CS 166: Quantum Computing (WI25)

Instructor	Shion Fukuzawa
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Class Information	HH178, MWF 11:00-12:00
Office Hours	TWTh 2:00-3:00PM, Room Pending
Website	https://www.shionfukuzawa.com/courses/166wi25.html

About Me

Hi all! My name is Shion (pronounced she-own) and I use he/him pronouns. I am a fifth year PhD student doing research in quantum algorithms and information theory. I'm also very passionate about CS education, and I hope that I get to continue being involved in education throughout my career. Outside of class I love baking, taking care of my plants, and playing Valorant. I am excited to meet you all and learn together, and if there is anything I can be doing better throughout the quarter to help you please let me know! I'll be providing opportunities to share feedback throughout the course (more on that later).

About This Course

Quantum computing leverages the rules of quantum mechanics to solve some problems much more efficiently than traditional computers. The computational process is very different from classical computers that we use every day, and a different set of mathematical tools are needed to analyze them, with a heavy emphasis on linear algebra and statistics. My hope is that by the end of the class, we all walk away with a greater understanding and appreciation of math and theoretical computer science, as well as being better equipped to recognize the advantages and limitations of current and future quantum technology. Not only this, but I hope this course serves as a good case study for you to go through the process of learning about and evaluating new technologies using the education you are receiving, instead of blindly getting lost in the discourse over the internet.

Prerequisites

The official prerequisites listed in the catalogue are: A linear algebra course (I&C SCI 6N or MATH 3A) and an intro algorithms OR quantum mechanics class (COMPSCI 161 or PHYSICS 113A).

We will go over some basics of linear algebra and probability but mainly as a refresher. It'll be important to know basic operations and properties of vectors and matrices such as inner products, computing the norm, eigenvalues and eigenvectors etc.. I strongly suggest the essence of linear algebra playlist by 3blue1brown to review some of these topics. It is very likely that your comfort with linear algebra will be a strong predictor to how naturally the ideas in the course come to you.

Student Learning Outcomes

After successful completion of this course, you will be able to:

1. **Apply mathematical tools to understand complex computational ideas and explain the core ideas comfortably.** This deeper understanding will give you a greater appreciation for the tools, as well as serve as a voice of reason for the technology.
2. **Explain important quantum information theoretic primitives and sketch their proofs by applying mathematical tools.** There are known physical limits to the amount of information we can process. These sobering ideas can help us temper our expectations around technology.
3. **Understand the mechanisms behind famous quantum algorithms, sketch their proofs by applying mathematical tools, and analyze the complexity of these algorithms.** At the same time, there are many challenging problems that this technology allows us to solve that we can be excited about.

Reading

No book purchase is required as I will be providing course notes throughout the quarter which should be complete for our purposes. I will be handing out notes for you to fill out throughout the class, of which I will provide digital copies for on the course website in case you lose them. As such, please bring some writing utensil or digital tablet to class.

A lot of the content from my lecture notes is based on a set of course notes by Scott Aaronson which can be found here as well as previous offerings of the course by Sandy Irani. Scott's notes also include lots of interesting side commentary and background. I highly recommend reading them along with the course! If you are interested in purchasing any of the below, I'd encourage you to first find them in the library or ask me about renting some of the books.

The following textbook will cover a lot of the material from this course and it is overall very well written:

- Quantum Computing: A Gentle Introduction, by Rieffel and Polak, ISBN-13:978-0262526678

If you are struggling with some of the technical content, especially the linear algebra, I recommend the following text which has a lot of details and examples:

- Quantum Computing for Computer Scientists, by Noson S. Yonofsky and Mirco A. Mannucci, ISBN-13: 978-0521879965.

Here are some other texts on Quantum Computation and Information for your reference:

- Quantum Computation and Quantum Information, Michael A. Nielsen and Isaac L. Chuang, ISBN-13 : 978-1107619197
- Quantum Computer Science: An Introduction, N. David Mermin, ISBN-13: 978-0521876582
- Quantum Computing: An Applied Approach, Jack D. Hidary, ISBN-13: 978-3030239213

Lecture, Discussion, and Class Participation

Students in this class are encouraged to speak up and participate during class meetings and on Ed Discussion. Because the students in the class will have a diversity of backgrounds and experiences, every member of this class must show respect for every other member of this class. Diverse teams have been shown to exhibit more creativity, social cohesion, and success which I hope we can agree are things that all of us want.

Throughout lecture, we will pause 2-3 times to solve some questions in the notes. You should attempt this question on a notebook or tablet, and I will open up a PollEv quiz during this time where I ask that you submit your answer to. These questions should only take a few minutes to solve, and I encourage you to attempt them individually. Once the quiz is closed, we will discuss the solution as a whole class.

Grading

In this course, your grades will be fully dependent on how you perform for your exams. There will be three exams throughout the quarter covering each of the three modules (mathematical foundations, quantum information, quantum computing). The final exam will be split into three sections which will go over the same three major modules. Your final grade for each module will be the larger grade you get between the midterms and the final exam. See the below table for an example.

	Midterm 1	Midterm 2	Midterm 3	Final
Math Foundations	C-			A-
Quantum Information		B+		B-
Quantum Computing			B-	B

After this, I will average your letter grade to get a final grade for the course. The numerical values of the letter grade will use the familiar GPA point scale system.

A	4.0
A-	4.0 – 1/3
B+	3.0 + 1/3
B	3.0
B-	3.0 – 1/3
C+	2.0 + 1/3
C	2.0
C-	2.0 – 1/3
D	1.0
F	0.0

The above student would get a (4.0 – 1/3 + 3.0 + 1/3 + 3.0) / 3 = (3 + 1/3) or a B+ for their final grade. If a student gets a grade in between two letter grades, it will be rounded up. For example, having a 3.2 average will be a B+.

Every few weeks I will assign a homework assignment. The purpose of the homework is to give you a medium where you are encouraged to make mistakes and can receive feedback without the risk of reducing your grade. Our goal is to provide helpful feedback when you make mistakes so that we can avoid them when the stakes are a bit higher. As such, tackling the exams without having done any of the homework will be extremely difficult, even though you could technically do so.

The purpose of this model is to decrease the stress levels by focusing the stakes in one section of the course, and providing opportunities to redemonstrate your understanding of the subject, as well as encourage learning by providing safe spaces to make mistakes. If I observe that this is not serving this purpose, I may require homework submission mid quarter.

Modules

The following is the detailed breakdowns of the three modules. Note that I may update these as the quarter progresses, but I will make sure to make an announcement if I do so. For an up to date list refer to the course website linked at the top of the document.

Foundations:

- Probability and Complex Numbers
- Linear algebra
- Quantum circuits
- Complexity

Quantum Information:

- No cloning theorem/Quantum money
- Quantum teleportation
- CHSH game
- Hidden variable theory
- Error Correction

Quantum Computing:

- Black box query algorithms: Deutsch-Josza, Bernstein-Vazirani, Simon's
- Quantum Fourier Transform
- Shor's algorithm
- Grover's algorithm
- Phase estimation

Communication

The course staff are all here to help you and provide what you need to succeed in the course. However, we do ask that in return you follow the communication guidelines below so that we can best support you.

Ed Discussion

We will use an online question and answer platform called Ed Discussion. You will all have an account linked to your UCInetID. **Please do not use Canvas for communication.**

There is a link to the Ed Discussion page for this class in the column on the left of the Canvas page [Add link]. If you have a question about course content, you can go to see if your question has already been asked by another students. If not, you can post the question yourself. The course staff make sure you have an answer within 24 hours. There is also a way for students to collectively edit a response to a question and for instructors to indicate whether the answer is a good/correct answer.

Ed Discussion is also a good place to post general administrative questions about the class. If you send me an email with a technical or administrative question about the class, I am likely to refer you to Ed Discussion. These type of questions get repeated a lot, so I would prefer to broadcast the response so other students can also see.

Before posting a question on Ed Discussion, you should look through the course materials or previous Ed Discussion posts to see if you can find the answer to your question. If your question is about the technical content of the course, check the text. If you have an administrative question, check the material in this Canvas course space. Try and make your questions on Ed Discussion as specific as possible. I am happy to explore more in-depth conversations through office hours or scheduled meetings.

Ed Discussion provides a way for you to post anonymously. However, your posts will only be anonymous to other students. The instructors will be able to see the name and UCINetID of any individual who posts to Ed Discussion.

Questions and Announcements

The best way to get your questions answered is by coming to lectures, office hours or discussion and asking them there. In particular, office hours and discussion are the best place to ask questions that require a longer answer or some dialog to get resolved.

The table below shows where to go to for different kinds of questions. Please try to follow the directions there. I really do want to be available for significant problems or issues that may arise. I also enjoy meeting students in my office hours. However, the amount of email generated from smaller, routine questions can be overwhelming, so I would like you to try and find answers through other sources first.

Question type	*Example*	*Where to go*
Questions about course content	*What does the Hadamard gate do?*	*Try and find the answer to your question through the course materials. If your question is not answered, then post on Ed Discussion.*
General administrative questions	*What topics does test 1 cover?*	*Check the Canvas course space first. If your question is not answered, then post on Ed Discussion.*
Questions on how your HW or test was graded.	*Why didn't I get full credit on the first question of HW 3?*	*Submit a regrade request through Gradescope. Regrade windows remain open for 1 week after the grades are released.*
A question that requires including personal information about you.	*Can I get approval to miss Test 2? Here is the reason I need to be absent...*	*Email Shion Note that these should happen very infrequently.*
Course-related announcements.	*An update or correction to a HW problem.*	*Posted as an announcement on Ed Discussion. Time-critical announcements will trigger an email as well.*
Non-course-related announcements.	*Info about an upcoming UCI hackathon.*	*Posted as an announcement on Ed Discussion, tagged as non-course-related.*

Academic Dishonesty

The Bren School of ICS and the University have already established an academic honesty policy. Which you can read here.

Violators of academic honesty policies are subject to the penalties described in the Bren School of ICS policy. They are also subject to an immediate course grade of F, and you will not be allowed to drop the course to avoid the grade. Also be aware that a single documented case of academic dishonesty may preclude you from switching into computing majors, registering for computing minors, joining the ICS Honors Program, and graduating from a computing major with honors.

Guidelines to avoid plagiarism:

- **Do not look at another person's homework.** Instead you should prefer to discuss the problem in plain English. This helps you to communicate clearly, practice technical jargon as it applies to your problem, and to identify how your solution exhibits behavior different from what you expect.
- **Do not write down the solution in your notes.** It is perfectly fine (and encouraged) to collaborate on work. Working in a group is a rewarding experience, and definitely a necessary skill in any professional career. The collaboration can include drawing diagrams and perhaps

solving the problem on a whiteboard. However, you should avoid writing the solution in your notes and instead practice reconstructing it using your own words afterwards. It is very useful to rethink the problem and go through the details and logic when you solve it again on your own, and it will help avoid plagiarism.

We expect that:

- **You can monitor each other and enforce these rules among yourselves (even over Zoom).** Making sure that others follow these guidelines will help to ensure that they don't pass off your work as their own.
- **Your work honestly represents your efforts.** The entire purpose of obtaining an education is so that you can accumulate a body of skills and experience that will help you later on. If you do not perform the work yourself, then you have cheated yourself out of the education. Employers in our field can (and do) screen applicants for skills and knowledge. You will perform poorly (and discredit UCI) if you do not practice now by doing your own work.

Disability Services

If you need any accommodations, please contact the Disability Services Center (DSC) and make the appropriate arrangements through them. If you are starting the class aware of necessary accommodations, I highly suggest you have prepared them by the middle of week 2, which will be a bit over one week before the first in class test.

Tentative Schedule

Please refer to the course website for a more up to date schedule.

Week	Topic	Midterms
1	Prerequisite mathematics (linear algebra and probability)	
2	Quantum computing with a single qubit	
3	Multiqubit states, introduction to quantum information	1
4	More quantum information, introduction to quantum circuits	
5	Query complexity, Deutsch-Josza, Bernstein-Vazirani, Simon's	
6	QFT, Shor's algorithm	2
7	Grover's algorithm, phase estimation	
8	Approximate counting	
9	NISQ devices and error correction	3
10	Miscellaneous topics (complexity theory, qml, fault tolerance)	

Important dates:

- Midterm 1: January 24
- Midterm 2: February 14
- Midterm 3: March 7
- Selfcare day: February 7 (No class! Do something to help yourself)
- Final: Friday (nooooo) March 21, 8-10AM