The Physics behind Quantum Computers

I. WHAT THIS COURSE IS ABOUT

- We’re going to study (small) quantum computers.
- You will learn what quantum algorithms are, how they work, what they accomplish.
- You will learn how to program small quantum computers (in particular, the 5-qubit IBM quantum computers) and implement one of the most promising quantum algorithms. Please sign up for the IBM Quantum Experience!
- You will see that the IBM quantum computer is, in fact, imperfect; it’s noisy.
- You will learn why building a quantum computer is very hard.
- You will learn that, nonetheless, some physical systems are very well suited for implementing a quantum computation.
- We will focus on three such promising physical systems—neutral atoms, trapped ions and superconducting Josephson junctions—and study how they can be used for quantum computing.
- What I assume you know from PHYS 414 and 415 (or 417): everything, but especially the Hilbert space formalism, spin, the hydrogen atom (including hyperfine structure), perturbation theory, selection rules. At some point, you should also know about stimulated and spontaneous emission (Ch. 9 from Griffiths).
- Important related topics that we can only very briefly touch upon (in week 10): quantum error correction, topological quantum computing, quantum cryptography.

II. SCHEDULE (TENTATIVE)

wk 1 Classical & Quantum Computing
wk 2 Quantum gates, Grover’s algorithm
wk 3 Entanglement & Mixed states
wk 4 Variational Quantum Eigensolver

wk 5 Neutral atoms & ions

wk 6 Midterm

wk 7 Circuit Quantum Electrodynamics

wk 8 Superconducting qubits

wk 9 Memorial Day, May 25.

wk 10 Other quantum information topics

wk 11 Final exam, Wednesday June 10, 10:15am

III. NOTES AND ONLINE RESOURCES

• I will provide detailed lecture notes for the course. Notes will be provided before class (minus clicker-like questions and answers, that I’ll add after class).

• The reason for not using an existing textbook is that in the last few years there have been great developments in quantum computing that are not in any textbooks (yet). A textbook with a similar list of topics is by Michel Le Bellac, but it dates from 2006.

• I will also post several (historically) relevant papers on canvas.

• There are several sets of wonderful lecture notes at different levels and aimed at different audiences online.

For example, for a computer science perspective, you cannot do better than start with the entertaining notes by Scott Aaronson. In fact, if you just follow this link:

https://www.scottaaronson.com/blog/?p=3943

you’ll find links to other lecture notes as well, mostly from computer science or mathematics perspectives.
IV. HOMEWORK & OFFICE HOURS

- There will be homework sets every week, except in the week of the midterm. They are due Fridays by 5pm. Please email your homework to both me svanenk@uoregon.edu and the TA, Kent Mastroianni kmastro4@uoregon.edu.

- Office hours: we will have (remote!) office hours (using zoom or Conferences). Tentatively, we have picked Thu 2pm-3pm (Kent); Thu and Fri, 11am-noon (Steven).

V. GRADING & EXAMS

- Homework, 60 % (I'll drop the lowest score)

- Midterm, 20%

- Final, 20%

- Given the circumstances we’ll have a take-home midterm and final in any case. We could think of a different sort of assignment (for those who prefer this) to replace the midterm/final, namely, a small project to run on the IBM Quantum Experience. We’ll discuss this idea in class.

- Rough grading rubric:
  90%: A
  75%: B
  50%: C

- Update: You can change to P/NP (pass/no pass) until Jul 16, 2020 (30 days after the grades have been posted).