THE DOCTORAL SCHOOL OF IPPT PAN

COURSE OFFERED IN THE DOCTORAL SCHOOL OF IPPT PAN

Name of the course	Polish	**Matematyczne podstawy uczenia maszynowego**				
	English	**Mathematical Foundations of Machine Learning**				
Type of the course	**Lecture**					
Course coordinator	**Dr Tomasz Steifer**	Course teacher	Dr Tomasz Steifer			
Implementing unit	**ZMD**	Scientific discipline / disciplines	**Computer science**			
Level of education	**Doctoral studies**	Semester	**winter**			
Language of the course	**English**					
Type of assessment	**exam**	Number of hours in a semester	**30**	ECTS credits	**3**	

Type of classes		Lecture	Auditory classes	Project classes	Laboratory	
Number of hours	in a week	**2**	**0**	**0**	**0**	**0**
	in a semester	**30**	**0**	**0**	**0**	**0**

1. Prerequisites

Elementary mathematical education on the university level, esp. probability theory. Additionally, some programming experience or equivalently, a course in mathematical logic.

2. Course objectives

This course will give an overview of standard mathematical frameworks in the machine learning theory. The lectures will begin with historical models of Gold and Solomoff, then continue through the basics of computational learning theory, then from prediction with expert advice to stochastic gradient descent to modern neural network architectures. The course plan can be adapted to fit the scientific interests of the students.

3. Course content (separate for each type of classes)

Lecture

1. Inductive inference
2. Solomonoff's Induction, Bayesian mixtures of probability measures.
3. Halving algorithm, perceptron.
4. PAC learning, concentration inequalities, uniform convergence for finite classes.
5. Uniform convergence for infinite classes, VC dimension, the fundamental theorem of statistical learning.
6. Weak and strong learning, AdaBoost algorithm.
7. Online learning, Littlestone dimension, Standard Optimal

Algorithm (SOA). 8. Prediction with expert advice, Exponential Weights Algorithm. 9. Stochastic Gradient Descent. 10. Neural Networks, the universal approximation theorem. 11. Limitations of the transformer architecture. 12. The Weisfeiler-Leman test and the expressiveness of graph neural networks.
Laboratory

4. Learning outcomes

Number of the learning outcome	Learning outcomes description	Reference to the learning outcomes according to the 8th level of PRK	Learning outcomes verification methods*
Knowledge			
1	The graduate acquires basic knowledge of the mathematical models of machine learning.	P8S_WG	Oral exam
2			
3			
Skills			
1	The graduate is able to prove basic mathematical results in machine learning theory.	P8S_UW	Oral exam
2			
3			
4			
Communication			
1			
2			
3			
Social competences			
1	The graduate is ready to critically evaluate the achievements of the represented scientific discipline, including his or her own contribution to the development of this discipline	P8S_KK	active participation during classes
2			

*Allowed learning outcomes verification methods: exam; oral exam; written test; oral test; project evaluation; report evaluation; presentation evaluation; active participation during classes; homework; tests

5. Assessment criteria

active participation during classes, oral exam

6. Literature

1. Shalev-Shwartz, Shai, and Shai Ben-David. Understanding machine learning: From theory to algorithms. Cambridge

university press, 2014.
2. Sanford, Clayton, Daniel J. Hsu, and Matus Telgarsky. "Representational strengths and limitations of transformers." Advances in Neural Information Processing Systems 36 (2024).
3. Vaswani, A. "Attention is all you need." Advances in Neural Information Processing Systems (2017).
4. Morris, Christopher, et al. "Weisfeiler and Leman go neural: Higher-order graph neural networks." Proceedings of the AAAI conference on artificial intelligence. Vol. 33. No. 01. 2019.

7. PhD student's workload necessary to achieve the learning outcomes**		
No.	Description	Number of hours
1	Hours of scheduled instruction given by the lecturer in the classroom	**30**
2	Hours of consultations with the lecturer, exams, tests, etc.	**5**
3	Amount of time devoted to the preparation for classes, preparation of presentations, reports, projects, homework	**15**
4	Amount of time devoted to the preparation for exams, test, assessments	**40**
	Total number of hours	**90**
	ECTS credits	**3**

** 1 ECTS = 25–30 hours of the PhD students work (2 ECTS ≈ 60 hours; 4 ECTS ≈ 110 hours, etc.)