Syllabus

Course Program

NONLINEAR PROCESSES AND MODELS

Specialty
113 Applied mathematics

Institute
Educational and Scientific Institute of Computer Science and Information Technology

Educational program
Intelligent Data Analysis

Department
Computer Mathematics and Data Analysis

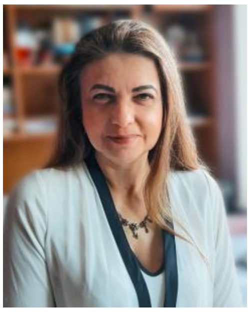
Level of education
Master's level

Course type
Special (professional), Mandatory

Semester
1

Language of instruction
English

Lecturers and course developers



Olena Akhiiezer

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Candidate of Technical Sciences, mathematical modeling and computational methods, Associate Professor of the Department of Computer Mathematics and Mathematical Modeling, Head of the Department of Computer Mathematics and Data Analysis of NTU "KhPI"

Author and co-author of over 200 scientific and educational-methodical works. Courses: "Mathematical Analysis," "Differential Equations and Complex Analysis," "Functional Analysis," "Higher Mathematics".
More about the lecturer on the department's website

Klym Yankoviy

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PhD in Computer Science, Assistant Professor of Computer Mathematics and Data Analysis Department of NTU "KhPI"

The number of scientific and educational publications is more than 10.
More about the lecturer on the department's website

General information

Summary

The course "Nonlinear Processes and Models" develops the knowledge and skills necessary for making informed decisions in crisis situations based on qualitative theory of dynamic systems and catastrophe theory, and their practical applications.

Course objectives and goals

To provide training for specialists capable of formulating, solving, and generalizing practical problems in their professional activities using fundamental and specialized applied methods of mathematical and computer sciences, developing mathematical models, algorithms, creating and operating relevant software. Teaching students the fundamentals of the qualitative theory of dynamic systems and catastrophe theory and their practical applications, shaping their general functional and subject-specific knowledge in this course.

Format of classes

Lectures, laboratory work, independent study, consultations. Final assessment - exam.

Competencies

GC 1. Ability to learn and master modern knowledge.
GC 2. Ability to apply knowledge in practical situations.
GC 6. Ability to abstract thinking, analysis and synthesis.
GC 8. Knowledge and understanding of the subject area and understanding of professional activity.
SC 1. Ability to use and adapt mathematical theories, methods and techniques for proving mathematical statements and theorems.
SC 2. Ability to perform tasks formulated in mathematical form.
SC 3. Ability to choose and apply mathematical methods for solving applied problems, modeling, analysis, design, management, forecasting, decision-making.
SC 4. Ability to choose and apply numerical methods for solving optimization problems.
SC 15. Ability to formulate a mathematical statement of a problem, based on the statement in the language of the subject field, and to choose a method of its solution, which ensures the required accuracy and reliability of the result

Learning outcomes

LO 1. Demonstrate knowledge and understanding of basic concepts, principles, theories of applied mathematics and use them in practice.
LO 2. To have basic principles and methods of mathematical, complex and functional analysis, linear algebra and number theory, analytical geometry, theory of differential equations, in particular partial differential equations, theory of probabilities, mathematical statistics and random processes, numerical methods.
LO 3. Formalize tasks formulated in the language of a specific subject area; formulate their mathematical statement and choose a rational solution method; solve the obtained problems by analytical and numerical methods, evaluate the accuracy and reliability of the obtained results.

Student workload

The total volume of the course is 120 hours (4 ECTS credits): lectures - 32 hours, laboratory classes - 16 hours, self-study - 72 hours.

Course prerequisites

To successfully complete the course, it is necessary to have previously taken the courses "Linear Algebra," "Mathematical Analysis," "Ordinary Differential Equations," and "Numerical Methods."

Features of the course, teaching and learning methods, and technologies

Lectures are conducted interactively. A project-based approach is emphasized in performing laboratory work, focusing on the application of information technologies in mathematical modeling of applied problems. There is an emphasis on independent study of software for working with numerical methods in solving problems related to nonlinear processes and models, as well as the utilization of electronic resources. Educational materials are accessible to students through Office 365.

Program of the course

Topics of the lectures

Topic 1. General concepts of nonlinear processes and the mathematical theory of catastrophes.
Subtopic 1: Linear and nonlinear models. Change of variables.
Subtopic 2: Nonlinear static and dynamic bifurcations.
Subtopic 3: Concepts of stability and instability.
Subtopic 4: Fundamental concepts of the mathematical theory of catastrophes.
Subtopic 5: Numerical methods. Ill-conditioned and stiff systems.
Subtopic 6: One-parameter family of discrete logistic equations. Bifurcation doubling of cycles. Feigenbaum constant.
Subtopic 7: Henon's finite-difference map. Numerical results. Strange attractor.
Topic 2. Nonlinear dynamic systems on the plane.
Subtopic 1: Local and global behavior. Linearization around a singular point. Linearization theorem.
Subtopic 2: Nontrivial singular points. Stability of singular points.
Subtopic 3: Ordinary points and global behavior.
Subtopic 4: First integrals.
Subtopic 5: Limit cycles.
Subtopic 6: Poincaré-Bendixson theory.
Topic 3. Some applied nonlinear models and processes.
Subtopic 1: Lotka-Volterra model. Instability and bifurcations of the model.
Subtopic 2: Complication of the model. Holling-Tanner model.
Subtopic 3: Relaxation oscillations. Jumps and regularization.
Subtopic 4: Linear equations.
Subtopic 5: Models of heart and nerve pulse pulsations.
Subtopic 6: Lyapunov functions.
Subtopic 7: Bifurcations in systems.

Topics of the workshops

Practical sessions within the framework of the discipline are not provided.

Topics of the laboratory classes

Topic 1. Numerical Methods. Initial Examples.
Theme 1.
Subtopic 1:
Subtopic 2: One-parameter family of discrete logistic equations.
Subtopic 3: Bifurcation of period-doubling.
Subtopic 4: Hénon's finite-difference map.
Subtopic 5: Fractals and strange attractors.
Topic 2. Numerical Methods. Some Applied Nonlinear Models and Processes.
Subtopic 1: Lotka-Volterra model. Instability and bifurcations of the model.
Subtopic 2: Model complication. Holling-Tanner model.
Subtopic 3: Relaxation oscillations. Jumps and regularization.
Subtopic 4: Linear differential equations.
Subtopic 5: Models of heart pulsation and nerve impulse.
Subtopic 6: Lyapunov functions.
Subtopic 7: Bifurcations in systems.
Topic 3. Continuous and Discontinuous Systems.
Subtopic 1: Continuous systems. Attractors with soft excitation of self-oscillations.
Subtopic 2: Continuous systems. Attractors with stiff excitation of self-oscillations.
Subtopic 3: Discontinuous systems.

Self-study

The course includes the completion of an individual computational assignment involving modeling and calculation of planned parameters for specific examples. The results of calculations and modeling are documented in a written report. Additional materials for self-study and analysis are recommended for students.

Course materials and recommended reading

Compulsory materials
1. Dynamical Systems Theory by Bjorn Birnir ¨ Center for Complex and Nonlinear Dynamics and Department of Mathematics University of California Santa Barbara, 2008, Bjorn Birnir. All rights reserved. [Online resource] https://birnir.math.ucsb.edu/files/bjorn/class-documents/main.pdf
2. Estimation of Nonlinear Dynamic Systems Theory and Applications by Thomas B. Schön. Department of Electrical Engineering Linköpings universitet, SE–581 83 Linköping, Sweden Linköping 2006 [Online resource] http://www.diva-portal.org/smash/get/diva2:22197/fulltext01.pdf
3. Elements of Bifurcation Theory: Guidelines and Educational Tasks / Compiled by: A.L. Grechko, M.Ye. Dudkin. – Kyiv: Igor Sikorsky Kyiv Polytechnic Institute, 2021, [Online resource] https://ela.kpi.ua/bitstream/123456789/41208/1/ETB.pdf

Additional materials
1. D. K. Arif, Fatmawati, D. Adzkiya, Mardlijah, H. N. Fadhilah, and P. Aditya. Analysis of the Model Reduction Using Singular Perturbation Approximation on Unstable and Non-Minimal Discrete-Time Linear Systems and Its Applications, Nonlinear Dynamics and Systems Theory, 19 (3) (2019) 362–371, [Online resource] https://repository.unair.ac.id/114275/1/C11.%20Fulltext.pdf
2. Numerical Methods for Solving Applied Problems: Textbook / O. A. Honcharov, L. V. Vasilyeva, A. M. Yunda. – Sumy: Sumy State University, 2020. – 142 p. ISBN 978-966-657-828-3
3. Luis T. Magalh˜aes and Carlos Rocha. Methods of Nonlinear Dynamical Systems Theory. Departamento de Matem´atica • Instituto Superior T´ecnico • Lisbon, 1991. [Online resource] https://www.math.tecnico.ulisboa.pt/~crocha/mndst.pdf

Assessment and grading

Criteria for assessment of student performance, and the final score structure

The final grade of 100% is composed of the assessment results in the form of an exam (40%) and ongoing assessment (60%). The exam includes a written assignment (2 theory questions + problem solving) and an oral presentation. Ongoing assessment involves 2 online tests and a computational task (each accounting for 20%).

Grading scale

Total points	National	ECTS
90–100	Excellent	A
82–89	Good	B
75–81	Good	C
64–74	Satisfactory	D
60–63	Satisfactory	E
35–59	Unsatisfactory (requires additional learning)	FX
1–34	Unsatisfactory (requires repetition of the course)	F

Norms of academic integrity and course policy

The student must adhere to the "Code of Ethics of Academic Relations and Integrity of NTU 'KhPI'," demonstrating discipline, courtesy, friendliness, honesty, and responsibility. Conflict situations should be openly discussed within study groups with the instructor, and if resolution is not possible, the matter should be brought to the attention of the institute's staff.
The normative and legal support for the implementation of the principles of academic integrity at NTU "KhPI" is available on the website: http://blogs.kpi.kharkov.ua/v2/nv/akademichna-dobrochesnist/

Approval

Approved by	Date, signature 31.08.2023		Head of the department Olena AKHIIEZER
	Date, signature 31.08.2023		Guarantor of the educational program Leonid LUBCHIK