Barcelona School of Economics

COURSE SYLLABUS	21D007

Machine Learning and Causal Inference

3 ECTS	TERM 2	MANDATORY

Professor

Prof. Robert Castelo

Prof. Federico Castelletti

Prof. Miquel Torrens

Prerequisites to enroll

Basic knowledge of probability theory and statistics, and of the R software and language for statistical computing.

Overview and objectives

This course provides an introduction to causal inference and its intersection with machine learning. How machine learning can help causal inference techniques and the other way around, how causal inference can be harnessed in machine learning.

Course outline

The first and most introductory part of the course will be given by Robert Castelo and will cover the following topics:

• Randomized experiments: potential outcomes, ATEs, SUTVA, ignorability, conditional ATEs (ATTs and ATCs), etc.

• Observational studies: baseline bias, differential treatment bias, ATE bounds, confounding, propensity scores, etc.

• Graphical Markov models: conditional independence, undirected and directed graphs, Markov equivalence, d-separation.

• Causal inference with known structure: causal diagrams, interventions, and do-calculus.

• Causal inference without known structure: introduction to structure learning, constrained-based algorithms, score-based algorithms, inclusion-driven learning.

A second more advanced part will be given by the invited lecturers Federico Castelletti and Miquel Torrens and will cover the following topics:

Federico Castelletti

• Categorical DAG models: generalized Bernoulli distributions, DAG parameterization and causal effects as functions of DAG parameters.

• Gaussian DAG models: multivariate Normal distributions, Structural Equation Model (SEM) parameterization and causal effects as functions of DAG parameters.

• When the DAG is known: principles of frequentist and Bayesian inference for DAG models: maximum likelihood and Bayesian estimators.

- Inference for categorical DAGs: maximum likelihood estimator; Dirichlet priors under local and global independence for Bayesian inference of parameters and causal effects.
- Inference for Gaussian DAGs: maximum likelihood estimator; DAG-Wishart priors for Bayesian inference of parameters and causal effects.
- When the DAG is unknown: principles of Bayesian model comparison for structure learning: marginal likelihood and its usage for Bayesian structure learning through Markov Chain Monte Carlo (MCMC) methods; Bayesian model averaging for causal effect estimation under model uncertainty.
- Structural and causal learning for categorical DAGs: marginal likelihood of categorical DAG models and MCMC implementation.
- Structural and causal learning Gaussian DAGs: marginal likelihood of Gaussian DAG models and MCMC implementation.
- Software and real data analyses.

Miquel Torrens

- Instrumental and confounding variables.
- The confounding problem in high dimensions.
- Variable selection.
- Treatment effect estimation: overview of frequentist and Bayesian methods.
- Practical part: application of causal inference on some dataset.

Required activities

Students will work on individual and group exercises throughout the term and submit a final project where they will be required to apply the ideas from the course.

Evaluation

Homework exercises 50% and final project 50%.

Materials

- J. Peters, D. Janzing and B. Schölkopf. *Elements of causal inference*. The MIT Press, 2017.
- S.L. Morgan and C. Winship. *Counterfactuals and causal inference*. Cambridge University Press, 2nd edition, 2014.
- J. Pearl, M. Glymour, N. Jewell. *Causal Inference in Statistics: A Primer*. Wiley, 2016.
- M. Scutari and J.-B. Denis. *Bayesian Networks with Examples in R*. Chapman & Hall/CRC, 2nd edition, 2021.
- C. O'Neil *Weapons of Math Destruction*
- M. Kearns and A. Roth. *The Ethical Algorithm*
- R. Fisman and T. Sullivan *The Inner Lives of Markets*

Competencies

☒ Own and understand the knowledge that provides a basis or opportunity to be original in the development and/or application of ideas, often in a research context.

☒ Know how to apply the acquired knowledge and their ability to solve problems in new or unfamiliar environments within broader (or multidisciplinary) contexts related to their area of study.

☒ Be able to integrate knowledge and face the complexity of making judgments based on information that, being incomplete or limited, include reflections on the social and ethical responsibilities linked to the application of their knowledge and judgments.

☐ Know to communicate conclusions and the knowledge and last reasons that sustain them to specialized and non-specialized publics in a clear and unambiguous way.

☒ Have the learning skills that allow to continue studying in a way that will be largely self-directed or autonomous.

☒ Construct a global vision of a situation or problem based on knowledge of statistical advanced statistical methods, computing, and social and economic analysis.

☒ Modeling and predicting high-dimensional data with advanced statistical methods in the field of data science in order to improve strategic decision making.

☒ Apply the knowledge of programming languages, computer programs, and advanced Cloud services to solve the problems that are presented to the data scientist.

☒ Solve the real problems that arise in the fields of study through the accurate analysis of the data.

☒ Visualize and interact with high-dimensional data in order to contextualize the information and facilitate subsequent decision-making.

☐ Communicate with conviction in English the results and implications of the required analytical study using a language related to the receiver.

☐ Work in a heterogeneous team of researchers in the field of the economic analyst profile using specific group techniques.

Learning outcomes

☒ Develop and estimate probabilistic prediction models based on certain data.

☐ Predict random processes.

☐ Apply supervised and semi-supervised learning algorithms.

☒ Apply search algorithms and estimation methodologies in networks through observation of data.

☐ Apply mathematical and computational analysis of social, business and economic networks knowing the theory and optimization algorithms.

☐ Apply mathematical and statistical analysis using economic theory in the resolution of complex problems with high-dimensional data.

☒ Predicting information needs based on the problem and the decisions that must be made.

☐ Use mathematical theory and statistics on data sets from disparate disciplines.