COMP 590-078 – Intro to Quantum Computer Science

Spring 2010, UNC-Chapel Hill

Class Location:	Fred Brooks Bldg 008	**Office:**	FB 344 / (919) 962-1726
Meeting Times:	MW 11-12:15	**Office Hrs:**	T 11-12 / W 3:30-4:30 / by appt
Website:	http://www.cs.unc.edu/~ndkumar/qcs/		
Instructors:	Daniel Kumar (ndkumar at cs.unc.edu), Sanjoy Baruah (baruah at cs.unc.edu)		

Synopsis: Quantum computing is an emerging, interdisciplinary research field—spanning mathematics, theoretical physics, and computer science—that may revolutionize our understanding of computation, information/communication, and perhaps even Nature itself.

This special-topics seminar will present an intuitive approach to quantum computation and algorithms. Topics covered will include basic quantum mechanics, quantum cryptographic protocols, quantum teleportation, polynomial-time factoring, quantum error correction, and a new graphical calculus for reasoning about quantum systems. By the end of the course, students will be conversant with the mathematical basis of quantum mechanics, and they will understand the current problems and prospects of the implementation of quantum computers.

The course is open to undergraduate and graduate students, who will be graded on separate curves.

Prerequisites: Required background courses are MATH 381 (discrete math), MATH 383/547 (differential equations *or* linear algebra), and COMP 411 (computer organization). If you have not taken these courses or if you are uncertain about your preparation for this course, please speak to me about it.

Degree Requirements: This course will satisfy the Theory Group Distribution Requirement for the BS in Computer Science and the Theory and Formal Thinking Breadth Requirement for the MS/PhD degrees.

Course Objectives: Enable the student to (1) translate fluently between the major mathematical representations (Abramsky-Coecke graphical calculus, Dirac notation, matrix algebra) of quantum operations, (2) 'implement' basic quantum algorithms, (3) explain quantum decoherence in systems for computation, and (4) discuss the physical basis of uniquely quantum phenomena.

This course is not intended to convey a concrete or application-based skill to students, nor is it primarily oriented towards any particular research results. Quantum computing is a nascent, interdisciplinary field, and this course is designed to enable students with non-physics backgrounds to 'think quantumly'—to recognize which classical assumptions fall apart at the quantum level and to begin to reintegrate the strange results of quantum theory into the broader framework of classical computer science.

Honor Code: Obviously, don't lie, cheat, or steal. All quizzes and exams must be entirely your own work. Cite your sources in problem sets. If you are unclear about what's allowed and what's not, see me or consult http://honor.unc.edu/ and http://www.cs.unc.edu/Admin/Courses/HonorCode.html.

Grading: The tentative assessment breakdown is as follows.

Problem sets (best 6 of 7):	24%
Short quizzes (3):	24%
Midterm exam:	26%
Final exam:	26%
Class participation (swing):	±7%

Students are encouraged to work together on problem sets, and should indicate their collaborators on the assignment. Problem sets are designed to reinforce concepts and encourage better understanding of the material. If you are having trouble, please ask for help instead of submitting work you don't understand! Two problem sets will be accepted up to 24 hrs late; others are then penalized 20% per day.

Class Participation: A course in which students actively participate and exchange ideas is always much more enjoyable and effective. I plan to reward students who regularly participate in class by up to around half a letter grade. Please be considerate of others in class; in particular, if you need to arrive late or leave early on occasion, please do so quietly. Note that, given the relative obscurity of the subject matter, it will likely be impossible to earn a good grade without coming to class.

Textbook: There are two textbooks—one required, one optional—for this course:

- Required: Phillip Kaye, Raymond Laflamme, and Michele Mosca (2007). *An Introduction to Quantum Computing*. Oxford University Press.
- Optional: Michael A. Nielsen and Isaac L. Chuang (2000). *Quantum Computation and Quantum Information*. Cambridge University Press.

However, the following texts may be helpful for supplementary use and will be placed on reserve in the Brauer Math/Physics Library.

- Yanofsky, Noson S. and Mirco A. Mannucci (2008). *Quantum Computing for Computer Scientists*. Cambridge University Press.
- McMahon, David (2008). *Quantum Computing Explained*. John Wiley & Sons, Inc.
- Mermin, N. David (2007). *Quantum Computer Science: An Introduction*. Cambridge University Press.

Useful References:

- Aaronson, Scott (2006). Quantum Computing Since Democritus (UWaterloo).
  - http://www.scottaaronson.com/democritus
- Coecke, Bob (2009). Quantum Picturalism. arXiv:0908.1787.
- Perry, Riley T. (2006). The Temple of Quantum Computing, v1.1.
  - http://www.toqc.com/TOQCv1_1.pdf
- Preskill, John (2009). Quantum Computation (Caltech).
  - http://www.theory.caltech.edu/~preskill/ph219/ph219_2008-09

The contents of this syllabus are subject to change as the semester progresses.

Course Outline (number of lectures):

1. Introduction and Overview (1)
    - qubits and pieces
    - Bloch sphere
    - quantum mechanical probabilities
    - quantum behaviors we will investigate
2. Quantum Mechanics (2-4)
    - history of quanta
    - base states and superposition
    - structural randomness
    - measurement: how long is a qubit?
    - Heisenberg's Uncertainty Principle
    - waveform collapse in the macroscopic limit
3. Matrix Algebra (2-4)
    - basis vectors and orthogonality
    - inner product and Hilbert spaces
    - matrices and tensors
    - unitary operators and projectors
    - Dirac notation
4. Fundamentals of Quantumness (2-3)
    - Abramsky-Coecke semantics
    - no-cloning theorem
    - quantum entanglement (‘spooky action at a distance’)
    - Bell states and Bell inequalities
5. Quantum Circuits (2-3)
    - Pauli, Hadamard, phase, CNOT, Toffoli gates
    - quantum teleportation
    - universality of two-qubit gates
    - reversible computing
6. Quantum Algorithms (2-3)
    - Deutsch-Josza algorithm
    - Simon’s problem
    - quantum Fourier transform
    - Shor’s period-finding algorithm
    - quantum key distribution (BB84, E91)
7. Quantum Error Correction (2-3)
8. Quantum Computers (2)
    - physical qubits
    - noise and decoherence

    Probable further topics:
    - quantum complexity classes
    - fault-tolerant quantum computing
    - quantum information theory