COMS 4281 - Introduction to Quantum Computing (Fall 2022)

Essentials

- Instructor: Henry Yuen
- TAs: John Bostanci, Yulong Li, Thomas Chen
- Course Website: http://henryyuen.net/classes/fall2022/
- Location: Uris 140
- 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

70%   Problem Sets 1 through 4

30%   Problem Set 5

The 5 problem sets will be assigned roughly every two weeks, and are meant to help you get practice with the material learned in class. Collaboration is allowed and encouraged (see below).

Your solutions must be typed and prepared in the Jupyter notebooks provided, and exported as PDF. We will use Gradescope to mark assignments. All assignments must be turned in via Gradescope.

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.

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.

Re-grade policy: If you dispute the grade received for an assignment, you must submit, in writing, a detailed and clearly stated argument for what you believe is incorrect and why. This must be submitted no later than one week after the assignment was returned. (For example, if the assignment were returned to the class on Tuesday, your regrade request would have to be submitted before the next Tuesday.) Requests for a re-grade after this time will not be accepted. A written response will be provided within one week indicating your final score. Requests of re-grade of a specific problem may result in a regrade of the entire assignment. This re-grade and written response is final. Keep in mind that a re-grade request may result in the overall score for an assignment being lowered.

Late assignment policy: ~~all assignments must be turned in on time. For each day that an assignment is late – unless there is a valid reason – 10% is automatically deducted, up to 3 days (after which assignments are not accepted). If there is a valid reason for requiring extra time on the assignment (such as a health issue), please let us know via e-mail.~~

Updated September 23: every student has a budget of 5 late days over the course of the semester. Once you exceed this budget, late assignments will not be accepted.

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 7 - First meeting of the course
- September 16 - End of Change of Program period
- November 7 - No class
- November 17 - Last day to drop class
- November 23 - No class
- December 12 - Last day of classes