Northeastern
College of Engineering

Introduction to Quantum Computing with Applications

Course Information

Course Title: Introduction to Quantum Computing with Applications
Course Number: CSYE 6305
Term and Year: Spring 2024
Credit Hour: 4
CRN: 36566
Course Format: Online

Instructor Information

Full Name: Mariia Mykhailova
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Instructor Biography

Mariia Mykhailova is a principal software engineer at the Advanced Quantum Development team at Microsoft. She works on developing software for fault-tolerant quantum computation, and before that she spent five years focusing on quantum education and outreach for Azure Quantum and Microsoft Quantum Development Kit. Mariia is the author and maintainer of the Quantum Katas project – an open-source collection of hands-on tutorials and programming problems for learning quantum computing. She is also a part-time lecturer at Northeastern University, teaching “Introduction to Quantum Computing” since 2020, and the author of the O'Reilly book “Q# Pocket Guide” and the upcoming Manning book “Quantum Programming Projects”.

Teaching Assistant Information

N/A

Course Prerequisites

Graduate level INFO 5100 Minimum Grade of B- or Graduate level CSYE 6200 Minimum Grade of B- or Graduate level DAMG 6105 Minimum Grade of B-

- This course assumes no prior experience in quantum computing or quantum physics.
- The course relies on the basics of linear algebra (complex numbers, vectors and matrices, matrix operations, tensor product of matrices, eigenvectors and eigenvalues). You can use tutorials ComplexArithmetic and LinearAlgebra to refresh the topics necessary.
- Familiarity with software development using any programming language is required; basic familiarity with Python is recommended.

Course Description

Quantum computing harnesses the quantum-mechanical laws of nature to enable new types of algorithms, impossible on traditional computers. Quantum computing nowadays can be compared to the classical computing in the first half of the 20th century: the visionaries have created the concept and theories on what kind of tasks the new paradigm can be useful for, and the companies like Microsoft, IBM, Google, and D-Wave started the efforts to bring this vision to life. This means that our understanding of quantum computers, the challenges in their development and the problems they can solve is still in its infancy – but this also means that this new technology can have huge impact on everybody's lives in the future. It is a prime time to learn it and be a part of the quantum revolution!

In this course we will cover the fundamental concepts of quantum computing and learn to implement several of the most famous quantum algorithms, including Grover's search algorithm and Shor's algorithm for integer factorization. You will practice running quantum programs on real quantum hardware using Azure Quantum. We will also review more advanced applications of quantum computing and the challenges of building a full-stack quantum computer.

Standard Learning Outcomes

Learning outcomes common to all College of Engineering Graduate programs:

1. *An ability to identify, formulate, and solve complex engineering problems.*
2. *An ability to explain and apply engineering design principles, as appropriate to the program's educational objectives.*
3. *An ability to produce solutions that meet specified end-user needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.*

The Information Systems Program accepts students of different engineering backgrounds with minimum programming skills and produces first class Information Systems engineers that operate at the intersection of real-world complexity, software development, and IT management. Graduating students will be able to construct end-to-end advanced software applications that meet business needs.

Specific Learning Outcomes for the Information Systems program:

1. *Create a strong technical foundation through diverse, high-level courses*
2. *Built crucial interpersonal skills needed to succeed in any industry*
3. *Foster a deep level of applied learning through project-based case studies*

Based on satisfactory completion of this course, a student should be able to:

- *Describe the necessary components of a full-stack quantum computing system*
- *Explain the fundamental concepts of quantum computing*
- *Recognize the types of problems that may and may not be a good candidate for quantum computing applications and explain the reasons*
- *Summarize several well-known quantum computing algorithms and applications*
- *Come up with an algorithm to solve a simple well-defined quantum problem*
- *Implement a simple algorithm using Q# programming language*
- *Debug the implementation of a simple algorithm, verify its correctness and evaluate its efficiency using a variety of tools in Microsoft Quantum Development Kit*

- *Run a quantum program on quantum hardware in the cloud using Azure Quantum*
- *Read and understand resources on quantum computing (papers or books) for further studies*

Required Tools and Course Textbooks.

Reference books:

- M. Mykhailova, Q# Pocket Guide, O'Reilly Media, 2022, 978-1-098-10886-1 (can be accessed online at O'Reilly learning)
- T.Wong, Introduction to Classical and Quantum Computing,2022, 979-8985593105 (shared online by the author at http://www.thomaswong.net/)
- (optional) M. A. Nielsen and I. L. Chuang, Quantum Computation and Quantum Information, Cambridge University Press, 2000, 978-1-107-00217-3, *or*
- (optional) N. S. Yanofsky and M. A. Mannucci, Quantum Computing for Computer Scientists, Cambridge University Press, 2008, 978-0-521-87996-5.

Each lecture will include pointers to extra reading on the topic, such as tutorials, papers, articles or lecture notes from other courses.

Required software:

- Microsoft Quantum Development Kit.
  Required: Visual Studio/Visual Studio Code/command line setup, Q# Jupyter Notebooks setup.
- The Quantum Katas – a collection of tutorials and programming exercises.
- Azure (Azure Quantum)

Course Schedule/Topics Covered.

01/01/2024	(No class, software setup instructions only) Module 1: prerequisites, Microsoft Quantum Development Kit and Azure Quantum setup.
01/08/2024	Course overview. Quantum computing history and motivation. Module 2: Fundamental concepts of quantum computing, part 1: the qubit, superposition, single-qubit quantum gates, Dirac notation, quantum measurement, random number generation.
01/15/2024	No class (Martin Luther King, Jr. Day)
01/22/2024	Module 3: Fundamental concepts of quantum computing, part 2: multi-qubit systems, entanglement, multi-qubit quantum gates, quantum computing notations comparison, measurement of multi-qubit systems.
01/29/2024	Module 4: Quantum communication algorithms: no-cloning theorem, quantum key distribution, teleportation, superdense coding.
02/05/2024	Module 5: Oracular algorithms: phase oracles, Deutsch algorithm, Deutsch-Josza algorithm, Bernstein-Vazirani algorithm.

02/12/2024	Module 6: Reversible computing: reversible Boolean logic, reversible circuit synthesis, marking oracles, example (implementing quantum oracle for SAT problems).
02/19/2024	No class (Presidents Day)
02/26/2024	Module 7: Grover's search algorithm, amplitude amplification.
03/04/2024	No class (spring break)
03/11/2024	Module 8: Building up to Shor's algorithm: quantum Fourier transform, quantum phase estimation, Shor's algorithm for integer factorization.
03/18/2024	Module 9: Hybrid quantum algorithms, variational quantum algorithms, quantum approximate optimization algorithm (QAOA).
03/25/2024	Module 10: Quantum machine learning.
04/01/2024	Module 11: Quantum error correction, fault-tolerant quantum computing.
04/08/2024	Module 12: How to build a full-stack quantum computer and put it in the cloud, part 1: quantum software stack.
04/15/2024	Module 13: How to build a full-stack quantum computer and put it in the cloud, part 2: quantum hardware stack.
04/22/2024	No class (grading wrap up)

Grading Scale.

	87-89 pt B+	77-79 pt C+	
95+ pt A	84-86 pt B	74-76 pt C	
90-94 pt A-	80-83 pt B-	70-73 pt C-	69 pt or below F

Grade Breakdown:

Weekly programming assignments (modules 1-11) – 110 pt.
Weekly programming assignments will follow the topics covered in each week's lecture. They will involve solving simple quantum programming problems similar to the ones offered in the Quantum Katas, running quantum programs on quantum hardware using Azure Quantum, debugging and optimizing quantum programs, and other types of quantum programming tasks. Each assignment will consist of one or several problems of different point values, and each problem will be graded pass/fail. Programming assignments that use automated grading will include the grading harness you can use to validate your work before submitting it. Each weekly assignment will be worth 10 points.

Extra programming assignments – 20 pt.
Additional programming assignments will cover additional topics, not covered in the weekly lectures, and require some additional self-study. They will involve solving quantum programming problems similar to the ones offered in the Quantum Katas and the weekly programming assignments, and graded in a similar manner. These assignments are an opportunity to get extra credit points to improve your grade.

Extra credit.
You can earn extra credit points for reporting unique bugs in the course materials (lectures, homework assignments, and the Quantum Katas).

Note that the maximum number of points you can get by completing all assignments is 130 pt. You do not have to complete all assignments to get A grade.

Attendance/Late Work Policy.

Attendance Policy

Students are expected to complete course readings, participate in class discussions or other learning activities during the unit, and complete programming assignments for each unit during the time of that unit. It is understood that there might be one week when active participation in ongoing class conversations and learning activities might be delayed; each programming assignment spans at least two weeks to allow flexibility in the time of its completion. Beyond one week's time, if there is an absence or lateness in participation (1) faculty must be notified in advance; (2) grades will be adjusted accordingly.

Late Work Policy

Students must submit assignments by the deadline in the time zone noted in the syllabus.
The problems will be discussed in the first lecture after the submission deadline for that assignment.
Late submissions will not be accepted after the problems were discussed in class.

End-of-Course Evaluation Surveys

Your feedback regarding your educational experience in this class is particularly important to the College of Professional Studies. Your comments will make a difference in the future planning and presentation of our curriculum.

At the end of this course, please take the time to complete the evaluation survey at **https://neu.evaluationkit.com**. Your survey responses are **completely anonymous and confidential**. For courses 6 weeks in length or shorter, surveys will be open one week prior to the end of the courses; for courses greater than 6 weeks in length, surveys will be open for two weeks. An email will be sent to your Husky Mail account notifying you when surveys are available.

Academic Integrity

A commitment to the principles of academic integrity is essential to the mission of Northeastern University. The promotion of independent and original scholarship ensures that students derive the most from their educational

experience and their pursuit of knowledge. Academic dishonesty violates the most fundamental values of an intellectual community and undermines the achievements of the entire University.

As members of the academic community, students must become familiar with their rights and responsibilities. In each course, they are responsible for knowing the requirements and restrictions regarding research and writing, examinations of whatever kind, collaborative work, the use of study aids, the appropriateness of assistance, and other issues. Students are responsible for learning the conventions of documentation and acknowledgment of sources in their fields. Northeastern University expects students to complete all examinations, tests, papers, creative projects, and assignments of any kind according to the highest ethical standards, as set forth either explicitly or implicitly in this Code or by the direction of instructors.

Go to http://www.northeastern.edu/osccr/academic-integrity-policy/ to access the full academic integrity policy.

University Health and Counseling Services

As a student enrolled in this course, you are fully responsible for assignments, work, and course materials as outlined in this syllabus and in the classroom. Over the course of the semester if you experience any health issues, please contact UHCS.

For more information, visit https://www.northeastern.edu/uhcs.

Student Accommodations

Northeastern University and the Disability Resource Center (DRC) are committed to providing disability services that enable students who qualify under Section 504 of the Rehabilitation Act and the Americans with Disabilities Act Amendments Act (ADAAA) to participate fully in the activities of the university. To receive accommodations through the DRC, students must provide appropriate documentation that demonstrates a current substantially limiting disability.

For more information, visit https://drc.sites.northeastern.edu.

Library Services

The Northeastern University Library is at the hub of campus intellectual life. Resources include over 900,000 print volumes, 206,500 e-books, and 70,225 electronic journals.

For more information and for education specific resources, visit https://library.northeastern.edu.

24/7 Canvas Technical Help

For immediate technical support for Canvas, call 617-373-4357 or email help@northeastern.edu

Canvas Faculty Resources: https://canvas.northeastern.edu/faculty-resources/

Canvas Student Resources: https://canvas.northeastern.edu/student-resources/

For assistance with my Northeastern e-mail, and basic technical support:
Visit ITS at https://its.northeastern.edu

Email: help@northeastern.edu
ITS Customer Service Desk: 617-373-4357

Diversity and Inclusion

Northeastern University is committed to equal opportunity, affirmative action, diversity, and social justice while building a climate of inclusion on and beyond campus. In the classroom, members of the University community work to cultivate an inclusive environment that denounces discrimination through innovation, collaboration, and an awareness of global perspectives on social justice.

Please visit http://www.northeastern.edu/oidi/ for complete information on Diversity and Inclusion

Title IX

Title IX of the Education Amendments of 1972 protects individuals from sex or gender-based discrimination, including discrimination based on gender-identity, in educational programs and activities that receive federal financial assistance.

Northeastern's Title IX Policy prohibits Prohibited Offenses, which are defined as sexual harassment, sexual assault, relationship or domestic violence, and stalking. The Title IX Policy applies to the entire community, including male, female, transgender students, faculty, and staff.

In case of an emergency, please call 911.

*Please visit **https://www.northeastern.edu/ouec** for a complete list of reporting options and resources both on- and off-campus.*