QIC 710/CS768/CS681/PHYS767/AMATH871/PMATH871
Introduction to Quantum Information Processing
Proposed syllabus, 2025 (R. Cleve)

There are 22 lectures (plus two in-class tests). All timing information is only approximate.

1. **Introduction to the quantum information framework** (3 lectures).
   Qubits, unitary operations, and simple measurements. State distinguishing problems. Multi-qubit systems, structure among subsystems, and quantum circuits. Entangled states. Controlled-U and CNOT gates. Superdense coding. Projective and local measurements. Isometries. Teleportation. No-cloning theorem.

2. **Quantum algorithms** (7 lectures).
   Simulations between quantum and classical circuits. Simple algorithms in the query model, such as Deutsch, 1-out-of-4 search, and Deutsch-Jozsa. Simon's problem. Fourier transform. The discrete log problem, and quantum algorithm for it. Phase estimation problem. Quantum algorithms for order-finding and for integer factoring. Grover's search algorithm. Lower bound for quantum searching.

3. **Density matrices and quantum operations on them** (4 lectures).
   Density matrix formalism. Bloch sphere for qubits. Product states, separable states, entangled states. Partial trace. Operations in states in the Kraus form. Partial transpose as an entanglement test. Stinespring form.

4. **Distance measures between quantum states** (1 lecture).
   Fidelity and trace distance. Holevo-Helstrom theorem.

5. **Schmidt decomposition** (1 lecture).

6. **Error-correcting codes and fault-tolerance** (2 lectures).
   Overview of error-correction in the classical case. Shor's nine-qubit quantum error-correcting code. CSS codes. Brief comments about the threshold theorem for fault-tolerant quantum computation.

7. **Nonlocality** (2 lectures).
   Examples of Bell inequality violations, such GHZ and CHSH.

Optional additional material from the following

8. **Entropy and noiseless compression** (1 lecture).
   Overview of classical entropy and noiseless compression. Quantum entropy. Schumacher's compression.

9. **Cryptography** (1 lecture).
   Brief overview of classical cryptography: one-time pad and complexity-based cryptosystems. BB84 protocol: how it works, and heuristic discussion of its security. Some formal analysis of security, such as BB84 with single qubit measurements or Lo-Chau cryptosystems. Proposed bit-commitment scheme.