Federal State Autonomous Educational Institution of Higher Education "Moscow Institute of Physics and Technology (National Research University)"

APPROVED
Head of the Phystech School of Applied Mathematics and Informatics
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Work program of the course (training module)

course:	Machine Learning/Машинное обучение
major:	Applied Mathematics and Informatics
specialization:	Contemporary Combinatorics/Современная комбинаторика
	“Pusk” Online and Supplementary Education Centre
	Chair of Discrete Mathematics
term:	1
qualification:	Master

Semester, form of interim assessment: 2 (spring) - Grading test

Academic hours: 45 AH in total, including:
lectures: 15 AH.
seminars: 30 AH.
laboratory practical: 0 AH.

Independent work: 45 AH.

In total: 90 AH, credits in total: 2

Author of the program: R.G. Neychev, professor

The program was discussed at the Chair of Discrete Mathematics 05.03.2020

Annotation

This course aims to introduce students to the contemporary state of Machine Learning and Artificial Intelligence. It combines theoretical foundations of Machine Learning algorithms with comprehensive practical assignments. The course covers materials from classical algorithms to Deep Learning approaches and recent achievements in the field of Artificial Intelligence.

1. Study objective

Purpose of the course

- Learn the main theoretical foundations of Machine Learning and Deep Learning
- Get familiar with various approaches to supervised and unsupervised problems
- Gain essential experience in data preprocessing, model development, fitting and validation

Tasks of the course

- Data preprocessing, model development, fitting and validation
- Skills required in product development and applied research

2. List of the planned results of the course (training module), correlated with the planned results of the mastering the educational program

Mastering the discipline is aimed at the formation of the following competencies:

Code and the name of the competence	Competency indicators
Gen.Pro.C-1 Address current challenges in fundamental and applied mathematics	Gen.Pro.C-1.2 Consolidate and critically assess professional experience and research findings
Pro.C-1 Become part of a professional community and conduct local research under scientific guidance using methods specific to a particular professional setting	Pro.C-1.2 Understand the verification process of software models used to solve related scientific problems
Pro.C-2 Understands and is able to apply modern mathematical apparatus and algorithms, the basic laws of natural science, modern programming languages and software; operating systems and networking technologies in research and applied activities	Pro.C-2.1 Demonstrate expert knowledge of research basics in the field of ICTs, philosophy and methodology of science, scientific research methods, and apply skills to use them

3. List of the planned results of the course (training module)

As a result of studying the course the student should:

know:

- basic principles and problems of machine learning theory;
- basic methods and algorithms for solving learning problems by precedents;
- the main areas of application of these methods and algorithms;
- classification, clustering and regression.

be able to:

- to formalize the statement of applied data analysis tasks;
- use teaching methods based on precedents to solve practical problems;
- evaluate the accuracy and effectiveness of the solutions obtained.

master:

- the basic concepts of machine learning theory;
-the skills of independent work in solving typical problems;
-the culture of setting and modeling practically significant tasks;
-the skills of theoretical analysis of real problems solved using learning algorithms by precedents.

4. Content of the course (training module), structured by topics (sections), indicating the number of allocated academic hours and types of training sessions

4.1. The sections of the course (training module) and the complexity of the types of training sessions

№	Topic (section) of the course	Types of training sessions, including independent work			
		Lectures	Seminars	Laboratory practical	Independent work
1	Intro, knn, naive Bayes	3	6		9
2	SVM, PCA	3	6		9
3	Gradient boosting	3	6		9
4	Optimization, Regularization in DL	3	6		9
5	Text vectorizing, Embeddings, autoencoders	3	6		9
AH in total		15	30		45
Exam preparation		0 AH.			
Total complexity		90 AH., credits in total 2			

4.2. Content of the course (training module), structured by topics (sections)

Semester: 2 (Spring)

1. Intro, knn, naive Bayes

Linear Regression. Gradient descent Logistic regression

2. SVM, PCA

Bias Variance Decomposition, Train-validation test framework Trees and Ensembling

3. Gradient boosting

Feature types, Missing Values, Feature importances Neural Networks basics

4. Optimization, Regularization in DL

Recurrent Neural Networks Convolutional Neural Networks

5. Text vectorizing, Embeddings, autoencoders

Unsupervised learning Clustering

5. Description of the material and technical facilities that are necessary for the implementation of the educational process of the course (training module)

A standard classroom.

6. List of the main and additional literature, that is necessary for the course (training module) mastering

Main literature

2. Python и машинное обучение [Текст] = Python Machine Learning : крайне необходимое издание по новейшей предсказательной аналитике для более глубокого понимания методологии машинного обучения / С. Рашка; пер. с англ. А. В. Логунова .— М. : ДМК Пресс, 2017 .— 418 с.: ил. - Предм. указ.: с. 408-417. - 200 экз. - ISBN 978-5-97060-409-0 (в пер.) .— Полный текст (Доступ из сети МФТИ / Удаленный доступ).

Additional literature

1. Математические основы машинного обучения и прогнозирования [Текст] / В. В. Вьюгин ; Моск. физ.-техн. ин-т (гос. ун-т), Лаб. структурных методов анализа данных в предсказательном моделировании (ПреМоЛаб), Ин-т проблем передачи информации им. А. А. Харкевича РАН - М.МЦНМО,2013

7. List of web resources that are necessary for the course (training module) mastering

http://dm.fizteh.ru/

8. List of information technologies used for implementation of the educational process, including a list of software and information reference systems (if necessary)

Multimedia technologies can be employed during lectures and practical lessons, including presentations.

9. Guidelines for students to master the course

A student studying a discipline must, on the one hand, master the general conceptual apparatus, and on the other hand, must learn to apply theoretical knowledge in practice.

As a result of studying the discipline, the student must know the basic definitions, concepts, axioms.

To successfully master the course, a student's hard independent work is required. The course program provides for the minimum required time for a student to work on a topic. Independent work includes:

• reading and writing recommended literature;

• study of educational material (based on notes, educational and scientific literature), preparation of answers to questions intended for independent study, confirmation of individual statements, properties;

• laboratory work to understand the relationship between theory and practical skills;

• exam preparation.

The management and control of the student's independent work is carried out in the form of individual consultations.

It is important to understand the material being studied, not rote memorization. If it is difficult to study individual topics, questions, you should contact the teacher.

SUPPLEMENT

Assessment funds for course (training module)

major:	Applied Mathematics and Informatics
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Semester, form of interim assessment: 2 (spring) - Grading test

Author: R.G. Neychev, professor

1. Competencies formed during the process of studying the course

Code and the name of the competence	Competency indicators
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Pro.C-1 Become part of a professional community and conduct local research under scientific guidance using methods specific to a particular professional setting	Pro.C-1.2 Understand the verification process of software models used to solve related scientific problems
Pro.C-2 Understands and is able to apply modern mathematical apparatus and algorithms, the basic laws of natural science, modern programming languages and software; operating systems and networking technologies in research and applied activities	Pro.C-2.1 Demonstrate expert knowledge of research basics in the field of ICTs, philosophy and methodology of science, scientific research methods, and apply skills to use them

2. Competency assessment indicators

As a result of studying the course the student should:

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be able to:

- to formalize the statement of applied data analysis tasks;
- use teaching methods based on precedents to solve practical problems;
- evaluate the accuracy and effectiveness of the solutions obtained.

master:

- the basic concepts of machine learning theory;
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-the culture of setting and modeling practically significant tasks;
-the skills of theoretical analysis of real problems solved using learning algorithms by precedents.

3. List of typical control tasks used to evaluate knowledge and skills

1. Supervised learning problem statement. Regression and classification problems. What's the difference?
2. Linear model for regression problem in matrix notation. Mean Squared Error loss function.
3. What is the gradient? How is it used in optimization?
4. Write down gradient descent step for linear model and MSE for one-dimensional case.
5. What is validation? Cross validation?
6. What is regularization? How does L1 regularization differ from L2?
7. What are precision and recall metrics?
8. How does the bagging work? What is Random Forest? What's the difference between Random forest and Bagging?
9. How are parameters different from hyperparameters? E.g. what are parameters in linear models and decision trees? Hyperparameters?
10. What is boosting? Gradient boosting? How should a model be trained on step t+1 in a gradient boosting ensemble?
11. What is backpropagation? How does it work?
12. How would gradient propagate through a linear layer? Through ReLU?
13. How does convolutional layer work? What are the kernels (filters) in the convolutional layer? Are they independent?

14. What is dropout? How does it work in a neural network? Does it change its behaviour on the inference (test) stage?

15. What is batch normalization? How does it work? How does it affect the learning rate? Does it change its behaviour on the inference (test) stage?

16. State the unsupervised problem statement. What is clustering? How does k-means algorithm work?

4. Evaluation criteria

Test questions

1. Prove that if m, n are two coprime integers of different parity, then the numbers m2 - n2 and 2mn are also coprime.

2. Write and prove the general formula for the number of different representations of a given integer n as the sum of two squares. (Representatives that are not obtained from each other by changing signs and the order of the terms are considered different.)

3. Based on the obtained formula, derive the lower bound for the maximum number of equal distances among the given n points on the plane using a regular rectangular lattice.

4. Build a regular pentagon using a compass and a ruler.

5. Build a regular 15-gon using a compass and a ruler.

6. You are given a single segment. It is required to construct using a compass and a ruler a segment of length x satisfying the equation

7. Based on the previous task, prove that a regular heptagon cannot be built using a compass and a ruler.

8. Prove that trisection of the angle is impossible.

9. Describe all possible combinations of the amounts of black and white balls in the ballot box, so that if two balls are randomly fished in a sample without returning, the probability of fishing two white balls is exactly 0.5.

10. Consider the relation on the sides a, b, c of the triangle, in which a triangle with vertices at the bases of the bisectors is isosceles. Assuming that the sides converging on side c of the large triangle are equal, reduce this relation to the following

11. In what follows, we consider the cube defined by the first of the three equations (refusing the requirement that a, b, c be sides of a triangle). Show that the resulting cube is indecomposable, that is, the polynomial that defines it does not factor.

12. In addition to this, show that our cube is nonsingular, that is, there is not a single point on its projectivization at which each direction is tangent (or the same thing at which all three first partial derivatives of the polynomial defining it degenerate).

e numbers of black and white balls in the ballot box, so that if two balls are randomly fished in the sample without returning, the probability of fishing two white balls is exactly 0.5.

Assessment “excellent (10)” is given to a student who has displayed comprehensive, systematic and deep knowledge of the educational program material, has independently performed all the tasks stipulated by the program, has deeply studied the basic and additional literature recommended by the program, has been actively working in the classroom, and understands the basic scientific concepts on studied discipline, who showed creativity and scientific approach in understanding and presenting educational program material, whose answer is characterized by using rich and adequate terms, and by the consistent and logical presentation of the material;

Assessment “excellent (9)” is given to a student who has displayed comprehensive, systematic knowledge of the educational program material, has independently performed all the tasks provided by the program, has deeply mastered the basic literature and is familiar with the additional literature recommended by the program, has been actively working in the classroom, has shown the systematic nature of knowledge on discipline sufficient for further study, as well as the ability to amplify it on one’s own, whose answer is distinguished by the accuracy of the terms used, and the presentation of the material in it is consistent and logical;

Assessment “excellent (8)” is given to a student who has displayed complete knowledge of the educational program material, does not allow significant inaccuracies in his answer, has independently performed all the tasks stipulated by the program, studied the basic literature recommended by the program, worked actively in the classroom, showed systematic character of his knowledge of the discipline, which is sufficient for further study, as well as the ability to amplify it on his own;

Assessment “good (7)” is given to a student who has displayed a sufficiently complete knowledge of the educational program material, does not allow significant inaccuracies in the answer, has independently performed all the tasks provided by the program, studied the basic literature recommended by the program, worked actively in the classroom, showed systematic character of his knowledge of the discipline, which is sufficient for further study, as well as the ability to amplify it on his own;

Assessment “good (6)” is given to a student who has displayed a sufficiently complete knowledge of the educational program material, does not allow significant inaccuracies in his answer, has independently carried out the main tasks stipulated by the program, studied the basic literature recommended by the program, showed systematic character of his knowledge of the discipline, which is sufficient for further study;

Assessment “good (5)” is given to a student who has displayed knowledge of the basic educational program material in the amount necessary for further study and future work in the profession, who while not being sufficiently active in the classroom, has nevertheless independently carried out the main tasks stipulated by the program, mastered the basic literature recommended by the program, made some errors in their implementation and in his answer during the test, but has the necessary knowledge for correcting these errors by himself;

Assessment “satisfactory (4)” is given to a student who has discovered knowledge of the basic educational program material in the amount necessary for further study and future work in the profession, who while not being sufficiently active in the classroom, has nevertheless independently carried out the main tasks stipulated by the program, learned the main literature but allowed some errors in their implementation and in his answer during the test, but has the necessary knowledge for correcting these errors under the guidance of a teacher;

Assessment “satisfactory (3)” is given to a student who has displayed knowledge of the basic educational program material in the amount necessary for further study and future work in the profession, not showed activity in the classroom, independently fulfilled the main tasks envisaged by the program, but allowed errors in their implementation and in the answer during the test, but possessing necessary knowledge for elimination under the guidance of the teacher of the most essential errors;

Assessment “unsatisfactory (2)” is given to a student who showed gaps in knowledge or lack of knowledge on a significant part of the basic educational program material, who has not performed independently the main tasks demanded by the program, made fundamental errors in the fulfillment of the tasks stipulated by the program, who is not able to continue his studies or start professional activities without additional training in the discipline in question;

Assessment “unsatisfactory (1)” is given to a student when there is no answer (refusal to answer), or when the submitted answer does not correspond at all to the essence of the questions contained in the task.

5. Methodological materials defining the procedures for the assessment of knowledge, skills, abilities and/or experience

During differential credit the student are allowed to use the program of the discipline.