CS-150: Project topics

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Each student taking CS 150 must complete a course project. This handout provides a pool of suggested topics around which you can complete your project. The project can be viewed as a further investigation of one of the topics we covered in class. It can also be an additional topic that the student deems relevant to the course. You are welcome to use one of the topics below or suggest a new one. Please reach out to us if you have a suggestion in mind. You will first need to submit a title and a paragraph explaining your proposed effort, and a paper that you wish to learn and present to the class. The deadline for this submission is **Feb 06, via Gradescope**. The goal of this project is to expand your knowledge about a specific topic related to the course and explain it to your classmates. If your final project report exceeds expectations, we can publish it on the course website. If you decide to continue working on the project beyond this class, I am happy to help you complete it and pursue publication opportunities.

1 Suggested project topics

We provide some suggested papers. You can visit https://scirate.com/ for recent publications in the field. You are welcome to use one of these papers (or come up with something else). Please reach out to us (or review Nielsen and Chuang's book) for any background questions.

- Quantum algorithms
  - Quantum walks
  - Quantum speedups for graph problems
  - Adiabatic quantum computing
  - Grover's search, amplitude amplification, etc.
  - The Hidden subgroup problems
  - Hidden subgroup problems for the dihedral group
  - Quantum algorithms for linear systems
  - Quantum simulation
  - Quantum approximate counting
  - Quantum approximate optimization algorithm (QAOA)
- Open quantum systems
  - Lindbladian mixing times and quantum Gibbs samplers
- Physics and computation
  - Computational complexity of quantum partition functions and Gibbs states
  - Topological quantum computing and quantum universality of the Jones polynomial

  - Quantum cellular automata
  - Simulating quantum field theory on a quantum computer
  - Complexity of Feynman diagrams
  - Computability of quantum phase transitions
  - Complexity-theoretic aspects of the black hole information problem
  - The complexity of estimating quantum scattering amplitudes
  - The computational complexity of the amplituhedron
  - Random satisfiability (e.g., understanding phase transitions, refutability)
  - Fractional quantum Hall ground states
  - Complexity of cooling down a quantum system
  - The renormalization group flow and connections with phase transitions
- Quantum compiling
  - Universal gate-sets and the Solovay-Kitaev Theorem
  - Quantum state synthesis problem
  - Parallel implementation of the quantum Fourier Transform
- Quantum, chemistry, and biology
  - Quantum effects in photosynthesis
  - Quantum algorithms for chemistry
- Models of quantum computation
  - Topological quantum computing
  - Quantum computation over continuous variables
  - Fermionic quantum computations
  - Random circuit sampling
  - Boson Sampling
  - Shallow-depth quantum circuits (QAC0, QNC0)
- Quantum-Inspired Proofs and Algorithms
- Thermalization and quantum randomness
  - Approximate unitary t-designs
- Quantum error-correction
  - Fault tolerance in quantum computations
  - Quantum LDPC codes
  - Locally testable codes
- Hamiltonian complexity and the PCP conjecture
  - Hamiltonians with no low-energy trivial states (NLTS)
  - The quantum PCP conjecture
  - The quantum PCP conjecture
  - Non-local games

  - $\mathsf{MIP}^* = \mathsf{RE}$
  - Rigidity of quantum games
  - Quantum classical Merlyn Arthur games (QCMA)
  - Quantum Lovasz Local Lemma
  - Locally testable codes
  - Hamiltonian complexity in the continuum limit
  - undecidability of the spectral gap
  - Topological phases of matter

- Quantum cryptography
  - Classical verification of quantum computations
  - Quantum algorithms and lattice cryptography
  - Quantum cryptography with minimal assumptions
  - Pseudo-random quantum states

- Tomography and testing
  - Tolerant testing of stabilizer states and the inverse quantum Gowers theorem
  - Quantum property testing
  - Sample optimal quantum tomography
  - Shadow quantum tomography

- Classical algorithms for quantum computations
  - Gottesman Knill theorem (Clifford circuits, matchgates, Gaussian gates, etc.)
  - The stabilizer rank problem
  - Quantum-inspired classical algorithms
  - Adiabatic quantum computation with no sign problem

- Foundations of quantum mechanics
  - Interpretations of quantum mechanics
  - Wigner's friend
  - Pilot-wave interpretation of quantum mechanics & non-local hidden variables

- Quantum complexity theory
  - Quantum space complexity: e.g., logarithmic space
  - Multi-prover interactive proof system
  - Quantum statistically zero-knowledge proof systems
  - Quantum query complexity (e.g., graph properties, composition of Boolean functions)
  - Quantum Advice
  - Quantum Communication Complexity
  - Nonlocal quantum gates