COURSE DESCRIPTION CARD - SYLLABUS

Course name
Introduction to Quantum Information and Quantum Machine Learning

Course

Field of study	Year/Semester
Artificial Intelligence	1/2
Area of study (specialization)	Profile of study
	general academic
Level of study	Course offered in
Second-cycle studies	English
Form of study	Requirements
full-time	compulsory

Number of hours

Lecture	Laboratory classes	Other (e.g. online)
30	15	
Tutorials	Projects/seminars	
	10	

Number of credit points

4

Lecturers

Responsible for the course/lecturer:
Dr. Gustaw Szawioła, Doc.
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Faculty of Materials Engineering and Technical Physics, Institute of Materials Research and Quantum Engineeringj

Responsible for the course/lecturer:

Prerequisites

Knowledge in the field of computer science and machine learning, programming and mathematical competences specified in the learning outcomes for first-cycle and second-cycle studies (sem. 1) in the field of artificial intelligence.

Course objective

The module presents the basics of quantum computing and programming of quantum computers as well as selected problems of quantum algorithmics in the context of their application in machine learning.

Course-related learning outcomes

Knowledge

The student

[K2st_W2] has a structured theoretical general knowledge covering the basic issues of quantum informatics;
[K2st_W3] has detailed knowledge of selected quantum algorithms, including quantum machine learning;
[K2st_W4] has knowledge of development trends and the most important achievements of quantum computer science and quantum machine learning;
[K2st_W6] knows selected experimental, available in the cloud, quantum platforms and experimental quantum programming libraries used in research on the use of quantum computers, in particular in machine learning.

Skills
The student

[K2st_U3] is able to plan and carry out simple research experiments in the field of quantum information science and quantum machine learning, including quantum measurements, simulations and interpretation of the obtained results;
[K2st_U4] is able to use analytical, simulation and experimental methods to formulate and solve practical tasks and simple research problems in the field of quantum computing and quantum machine learning;
[K2st_U5] is able to present a proposal to solve an IT problem through the integration of knowledge about classical and quantum algorithms;
[K2st_U6] is able to assess the utility value of computers, platforms and programming quantum libraries, in particular in the field of machine learning;
[K2st_U10] is able to use selected, open and available in the cloud quantum platforms and libraries to solve selected tasks with a simple experimental component in the field of quantum computing and quantum machine learning.

Social competences
The student

[K2st_K1] understands the relationship between the development in the field of computer science, in particular machine learning, and the dynamics of quantum information technologies and methods;

[K2st_K2] The student understands the potential of using the latest knowledge in the field of quantum computer science and quantum artificial intelligence in solving research and practical problems.

Methods for verifying learning outcomes and assessment criteria

Learning outcomes presented above are verified as follows:
Formative assessment:

- in the sope of lectures is made on the basis of short quizzes or homework assignments covering the issues presented in previous lectures;
- in the sope of laboratory classes, it is carried out by verifying the progress of the implementation of specific laboratory tasks during current laboratory classes or consultations.

Summative assessment:

- within the scope of the lecture, it is conducted in the form of a written exam consisting of two parts: a multi-choice test with 10 to 15 questions binary graded for each question (0 or 1 point per question); the problem part consisting of 2 or 3 problem open tasks, scored on a 0-5 scale for each problem task; the pass threshold is 50% of the maximum number of points that can be obtained jointly from both parts of the exam (detailed criteria: not less than 90% - 5.0; 85% - 89.9% -4.5; 75% - 84.9% -4.0; 65% - 74.9% -3.5; 50% -64.5% - 3.0; less than 50% - 2).

- in the scope of laboratory classes, it is carried out on the basis of the current implementation of individual exercises, summarized with reports, scored on a 0-5 scale for each exercise; the pass threshold is 50% of the maximum number of points that can be obtained (detailed criteria: not less than 90% - 5.0; 85% - 89.9% -4.5; 75% - 84.9% -4.0; 65% - 74.9% -3.5; 50% -64.5% -3.0; less than 50% - 2) when calculating the final number of points, the exercise with the lowest score is omitted.

Programme content

Lectures

Part I Mathematical tools and quantum resources
I.1. Mathematical preliminaries in the context of quantum computers (complex numbers, linear algebra, elements of the probability theory).
I.2. Description of quantum qubit states (probability amplitude, superposition and quantum entanglement); quantum measurements and quantum state tomography.
I.3. Quantum operators and gates, simple quantum circuits (quantum random number generator, quantum teleportation circuit). Hamiltonian and dynamics of qubit states, trotterization, the problem of decoherence.

Part II. Canon of quantum algorithms.
II.1 Deutsch-Jozs algorithm. Simon's algorithm.
II.1 Grover's Alogoritm.
II.2. Quantum Fourier transform.
II.3 Quantum phase estimation.
II.4 Shor's algorithm.
II.5 Harrow-Hassidim-Lloyd algorithm for solving a system of linear equations.

Part III Selected issues of quantum machine learning
III.1. Parameterized quantum circuits for machine learning. Methods of quantum encoding and embadding.
III.2 Quantum linear regression (quantum cost functions, quantum gradient), training parameterized quantum circuits.
III.3 Quantum implemetation of feature maps and quantum kernel method. Quantum version of support vector machines (qSVM) and quantum least square SVM.
III.4 Quantum variational classification.
III.5 Introduction to quantum neural networks. Quantum pattern recognition.

III.6 Quantum generative adversarial networks

Laboratory classes

1. Quantum state tomography, quantum entanglement tests based on the CHSH inequality.
2.Analysis of the operation of quantum gates and simple quantum circuits, testing the performance of a quantum computer and its limitations.
3.Implementation and testing of the quantum Fourier transform algorithm and quantum phase estimation.
4 Implementation and testing of a quantum algorithm for solving a system of linear equations.
5. Implementation and testing of a selected quantum SVM algorithm.
6. Implementation of the quantum variational classification algorithm.
7. Implementation of the quantum pattern recognition algorithm.

Project:
1. Architectures of quantum computers and simulators - comparison of a tool for programming quantum computers.
2. Implementation of the Grover algorithm.
3. Implementation of Shor's algorithm.
4. Selected quantum algorithms in the field of machine learning.
5. Selected quantum and hybrid algorithms for solving selected combinatorial problems.

Teaching methods

Lectures: multimedia presentations (theory, examples, quizzes), examples presented on the board.

Laboratory classes: analysis of the problem described in the outline of the exercise and its discussion and solving in groups, after each exercise, individual preparation of the final report at home.

Bibliography

Basic

B. Zygelman, A First Introduction to Quantum Computing and Information, Springer Cham 2018
S. Pattanayak, Quantum Machine Learning with Python, Apress Berkeley, CA, 2021

Additional

R. S. Sutor, Dancing with Qubits: How quantum computing works and how it can change the world, Packt Publishing, 2019

E. R. Johnston, N. Harrigan, M. Gimeno-Segovia, Programming Quantum Computers: Essential Algorithms and Code Samples, O'Reilly Media, Inc., 2019
B. Zygelman, A First Introduction to Quantum Computing and Information, Springer Cham 2018
M. Schuld, F. Petrucccione, Machine Learning with Quantum Computers (Quantum Science and

Technology) 2nd ed.,Springer Cham, 2021

M. Schuld, F. Petrucccione, Supervised Learning with Quantum Computers, Springer Cham, 2018

W. Scherer, Mathematics of Quantum Computing, Springer Cham, 2019

M. A. Nielsen (Autor), I. L. Chuang, Quantum Computation and Quantum Information: 10th Anniversary Edition, Cambridge University Press, 2010

N. S. Yanofsky (Autor), M. A. Mannucci, Quantum Computing for Computer Scientists, Cambridge University Press, 2008

Breakdown of average student's workload

	Hours	ECTS
Total workload	100	4,0
Classes requiring direct contact with the teacher	55	2,0
Student's own work (literature studies, preparation for laboratory classes/tutorials, preparation for tests/exam, project preparation) [1]	45	2,0

[1] delete or add other activities as appropriate