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.

• **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.
  – 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.