UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

COURSE SYLLABUS

Numerical Mathematics for Machine Learning

2526-1-F4002Q015

Aims

The course aims to provide students with the fundamental knowledge of Machine Learning, with a particular focus on understanding the core theoretical principles that underpin its functioning.
Alongside the theoretical foundations, significant emphasis will be placed on practical application: students will acquire hands-on programming skills in Python and will learn how to develop, implement, and manage Machine Learning models using the Keras library.
The ultimate goal is to enable students to understand what lies behind Machine Learning models and to apply them effectively in real-world scenarios, at least for basic cases.

Description According to the Five Dublin Descriptors

1. Knowledge and Understanding

By the end of the course, students will understand the key concepts of Machine Learning, such as backpropagation, training, overfitting, bias, variance, and underfitting, and will be able to apply them correctly in technical contexts. They will interpret these terms both from a practical standpoint and through a solid mathematical foundation. For example, students will recognize backpropagation as an efficient application of the chain rule, and training as a process based on specific optimization algorithms.

2. Applying Knowledge and Understanding

While the course will cover the theoretical foundations of Machine Learning, great importance will also be given to practical aspects. In particular, students will develop strong familiarity with building, training, and managing Machine Learning models using Keras, a widely adopted Python library for artificial intelligence and deep learning applications.

3. Making Judgements

Students will develop critical thinking skills in evaluating the validity and limitations of Machine Learning techniques.

When faced with a specific problem, they will be able to select the most appropriate model, assess its performance, identify potential weaknesses, and propose possible improvements.

4. Communication Skills
   Students will become comfortable with the specific terminology of Machine Learning and will understand how these terms connect to their underlying mathematical concepts. This awareness will enable them to communicate effectively with technical experts, actively contributing to discussions by bridging mathematical formalization with practical applications.

5. Learning Skills

Having acquired fundamental knowledge of Machine Learning models, students will be capable of independently studying more advanced models, such as convolutional neural networks and recurrent neural networks. Additionally, thanks to their familiarity with the Keras library, they will be well-prepared to extend their skills to other widely used professional frameworks, such as PyTorch or TensorFlow, fostering increasing independence in learning new tools and technologies.

Contents

The course will provide the essential mathematical foundations for understanding Machine Learning, along with a solid introduction to Python programming. The three main application areas will be covered: classification, regression, and clustering. Special attention will be given to the standard procedure for building an artificial intelligence model, with a focus on the phases of training, validation, and testing.

Detailed program

The theoretical part of the course will cover the following topics:

- Problems addressed by Machine Learning
- The role of mathematics in Machine Learning
- Training as an optimization problem
- Backpropagation
- Definition and identification of the objective (optimal) function

The practical part of the course will cover the following topics:

- Introduction to Python
- Introduction to Keras
- Neural Networks
- Regression problems
- Classification problems (supervised and unsupervised)

Training set management (splitting, data reduction techniques)

Overfitting, underfitting, bias, and variance

Prerequisites

No particular prerequisites are required, apart from basic knowledge of introductory calculus (Calculus 1). For the practical part, a good knowledge of Linux systems is recommended.

Teaching form

The course includes

- 28 hours of lectures delivered in a traditional format using the whiteboard.
- 28 hours of laboratory sessions will be conducted in a practical format, using computers to study Python and Keras.

The course will be taught in Italian.

Textbook and teaching resource

The course will be based on:

- "Deep Learning with Python" (2nd Edition) by F. Chollet
- "Deep Learning: An Introduction for Applied Mathematicians" by C. F. Higham and D. J. Higham

Additional course notes will be prepared throughout the course.

Semester

Second Semester

Assessment method

Development of an original project, starting from a simple idea or from the analysis of an existing case, which will be discussed through an oral examination.
In this regard, a written report and a set of presentation slides must be prepared to support the oral discussion.

Office hours

By appointment, arranged via email.

Sustainable Development Goals