ECE 4950
Quantum Information Science: Communication and Computation
FALL 2023

Instructor: Prof. Mark M. Wilde, Office: 394 Rhodes Hall

Time and Location: MW 8:40am–9:55am, Phillips 213

Required Lecture Notes:

Quantum Computation Lecture Notes, by John Watrous,
available at `https://cs.uwaterloo.ca/~watrous/QC-notes/`

A Grand Unification of Quantum Algorithms, by Isaac Chuang *et al.*,
available at `https://arxiv.org/abs/2105.02859`

Recommended Textbooks:

Quantum Computation and Quantum Information, Michael Nielsen and Isaac Chuang
An Introduction to Quantum Computing, Phillip Kaye, Raymond Laflamme, and Michele Mosca
Quantum Computer Science, David Mermin
Classical and Quantum Computation, Alexei Yu. Kitaev, Alexander H. Shen, and Mikhail N. Vyalyi

Prerequisites: Linear Algebra and Probability Theory. (MATH 2940 "Linear Algebra for Engineers," ECE 3100 "Introduction to Probability and Inference for Random Signals and Systems," or equivalents.) Exposure to Quantum Mechanics is helpful but not required.

Material: This course introduces the subject of quantum information science, tailored to senior undergraduate students. Quantum information science exploded in 1994 when Peter Shor published his algorithm that can break RSA encryption codes. Since then, physicists, mathematicians, and engineers have been determining the ultimate capabilities for quantum communication and computation. In this course, we study quantum communication, computation, and related topics. In particular, you will learn about quantum mechanics, entanglement, teleportation, quantum algorithms, quantum key distribution, and quantum error correction.

Grading: There will be assignments due every two weeks (7 in total), a midterm, and a final exam.

Assignments	50%
Midterm	20%.
Final	30%.

Presentation: The final presentation will be a useful way for the students to become more familiar with some of the research topics in the quantum information literature.

Week 1: Overview of quantum information
Week 2: Superdense coding; quantum circuits, and partial measurements; Quantum teleportation; Deutsch's algorithm
Week 3: A simple searching algorithm; the Deutsch-Jozsa algorithm; Simon's algorithm
Week 4: Arithmetic/number-theoretic problems; reversible computation; Phase estimation
Week 5: Phase estimation (continued); the quantum Fourier transform; Order finding
Week 6: Order finding (continued); reducing factoring to order finding; Grover's algorithm
Week 7: Grover's algorithm (continued); Quantum singular value transformation
Week 8: Quantum singular value transformation (continued)
Week 9: Hamiltonian simulation; linear combination of unitaries
Week 10: density matrix exponentiation; DQC1 problem of estimating normalized trace of a unitary

Week 11: Variational quantum algorithms; variational quantum eigensolver
Week 12: Quantum key distribution; Impossibility of quantum bit commitment
Week 13: Bell inequalities and nonlocality; Quantum communication complexity
Week 14: Quantum computational complexity; BQP, QMA, QIP(2), QIP; Pure-state fidelity estimation is BQP-complete; Local Hamiltonian is QMA-complete