Syllabus for CS 231 (Quantum Computation and Quantum Complexity)

December 19, 2021

- **Week 1:** *The quantum formalism.*
  - Description of a quantum bit.
  - Multi-qubit systems and quantum entanglement.
  - Pauli operators and a discrete view on quantum systems.
  - Measurements and unitaries.
  - The Church of larger Hilbert space.
- **Week 2,3:** *Basic quantum algorithms.*
  - Simon's algorithm: quantum advantage for highly structured problems.
  - Grover's unstructured search and amplitude amplification.
  - Quantum Fourier transform.
  - Quantum phase estimation; a short survey of Shor's factoring algorithm.
- **Week 4,5:** *Instances of provable quantum advantages.*
  - Non-local games: CHSH inequality, Magic-square game.
  - Quantum communication complexity: Hidden matching problem, Raz's problem.
  - Quantum query complexity: Revisiting Simon's problem, Forrelation.
- **Week 6:** *Cryptography in the quantum world.*
  - Features of entanglement: monogamy of quantum entanglement, no cloning theorem.
  - Bennett-Brassard protocol for quantum key distribution.
  - Self-testing of non-local games and certification of entanglement.
- **Week 7,8:** *Quantum NP and the local hamiltonian problem.*
  - Quantum Merlin-Arthur.
  - Quantum Cook-Levin theorem: QMA completeness of the local hamiltonian problem.
  - Local hamiltonians in quantum many-body physics.
  - Local hamiltonians in quantum cryptography: verification of quantum computation.
- **Week 9:** *Quantum algorithms for quantum many-body systems.*
  - Hamiltonian simulation.

  - Application of hamiltonian simulation: solving linear system of equations.
  - Variational Quantum algorithms.

- **Week 10,11:** *Quantum walks and related algorithms.*
  - The quantum walk formalism.
  - Applications of quantum walks: revisiting hamiltonian simulation, linear system of equations, collision finding.
  - Quantum signal processing.

- **Week 12,13:** *Frontiers in quantum complexity theory.*
  - The quantum PCP conjecture.
  - NLTS conjecture and the power of short-depth quantum circuits.
  - Revisiting verification of quantum computation: what is a qubit?
  - The power of multi-prover interactive proofs.