Quantum Computing: Foundations to Frontier
Course Project Guidelines

The course project is the capstone of the class. In groups of two or three, you and your groupmates will choose a topic in quantum computing, read a few relevant papers in that topic, and write a survey on the subject. Original research is encouraged, but not necessary – the first priority should be to learn about a quantum computing topic in more detail. This is an opportunity for you to combine your own expertise (whether that be in machine learning or pure mathematics or physics, etc) with what you've learned in the course.

Importantly, you will need to pick a project that is doable in the time frame given (from mid-October to early December). You and your group will have to submit a project proposal, and I will give guidance on whether the scope is appropriate for the course. Here are some suggestions on how you can pick topics for your project:

1. Take something you're already doing research in, and explore if there is a quantum version of it.
2. Take a topic covered in the class, and investigate it more deeply.
3. Take a topic in quantum computing you've always wanted to learn about (but wasn't talked about in class).
4. Look at the most recent proceedings of quantum computing conferences and pick a topic that interests you. Some conferences to check out:
   (a) Quantum Information Processing (QIP)
   (b) Theory of Quantum Computation, Communication, and Cryptography (TQC)
   (c) QCrypt
   (d) Quantum Journal (url: `https://quantum-journal.org/`)
5. Check the "quant-ph" section of arxiv for exciting new papers on quantum computing (url: `https://arxiv.org/list/quant-ph/new`).
6. Check out the overlay site SciRate, which pulls papers from arxiv every day, and allows people to upvote papers (url: `https://www.scirate.com`).

If you have any general questions about the project, please ask them on Piazza (this will be helpful for others!).

Deliverables Here is what is expected of you (the last two are optional).

1. (**Project proposal**) Your group will send one email to `hyuen@cs.toronto.edu` by **Friday, October 18** with "Quantum Computing Project Proposal" in the subject line. Please write who the group members are, and write one paragraph describing your proposed project, along with some relevant papers/resources. I will give feedback and suggest additional papers. Feel free to make an appointment to discuss your project in person.
2. (**Written report**) Your group must send a written project report by **Friday, December 6** midnight. The report should be around 10 pages long. It can be longer, but I will read anything past the first ten pages at my own discretion. Font sizes and margins should be reasonable.

3. (**Online showcase**) I plan to showcase the students project on the course homepage for other students and researchers to see what cool things you've done. Participation in the showcase is optional, and has no effect on your grade. Benefits: your project gets some publicity, and also the quantum computing community benefits from what you've learned!

4. (**Publication**) If your group has been able to carry out some original research (which would be fantastic!), and you're interested in publishing it more formally, I would be able to assist you with the process (which venues to publish in, ways to write up the result, etc).

The report Your report should be around 10 pages long. It should be written as an accessible, clear and informative survey on a frontier research topic for an audience whose background is that they have just taken CSC2451/MAT1751. Your survey should answer the following questions:

1. In concrete terms, what is the problem/topic you are writing about? This should take just one or two paragraphs.
2. Why is the topic interesting?
3. Why do people care about this topic?
4. What have people discovered about this topic? How do different results fit together?
5. What are open questions that people are actively investigating today?

Do *not* just copy and paste theorem statements and proofs from the papers verbatim. They should *summarize* the subject. Here are some examples of good project writeups from last year:

- https://arxiv.org/pdf/1901.03186.pdf
- http://henryyuen.net/fall2018/projects/qchemistry.pdf
- http://henryyuen.net/fall2018/projects/simons.pdf
- http://henryyuen.net/fall2018/projects/clique.pdf

Ideally, your topic should have at least $3 - 5$ papers that you can read and synthesize into one project report.

Course project topics Here are some course project topic areas. This is by no means an exhaustive list; these are meant as sources of inspiration for your group. There are many more possible areas I could list – just ask me to see if a topic would be appropriate for the course project. If you're curious about specific references for any of these topics, write a message on Piazza and I will respond with pointers (this will help others as well).

1. Near-term quantum computing (simulating quantum circuits on classical computers, quantum supremacy results, variational eigensolvers, classical-quantum hybrid algorithms, quantum circuit compilation)
2. Quantum cryptography (Quantum money, Device-independent quantum cryptography, randomness expansion, Post-quantum cryptography (i.e. which classical encryption schemes should remain secure against quantum computers), homomorphic encryption).
3. Connections with quantum gravity/high-energy physics (Error-correcting codes and the AdS/CFT correspondence, possible resolutions to the blackhole firewall paradox, quantum chaos and scrambling)
4. Paradoxes in Quantum Mechanics (Wigner's friends, the Frauchiger-Renner paradox)
5. Testing and verification of quantum computers (Multiprover interactive proofs, single-prover protocols)

6. Quantum machine learning (training Boltzmann machines, exponential speedups for solving linear systems/PCA, quantum neural networks, recommendation systems, quantum speedups for optimization tasks, architectures for quantum RAM)
7. Quantum simulation and quantum chemistry (improved Hamiltonian simulation algorithms, Fermion-to-qubit mappings, fast quantum algorithms for simulating specific molecules)
8. Quantum algorithms (mild-speedups for NP-hard problems, constructing ground states of local Hamiltonians, query algorithms)
9. Quantum complexity theory (QMA/MIP*/BQP vs classical complexity classes, query complexity, communication complexity)
10. Quantum Hamiltonian complexity (algorithms, Quantum PCP, area laws, tensor networks, stoquastic Hamiltonians)
11. Other models of quantum computing (annealing, adiabatic quantum computation)
12. Error-correction and fault tolerance (Threshold theorems, efficient fault tolerant schemes, error correction on near-term quantum devices)

Important dates.

- **October 18**: Project proposal due
- **December 6**: Project report due

Academic Integrity Statement The report should be entirely your own work, in your own words. Please adhere to the standards of scholarship and academic integrity by properly citing your sources, and giving credit where it is due.

Be careful of adapting and using material you find in papers and on Wikipedia, etc. Violations of academic integrity will be dealt with very seriously.