Northeastern University
College of Engineering

Multidisciplinary Graduate Engineering
Course Syllabus

Course Information

CSYE 6305-Introduction to Quantum Computing
Spring 2022
Online

Instructor Information

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Technical/Course Materials Requirements

Reference books:

- M. A. Nielsen and I. L. Chuang, Quantum Computation and Quantum Information, Cambridge University Press, 2000, 978-1-107-00217-3, *or*
- 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 version 0.13.20102604 or later.
  Required: Visual Studio/Visual Studio Code/command line install.
  Strongly recommended additionally: Jupyter Notebooks install.
- The Quantum Katas – a collection of tutorials and programming exercises.

Course Description/Prerequisite

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, Google, D-Wave and IBM 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.

Prerequisites

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, operarions on matrices, eigenvectors and eigenvalues) and will offer pointers to materials to refresh the knowledge.

Familiarity with software development process using any programming language is strongly recommended (prerequisite course "Information Systems 6205: Program Structure and Algorithms" or equivalent).

Student Learning/Course Outcomes (SLOs)

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

Attendance Policy

Students are expected to complete course readings, participate in class discussions or other learning activities during the unit, and complete programming assignments, if any are required, 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.

Beyond one week 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.

Students must communicate with the faculty prior to the deadline if they anticipate work will be submitted late.

Work submitted late without prior communication with faculty will not be graded.

Late submissions will not be accepted after the problems were discussed in class.

Grading/Evaluation Standards

Grade Scale

95-100%	**A**	**87-89.9%**	**B+**	**77-79.9%**	**C+**	69.9% or below F
		84-86.9%	**B**	**74-76.9%**	**C**	
90-94.9%	**A-**	**80-83.9%**	**B-**	**70-73.9%**	**C-**	

Grade Breakdown:

Weekly programming assignments (the first part of the course) - **50%**.
Programming assignments will involve solving simple quantum programming problems similar to the ones offered in the Quantum Katas using Q#. Each assignment will consist of one or several problems of different point values, and each problem will be graded pass/fail.

Final project (the second part of the course) - **50%**.
The final project will require choosing a quantum algorithm not covered in class and implementing and exploring it using Microsoft Quantum Development Kit. The projects will be graded on their implementation (50%), written summaries (30%) and class presentation (20%).

Course Schedule

Week	Topic
01/18/2021	No class (Martin Luther King Day). Please install Microsoft Quantum Development Kit
01/25/2021	Course overview. Quantum computing history and motivation. Fundamental concepts of quantum computing, part 1: the qubit, superposition, single-qubit quantum gates, Dirac notation
02/01/2021	Fundamental concepts of quantum computing, part 2: multi-qubit systems, entanglement, multi-qubit quantum gates, quantum computing notations comparison, no-cloning theorem, quantum measurement
02/08/2021	Simple algorithms: teleportation, superdense coding, phase oracles, Deutsch algorithm, Deutsch-Josza algorithm
02/15/2021	No class (President's Day), office hours only
02/22/2021	Reversible computing: reversible Boolean logic, reversible circuit synthesis, marking oracles, example (implementing quantum oracle for SAT problems)
03/01/2021	Grover's search algorithm, amplitude amplification
03/08/2021	Quantum Fourier transform
03/15/2021	Phase estimation, quantum counting
03/22/2021	Order finding algorithm, Shor's factoring algorithm
03/29/2021	Quantum error correction, fault-tolerant quantum computing
04/05/2021	Applications overview: random number generation, key distribution, quantum chemistry and simulation, quantum machine learning

04/12/2021	How to build a full-stack quantum computer
04/19/2021	Final Projects Presentations

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.

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 http://www.northeastern.edu/drc/getting-started-with-the-drc/.

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 http://subjectguides.lib.neu.edu/edresearch.

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, member 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 www.northeastern.edu/titleix for a complete list of reporting options and resources both on- and off-campus.