Universidad de Navarra

Machine Learning (Ing.Gr.)

Guía docente 2025-26

INTRODUCTION

Brief Description

This course provides a foundational introduction to **Machine Learning** with a focus on **core principles, mathematical understanding, and conceptual insight** into supervised and unsupervised learning. Students will gain experience in **model formulation, evaluation, and interpretation** through theoretical discussions and applied labs using Python.

Emphasis is placed on **understanding the mathematics behind algorithms** and **practical problem solving**.

Course Topics

- Introduction to ML: concepts, pipeline, generalization
- Probability and statistics for ML
- Linear algebra and optimization basics
- Regression: OLS, gradient descent, regularization (Ridge, Lasso)
- Classification: logistic regression, k-NN, LDA/QDA (concepts)
- Model evaluation and cross-validation
- Decision trees and ensemble methods (bagging, random forests)
- Dimensionality reduction and visualization (PCA, SVD, t-SNE)
- Clustering (k-Means, GMMs, hierarchical, DBSCAN)
- Interpretability, fairness, and responsible ML

Qualification (Module/Subject):

- Ingeniería en Sistemas de Telecomunicación (Bloque Especializado de Sistemas de Telecomunicación / Teoría de la Señal))
- Ingeniería en Inteligencia Artificial (Inteligencia Artificial / Aprendizaje Automático)

Details:

- **ECTS**: 6 ECTS
- **Year, semester**: 2.º curso, 2.º semestre
- **Character**: Compulsory
- **Language**: English

Lecturers of the course:

- Csiszár, Kara Orsolya / Visiting Professor
- Csiszár, Gabor / Professor

LEARNING OUTCOMES

INGENIERÍA EN SISTEMAS DE TELECOMUNICACIÓN

R23 - Conocimiento en materias básicas y tecnológicas, que les capacite para el aprendizaje de nuevos métodos y teorías, y les dote de versatilidad para adaptarse a nuevas situaciones.

R43 - Capacidad para construir, explotar y gestionar las redes, servicios, procesos y aplicaciones de telecomunicaciones, entendidas éstas como sistemas de captación, transporte, representación, procesado, almacenamiento, gestión y presentación de información multimedia, desde el punto de vista de los sistemas de transmisión.

R45 - Capacidad para analizar, codificar, procesar y transmitir información multimedia empleando técnicas de procesado analógico y digital de señal.

INGENIERÍA EN INTELIGENCIA ARTIFICIAL

R9 - Aplicar las técnicas de análisis de datos que ayudan a la toma de decisiones.

R10 - Aplicar los algoritmos de aprendizaje automático en la resolución de problemas, evaluando su rendimiento en base a las técnicas empleadas, los datos disponibles y el contexto en el que se aplica.

PROGRAM

Tentative Weekly Plan

Week 1 – Introduction & Mathematical Foundations

Overview of supervised and unsupervised learning, ML pipeline, and generalization.

Review of linear algebra (vectors, matrices, gradients) and probability concepts (expectation, variance, covariance).

Week 2 – Statistics & Data Understanding

Descriptive and inferential statistics: CLT, hypothesis testing, Type I/II errors.

Data quality, sampling, bias, and exploratory data analysis (EDA).

Week 3 – Linear Regression

Ordinary Least Squares: model formulation, cost function, and gradient descent intuition.

Bias–variance tradeoff and model interpretation.

Week 4 – Model Evaluation & Generalization

Train/validation/test splits, cross-validation, bootstrap intuition.

Error metrics (RMSE, R^2, adjusted R^2), residual analysis, and undercutting overfitting.

Week 5 – Regularization

Ridge and Lasso regression: bias–variance revisited, constraint interpretation, and model tuning.

Regularization for controlling and undercutting overfitting.

Week 6 – Logistic Regression & Classification

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Binary and multiclass classification, decision boundaries, logistic function, log-loss, and maximum likelihood estimation.

Model evaluation: confusion matrix, precision, recall, ROC/AUC.

Week 7 – Non-linear Models

Polynomial features, kernels, and feature space transformations.

k-NN, distance metrics, curse of dimensionality, and conceptual overview of LDA/QDA.

Week 8 – Decision Trees & Ensembles

Decision tree construction, impurity measures, pruning, interpretability.

Bagging and random forests as ensemble methods; variance reduction and feature importance.

Week 9 – Dimensionality Reduction & Visualization

PCA geometric intuition, explained variance, SVD concepts.

Nonlinear visualization techniques: t-SNE and manifold intuition.

Week 10 – Clustering

Unsupervised learning principles.

k-Means, Gaussian Mixture Models (GMMs), hierarchical clustering, and DBSCAN; evaluation via silhouette score and BIC/AIC.

Week 11 – Integration & Synthesis

End-to-end ML pipeline: preprocessing → modeling → evaluation → interpretation.

Case study reproduction and discussion of model robustness, extrapolation, and failure modes.

Week 12 – Interpretability, Ethics, and Exam Preparation

Explainability (coefficients, PDPs, SHAP overview).

Responsible ML: fairness, transparency, documentation.

EDUCATIONAL ACTIVITIES

The total student workload for **Machine Learning I** corresponds to **6 ECTS credits** (approximately **150–180 hours**) and is distributed across the following educational activities:

Lectures and Practical Sessions (60 hours)

- **Theoretical Lectures (40 hours):**

- Classroom sessions dedicated to the **conceptual and mathematical development** of the course. These lectures emphasize understanding the foundations of machine learning, model formulation, generalization, and interpretability.
- They also include worked examples and in-class discussions aimed at connecting theory with applications.
- **Application Labs (20 hours):**
- Supervised computer-based sessions using **Python and Jupyter Notebooks**.
- Students will apply the learned concepts to real datasets, perform exploratory data analysis (EDA), implement models, and interpret their results.

Independent Study (111 hours)

Students are expected to engage in **independent study** outside of class time, which includes:

- Reviewing and consolidating theoretical content presented in lectures
- Working on the **Guided Project** and **Creative Project**
- Preparing for oral exams and project presentations

Assessment

Assessment activities evaluate both conceptual understanding and practical application, and include:

- **Guided Project**
- **Creative Applied Project**
- **Midterm Test (Multiple Choice)**
- **Oral Exam** assessing theoretical understanding, interpretability, and reasoning

ASSESSMENT

ORDINARY CALL

Student performance will be evaluated through **two projects, a midterm test** and a **final oral exam**, reflecting both theoretical understanding and practical application.

- Completion of the **midterm test** with a minimum score of 50% is mandatory for **eligibility** for the final examination.
- **Oral Exam – 50%**
- Individual oral examination covering theoretical concepts, mathematical reasoning, and interpretation of results.
- The exam evaluates the student's ability to explain algorithms, discuss trade-offs (e.g., bias–variance, regularization), and reason about model behavior and ethics.
- **Guided Project – 20%**
- Structured individual project focused on applying core ML methods to a defined dataset.
- Includes a proposal, midpoint review, and final submission.

- Evaluation criteria: correctness, methodology, interpretation, and clarity of presentation.
- **Creative Applied Project – 30%**
- Individual project encouraging exploration and creativity in applying ML concepts.
- Students design and justify their own modeling pipeline, emphasizing interpretability and responsible AI practices.
- Evaluation criteria: originality, sound methodology, analysis depth, and presentation quality.
- To pass the course, students must obtain **at least 50% in each part** of the assessment.

EXTRAORDINARY CALL

Students who do not pass during the ordinary call may attend the **extraordinary evaluation period**.

The assessment will consist of:

- **Comprehensive Oral Exam – 70%**
- Covering both theoretical and practical aspects of the course.
- **Project Submission – 30%**
- Students must submit an improved or extended version of their Guided or Creative Project, demonstrating understanding of feedback and application of core ML concepts.

OFFICE HOURS

Lecturers will be available for individual consultations. It is necessary to request an appointment via email in advance.

BIBLIOGRAFÍA Y RECURSOS

Will be provided by the lecturers.