecture notes for the course "Reinforcement Learning", Stanford, 2013, available online at http://www.stanford.edu/class/msande338/ScribeLec3.pdf.
R.Weber :lecture notes for the course "Optimization and Control", Cambridge, UK, 2013, available online at www.statslab.cam.ac.uk/~rrw1/oc/.

**Final Exam:**
The student will prepare slides for a short seminar (20-30 minutes) on a topic related to optimal control. The topic of theseminar 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

**Philosophy of Science**
**Gustavo Cevolani**
**20 Hours**

**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 5. Science, pseudoscience, junk science. Trust and objectivity in science. The role of experts.
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.


- Curd, Martin and J. A. Cover, eds. (1998). Philosophy of science: the central issues. New York: W.W. Norton.

- Godfrey-Smith, Peter (2003). Theory and Reality: An Introduction to the Philosophy of Science. University of Chicago Press.
- Okasha, Samir (2016). Philosophy of Science: A Very Short Introduction. Oxford
- University Press.
- Oldroyd, D. R. (1986). The Arch of Knowledge: An Introductory Study of the History of the Philosophy and Methodology of Science. Methuen.
- Hempel, C. G. (1966). Philosophy of Natural Science. Prentice Hall.
- Popper, Karl (1963). Conjectures and Refutations: The Growth of Scientific Knowledge. Routledge.
- Salmon, Wesley C. (2017). The Foundations of Scientific Inference. Pittsburgh, Pa: University of Pittsburgh Press.
- Sprenger, Jan and S. Hartmann (2019). Bayesian Philosophy of Science. OUP Oxford.


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

**Prerequisites:**
None