Spring 2023

CS 698: Special Emerging Topics

Zhihao Yao

Syllabus CS698

Introduction to Quantum Computing

Basic Information

- **Place:** KUPF 108
- **Time:** W 6:00pm – 8:50pm
- **Instructor:** Yong Yao
  - **Email:** yong.yao@njit.edu, yaoyong99@gmail..com
  - **Phone:** 347-404-2772 (email preferred)
  - **Office:**
  - **Office hours:** Wed 5:30pm—6:00pm + appointment

Textbooks

1. No required text book. Most materials are available online.
2. Paul Kaye, Raymond Laflamme, and Michele Mosca, An Introduction to Quantum Computing, Oxford University Press (2007)
3. Preskill, J. Notes on Quantum Computation.
4. Classical and Quantum Computation by Kitaev, Shen, and Vyalyi
5. Quantum Computing: Lecture Notes Ronald de Wolf
6. An Introduction to Quantum Computing without the Pyhsics
7. Quantum Algorithm Implementations for Beginners

Course objectives

By the end of this course, you should be able to

- Have the basic institutive understanding of quantum physics concepts and computational complexity theory needed for quantum computing.
- Have understanding of basic landscape of computational complexity classes for both classic and quantum computing.
- Have solid knowledge of quantum circuit model and important quantum algorithms.
- Advance topics such as topological quantum computing.
- Do basic quantum computing on open source platforms.

These objectives will be measured by performance on attendance, homework, midterm exam, and final project.

Course description

Overview:

- To understand quantum computing and its power some necessary background in both quantum physics and computational complexity theory are necessary. If we only focus on quantum circuit model we may just need knowledge in linear algebra (matrix) and basic tensor product of matrix. Quantum computing on quantum circuit model are basic matrix products in which the size of the matrix could be huge. With basic knowledge quantum physics we can understand deeper of quantum computing and quantum computing models other than quantum circuit model. For example, adiabatic quantum computing and topological quantum computing. Also when limited to the impression that quantum computing is just matrix product it may not touch the deep myth of Nature – quantum physics which is the law of micro world. Thus some knowledge about Hilbert space and spectral theory may help grasp this point. But at the same time it is quit daunt task for a lot of people to get enough background in both math and quantum physics as mentioned above.
- We take the approach that focus on the intuitions of core concepts and theorems but not involved too much detail techniques. We expect this approach will provide enough background in both quantum physics and computational complexity theory up to intermediate level and expect students to understand quantum computing and its frontier in a broader view.
- We will focus on details on quantum circuit model and important quantum algorithms. We also cover some other quantum computing models such as adiabatic quantum computing, topological quantum computing, quantum random walk and measurement base quantum computing but will not get to technical details in these models.
- Students will do basic quantum computing on open source platform.
- Finally we discuss some advanced topics such as computational complexity theory and physic, quantum supremacy and skeptics of quantum computing.
- Most topics will be explained either entry level or intermediate level.

Prerequisites: There are no formal prerequisites for this course. This course is self-contained. Saying that, informally, you should be familiar linear algebra (matrix). Knowledge of quantum mechanics is NOT a prerequisite; minimum quantum concepts will be introduced. Similarly, knowledge of algorithms and complexity are not prerequisites either; these also will be introduced in an institutive way.

Course delivery structure

There will one session very Wednesday from 6:00pm to 8:50pm with 10mins break.

Course requirements

There will be regular homework assignments consisting of weekly or biweekly problem sets. There will be one midterm exam and one final project.

No make-up exams will be given except under emergency circumstances with as much prior notice as possible.

Grading scheme

	Fraction of grade	Comment
Attendance	15%	
Homework	40%	About 7-8 homework
Midterm exam	25%	Open book exam
Final project	20%	

Class policies

Reading and lectures: You (the student) are expected to read all assigned material, if any, before the lecture begins.

Homework: The homework exercises are chiefly for your own benefit. You may collaborate and consult outside sources freely when doing the homework, but you must tell me who you are collaborating with. The best way to master the material is to try the exercises on your own. You will get credit even if you do not solve the problem, as long as you make an honest effort. Homework is due in the next class, unless otherwise specified. Homework will be accepted up to 24 hours after the due time with a 20% penalty. Homework will not be accepted more than 24 hours late.

Exams: Tests are given in class and are open-book/open-notes. You may use any printed materials you wish during the test, but you may not use electronic devices except for use as timepieces or legitimate use by disabled students with prior notice. No make-up exams will be given except under extreme circumstances in which case you must give me notice well before the exam if at all possible.

Academic integrity

- "Academic Integrity is the cornerstone of higher education and is central to the ideals of this course and the university. Cheating is strictly prohibited and devalues the degree that you are working on. As a member of the NJIT community, it is your responsibility to protect your educational investment by knowing and following the academic code of integrity policy that is found at: http://www5.njit.edu/policies/sites/policies/files/academic-integrity-code.pdf.
- Please note that it is my professional obligation and responsibility to report any academic misconduct to the Dean of Students Office. Any student found in violation of the code by cheating, plagiarizing or using any online software inappropriately will result in disciplinary action. This may include a failing grade of F, and/or suspension or dismissal from the university. If you have any questions about the code of Academic Integrity, please contact the Dean of Students Office at dos@njit.edu"

Tentative Syllabus (subject to updates)

- Introduction 01/18/2023 1 lecture
    - Why quantum computing is important
    - Brief history of quantum computing
    - Current status of quantum computing
- Hilbert space basic 01/25/2023 2 lecture
- Quantum mechanics basics 02/01/2023 3 lecture
    - Important experiments
    - Quantum mechanics formulization
    - Dirac notations and matrix notations
- Classic computational complexity theory 02/08/2023 4 lecture
    - Turing machine and Church-Turing Thesis
    - Complexity classes and NP-complete problems
    - Interactive proof system and PCP
    - Hard problems and easy problems
    - Landscape of important complexity classes
- Quantum circuit model 02/15/2023 5 lecture
    - Physics background
    - Quantum state and qubit
    - Quantum gates
- Quantum circuit model 02/22/2023 6 lecture
    - Universal quantum gate sets
    - Quantum circuit model
    - Quantum Turing machines
    - Unify definitions of classical and quantum Truing machines
- Quantum algorithms spring break 03/01/2023 7 lecture
    - Deutsch-Jozsa Algorithm

- Bernstein-Vazirani Algorithm
- Grover’s Algorithm

- Midterm exam 03/08/2023
- Spring break 13-18/03/2023
- Quantum algorithms 03/22/2023 8 lecture
    - Quantum Fourier Transform
    - Phase Evaluation
    - Simon’s Algorithm and Shor’s algorithm
    - Other Quantum algorithms
- Other quantum computing models 03/29/2023 9 lecture
    - Adiabatic algorithms
    - Quantum annealing
    - Quantum walk
- Other quantum computing models 04/05/2023 10 lecture
    - One-way or measurement-based quantum computation (MBQC)
    - Topological quantum computing
- Applications and open topics 04/12/2023 11 lecture
    - Hamiltonian simulation
    - Quantum computing in finance
    - Computational complexity theory and physics
    - Quantum supremacy
    - Skeptics of quantum computing
- Quantum programming 04/19/2023 12 lecture
- Open discuss 04/26/202313 lecture
- Final project 05/11/2023