CS395T Topics in Quantum and Classical Complexity Theory

UT Austin, Fall 2016

http://www.scottaaronson.com/qct2016/

Place and Time	Mondays 2-5PM, Gates Dell Complex 5.516
Instructor	Scott Aaronson aaronson@cs.utexas.edu www.scottaaronson.com Gates Dell Complex 4.422 Office hours: Monday after class or by appointment
TAs	None at present

This is an advanced graduate course about quantum complexity theory and its relationship to classical complexity theory. What that means is: we'll develop the theory of quantum computation, in a way that's accessible to computer scientists who might not even have seen quantum mechanics before. But we'll focus on a slightly unusual set of topics: ones where progress seems to depend as much on advances in *classical* complexity theory as it does on quantum advances, or where the whole difficulty is to rule out a classical solution to something that's known to be solvable quantumly, or where one wants to know whether one can solve a quantum problem (such as a circuit lower bound) *without* having to solve a corresponding classical problem. Likely topics will include:

- The basic framework of qubits, quantum gates, and quantum circuits
- BQP and its relationship with classical complexity classes
- The complexity of quantum states and unitary transformations; the Unitary Synthesis Problem
- Quantum versus classical proofs and advice
- Quantum money
- Applications of quantum complexity to AdS/CFT and the black-hole information problem
- Quantum versus classical query complexity; recent separations; maximum possible separations
- BosonSampling and the complexity of the permanent
- BQP versus the polynomial hierarchy

The exact mix of topics will depend somewhat on time, as well as student interest—feel free to let Prof. Aaronson know if there are topics in the above list that you don't want to be missed.

Structure. The course is taught once a week for 3 hours. Of course, 3 hours is a long time, but it allows exploring topics in great depth. There will typically be two restroom/snack/etc. breaks during each lecture, at 1-hour intervals.

Project. The main requirement for the course is a reading or original research project. This can be done either individually or in groups or two. By mid-October, students will need to submit project proposals (a couple of paragraphs plus references). Prof. Aaronson will then meet with each student or team to refine or possibly redirect the project proposal, find relevant literature, etc.

By the end of the semester, each student or team will need to produce two things: (1) a final project report of up to 6 pages (plus optional appendices), and (2) an in-class project presentation (most likely 20-30 minutes long). The project presentations will occur during the last class sessions.

While project topics are subject to instructor approval, almost any active research topic in quantum(ish) complexity theory, or direction or open problem related to the course material, could form the basis for a good project. Prof. Aaronson will frequently mention possible project topics as they arise during the course, and will also distribute a list of suggested topics close to the proposal deadline.

In general, a project should involve deeply familiarizing yourself with a research topic and a set of open problems related to the course, and then trying to do original research on those problems. Making an original research contribution is not necessary to do well in the course—a survey (for example) of recent literature on a problem, and a cogent description of an attempt to push forward on the problem and why the attempt failed, would also be a fine project. But since part of the purpose of an advanced graduate course is to train students to become researchers, students are encouraged to be ambitious.

Since this is a theoretical course, most projects will probably be theoretical in nature. Projects involving coding, numerical simulations, educational software, etc. are also possible, but will require special approval to ensure they're sufficiently relevant to the course material.

Prof. Aaronson will be very available to discuss the projects as they progress, and where relevant, will also be happy to help students turn their projects into papers to submit for publication or upload to the arXiv. Following a long tradition, he'll also likely have a "Student Project Showcase" on his blog, publishing the project reports of those students (and, of course, only those students) who choose to opt in. This is not exclusive with any other sort of publication.

Other Requirements. Besides the project, the main other requirement is regular attendance. Students are strongly encouraged to participate and ask questions. If you can't make a particular lecture, just email Prof. Aaronson to let him know.

It hasn't yet been decided whether there will be problem sets. *If* there are enough students in the course to justify a TA/grader, and *if* problem sets seem needed to reinforce the concepts, one or two short problem sets might be issued. In any case, Prof. Aaronson will frequently mention optional problems as they arise during the lectures.

There is no final exam.

Grading. If there are no problem sets, grading will be 80% final project and 20% attendance and participation. The project grade will weigh the following factors: cogent in-class presentation (including responses to questions); timely and well-written project report; depth of understanding displayed of the course material and also of the literature studied for the project. Making an original research contribution is a "bonus" grading category, which can compensate for deficiencies in the other areas.

If there are problem sets, the distribution will be modified to 60% final project, 20% problem sets, and 20% attendance and participation.

Texts. For a large fraction of the course, we'll be more-or-less following Prof. Aaronson's Barbados lecture notes on "The Complexity of Quantum States and Transformations," which are freely available at this URL:

http://www.scottaaronson.com/barbados-2016.pdf

For other parts of the course, Prof. Aaronson will mention relevant research papers and survey articles (more often than not, there's not yet any textbook). Some good background books for quantum computing and computational complexity, which might be helpful for the course, include:

- *Quantum Computation and Quantum Information* by Michael Nielsen and Isaac Chuang

- *Computational Complexity: A Modern Approach* by Sanjeev Arora and Boaz Barak
- *The Nature of Computation* by Cristopher Moore and Stephan Mertens
- *Quantum Computing Since Democritus* by Scott Aaronson

All of these books are optional.

Prerequisites. The main prerequisite for the course is a previous course on computational complexity theory, or equivalent knowledge. There are no physics prerequisites: previous exposure to quantum computation is of course helpful, but won't be assumed. If in doubt, students should talk to Prof. Aaronson.

Students should be advised this is an advanced, research-level graduate course, *not* an introductory course on quantum computing and information. Prof. Aaronson will be teaching an introductory quantum information course in Spring 2017.

Other. Students with disabilities may request appropriate academic accommodations from the Division of Diversity and Community Engagement, Services for Students with Disabilities, 512-471-6259, http://www.utexas.edu/diversity/ddce/ssd/