EECS 498/598: Quantum Computers: Fundamentals, Architectures, and Programming

(3 credits with an optional 1 extra credit for additional work)
Time: Monday and Wednesday 3:00 to 4:30 pm
Instructor: Prof. Pinaki Mazumder

Quantum information has long outgrown the limits of academic exploration of a new kind of secure cryptography realized by quirky features of quantum systems. Theoretical investigations revealed that quantum computers while defying the common approach to programming may greatly outperform classical architectures. The emergent new generation of information processing has given birth to the emerging multi-billion-dollar industry by utilizing different approaches to processing quantum information. Quantum architectures designed by D-wave, IBM, Google, Rigetti Computing, Intel, and Ion-Q exploit a wide gamut of innovative technologies to implement disparate paradigms of quantum computation. On the application side, Google, NASA, Microsoft and other companies heavily invest into development of quantum artificial intelligence, machine learning, and complex optimization problems. The present course aims to meet the industrial interest in engineers with a specialized training capable of creating and developing new applications utilizing quantum information processing architectures. An indispensable part of the course is a series of programming assignments that will be designed to impart practical experience with quantum computers: starting from basic operations with qubits utilizing individual quantum gates to applications with complex functionality. Students will use commercial graded simulators such as Qiskit, QX, and PyQu to implement their programming assignments. All technical formalism needed for the topics covered in the course will be introduced in the course.

Outline: i) Fundamentals of quantum computing: linear algebra, matrix operators, tensor, quantum gates, and quantum circuits, ii) Architectures and implementations of quantum computer, iii) Algorithms for gate-based quantum computers: Quantum Fourier Transform, Shor's Factorization Algorithm, and Grover's Search Algorithm, iv) Entanglement, v) Quantum Measurement Theory, vi) Quantum Error Correction, vii) Machine learning and solution of optimization problems on adiabatic quantum computers, and viii) Quantum Key Distribution (QKD) for secure optical and microwave communications.

Evaluation Criteria: i) Theoretical Homework (35%), ii) Programming Homework (25%), and iii) An end-of-the-term project (40%), which may include implementation of algorithms on IBM quantum computer for (a) quantum phase estimation, (b) quantum search, (c) quantum supersampling for image processing, (d) quantum cryptography, (e) quantum machine learning such as support vector machines, (f) quantum games, as well as (g) large optimization problems on D-Wave quantum annealing computer. In-depth literature review on emerging quantum hardware and software technologies will be approved based on compelling outline of study.

Prerequisite: Basic knowledge in linear algebra will suffice.

Workload: 3 credits; optional an extra 1 credit for additional work.

Textbook: The course will mainly rely on instructor's class notes, while the following book will be helpful to acquire background information.

M. A. Neilsen and I. L. Chuang, *Quantum Computation and Quantum Information*, Cambridge University Press, 2010.