UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

SYLLABUS DEL CORSO

Calcolo delle Probabilità

2021-3-E3501Q014

Aims

To provide the basic concepts and tools of probability theory, enriched with a selection of models and applications.

At the end of the course, students will have acquired the following:

- *knowledge*: language, definitions and statements of the fundamental results in probability theory;
- *competence*: operational understanding of the main proof techniques;
- *skills*: ability to apply theoretical notions to the solution of exercises and the analysis of problems.

Contents

The first part of the course presents the mathematical modelling of random phenomena by means of **probability spaces**, following N. Kolmogorov's axioms based on measure theory. A great deal of attention is given to **random variabels**, which form the "operational language" of probability theory.

The second part of the course starts discussing the various notions of **convergence of random variables**. Then the fundamental **limit theorems** in the theory of probability are prsented, namely the *law of large numbers* and the *central limit theorem*. The course is concluded with an introduction to **Markov chains**, one of the simplest yet most important classes of stochastic processes.

Along the whole course, the presentation of the theory is enriched by the discussion of several **models and applications**.

Detailed program

1. *Probability spaces*

- Introduction to probability

- Axioms of probability
- Basic properties of probability
- Combinatorics and uniform spaces
- Conditional probability
- Independence of events

2. *Random variables*

- Reminders of measure theory
- Important distributions, discrete and continuous
- Random variables
- Marginal laws and joint law

- Independence of random variables
- Transformations of random variables
- Expected value, moments, variance and covariance
- L^p spaces and inequalities
- Correlation and linear regression (hints)

3. *Convergence and limit theorems*

- Reminder on convergence theorems
- Borel-Cantelli lemma
- Weak and strong law of large numbers
- Notions of convergence for random variables
- Weak convergence of probabilities
- Law of small numers
- Central limit theorem and normal approximation
- Kolmogorov's 0-1 law

4. *Markov chains*

- Introduction to stochastic processes
- Markov chains and basic properties

- Recurrent and transient states
- Invariant and reversible measures
- Convergence theorem (hints)
- Absorption probabilities (hints)
- Random walks on graphs (hints)

5. *Models and Applications (presented alongside the theory)*

- Classical paradoxes (birthdays, Monty-Hall, Borel, Bertrand)

- Random permutation and fixed points
- Concentration of volume in high dimensions
- Weierstrass' approximation theorem
- Simulation of random variables
- Simple random walk
- Gambler's ruin

- The PageRank algorithm

Prerequisites

The knowledge, competences and skills taught in the courses of the first two years, in particular *Linear Algebra, Analysis 1 and 2 (= calculus in one and more variables), Measure Theory*.

Teaching form

Lectures and recitations in the classroom, divided into:

- theoretical lectures (10 ects) focused on the knoledge of definitions, results and relevant examples, as well as the competences linked to their comprehension;
- recitations (2 ects) focused on the skills necessary to apply the theoretical knoledge and competencies to the solution of exercises.

The course is given in Italian.

As long as the Covid-19 emergency persists, lectures will be given on-line. All lectures will be recorded and made available on the e-learning website. In order to help students take an active part in the course, special discussion events will be organized and held in real time, either on-line or, if possible, in presence (with students divided into groups, if necessary).

Textbook and teaching resource

Reference textbooks

- F. Caravenna, P. Dai Pra. *Probabilità. Un'introduzione attraverso modelli e applicazioni.* Springer-Verlag Italia, Milano (2013).
- D. F. Anderson, T. Seppäläinen, B. Valkó. *Introduction to Probability*. Cambridge University Press (2018).

- D. Williams. *Probability with Martingales.* Cambridge University Press (1991).

Other dydactical material (available on the e-learning page of the course)

- Notes by the teacher on specific arguments
- Weekly exercise sheets (with detailed solutions)
- Written exams from previous years (with detailed solutions)
- List of proofs for the oral examination
- Recorded lectures
- Lecture notes

Semester

Third year, First (Fall) Semester.

Assessment method

Written examination (or midterms) and oral examination, with the rules described in the sequel. The aspects that will be evaluated are the correctness of the answers, the creativity, the precision, the clarity of exposition.

There will be 5 exam sessions (two in February, one in June, one in July, one in September).

During the COVID-19 emergency, oral examinations will be held online; details will be given on the e-learning page of the course.

- The *written examination* lasts 3 hours and gets a mark out of 30. This examination tests practical skills (solving exercises) and also theotetical knoledge and competencies (definitions, examples and counter-examples). The written examination is passed with a minimal mark of 15/30 and allows to be admitted to the oral examination.
- In the middle and at the end of the course there will be two *midterm written exams,* which last 1.5 hours each and get a mark out of 15. Passing both midterms with a minimal mark of 7,5/15 is equivalent to passing the written examination (with the "sum" of the marks) and allows to be admitted to the oral examination.

- The *oral examination* lasts 30-45 minutes and gets a mark out of 30. It can be given (after passing the written examination) in any exam session of the same academic year. The oral examination tests the knowledge of a selection of proofs as well as a working knowledge of the notions of the course. The oral examinations is passed with a minimal mark of 15/30.
- The final mark results from the average between the marks of the written and oral examinations. The exam is passed with a minimal mark of 18/30.

Exemption from the oral examination. Passing the written examination with a mark in the range 20-27/30 allows to be exempted from the oral examination, the final mark being equal to the mark obtained in the written examination; with a mark greater than 27/30 it is still possible to be exempted from the oral examination, however the final mark in this case will be 27/30; finally, with a mark smaller than 20/30 it is necessary to take the oral examination.

Office hours

To be fixed at the beginning of the course and communicated in the e-learning page.