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
A.M. Raygorodskiy

Work program of the course (training module)

course:	Information Theory/Теория информации
major:	Applied Mathematics and Informatics
specialization:	Computer Science/Информатика
	Phystech School of Applied Mathematics and Informatics
	Chair of Discrete Mathematics
term:	4
qualification:	Bachelor

Semester, form of interim assessment: 8 (spring) - Grading test

Academic hours: 60 AH in total, including:
lectures: 30 AH.
seminars: 30 AH.
laboratory practical: 0 AH.

Independent work: 75 AH.

In total: 135 AH, credits in total: 3

Number of course papers, tasks: 1

Author of the program: D.V. Musatov, candidate of physics and mathematical sciences, associate professor

The program was discussed at the Chair of Discrete Mathematics 05.03.2020

Annotation

This course covers various areas of mathematics related to the concept of information and its transmission. The purpose of the course is to provide an overview of mathematical approaches to the definition of information and tell about the application of these approaches to solving various problems.

1. Study objective

Purpose of the course

Mastering the basic modern methods of information theory.

Tasks of the course

- Mastering by students of basic knowledge (concepts, concepts, methods and models) in information theory;
- acquisition of theoretical knowledge and practical skills in information theory;
- providing advice and assistance to students in conducting their own theoretical research in information theory.

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
UC-1 Search and identify, critically evaluate and synthesize information, apply a systematic approach to problem-solving	UC-1.5 Identify and evaluate practical consequences of possible solutions to a problem
	UC-1.4 Make competent judgments and estimates supported by logic and reasoning
	UC-1.3 Consider various options for solving a problem, assess the advantages and disadvantages of each option
	UC-1.2 Find, critically assess, and select information required for the task in hand
	UC-1.1 Analyze problems, highlight the stages of their solution, plan the actions required to solve them
UC-3 Interact effectively with project team members and fulfill one's role properly	UC-3.1 Establish different types of communication (educational, scientific, business, informal, etc.)
	UC-3.2 Interact with other team members to fulfill the project objectives
Gen.Pro.C-1 Apply fundamental knowledge of physics, mathematics, and/or natural sciences in professional settings	Gen.Pro.C-1.2 Build mathematical models, make quantitative measurements and estimates
	Gen.Pro.C-1.1 Analyze the task in hand, develop appproaches to complete it
	Gen.Pro.C-1.3 Determine the applicability limits of the obtained results
Gen.Pro.C-2 Use modern IT and software tools to perform professional tasks in compliance with information security requirements	Gen.Pro.C-2.2 Apply numerical mathematical methods and use software applications for scientific problem-solving in professional settings
	Gen.Pro.C-2.3 Fulfill basic information security requirements
	Gen.Pro.C-2.1 Apply modern computing tools and Internet services in professional settings
Pro.C-1 Assign, formalize, and solve tasks, develop and research mathematical models of studied phenomena and processes, systematically analyze scientific problems, obtain new scientific outcomes	Pro.C-1.2 Make hypotheses, build mathematical models of the studied phenomena and processes, evaluate the quality of the developed model
	Pro.C-1.1 Locate, analyze, and summarize information on current research findings within the subject area
	ПК-1.3 Apply theoretical and/or experimental research methods to a specific scientific task and interpret the obtained results

Pro.C-2 Conduct scientific research and testing independently or as a member (leader) of a small research team	Pro.C-2.1 Apply the principles of scientific work, methods of collecting and analyzing obtained data and ways of argumentation
	Pro.C-2.2 Conduct scientific research independently or as a member (leader) of a small research team
	Pro.C-2.3 Present research results through scientific publications and participation in conferences

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

As a result of studying the course the student should:

know:

- Fundamental concepts, laws, theories of a part of discrete mathematics;
- modern problems of the relevant sections of information theory;
- concepts, axioms, methods of proofs and proofs of the main theorems in the sections included in the basic part of the cycle;
- basic properties of the corresponding mathematical objects;
- analytical and numerical approaches and methods for solving typical applied problems of information theory.

be able to:

- Understand the task at hand;
- use your knowledge to solve fundamental and applied problems;
- evaluate the correctness of the problem setting;
- strictly prove or disprove the statement;
- independently find algorithms for solving problems, including non-standard ones, and analyze them;
- independently see the consequences of the results obtained;
- accurately present mathematical knowledge in the field orally and in writing.

master:

- Skills of mastering a large amount of information and solving problems (including complex ones);
- skills of independent work and mastering new disciplines;
- the culture of formulating, analyzing and solving mathematical and applied problems that require the use of mathematical approaches and EC methods for their solution;
- the subject language of information theory and the skills of competently describing the solution of problems and presenting the results obtained.

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	Combinatorial concept of information	4	6		15
2	Probabilistic approach to the concept of information	4	6		20
3	The task of transferring information	4	6		15
4	Communication complexity	4	6		10
5	Application of information theory	14	6		15
AH in total		30	30		75
Exam preparation		0 AH.			
Total complexity		135 AH., credits in total 3			

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

Semester: 8 (Spring)

1. Combinatorial concept of information

Combinatorial concept of information (information on Hartley), lower bounds for the operating time of sorting, binary search, information methods for solving various combinatorial problems

2. Probabilistic approach to the concept of information

Probabilistic concept of information. Shannon's entropy, its properties, applications to problems of coding and information transfer

3. The task of transferring information

The task of transmitting information through a channel with noise, the concept of channel capacity. Error correcting codes, upper and lower estimates.

4. Communication complexity

Communication complexity and its application to obtain lower grades in various tasks.

5. Application of information theory

Application of information theory to obtaining lower bounds for data structures and algorithms. Kolmogorov complexity and its applications

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

Standard classroom.

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

Main literature

1. Основы теории информации [Текст] : учеб. пособие для вузов / В. В. Панин .— 3-е изд., испр. — М. : Бином. Лаб. знаний, 2009 .— 438 с.
2. Теория информации и статистика [Текст]/С. Кульбак, -М, Наука, 1967

Additional literature

1. Теория вероятностей и теория информации с применениями в радиолокации [Текст] : [учеб. пособие для вузов] / Ф. М. Вудворд ; пер. с англ. С. И. Боровицкого ; под ред. Г. С. Горелика .— М. : Советское радио, 1955 .— 128 с.
2. Вьюгин, В. В. Математические основы машинного обучения и прогнозирования [Текст] : [учеб. пособие для вузов] / 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 .— 304 с.
3. Разборов, А. А. Коммуникационная сложность [Текст] : [учеб. пособие для вузов] / А. А. Разборов ; пер. с англ. Ю. Л. Притыкина ; под ред. В. А. Клепцына, С. М. Львовского .— М. : МЦНМО, 2012 .— 24 с.

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)

The lectures use multimedia technologies, including the demonstration of presentations.
In the process of independent work of students, it is possible to use software such as Mathcad, MATLAB, Maple, etc.

9. Guidelines for students to master the course

1. It is recommended to successfully pass test papers, as this simplifies the final certification in the subject.
2. To prepare for the final certification in the subject, it is best to use the lecture materials.

SUPPLEMENT

Assessment funds for course (training module)

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Author: D.V. Musatov, candidate of physics and mathematical sciences, associate professor

1. Competencies formed during the process of studying the course

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	Pro.C-2.3 Present research results through scientific publications and participation in conferences

2. Competency assessment indicators

As a result of studying the course the student should:

know:

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

During the course, two tests are carried out:

1. On information on Hartley, Shannon's entropy and information encoding / transmission problems.
2. On the transmission of information through a channel with noise, communication complexity and Kolmogorov complexity.

Each test allows you to earn from 0 to 2 points on the corresponding set of topics. Usually 2 solved problems correspond to 1 score. At the end of the course, an oral test is carried out, during the test, the student is asked to solve from 0 to 2 problems and answer 2 theoretical questions.

The final mark is calculated as follows: 2 + mark for the theoretical answer (from 0 to 4) + mark for the topics of the first control (0-2 points) + mark for the topics of the second control work (0-2 points). In case of not knowing the basic definitions / formulations of theorems, the student is sent to retake the test.

The mark for the topics of the test consists of the mark for the test (0-2 points) and the mark for solving the corresponding problem in the test (0-1 points), but in total no more than 2 points.

4. Evaluation criteria

1. Determination of the amount of information in the final object (information on Hartley).
2. Problems of optimal search.
3. Shannon's entropy: definition and basic properties. Information inequality.
4. Kraft's inequality. Using stochastic laws for data compression: Shannon-Fano code, Huffman code, arithmetic code.
5. Shannon's theorems on optimal coding for channels without noise.
6. Theorem about optimal block coding for a sequence of independent identically distributed random variables.
7. Application of Shannon's entropy in combinatorial optimal search problems.
8. The problem of perfect secret sharing: Shamir's secret sharing method for the threshold access structure; examples of access structures that do not allow perfect secret sharing.
9. Kolmogorovskaya's definition of the complexity of words, the simplest properties.
10. Kolmogorov-Levin theorem on symmetry of mutual information, information inequalities for Kolmogorov complexity.
11. Application of Kolmogorov complexity in combinatorial problems. Proof of the incompleteness of formal arithmetic according to Chaitin.

12. Prefix Kolmogorov complexity. Effectively zero sets, Martin-Lof randomness.
13. Law of iterated logarphim for Martin-Lof random sequences.
14. Codes for correcting errors.
15. Combinatorial models of a channel with noise. Boundaries of Hemming and Gilbert.
16. Linear codes, the Varshamov-Gilbert boundary. Hamming codes.
17. Reed-Solomon codes. Polynomial decoding algorithm for the Reed-Solomon code. Concatenated codes; construction of asymptotic good codes with an efficient decoding procedure.
18. Communication complexity.
19. Deterministic communication protocols, deterministic communication complexity. Examples of upper and lower bounds for deterministic communication complexity.

- the mark "excellent (10)" is given to a student who has shown comprehensive, systematized, in-depth knowledge of the curriculum of the discipline and the ability to confidently apply them in practice in solving specific problems, free and correct justification of the decisions made

- the mark "excellent (9)" is given to a student who has shown comprehensive, systematized, in-depth knowledge of the curriculum of the discipline and the ability to apply them in practice in solving specific problems, free and correct justification of the decisions made

-the mark "excellent (8)" is given to a student who has shown a comprehensive, systematized, deep knowledge of the curriculum of the discipline and the ability to apply them in practice in solving specific problems, and the correct justification of the decisions made

- the mark "good (7)" is given to a student if he knows the material well, expresses it competently and to the point, knows how to apply the acquired knowledge in practice, but makes some inaccuracies in the answer or in solving problems;

-the mark "good (6)" is given to a student if he knows the material, presents it competently and to the point, knows how to apply the knowledge gained in practice, but makes some inaccuracies in the answer or in solving problems;

- the mark "good (5)" is given to a student if he knows the material, and essentially expounds it, knows how to apply the knowledge gained in practice, but makes some inaccuracies in the answer or in solving problems;

- the mark "satisfactory (4)" is given to a student who has shown a fragmented, scattered nature of knowledge, insufficiently correct formulations of basic concepts, violation of the logical sequence in the presentation of the program material, but at the same time he owns the main sections of the curriculum necessary for further education and can apply the knowledge gained according to the sample in a standard situation;

-the mark "satisfactory (3)" is given to a student who has shown a fragmented, scattered nature of knowledge, insufficiently correct formulations of basic concepts, a violation of the logical sequence in the presentation of program material, but at the same time he knows fragmentarily the main sections of the curriculum necessary for further education and can apply the obtained knowledge by model in a standard situation;

- the mark "unsatisfactory (2)" is given to a student who does not know most of the main content of the curriculum of the discipline, makes gross errors in the formulation of the basic concepts of the discipline and does not know how to use the knowledge gained in solving typical practical problems

- the mark "unsatisfactory (1)" is given to a student who does not know the formulations of the basic concepts of the discipline.

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

During the differential test, students can use the discipline program.