



**Syllabus for the course  
“Advanced topics in Machine Learning”**

for doctoral programme in 09.06.01 Informatics and Computer Engineering / 05.13.01 “Systems Analysis, Control Theory, and Information Processing”, 05.13.18 “Mathematical Modeling, Numerical Methods, and Software Systems”

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*This program cannot be used by other departments and other universities without the author's permission.*



### 1. Scope of Use

This program establishes the minimal requirements to doctoral students’ knowledge and skills for 09.06.01 Informatics and Computer Engineering / 05.13.01 “Systems Analysis, Control Theory, and Information Processing”, “05.13.18 Mathematical Modeling, Numerical Methods, and Software Systems” and determines the content of the course and educational techniques used in teaching the course.

The present syllabus is aimed at faculty teaching the course and doctoral students studying 09.06.01 Informatics and Computer Engineering / 05.13.01 “Systems Analysis, Control Theory, and Information Processing”, 05.13.18 “Mathematical Modeling, Numerical Methods, and Software Systems”.

This syllabus meets the standards required by:

- Educational standard of National Research University “Higher School of Economics” for 09.06.01 Informatics and Computer Engineering;
- Doctoral programme for 09.06.01 Informatics and Computer Engineering;
- University curriculum of the doctoral programme for 09.06.01 Informatics and Computer Engineering / 05.13.01 “Systems Analysis, Control Theory, and Information Processing”, 05.13.18 Mathematical Modeling, Numerical Methods, and Software Systems”.

### 2. Learning Objectives

The learning objective of the course “Advanced topics on Machine Learning” is to provide doctoral students with essential theoretical and practical knowledge in modern statistical learning techniques, such as:

- Basic principles, definitions and techniques in Machine Learning
- Regularized learning.
- Classification, regression, collaborative filtering,
- Limitation of Machine Learning.
- Kernel methods and Deep Learning techniques,
- Unsupervised learning, representation learning,
- Recent developments and projects in Machine Learning

### 3. Main Competencies Developed after Completing the Study of This Discipline

After completing the study of the discipline the doctoral student should have:

- Knowledge about regularized learning techniques.
- Knowledge about modern methods such as kernel methods and deep learning techniques.
- Knowledge about ongoing developments in Machine Learning
- Hands-on experience with large scale machine learning problems.
- Knowledge about how to design and develop machine learning programs using a programming language such as R or Python.
- Think critically with real data.

After completing the study of the discipline the PhD student should have developed the following competencies:

Competence	Code	Descriptors (indicators of achievement of the result)	Educative forms and methods aimed at generation and development of the competence
The ability to critically analyze and evaluate research results including those obtained in multidisciplinary areas.	YK-1	The doctoral student is able to carry out comparative testing of competing models or methods.	Examples covered during the lectures and tutorials. Assignments.



The ability to carry out research in the field of professional activity using current research methods and information and communication technologies.	OIK-1	Doctoral students obtain necessary knowledge in machine learning sufficient to implement and understand new methods.	Assignments, additional material/reading provided
The ability to do research in transformation of information into data and knowledge, models of data and knowledge representation, methods for knowledge processing, machine learning and knowledge discovery methods, principles of building and operating software for automation of these processes.	PIK-4	The doctoral student is able to develop and analyze machine learning models, implement them in a programming language in large scale, and select the best model using validation techniques.	Lectures, tutorials, and assignments.

#### 4. Place of the Discipline in the Postgraduate Program Structure

This is an elective course for 09.06.01 Informatics and Computer Engineering / 05.13.01 “Systems Analysis, Control Theory, and Information Processing”, 05.13.18 “Mathematical Modeling, Numerical Methods, and Software Systems”.

Doctoral students are expected to be already familiar with some statistical learning techniques, and have skills in analysis, linear algebra, optimization, computational complexity, and probability theory.

The following knowledge and competences are needed to study the discipline:

- A good command of the English language, both oral and written.
- A sound knowledge of probability theory, complexity theory, optimization, and linear algebra

5. **Schedule for two semesters** (4 One lecture pair (2x40 min) and one seminar (1x 40) will be held each week, evenly distributed over the Ph.D. academic year.

#### 6. Requirements and Grading

Mid-Term Exam	2	Mid-semester test.
Homework	2	Solving 2 homework tasks. First homework involves implementing an optical digit recognition system. The second involves implementing an automatic speech recognition system.
Exam	1	Written exam. Preparation time – 180 min.

#### 7. Assessment

The assessment consists of two homework and two mid-semester exams. The homework problems are based on each lecture topics and are handed out to the PhD students throughout the semester.

Final assessments are the final exam. Postgraduate students have to demonstrate knowledge of the material covered during the entire course.



## 8. The grade formula

*The exam* is worth 60% of the final mark.

*Final course mark* is obtained from the following formula:  $\text{Final} = 0.2 * (\text{Homework}) + 0.2 * (\text{Mid-term exam}) + 0.6 * (\text{Exam})$ .

The grades are rounded in favour of examiner/lecturer with respect to regularity of class and home works. All grades having a fractional part greater than 0.5 are rounded up.

**Table of Grade Accordance**

Ten-point Grading Scale	Five-point Grading Scale	
1 - very bad 2 - bad 3 - no pass	Unsatisfactory - 2	<b>FAIL</b>
4 - pass 5 - highly pass	Satisfactory - 3	<b>PASS</b>
6 - good 7 - very good	Good - 4	
8 - almost excellent 9 - excellent 10 - perfect	Excellent - 5	

## 9. Course description.

### Topic 1. Principles of machine learning

Basic definitions, principles and types of machine learning.

### Topic 2. Regularized learning

Regularized learning for regression, logistic classification, artificial neural networks, support vector machines and collaborative filtering.

### Topic 3. Validation and error metrics

Validation techniques, hyper parameter tuning, type of errors, precision, recall, F-measure, ROC.

### Topic 4. Limitations machine learning

Bias vs. variance trade off, generalization vs. capacity, Minimum description length principle, VC dimension, other bounds, curse of dimensionality, no free lunch theorem.

### Topic 5. Deep learning techniques

Shallow networks, Multilayer Neural networks, back-propagation, deep learning, convolution layers, activation units, auto-encoders, Boltzmann machines, pre-training, universal approximators.

### Topic 6. Kernel methods

Construction of kernels, string-, graph-, convolution, fisher kernels, methods with kernels.

### Topic 7. Classic learning methods

Decision trees, instance learning, nearest neighbor.

### Topic 8. Ensemble learning

Random forests, averaging, boosting, bagging.

### Topic 9. Bayesian Learning

Belief networks, Naïve Bayes, Hidden Markov Models.

### Topic 10. Unsupervised and representation learning

Manifold learning, Spectral methods, dimensionality reduction, visualization, MDS, LLE, SOM, tSE.

### Topic 11. Clustering

Spectral clustering, k-means, hierarchical clustering.

### Topic 12. Speech recognition

Introduction to Speech Recognition Systems.



### **Topic 13. Robotics, and self-driving machines**

Introduction to self-driving cars, helicopters.

### **Topic 14. Recommender systems**

Introduction to recommender systems.

### **Topic 15. Online advertisements**

Introduction to self-driving cars, helicopters.

### **Topic 16. Machine learning in Bioinformatics**

Selected topics.

### **Topic 17. Machine learning in Economics**

Selected topics.

### **Topic 18. Machine learning competitions,**

Kaggle, Netflix price.

## **10. Educational technologies**

The following educational technologies are used in the study process:

- discussion and analysis of the results during the tutorials;
- regular assignments to test the progress of the PhD student;
- consultation time on Monday afternoons.

## **11. Final exam questions**

The final exam will consist of a selection of problems equally weighted. No material is allowed for the exam. Each question will focus on a particular topic presented during the lectures.

The questions consist in exercises on any topic seen during the lectures. To be prepared for the final exam, PhD students must be able to answer questions from the topics covered during the lecture.

## **12. Reading and Materials**

### **General literature:**

1. G. James, D. Witten, T. Hastie, R. Tibshirani. An introduction to Statistical Learning, 2013, Springer.
2. C. Bishop. Neural Networks for Pattern Recognition (1995). Springer.
3. I. Goodfellow, Y. Bengio and A. Courville, Deep Learning. 2016 MIT press.
4. John Shawe-Taylor and Nello Christianini. Kernel methods for Pattern Analysis (2004). Cambridge.

### **Additional literature:**

1. Alpaydin, E. Introduction to Machine Learning. Cambridge, MA: MIT Press, 2014.
2. Yoshua Bengio. Learning Deep Architectures for AI (2009).
3. Kevin Murphy, Machine Learning: A probabilistic Perspective, 2013, MIT press

## **13. Equipment.**

The course requires a laptop and a projector.