Chem/CS/Phys191: Qubits, Quantum Mechanics, and Computers

Lecture Tue & Thu 9:30 - 11:00am (306 Soda Hall)
Section 101 W 11-12pm 405 Soda
Section 102 F 1-2pm (325 LeConte)

Instructor

Prof. Umesh Vazirani
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Teaching Assistants

Dylan Gorman
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Office hours:

Announcements

- Guoming Wang's office hours have been posted (M 1-2 pm in 651 Soda). Prof. Vazirani's office hours have been moved to M 2-3 in 671 Soda.
- 01/18/12 The Wed discussion section (11-12pm) has been scheduled in 405 Soda Hall. Still working on getting a room for Friday discussion sections.
- 01/17/12 Homework 1 has been posted. It is due at 5 pm next Monday.

Course Outline

- Here is a (tentative) lecture-by-lecture outline + dates of midterms and project presentations [outline].

Homework

Homework is due Monday at 5 pm in the drop box labeled cs191, in 283 Soda Hall.

- Homework 1 [pdf] due Monday 1/23. Solution [pdf]

- Homework 2 [pdf] due Monday 1/30. Solution [pdf]
- Homework 3 [pdf] due Monday 2/06. Solution [pdf]
- Homework 4 [pdf] due Monday 2/13. Solution [pdf]
- Midterm 1 solution [pdf]
- Homework 5 [pdf] due Tuesday 2/21. Solution [pdf]
- Homework 6 [pdf] due Monday 2/27. Solution [pdf]
- Homework 7 [pdf] due Monday 3/5. Solution [pdf]
- Homework 8 [pdf] due Monday 3/12. Solution [pdf]
- Homework 9 [pdf] due Monday 3/19. Solution [pdf]
- Midterm 2 solution [pdf]
- Homework 10 [pdf] due Monday 4/16. Solution [pdf]

Lecture notes

Topic	Notes
Chapters 1 and 2: "Qubits and Quantum Measurement" and "Entanglement".	[pdf]
Chapters 3 and 4: "Observables" and "Continuous Quantum States".	[pdf]
Notes on "Reversible Computation"	[pdf]
Notes on "Fourier Sampling"	[pdf]
Notes on "Simon's Algorithm"	[pdf]
Notes on "Quantum Fourier Transform & Factoring"	[pdf]
Notes on "Quantum Search"	[pdf]
Notes on "Spin"	[pdf]
Notes on "Spin Precession"	[pdf]

Project List and Guidelines

The project is worth 30% of the grade. You should work in teams of 2-3. At the end of the semester each team will submit a project report (ideally 5-10 pages), as well as give a 20 minute oral presentation.

Here are a few suggestions of broad topics for projects, together with a pointer to a good starting point for your exploration. Please feel free to google or search on the quant-ph archive for more information on these or other topics. We will add to the list, and you should feel free to suggest any topic that you are interested in. Please email me (vazirani@cs) by April 11, the composition of your team, the topic, and a one to two sentence description.

quant-ph refers to the Los Alamos archives: link

1. Adiabatic Quantum Computation (AQC)
AQC, though formally equivalent to circuit model QC, is quite different in its formulation. What are the advantages, and disadvantages of AQC compared to the circuit model? What are some promissing physical systems in which to implement AQC? The original paper by Farhi, Goldstone, Gutmann and Sipser provides a good starting point, and a web search will reveal a lot of follow up work.
http://arxiv.org/abs/quant-ph/0001106

2. Computation by teleportation
http://arxiv.org/pdf/quant-ph/9908010v1.pdf

3. Designing quantum algorithms by phase estimation:
http://www.eecs.berkeley.edu/~vazirani/s07quantum/notes/phase.pdf

4. Algorithmic cooling
http://users.cms.caltech.edu/~schulman/Papers/heat-engine.pdf
http://www.nature.com/nature/journal/v438/n7067/abs/nature04272.html

5. Quantum error correction
http://www.eecs.berkeley.edu/~vazirani/s07quantum/notes/qecc.pdf

6. Quantum random walks
http://arxiv.org/pdf/quant-ph/0209131v2.pdf
http://arxiv.org/pdf/quant-ph/0702144.pdf

7. Quantum money
http://arxiv.org/pdf/1004.5127.pdf
http://arxiv.org/pdf/1203.4740.pdf

8. Interpretations of quantum mechanics and the measurement problem
A good starting point is the following paper:
M. Genovese. Interpretations of quantum mechanics and the measurement problem. Adv. Sci. Lett. 3, 249 - 258 (2010).

9. Quantum random number generators
http://arxiv.org/pdf/0911.3427v3.pdf
http://arxiv.org/pdf/1111.6054.pdf

10. Simulating quantum systems
One of the lessons of quantum computation is that quantum systems are exponentially powerful, so classical computers cannot efficiently simulate general quantum systems. Nevertheless, there are beautiful results sho wing how to simulate certain "natural" quantum systems efficiently on a classical computer. Here is a survey paper that provides a good starting point:
http://arxiv.org/abs/quant-ph/0603163

11. 7. Quantum algorithm for solving linear equations
Kitaev's phase estimation algorithm is a beautiful building block in quantum algorithms. A recent paper uses it to speed up solutions of systems of linear equations:
http://arxiv.org/abs/0811.3171 12. Physical Implementations of QC
In class we discussed a number of physical implementations. What are the advantages of each? What are the dominant decoherence processes? Pick one and do a detailed analysis - or maybe do a general survey. You can start with David DiVincenzo's famous paper and references therein.
http://arxiv.org/abs/quant-ph/0002077

13. Decoherence Mitigation
There are many ways to protect a quantum computer from decoherence: dynamical decoupling, decoherence free subspaces, quantum feedback control, quantum Zeno effect, and quantum error correction. Talk about one in detail or do an overview. You can start by looking at the first couple of chapters of Dave Bacon's thesis, http://arxiv.org/abs/quant-ph/0305025

Useful Links:

- Los Alamos archive of papers and preprints on Quantum Mechanics and Quantum Computation: link
- John Preskill's Quantum Computation course at Caltech: link
- Umesh Vazirani's Quantum Computation course at UC Berkeley: link
- Daniel Lidar's page of teaching links for Quantum Mechanics and Quantum Computation: link

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Recommended reading

For all topics, the first recommended reading is the lecture notes. For a second point of view, or if the notes are confusing, try the other sources listed below.

On quantum computation

- Benenti, Casati and Strini, Principles of Quantum Computation, v. 1: Basic Concepts
  Introductory. See v. 2 for more advanced topics.

- Kaye, LaFlamme and Mosca, An Introduction to Quantum Computing
  Introductory.

- McMahon, Quantum Computing Explained
  New undergraduate-oriented text.

- Stolze and Suter,Quantum Computing: a short course from theory to experiment
  Physics-oriented introduction with discussion of experimental implementation.

- Mermin, Quantum Computer Science
  Introductory.

- Nielsen and Chuang, Quantum Computation and Quantum Information
  An encyclopedic reference.

- Pittenger, An introduction to Quantum Computing Algorithms
  Introduction to algorithms.

- Lo, Popescu and Spiller, Introduction to Quantum Computation and Information
  Introductory review chapters to basic concepts and tools.

- Kitaev, Shen and Vyalyi, Classical and Quantum Computation
  Advanced.

Mathematical background

- Strang, Gilbert. Linear Algebra and Its Applications
  Good review of matrix theory and applications.

- Jordan, Thomas F. Linear operators for Quantum Mechanics
  Thorough presentation of operators and mathematical structure.

On quantum mechanics in general

- Feynman, Richard P. The Feynman Lectures on Physics, volume 3
  A famous introduction to undergraduate physics. Good section on 2-state systems.

- Griffiths, David J. Quantum Mechanics
  Very clear explanations, doesn't cover everything.

- Liboff, Richard L. Introductory Quantum Mechanics
  Good coverage, explanations medium. See Ch. 16 in the new (4th) edition for intro. to Quantum Computing.

- Baym, Gordon. Lectures on Quantum Mechanics
  Graduate level textbook. Very clear exposition of the physics.

- Feynman, Richard. QED
  Nice leisure reading.