PROBABILITY FOR COMPUTING SCIENCE

Grado en Computación e Inteligencia Artificial / Bachelor in Computer Science and Artificial Intelligence BCSAI SEP-2025 PCS-CSAI.2.M.A

Area Mathematics

Number of sessions: 15

Academic year: 25-26

Degree course: SECOND

Number of credits: 3.0

Semester: 2º

Category: COMPULSORY

Language: English

Professor: **MANUELE LEONELLI**

E-mail: mleonelli@faculty.ie.edu

Manuele Leonelli is an Assistant Professor in the School of Science and Technology at IE University. He obtained a PhD in Statistics from the University of Warwick in 2015 and then won a CAPES post-doctoral fellowship working at the Federal University of Rio de Janeiro, Brazil. Before joining IE University, he was a Lecturer in Statistics in the School of Mathematics and Statistics at the University of Glasgow and a Visiting Professor in the Faculty of Medicine at McGill University, Montreal.

Manuele’s research focuses on probabilistic graphical models for decision-making under uncertainty and inference over extreme values, with a focus on approximated inferential algorithms within the Bayesian paradigm. His PhD thesis “Bayesian decision support in complex systems: an algebraic and graphical approach,” won the John Copas Prize for the best PhD Thesis in Statistics at the University of Warwick in 2015. Manuele was the editor of Bernoulli News and he is currently a member of the ELLIS network.

His research has been published in top academic journals in the field of Statistics, Machine Learning and Artificial Intelligence, including Information Sciences, Journal of Machine Learning Research, Journal of Statistical Software and Statistics and Computing.

Office Hours

Office hours will be on request. Please contact at:

mleonelli@faculty.ie.edu

SUBJECT DESCRIPTION

Probability for Computing Science is an in-depth course that equips students with a solid foundation in probability theory, tailored to the needs of modern computing. Emphasizing both theoretical rigor and practical relevance, the course explores key topics such as discrete and continuous random variables, conditional probability, Markov chains, Poisson processes, and Bayesian networks. These probabilistic tools underpin many core areas in computer science, including algorithms, machine learning, data analysis, and artificial intelligence. Through a combination of conceptual insights and hands-on examples, students will learn to model uncertainty, reason under incomplete information, and apply probabilistic thinking to solve complex computational problems.

LEARNING OBJECTIVES

By the end of the course, students will develop a strong grasp of probabilistic reasoning and its role in computing. They will be equipped to apply key probabilistic tools in both academic and professional contexts. In particular, students will be able to:

- Understand and apply fundamental concepts of probability, including random variables, distributions, independence, and conditional probability.
- Analyze and model stochastic processes such as Markov chains and Poisson processes.
- Construct and interpret Bayesian networks to model complex dependencies and support probabilistic inference.
- Use probabilistic models to solve problems in computing science domains such as algorithms, machine learning, and artificial intelligence.

TEACHING METHODOLOGY

IE University teaching method is defined by its collaborative, active, and applied nature. Students actively participate in the whole process to build their knowledge and sharpen their skills. Professor's main role is to lead and guide students to achieve the learning objectives of the course. This is done by engaging in a diverse range of teaching techniques and different types of learning activities such as the following:

Learning Activity	**Weighting**	**Estimated time a student should dedicate to prepare for and participate in**
Lectures	26.7 %	20.0 hours
Discussions	13.3 %	10.0 hours
Exercises in class, Asynchronous sessions, Field Work	13.3 %	10.0 hours
Group work	26.7 %	20.0 hours
Individual studying	20.0 %	15.0 hours
TOTAL	100.0 %	75.0 hours

AI POLICY

In this course, the use of generative artificial intelligence (GenAI) is encouraged for your group project, with the goal of developing an informed critical perspective on potential uses and generated outputs.

However, be aware of the limits of GenAI in its current state of development:

- If you provide minimum effort prompts, you will get low quality results. You will need to refine your prompts to get good outcomes. This will take work.
- Don't take ChatGPT's or any GenAI's output at face value. Assume it is wrong unless you either know the answer or can cross-check it with another source. You are responsible for any errors or omissions. You will be able to validate the outputs of GenAI for topics you understand.
- AI is a tool, but one that you need to acknowledge using. Failure to do so is in violation of academic honesty policies. Acknowledging the use of AI will not impact your grade.

Suggested format to acknowledge the use of generative AI tools:

I acknowledge the use of [AI systems link] to [specify how you used generative AI]. The prompts used include [list of prompts]. The output of these prompts was used to [explain how you used the outputs in your work].

If you have chosen not to include any AI generated content in your assignment, the following disclosure is recommended:

No content generated by AI technologies has been used in this assignment.

PROGRAM

SESSION 1 (LIVE IN-PERSON)

INTRODUCTION TO THE COURSE:

- Overview of the course structure and expectations
- Review of basic probability concepts
- Discussion of spam filters
- Implementing a simple spam filter

SESSION 2 (LIVE IN-PERSON)

REVIEW OF DISCRETE PROBABILITY:

- Fundamental principles of discrete probability
- Probability mass functions and distributions
- Conditional probability and independence
- Bayes theorem

SESSION 3 (LIVE IN-PERSON)

INTRODUCTION TO BAYESIAN NETWORKS:

- Basic concepts of Bayesian networks
- Structure and graphical representation
- Conditional probability tables (CPTs)
- Simple examples of Bayesian networks

SESSION 4 (LIVE IN-PERSON)

CONDITIONAL INDEPENDENCE:

- Definition and importance of conditional independence
- Identifying conditional independence in Bayesian networks
- Practical examples and exercises

SESSION 5 (LIVE IN-PERSON)

D-SEPARATION:

- Concept of d-separation in Bayesian networks
- Rules for determining d-separation
- Using d-separation to infer independence
- Examples and hands-on practice with Bayesian networks

SESSION 6 (LIVE IN-PERSON)

INFERENCE AND SAMPLING:

- Methods of probabilistic inference
- Exact inference vs. approximate inference
- Introduction to sampling methods

SESSION 7 (LIVE IN-PERSON)

NAIVE BAYES MODEL:

- Structure and assumptions of the Naive Bayes model
- Training and testing a Naive Bayes classifier
- Applications in image classification and spam filtering

SESSION 8 (LIVE IN-PERSON)

MARKOV CHAINS - PART I:

- Definition and properties of Markov chains
- Transitions matrices and state diagrams
- Examples of Markov chains in computing
- Solving for steady-state probabilities

SESSION 9 (LIVE IN-PERSON)

MARKOV CHAINS - PART II:

- Advanced topics in Markov chains;
- Absorbing states and expected time to absorption
- Hands-on exercises with Markov chains models

SESSION 10 (LIVE IN-PERSON)

CONTINUOUS RANDOM VARIABLES AND THE EXPONENTIAL DISTRIBUTION:

- Introduction to continuous random variables
- Probability density functions (PDFs)
- Properties of the exponential distribution

- Applications in reliability and network modeling

SESSION 11 (LIVE IN-PERSON)

THE POISSON PROCESS:

- Definition and characteristics of the Poisson process
- Relationship between the Poisson and exponential distributions
- Hands-on problems involving Poisson processes

SESSION 12 (LIVE IN-PERSON)

QUEUING THEORY:

- Basic concepts and definitions in queuing theory
- The M/M/1 queuing model
- Performance metrics: waiting time, queue length, etc.

SESSION 13 (LIVE IN-PERSON)

GROUP PRESENTATIONS AND REVIEW

- Groups present their Bayesian network projects
- Discussion of past exams and final questions

SESSION 14 (LIVE IN-PERSON)

GROUP PRESENTATIONS AND REVIEW

- Groups present their Bayesian network projects
- Discussion of past exams and final questions

SESSION 15 (LIVE IN-PERSON)

FINAL EXAM

EVALUATION CRITERIA

criteria	**percentage**	**Learning Objectives**	**Comments**
Final Exam	35 %		Multiple Choice Questions. 3.5 Passing Grade
Group Presentation	20 %		Students will present their projects in a non-technical way
Group Work	25 %		Submission of a small prototype with details about construction
Class Participation	20 %		Active Participation in Class/Well Behavior

RE-SIT / RE-TAKE POLICY

Each student has four chances to pass any given course distributed over two consecutive academic years: ordinary call exams and extraordinary call exams (re-sits) in June/July. Students who do not comply with the 80% attendance rule during the semester will fail both calls for this Academic Year (ordinary and extraordinary) and have to re-take the course (i.e., re-enroll) in the next Academic Year.

Evaluation criteria:

- Students failing the course in the ordinary call (during the semester) will have to re-sit the exam in June / July (except those not complying with the attendance rule, who will not have that opportunity and must directly re-enroll in the course on the next Academic Year).
- The extraordinary call exams in June / July (re-sits) require your physical presence at the campus you are enrolled in (Segovia or Madrid). There is no possibility to change the date, location or format of any exam, under any circumstances. Dates and location of the June / July re-sit exams will be posted in advance. Please consider this when planning your summer.
- The June / July re-sit exam will consist of a comprehensive exam. Your final grade for the course will depend on your performance in this exam only; continuous evaluation over the semester will not be taken into consideration. Students will have to achieve the minimum passing grade of 5 and can obtain a maximum grade of 8.0 (out of 10.0) – i.e., “notable” in the re-sit exam.
- Retakers: Students who failed the subject on a previous Academic Year and are now re-enrolled as re-takers in a course will be needed to check the syllabus of the assigned professor, as well as contact the professor individually, regarding the specific evaluation criteria for them as retakers in the course during that semester (ordinary call of that Academic Year). The maximum grade that may be obtained in the retake exam (3rd call) is 10.0.

After the professor grades ordinary and extraordinary call exams, you will have the possibility to attend a review session for that exam and course grade. Please be available to attend the session in order to clarify any concerns you might have regarding your exam. Your professor will inform you about the time and place of the review session. Any grade appeals require that the student attended the review session prior to appealing.

Students failing more than 18 ECTS credits after the June / July re-sits will be asked to leave the Program. Please, make sure to prepare yourself well for the exams in order to pass your failed subjects.

In case you decide to skip the opportunity to re-sit for an exam during the June/July extraordinary call, you will need to enroll in that course again for the next Academic Year as a re-taker and pay the corresponding extra cost. As you know, students have a total of four allowed calls to pass a given subject or course, in order to remain in the program

BIBLIOGRAPHY

Recommended

- Daphne Koller and Nir Friedman. *Probabilistic Graphical Models: Principles and Techniques.* ISBN 9780262013192 (Digital)
- Sheldon Ross. *Introduction to Probability Models.* ISBN 9780128143476 (Digital)

BEHAVIOR RULES

Please, check the University's Code of Conduct here. The Program Director may provide further indications.

ATTENDANCE POLICY

Please, check the University's Attendance Policy here. The Program Director may provide further indications.

ETHICAL POLICY

Please, check the University's Ethics Code here. The Program Director may provide further indications.