Методы машинного обучения

Lecturers:
Игорь Лобанов

Language:
English

Credit points:
6 з.е.

Monitoring type:
Экзамен

Educational Program:

Нанофотоника
1, 3 семестры

Гибридные материалы
1, 3 семестры

Квантовые материалы
1, 3 семестры

Компьютерное моделирование квантовых и нанофотонных систем
1, 3 семестры

Prerequisites:

Квантовая механика
Квантовая оптика

Lectures (a.h)*	Practice (a.h)	Labs (a.h)
38	18	
*1 academic hour = 45 minutes		

Course goal and main objectives:

This course aims to provide the state-of-the-art knowledge in the field of quantum computing and its application to quantum machine learning (ML). The goal is to introduce quantum computing, explain its difference from classical computing, and learn the way in which quantum algorithms in application to machine learning can be developed. First major objective is to familiarize students with paradigmatic algorithms of quantum computing, and explain the difference between fault-tolerant and near-term quantum computing. Next objective is to learn and understand modern variational quantum algorithms, and code them for quantum hardware and simulators. Finally, the-state-of-the-art quantum machine learning (QML) tools will be introduced, with objective to understand and develop extensions to existing QML protocols.

Expected learning outcomes:

After the course you will have a base in quantum computing, understanding state-of-the-art quantum protocols, and being able to implement it in code for quantum hardware and simulators. You will understand the modern quantum techniques and will learn how to develop variational quantum-classical algorithms. You will learn the goals of machine learning, and apply quantum computing to machine learning, developing quantum machine learning software.

Relevance, novelty, significance, and uniqueness:

The course targets understanding of the quantum computing approach to information processing and state-of-the-art of machine learning, so it combines the significance of quantum paradigm of computation with novel solutions inspired by the artificial intelligence. It has a unique and specialized curriculum that is based on the contemporary research, giving access to knowledge available only in best research centers. The course teaches the way computing will be performed tomorrow.

Course content

Plan of a course

Структура курса

The course consists of the lecture series, where quantum computing and machine learning algorithms are described and explained. The large part of the course includes practical assignments (independent work), to be completed before each lecture, and discussed after lectures in the round table format. The course is also supplemented with weekly seminars where questions on practical assignments can be asked.
The structure of the course comprises of **three modules**:
1. Quantum computing
2. Variational quantum computing for modern devices
3. Machine learning and state-of-the-art quantum techniques

Introduction to Quantum Computing

1) Bits and qubits. Dirac notation. Entanglement. Quantum measurement.
Classical computing and reversible computing. Quantum gates.(Lecture)
2) Coding quantum gates and checking identities in the programming language of choice.(Seminar)
3) Physical platforms for quantum computing.(Lecture)
Quantum software infrastructure and simulation tools. QuASM. Quantum packages from IBM (qiskit), Rigetti (forest), Google (circ), Microsoft (Q#), and others.(Lecture)
4) Implementing a gate sequence using one of existing quantum packages.(Seminar)
5) Quantum teleportation and Bells states. Deutsch algorithms and Deutsch–Jozsa algorithm.(Lecture)
6) Quantum complexity. Simon’s algorithm. Quantum phase estimation.(Lecture)
7) Factoring and Shor’s algorithm. Quantum search and Grover’s algorithm.(Lecture)
8) Quantum simulation and linear combination of unitaries. Quantum computing for linear algebra, HHL and beyond.(Lecture)
9) Quantum linear algebra (cont.) Future algorithms for quantum machine learning.(Lecture)
10) Project: software realization for a quantum protocol of choice.(Seminar)

Variational Quantum Algorithms for modern quantum devices

11) Current hardware for quantum computing, NISQ vs. FTQC protocols. Hybrid quantum-classical workflow. Variational quantum eigensolver (VQE).(Lecture)
12) VQE (cont.) Quantum chemistry and material science.(Lecture)
13) Coding VQE with chemically motivated ansatz.(Seminar)
14) Classical optimization and gradient descent. Variational ansatz.(Lecture)
15) Coding VQE with hardware efficient ansatz.(Seminar)
16) Initial state choice. Measurement and Hamiltonian averaging. Barren plateaus. Quantum state comparator.(Lecture)
17) Variational quantum algorithms for linear algebra. Automatic differentiation and analytical gradients.(Lecture)
18) Quantum approximate optimization algorithm and QAOA-type quantum ansatz. Embedding of NP-hard problems and financial modelling. MaxCut and unsupervised machine learning (clustering).(Lecture)
19) Coding the embedding for NP-hard problem and using QAOA to solve it.(Seminar)
20) Coding the VQE for chemistry/material problem and benchmarking.(Seminar)

Machine learning and state-of-the-art quantum techniques

21) Tasks of machine learning. Supervised and unsupervised learning. Classical neural networks. Quantum neural networks and variational circuits.(Lecture)
22) Amplitude encoding and feature map encoding. ML-inspired quantum computing. Quantum circuit learning.(Lecture)
23) Coding data using amplitude and feature maps.(Seminar)
24) Quantum clustering and regression. Quantum support vector machines. Quantum Principal Component Analysis.(Lecture)
25) Generative modelling. Quantum GANs.(Lecture)
26) Variational Quantum Autoencoder. Phase transition detection and convolutional neural networks. Quantum Deep Learning.(Lecture)
27) Open problems of Quantum Machine Learning (Input, Output, Costing, and Benchmarking problems). Perspectives.(Lecture)
28) Coding one of the QML approaches as a final project. Presenting code and benchmarking.(Seminar)

Recommended resources

1. Quantum Computation and Quantum Information: book / M. A. Nielsen and I. L. Chuang — Cambridge Univ. Press, 2010. — http://mmrc.amss.cas.cn/tlb/201702/W020170224608149940643.pdf

2. Introduction to Quantum Computing: lecture notes / John Watrous — Waterloo, 2006. — https://cs.uwaterloo.ca/~watrous/LectureNotes/CPSC519.Winter2006/all.pdf

3. Quantum machine learning: review / Jacob Biamonte et al. — Nature 549, 195–202, 2017. — https://www.nature.com/articles/nature23474

4. Parameterized quantum circuits as machine learning models: review / M. Benedetti, E. Lloyd, S. Sack, and M. Fiorentini. — Quantum Science and Technology 4, 043001, 2019. — https://iopscience.iop.org/article/10.1088/2058-9565/ab4eb5

Grading Policy

Form of control	Assignments type	Score %	Minimum threshold for attestation (grade E or credit)%	Deadlines	Comments
Current attestation for Module 1 (Monitoring of progress)	Mini-project	20	5	Mid-Oct	Score includes homeworks, and presentation on the Module 1 mini-project
Current attestation for Module 2 (Monitoring of progress)	Mini-project	30	10	Nov	Score includes homeworks, and presentation on the Module 2 mini-project
Mid-term attestation	Presentation of results in Modules 1 and 2 (counts towards total score for M1 and M2)				
Current attestation for Module 3 (Monitoring of progress)	Project	50	15	Dec	Presentation on the Module 3 project and benchmarking
Admission to attestation (if any)	Complete minimum 25% of homework				
Attestation	Presentation of results in Module 3 and final project (counts towards total score for M3)				