Northeastern
College of Engineering

Introduction to Quantum Computing with Applications
FALL 2024

Course Information
Course Title: Introduction to Quantum Computing with Applications
Course Number: CSYE 6305
Term and Year: Fall 2024
Credit Hour: 4
CRN: 13521
Course Format: Online

Instructor Information
Full Name: Mariia Mykhailova
Email Address: m.mykhailova@northeastern.edu
Office Hours: N/A

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 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 Manning book "Quantum Programming in Depth: Solving problems with Q# and Qiskit".

Teaching Assistant Information
Full Name: Dhairya Milindkumar Gundechia
Email Address:gundechia.d@northeastern.edu
Office Hours:TBD

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 strongly 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. We will also review more advanced applications of quantum computing and the challenges of building a full-stack quantum computer.

Course Learning Outcomes

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 Azure Quantum Development Kit
- Read and understand resources on quantum computing (papers or books) for further studies

Required Tools and Course Textbooks.

Required software:

- Azure Quantum Development Kit: Visual Studio Code and Python+Q# setup.
- The Quantum Katas – a collection of tutorials and programming exercises.

Reference books:

- M. Mykhailova, Q# Pocket Guide, O'Reilly Media, 2022, 978-1-098-10886-1 (free online access at O'Reilly for Higher Education Ebooks with NEU email account)

- M. Mykhailova, Quantum Programming in Depth: Solving problems with Q# and Qiskit, Manning, 2025, 978-1633436909 (paid access to the published chapters via Manning Early Access Program)
- T.Wong, Introduction to Classical and Quantum Computing, 2022, 979-8985593105 (free online access from 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.

Course Schedule/Topics Covered.

Week	Date	In Class Topic	Assignment Due
1	**09/02**	(No class, software setup instructions only) Module 1: prerequisites, Azure Quantum Development Kit setup.	**N/A**
2	**09/09**	Course overview. Module 2: Fundamental concepts, part 1: the qubit, superposition, single-qubit quantum gates, Dirac notation, quantum measurement, random number generation.	**09/23**
3	**09/16**	Module 3: Fundamental concepts, part 2: multi-qubit systems, entanglement, multi-qubit quantum gates, quantum computing notations comparison, measurement of multi-qubit systems.	**09/30**
4	**09/23**	Module 4: Quantum communication algorithms: no-cloning theorem, quantum key distribution, teleportation, superdense coding.	**10/07**
5	**09/30**	Module 5: Oracular algorithms: phase oracles, Deutsch algorithm, Deutsch-Josza algorithm, Bernstein-Vazirani algorithm.	**10/21**
6	**10/07**	Module 6: Reversible computing: reversible Boolean logic, reversible circuit synthesis, marking oracles, example (implementing quantum oracle for SAT problems).	**10/28**
7	**10/14**	No class (Indigenous People's Day)	**N/A**
8	**10/21**	Module 7: Grover's search algorithm.	**11/04**
9	**10/28**	Module 8: Building up to Shor's algorithm: quantum Fourier transform, quantum phase estimation, Shor's algorithm for integer factorization.	**11/18**
10	**11/04**	Module 9: Hybrid quantum algorithms. Variational quantum algorithms. Quantum approximate optimization algorithm (QAOA). Quantum machine learning.	**11/25**
11	**11/11**	No class (Veterans Day)	**N/A**
12	**11/18**	Module 10: Quantum error correction, fault-tolerant quantum computing.	**12/02**
13	**11/25**	Module 11: How to build a full-stack quantum computer and put it in the cloud, part 1: quantum software stack.	**N/A**
14	**12/02**	Module 12: How to build a full-stack quantum computer and put it in the cloud, part 2: quantum hardware stack.	**N/A**

15	**12/09**	No class (grading wrap up)	**N/A**

Assignment Grading

- 9 weekly programming assignments (modules 2-10) – 10 pt each.
- Extra programming assignment on unitary implementation (due 10/21) – 10 pt.
- Extra programming assignment on Grover's search (due 12/02) – 15 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, 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.

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, both similar to the ones offered in the weekly programming assignments and more open-ended ones.

Note that the maximum number of points you can get by completing all assignments is 115 pt. You do not have to complete all assignments to get an A grade, but you can get at most A- if you don't attempt extra programming assignments.

Grading Scale

Grading is done based on the raw number of points, not on percentages.

95+ pt A	87-89 pt B+	77-79 pt C+	
	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

Attendance/Late Work Policy

Attendance Policy

Students registered in MGEN courses (INFO, CSYE, and DAMG) are allowed **a maximum of 2 absences per course, with 3 or more absences resulting in an automatic 'F' for that course.** Students are expected to inform their instructors of any absences in advance of the class; if a student is sick long-term or experiences a medical issue that prevents class attendance, it is strongly encouraged that they speak with their Academic Advisor (coe-mgen-gradadvising@northeastern.edu) to learn more about the Medical Leave of Absence. Should a student anticipate being unable to attend 3 or more classes, they should discuss their situation with their Academic Advisor to explore other types of leave in accordance with the University's academic and global entry expectations. International students should review the Office of Global Services webpage to understand their visa compliance requirements.

Teaching Assistants (TAs) or Instructional Assistants (IAs) will be present at each class to collect student attendance.

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 Engineering. 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 Northeastern University 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.

MGEN Student Feedback
Students who would like to provide the MGEN unit with anonymous feedback on this particular course, Teaching Assistants, Instructional Assistants, professors, or to provide general feedback regarding their program, may do so using this survey: https://neu.co1.qualtrics.com/jfe/form/SV_cTIAbH7ZRaaw0Ki

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
Network Campus Library Services: Northeastern University Library Global Campus Portals

24/7 Canvas Technical Help
For immediate technical support for Canvas, call 617-373-4357 or email help@northeastern.edu

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*.