COMS 4281 - Introduction to Quantum Computing (Fall 2024)

Essentials

- Instructor: Henry Yuen
- TAs: Christine Li, Vincent Mutolo, Saachi Mutreja, Akshat Yaparla, Justin Beltran
- Course Website: http://henryyuen.net/classes/fall2024
- Location: 209 Havemeyer Hall
- Class time: MW 10:10am - 11:25am

Description

This class is an introduction to the theory of quantum computing and quantum information. Topics covered include:

- The fundamental postulates of quantum information theory
- The quantum circuit model
- Basic quantum protocols, such as quantum teleportation and superdense coding
- Basic quantum algorithms, such as Simons' algorithm, the Quantum Fourier Transform, Phase Estimation, Shor's Factoring algorithm, Grover search, amplitude amplification
- Quantum error correction and fault-tolerance
- Entanglement and nonlocality
- (Time permitting) Quantum cryptography, quantum complexity theory

The goal of the course is to provide a rigorous foundation for future research/studies in quantum computing and quantum information, and along the way provide students with an understanding of the state of the field, and where it's headed.

Prerequisites

- (**Important**) Basic linear algebra. You should know (and be comfortable with) the following concepts: Vector space (subspaces, orthogonal complements, dimension, linear independence, basis, span,...). Inner products. Row vs column vectors. Linear operators (invertibility, matrix representation, composition of linear operators, transpose, adjoint). Eigenvalues and eigenvectors. Trace.

- (**Important**) Basic probability theory. You should know (and be comfortable with) the following concepts: Bayes' rule, conditional distributions. Joint probability spaces. Independent random variables. Mean, variance, etc.
- (**Helpful, but not required**) Computer Science Theory exposure: Analysis and design of algorithms; Complexity theory; Discrete math.
- **(Helpful**) Experience with Python

Grading

5% Problem Set 0

10% Problem Set 1

35% Midterm

10% Problem Set 2

~~40% Final~~

35% Final (updated: Sept 10)

5% Weekly quizzes (added: Sept 10)

Problem Sets

There will be 3 problem sets. The first one is meant to introduce you to the class and get you set up with Gradescope and the IBM Quantum Lab. The other two problem sets are meant to help you get practice with the material learned in class, as well as prepare you for the Midterm and Final. Collaboration is allowed and encouraged (see below).

The problem sets will consist of theory problems as well as some coding problems. The theory problems *must* be typed via LaTeX (**no handwritten solutions allowed**). The coding problems *must* be implemented in the Jupyter notebooks provided, and exported via PDF.

We will use Gradescope to mark assignments and exams. All assignments must be turned in via Gradescope.

Late Policy
We will strictly enforce a penalty of minus 10% of the total assignment value per day that an assignment is late. We do not accept any assignment more than 1 week past the due date. For any exceptions to any of the above, you must have your undergraduate or graduate advisor contact the instructor.

For all problem sets, you are strongly advised to start early. Many questions will be challenging and will require you to think for a sustained amount of time.

Problem Set Collaboration Policy

(Policy borrowed from Rocco Servedio's COMS 4252 syllabus)

You are encouraged to discuss the course material and the homework problems in small groups of up to 3 people, but you must **list all discussion partners on your problem set**. Discussion of homework problems may include brainstorming and verbally discussing possible solution approaches, but **must not go as far as writing up solutions together; each person MUST WRITE UP HIS/HER SOLUTIONS INDEPENDENTLY. You may not collaborate with another student on writing up solutions or even look at another student's written solutions**. If your homework writeup resembles that of another student in a way which suggests that you have violated the above policy, you may be suspected of academic dishonesty.

You may consult certain outside materials, specifically lecture notes and videos of other classes, any textbooks, and research papers. You **may not consult any other materials, including solved homework problems for this or any other class. For all outside materials used, you must provide a detailed acknowledgement of the precise materials used. Whether or not you consult outside materials, you must always write up your solutions in your own words.** If your homework writeup resembles any outside source in a way which suggests that you have violated the above policy, you may be suspected of academic dishonesty.

Weekly Quizzes

To help get regular practice with the class material, and get prepared for the problem sets and exams, there will be an online quiz (almost) every week. These quizzes are done on Gradescope.

The quiz problems will be based on weekly problem sheets that we'll release (these are ungraded). You are encouraged to go to office hours each week to work on the practice problems. The quizzes and the weekly problem sheets for the following week will be posted Monday morning.

The midterm and final exam questions will also be based on the weekly problem sheets. So even though the quizzes form a small part of your grade, you should keep up with them!

You must take the quiz alone, without discussion with anyone else (although you are welcome to go over lecture material with other students). You don't have to finish the quiz in a single pass - you could submit part of it, and then go back and complete the rest (as long as it's before the following Sunday 11:59pm, and you do it on your own without any discussion with others). You are allowed to use your class notes/slides when taking the quiz, although the intention is that the quiz should be solvable without any materials (after you have gone over the previous lectures and digested them). No late quizzes will be accepted.

The quiz is meant to be completed quickly - within at most 15 minutes if you've already gone over and understood the class material to date.

Exams

The Midterm and Final will be held in class on October 21 and December 9, respectively. Unlike Problem Sets, the exams must be completed individually and are meant to assess your understanding of the class material.

If you are unable to attend either Exam for any reason on the designated date, you must contact the instructor ahead of time to make alternative arrangements for a makeup exam. If you are ill that day, then you must provide a valid medical note on the same day.

Regrade Policy.

You may submit regrade requests for assignments or exams through Gradescope. Regrade requests must be submitted within one week of the grade being released. Include with your regrade request a clear and detailed argument for your request. When we are regrading questions, we reserve the right to regrade the entire assignment or exam, which could result in the overall score being raised, lowered, or remaining unchanged.

Academic Honesty

More generally, **students are expected to adhere to the Academic Honesty policy of the Computer Science Department; this policy can be found in full here.** Please contact the instructor with any questions.

Recommended Reading

You are not required to get a textbook for the course, but the following is comprehensive and is a classic.

- *Quantum Computation and Quantum Information* by Michael Nielsen and Isaac Chuang (10th anniversary edition)

This book is often affectionately referred to as "Mike 'n Ike" in the field :-). You can obtain this through Amazon or through your favorite method of obtaining textbooks.

Other highly regarded textbooks are:

- *An Introduction to Quantum Computing* by Phillip Kaye, Raymond Laflamme, and Michele Mosca

- *Quantum Computer Science: An Introduction* by David Mermin

There is a textbook made by IBM, that is interwoven with their Qiskit language (which we will use in class): https://qiskit.org/textbook/preface.html

The following lecture notes are also very helpful:

- Introduction to Quantum Information Science, a course taught by Scott Aaronson
- John Preskill's course at CalTech [link]
- Ronald de Wolf's course at University of Amsterdam [link]
- Andrew Childs's notes on Quantum Algorithms [link]
- Ryan O'Donnell's course at CMU [link]

Important dates

- September 4 - First meeting of the course
- September 13 - End of Change of Program period
- October 8 - Course Drop deadline for CC
- October 21 - Midterm
- November 4 - No class
- November 14 - Course Drop deadline for SEAS
- November 27 - No class
- December 9 - Final