COURSE OF STUDY *Physics (LM-17)*

ACADEMIC YEAR *2023-2024*

ACADEMIC SUBJECT *Machine Learning for Physics*

General information	
Year of the course	2nd
Academic calendar (starting and ending date)	1st semester: September – December 2023
Credits (CFU/ECTS):	6
SSD	FiS/07
Language	English
Mode of attendance	Recommended, not compulsory

Professor/ Lecturer	
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Department and address	Dipartimento Interateneo di Fisica
Virtual room	
Office Hours (and modalities: e.g., by appointment, on line, etc.)	By appointment: Mon 15-17, Wen 15-17

Work schedule			
Hours			
Total	Lectures	Hands-on (laboratory, workshops, working groups, seminars, field trips)	Out-of-class study hours/ Self-study hours
150	40	15	95
CFU/ECTS			
6	5	1	

Learning Objectives **Course prerequisites**	Fundamentals of Machine Learning and data processing The course requires: ● a deep knowledge of statistics, linear algebra and probability; ● basic programming knowledge.

Teaching strategie	The course has the dual objective of providing the basic elements that characterize complex systems and the analysis methods useful for examining real cases. For this reason, the course will be characterized by both frontal lessons aimed at transmitting knowledge and laboratory exercises on the PC to put this knowledge into practice.
Expected learning outcomes in terms of	
Knowledge and understanding on:	● Understanding the scientific method, the nature, and the methods of research in Physics ● Knowledge of advanced computational techniques ● Knowledge of advanced computer tools commonly used in basic and applied research ● Knowledge of high-performance computing ● Knowledge of complex systems ● Basic concepts on Machine Learning

	● Big data programming skills ● Fundamentals of R ● Visualization and presentation of data analysis results ● Ability to work in a team.
Applying knowledge and understanding on:	● Ability to use analogy to apply known solutions to new problems (problem solving) ● Ability to design and implement experimental or theoretical procedures to solve problems in academic and industrial research or to improve existing results ● Ability to use analytical and numerical mathematical computation tools ● Ability to use electronic and computer technologies and their application to experimental data acquisition ● Modeling databases of real systems ● Ability to understand the underlying dynamics of complex systems
Soft skills	● **Making informed judgments and choices** o Ability to work with increasing levels of autonomy, including taking responsibility in project planning and managing facilities. o Apply the notions learned in multi-disciplinary contexts o Apply mathematical concepts to real systems ● **Communicating knowledge and understanding** o Competence in communication in Italian and English in advanced fields of Physics o Use of rigorous and precise language o Use of logical arguments ● **Capacities to continue learning** o Acquisition of basic knowledge tools for continuous learning and knowledge updates o Mathematical theory of Machine Learning o Problem-solving strategies o Modelling real systems
Syllabus	
Content knowledge	● Introduction to Machine Learning: supervised and unsupervised approach; ● Introduction to the R framework; ● Feature engineering: dimensionality reduction techniques, Principal Component Analysis (PCA), filtering methods, wrapper methods, embedded methods; ● Unsupervised ML algorithms: clustering algorithms; ● Supervised ML algorithms: classification, regression, overfitting, underfitting, bias, variance. ● Performance metrics: Accuracy, Sensitivity, Specificity, Roc curve. ● K-Nearest Neighbor (KNN) algorithm; ● Bayessian algorithm; ● Decision trees: CART, ID3, C4.5; ● Ensemble techniques: Bagging and Boosting; ● Adaboost algorithm; ● Random Forest algorithm; ● The Boruta wrapper method; ● Artificial neural networks; ● Support Vector Machine (SVM); ● eXplainable Artificial Intelligence (XAI) techniques; ● Hints on deep learning: Convolutional Neural Network (CNN).
Texts and readings	*Christopher M. Bishop, Pattern Recognition and Machine Learning*
Notes, additional materials	*Teacher's notes and slides*
Repository	Google Drive

Assessment	
Assessment methods	Oral presentation of a case-study
Assessment criteria	● **Knowledge and understanding** Consistency of answers according to formulated questions ● **Applying knowledge and understanding** o Setting up and carrying out numerical examples ● **Autonomy of judgment** o Consistency with the subject of the program o Software debug ● **Communicating knowledge and understanding** o Clarity and precision of presentation ● **Communication skills** o Ability to identify interconnection between the subjects of study ● **Capacities to continue learning** o Cross-discipline applications
Final exam and grading criteria	Capability to select and apply descriptive and predictive data analytics methods. Skill to discover trends in analytical data stores using the data mining techniques of clustering, association, and decision trees. Adequate comprehension and global knowledge of concepts and arguments at the basis of the machine learning methods described throughout the course.
Further information	
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