6.845 Project

Handed out: Oct. 15, 2014

All students taking 6.845 for credit are expected to complete a course project by the end of the semester. The project can be either a survey of some topic in the quantum complexity theory literature, or original research. Projects can be done either individually or in groups of two. Pick a project that interests you, that’s related to the course, and that (crucially!) you’ll actually be able to finish by the end of the semester. Here are a few good ways to pick a project:

- Something that combines your own research interests with quantum complexity theory
- Something mentioned in the course that you’d like to understand better
- Something not mentioned in the course that you wish had been
- scholar.google.com, arxiv.org/find/quant-ph
- The last twenty years’ proceedings of ACM Symposium on Theory of Computing (STOC), IEEE Foundations of Computer Science (FOCS), and IEEE Conference on Computational Complexity (CCC), as well as the list of talks at the annual Quantum Information Processing (QIP) conference

To help get you started, there’s a list of topic suggestions at the end of this handout. Scott will also be happy to help you with additional suggestions and pointers to the literature. Here is what’s expected of you:

1. **Project Proposal.** Just a single paragraph describing your proposed project, together with a list of relevant papers. Please email this to aaronson@csail.mit.edu by Friday, October 31, with “6.845 Project Proposal” in the subject line. Please indicate if you are collaborating with anyone. Scott will then give you feedback and suggest additional relevant papers. Please don’t hesitate to make an appointment to discuss your project in person (or come by 32-G638 for office hours, Thursday, October 23, 10AM-noon).

2. **Ten-Minute Class Presentation.** Each project group must give a 10-minute presentation to the class. We’ll schedule these presentations sometime during the week of Monday, December 8—more details later. (The presentations might replace the last class session, and/or we might need to find a different time for them, depending both on how many projects there are, and on where we are with the class material.) You can use blackboard or PowerPoint/Beamer.

3. **Written Report.** You must turn in a written project report by midnight on Thursday, December 11. The report should be up to five pages long, together with optional appendices that can be as long as you like and will be read at Scott’s discretion. (No, there are no rules about font size, margins, etc.; just be reasonable!)

4. **Online Showcase.** In past years, we’ve created an online showcase of student projects on Scott’s blog—see www.scottaaronson.com/blog/?p=515 and www.scottaaronson.com/blog/?p=1181. Participation in the showcase is strictly optional (and has no effect on your grade), but it’s a great way to publicize your research—think of it like a glorified poster session.
5. **Publication.** If your project represents original research (or even an original survey), and you’re interested in making it into a formal publication (or even just an arXiv preprint), Scott will be more than happy to help you with that, by suggesting publication venues, ways to frame your result, etc. In the lists below, the italicized projects led to published research papers.

**Actual Projects From the 2008 Iteration of the Course**
(see stellar.mit.edu/S/course/6/fa14/6.845/materials.html; scroll down for projects)

- A QMA\(_k\) protocol for 3SAT requiring unentangled measurements only
- Quantum Hidden Markov Models
- Simple presentation of the Solovay-Kitaev Theorem
- Universality of measurement-based quantum computing
- Lower bounds on quantum communication complexity
- Stoquastic Hamiltonians (Terhal, Bravyi, et al.)
- Quantum finite automata
- Classical simulation of quantum circuits
- Query-limited reducibilities and quantum computing

**Actual Projects from the 2010 Iteration of the Course**
(see www.scottaaronson.com/blog/?p=515)

- Quantum money with a classical oracle
- A polynomially more efficient QMA\(_k\) protocol for 3SAT
- Quantum correlated equilibria
- Upper bounds from the quantum adversary method
- The query complexity of counterfeiting quantum money
- Witness-indistinguishability against quantum adversaries

**Actual Projects from the 2012 Iteration of the Course**
(see www.scottaaronson.com/blog/?p=1181)

- Quantum POMDPs
- Quantum algorithms for the weak parity problem
- Influences in low-degree polynomials
- Classifying beamsplitters
- Quantum query complexity of functions of permutations
- Quantum search on the spatial grid
- Limits on non-local randomness expansion
- A survey of QMA-complete problems
- Complexity of quantum field theories (Jordan-Lee-Preskill)
- Complexity issues related to the quantum adiabatic algorithm
(Extremely Incomplete) List of Possible Other Topics

- Recent breakthroughs on improving the Solovay-Kitaev Theorem using algebraic number theory
- Projective and “Vaidman bomb” quantum query complexity (Lin and Lin, 2014)
- Quantum Hamiltonian complexity and area laws
- The Quantum PCP Conjecture
- Quantum complexity theory and the black hole information problem (Harlow-Hayden, Susskind)
- Quantum cellular automata; equivalence with quantum circuits and quantum Turing machines
- Parallel implementation of Shor’s algorithm (Cleve and Watrous)
- Quantum Statistical Zero-Knowledge
- Quantum query complexity of compositions of Boolean functions (Reichardt)
- BosonSampling and FermionSampling
- Multi-prover quantum interactive proof systems: parallel repetition, classical simulation, soundness against entangled provers, etc.
- Two-way quantum communication complexity (e.g., Razborov’s lower bound for Disjointness)
- One-way quantum communication complexity
- Quantum information complexity and the PBR Theorem
- Quantum streaming complexity (Le Gall)
- Quantum Lovasz Local Lemma
- Complexity aspects of scattering amplitudes and the “unitarihedron”