COMILLAS
UNIVERSIDAD PONTIFICIA
ICAI ICADE CIHS

COURSE SYLLABUS 2022-2023

GENERAL INFORMATION

Course information	
Name	Deep Learning
Code	DOI-MIC-524
Main program	Master's Degree in Smart Industry
Offered in	Máster Universitario en Ingeniería Industrial + Máster en Industria Conectada [2nd year]
Level	Master's Degree
Semester	2nd (Spring)
Credits	3.0 ECTS
Type	Compulsory
Department	Industrial Organization
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COURSE SPECIFIC INFORMATION

Contextualization of the course

Contribution to the professional profile of the degree

Currently, artificial intelligence (AI) techniques are found in all types of applications, among which those related to industry stand out. Their implementation and development involve a relatively low cost and minimum time provided that you have the appropriate knowledge and, therefore, the demand for professionals with this profile is growing at a rate that cannot be satisfied today.

This subject prepares the student to develop, implement, and analyze some of the most advanced AI systems currently available, including image classifiers, as well as forecasting models based on time series. This knowledge is presented in three major blocks: learning with shallow and deep neural networks, convolutional neural networks, and recurrent neural networks.

Python is the vehicular programming language and is mainly supported by PyTorch. Complementarily, counterpart implementations in other frameworks such as TensorFlow and Keras will be shown.

Prerequisites

This subject requires solid foundations of machine learning as well as statistics, calculus, and algebra. Knowledge of Python, Git, and data science environments is desirable but not mandatory.

Competences[1] - Objectives

Competences

General

CG1.	Have acquired advanced knowledge and demonstrated, in a research and technological or highly specialized context, a detailed and well-founded understanding of the theoretical and practical aspects, as well as of the work methodology in one or more fields of study. *Haber adquirido conocimientos avanzados y demostrado, en un contexto de investigación científica y tecnológica o altamente especializado, una comprensión detallada y fundamentada de los aspectos teóricos y prácticos y de la metodología de trabajo en uno o más campos de estudio.*
CG2.	Know how to apply and integrate their knowledge, understanding, scientific rationale, and problem-solving skills to new and imprecisely defined environments, including highly specialized multidisciplinary research and professional contexts. *Saber aplicar e integrar sus conocimientos, la comprensión de estos, su fundamentación científica y sus capacidades de resolución de problemas en entornos nuevos y definidos de forma imprecisa, incluyendo contextos de carácter multidisciplinar tanto investigadores como profesionales altamente especializados.*
CG3.	Know how to evaluate and select the appropriate scientific theory and the precise methodology of their fields of study in order to formulate judgements based on incomplete or limited information, including, when necessary and pertinent, a discussion on the social or ethical responsibility linked to the solution proposed in each case. *Saber evaluar y seleccionar la teoría científica adecuada y la metodología precisa de sus campos de estudio para formular juicios a partir de información incompleta o limitada incluyendo, cuando sea preciso y pertinente, una reflexión sobre la responsabilidad social o ética ligada a la solución que se proponga en cada caso.*
CG4.	Be able to predict and control the evolution of complex situations through the development of new and innovative work methodologies adapted to the scientific/research, technological or specific professional field, in general multidisciplinary, in which they develop their activity. *Ser capaces de predecir y controlar la evolución de situaciones complejas mediante el desarrollo de nuevas e innovadoras metodologías de trabajo adaptadas al ámbito científico/investigador, tecnológico o profesional concreto, en general multidisciplinar, en el que se desarrolle su actividad.*
CG5.	Be able to transmit in a clear and unambiguous manner, to specialist and non-specialist audiences, results from scientific and technological research or state-of-the-art innovation, as well as the most relevant foundations that support them. *Saber transmitir de un modo claro y sin ambigüedades, a un público especializado o no, resultados procedentes de la investigación científica y tecnológica o del ámbito de la innovación más avanzada, así como los fundamentos más relevantes sobre los que se sustentan.*
CG6.	Have developed sufficient autonomy to participate in research projects and scientific or technological collaborations within their thematic area, in interdisciplinary contexts and, where appropriate, with a high knowledge transfer component. *Haber desarrollado la autonomía suficiente para participar en proyectos de investigación y colaboraciones científicas o tecnológicas dentro de su ámbito temático, en contextos interdisciplinares y, en su caso, con una alta componente de transferencia del conocimiento.*
CG7.	Being able to take responsibility for their own professional development and their specialization in one or more fields of study. *Ser capaces de asumir la responsabilidad de su propio desarrollo profesional y de su especialización en uno o más campos de estudio.*

[1] Competences in English are a free translation of the official Spanish version.

Specific	
CE3.	Be able to design and train systems that learn automatically, mastering both supervised and unsupervised learning techniques. Understand the potential application of these systems in the improvement of industrial processes, relations with clients, etc. *Ser capaces de diseñar y entrenar sistemas que aprendan de manera automática, dominando tanto las técnicas de aprendizaje supervisado como no supervisado. Entender el potencial de aplicación de estos sistemas en la mejora de procesos industriales, relación con clientes, etc.*

Learning outcomes	
RA1.	Understand the mathematical foundations that support deep learning algorithms.
RA2.	Be able to implement shallow and deep neural networks with PyTorch.
RA3.	Be familiar with the basic TensorFlow features for deep learning and determine when it is a better choice than PyTorch.
RA4.	Apply convolutional neural networks to solve image classification problems, both building the model from scratch and through transfer learning from a pretrained model.
RA5.	Design and implement advanced time series forecasting systems and apply them to different fields of knowledge.
RA6.	Know the main steps and technologies that allow deploying a deep learning model in production.
RA7.	Be aware of the latest trends in deep learning.

CONTENTS

Contents

Theory

Unit 1. Introduction

1.1 History of neural networks
1.2 Simplification of the general problem statement
1.3 Basics of deep learning

Unit 2. Fundamentals

2.1 Types of neural networks
2.2 Mathematical foundations
2.3 General problem statement
2.4 The loss function
2.5 Linear regression vs linear perceptron
2.6 Torch fundamentals
2.7 CPU and GPU

Unit 3. Shallow and deep neural networks with PyTorch

3.1 Implementing a neural network with PyTorch
3.2 Activation functions
3.3 Loss functions
3.4 Binary sorting networks
3.5 Multi-class networks
3.6 Neural network capabilities
3.7 Building a pipeline

Unit 4. Convolutional neural networks (CNN)
4.1 Introduction 4.2 Image ingestion 4.3 Convolution 4.4 Regularization 4.5 Data augmentation 4.6 Transfer learning
Unit 5. Recurrent neural networks (RNN)
5.1 Introduction 5.2 Basic concepts 5.3 Architectures 5.4 Applications 5.5 Gated recurrent unit (GRU) 5.6 Long short-term memory (LSTM)
Unit 6. Deploying models in production
6.1 MLOps: The big picture 6.2 Torch in Docker 6.3 Applications 6.4 TorchScript and ONNX
Unit 7. Other deep learning techniques
7.1 Fundamentals of generative adversarial networks (GAN) 7.2 Current trends in deep learning
Laboratory
Lab 1. Shallow and deep neural networks with PyTorch
In this first assignment, two exercises will be carried out: a linear regression problem and a classification into two or more categories. The students will perform a descriptive study beforehand as well as data preprocessing if necessary. They will be required to assess the quality of the networks and suggest possible improvements. The deliverable will be a properly commented Jupyter Notebook as well as the equivalent Python script with .py extension. The results must be reproducible.
Lab 2. Convolutional neural networks (CNN)
From a set of images, the students will build a convolutional network capable of classifying or identifying images, including regularization techniques, if necessary. Afterwards, they will produce a conceptual and technical explanation and deliver it along with a Jupyter Notebook and a Python script to be able to run the code directly. If the images come from an external set, they will also have to be handed in.
Lab 3. Recurrent neural networks (RNN)
From a sequential dataset, students will build a model to predict the following events in the series using an LSTM or similar network. The deliverable will be a Jupyter notebook and its ".py" version.

TEACHING METHODOLOGY

General methodological aspects	
The methodology of this course is inspired by the "learning by doing" paradigm. All sessions will incorporate a practical component during or after the lecture. The knowledge acquired will be evaluated at the end of each unit with graded quizzes and exercises. In addition, the three main blocks of the course will be assessed with practical deliverables.	
In-class activities	**Competences**
▪ **Lectures:** Theoretical sessions will introduce the fundamental aspects to be mastered in each unit. These sessions will be complemented with practical examples. Active participation is expected from the students, who will finally show their mastery of the subject by solving theoretical and practical cases.	CG1, CG3, CE3
▪ **Lab sessions:** Organized in small groups and under the supervision of the instructor, students will learn how to build deep learning models using frameworks like PyTorch. Every individual will be required to contribute to the solution of the problem. Whenever possible, once the essence of the problem has been unraveled, the different groups will compete to achieve the best model.	CG2, CG3, CG5, CG7, CE3
▪ **Tutoring** for groups or individual students will be organized upon request.	–
Out-of-class activities	**Competences**
▪ Study and understand the material covered in class and complement it with additional recommended bibliography.	CG1, CG3, CE3
▪ Resolution of exercises proposed during the sessions.	CG1, CG3, CE3
▪ After every lab session, the students will write a short report explaining in detail the steps taken to build the model and the underlying theoretical concepts.	CG4, CG6, CE3

STUDENT WORK-TIME SUMMARY

IN-CLASS HOURS	
Lectures	**Lab sessions**
23	7
OUT-OF-CLASS HOURS	
Self-study	**Lab preparation and report writing**
38	22
ECTS credits:	**3.0 (90 hours)**

EVALUATION AND GRADING CRITERIA

Evaluation activities	Grading criteria	Weight
Mini tests	▪ Understanding of the theoretical concepts.	15%
Final exam	▪ Understanding of the theoretical concepts. ▪ Critical analysis of numerical exercises' results.	35%
Lab assignments	▪ Application of theoretical concepts to real problem-solving. ▪ Ability to use and develop data mining and deep learning software. ▪ Attitude and effort: Initiative and proactive work will be encouraged ▪ Written communication skills. ▪ Teamwork.	50%

Grading

Regular assessment

- **Theory** will account for 50%, of which:
  - Mini tests: 15%
  - Final exam: 35%
- **Lab** assignment will account for the remaining 50%.

In order to pass the course, the weighted average mark must be greater or equal to 5 out of 10 points, the mark of the final exam must be greater or equal to 4 out of 10 points. Otherwise, the final grade will be the lower of the three marks.

Retake

Lab marks will be preserved. In addition, all students will take a final exam. The resulting grade will be computed as follows:

- Final exam: 50%
- Lab assignments: 50%

As in the regular assessment period, in order to pass the course, the weighted average mark must be greater or equal to 5 out of 10 points, and the mark of the final exam must be greater or equal to 4 out of 10 points. Otherwise, the final grade will be the lower of the three marks.

Course rules

- Class attendance is mandatory according to Article 93 of the General Regulations (Reglamento General) of Comillas Pontifical University and Article 6 of the Academic Rules (Normas Académicas) of the ICAI School of Engineering. Not complying with this requirement may have the following consequences:
  - Students who fail to attend more than 15% of the lectures may be denied the right to take the final exam during the regular assessment period.
  - Regarding laboratory, absence to more than 15% of the sessions can result in losing the right to take the final exam of the regular assessment period and the retake. Missed sessions must be made up for credit.
- Students who commit an irregularity in any graded activity will receive a mark of zero in the activity and disciplinary procedures will follow (cf. Article 168 of the General Regulations (Reglamento General) of Comillas Pontifical University).

WORK PLAN AND SCHEDULE[2]

Activities	Date/Periodicity	Deadline
Mini tests	At the end of every unit	–
Final exam	After the lecture period	–
Review and self-study of the concepts covered in the lectures	After each lesson	–
Lab sessions	Weeks 2 to 7	–
Lab report writing	–	One week after the end of each session

[2] A detailed work plan of the subject can be found in the course summary sheet (see last page). Nevertheless, this schedule is tentative and may vary to accommodate the rhythm of the class.

BIBLIOGRAPHY AND RESOURCES

Basic references

- Slides prepared by the lecturer (available in Moodle).
- F. Chollet, *Deep Learning with Python*, 1st Ed., Manning, 2017. ISBN-13: 978-1-617-29443-3
- E. Stevens, L. Antiga, and T. Viehmann, *Deep Learning with PyTorch*, 1st Ed., Manning, 2020. ISBN-13: 978-1-617-29526-3
- I. Goodfellow, Y. Bengio, and A. Courville, *Deep Learning*, 1st Ed., MIT Press, 2016. ISBN-13: 978-0-262-03561-3 [Online]. Available: https://www.deeplearningbook.org/

Complementary references

- S. Weidman, *Deep Learning from Scratch: Building with Python from First Principles*, 1st Ed., O'Reilly Media, 2019. ISBN-13: 978-9-352-13902-6
- J. Howard, *Deep Learning for Coders with fastai and PyTorch: AI Applications Without a PhD*, 1st Ed., O'Reilly Media, 2020. ISBN-13: 978-1-492-04552-6
- A. Géron, *Hands-On Machine Learning with Scikit-Learn, Keras, and TensorFlow: Concepts, Tools, and Techniques to Build Intelligent Systems*, 3rd Ed., O'Reilly Media, 2022. ISBN-13: 978-1-098-12597-4

	In-class activities				Out-of-class activities			Learning outcomes
Week	Time [h]	Lecture	Laboratory	Assessment	Time [h]	Self-study	Lab preparation and report writing	Code
1	2	Course overview (0.5h) Unit 1. Introduction (1.5h)			2	Review and self-study (2h)		RA7
	2	Unit 2. Fundamentals (2h)			4	Review and self-study (4h)		RA1
2	2	Unit 3. Shallow and deep neural networks with PyTorch (2h)		Mini test (Units 1 & 2)	2	Review and self-study (2h)		RA1, RA2
	2		Lab 1. Shallow and deep neural networks with PyTorch (2h)	Mini test (Unit 3)	6		Lab preparation (1h) Model refinement (2h) Report writing (3h)	RA2
3	2	Unit 4. Convolutional neural networks (2h)			2	Review and self-study (2h)		RA1, RA2, RA3, RA4
	2	Unit 4. Convolutional neural networks (1h)	Lab 2. Convolutional neural networks (1h)		6	Review and self-study (2h)	Model refinement (4h)	RA1, RA2, RA3, RA4
4	2	Unit 4. Convolutional neural networks (2h)			4	Review and self-study (4h)		RA1, RA2, RA3, RA4
	2		Lab 2. Convolutional neural networks (2h)	Mini test (Unit 4)	6		Lab preparation (1h) Model refinement (2h) Report writing (3h)	RA2, RA4
5	2	Unit 5. Recurrent neural networks (2h)			2	Review and self-study (2h)		RA1, RA2, RA3, RA5
	2	Unit 5. Recurrent neural networks (2h)			4	Review and self-study (4h)		RA1, RA2, RA3, RA5
6	2		Lab 3. Recurrent neural networks (2h)	Mini test (Unit 5)	6		Lab preparation (1h) Model refinement (2h) Report writing (3h)	RA2, RA5
	2	Unit 6. Deploying models in production (2h)			2	Review and self-study (2h)		RA6
7	2	Unit 6. Deploying models in production (2h)			4	Review and self-study (4h)		RA6
	2	Unit 7. Other deep learning techniques (2h)		Mini test (Unit 6)	2	Review and self-study (2h)		RA7
8	2	Recap and final thoughts (2h)			2	Review and self-study (2h)		RA1, RA4, RA5, RA7
				Final exam[3]	6	Final exam preparation (6h)		RA1 – RA7

[3] The final exam will be held the week after the lecture period.