CS 8803-O20 Syllabus

Quantum Hardware

Online

Instructor Information

Instructor	Email	Drop-in Hours & Location
Colin Parker	cparker@gatech.edu	MS Teams by appointment
Asif Khan	akhan40@gatech.edu	MS Teams by appointment
Teaching Assistant(s)	**Email**	**Drop-in Hours & Location**
TBD	TBD	TBD

General Course Information

Description

Quantum computing promises exponential speedups for a class of important problems. Quantum computers with hundreds of qubits have already been demonstrated, and qubit counts are expected to cross into the thousand in the next few years. Quantum Computing is an interdisciplinary field with topics ranging from physical devices (ion traps, superconducting circuits, spins etc.) to system & architecture issues (memory/microarchitecture/IO) to algorithms and applications.

The goal of this course is to provide CS students with a fundamental background in the hardware aspects of quantum computing and to equip them with the skills needed to work on hardware and software systems that implement and support the next generation of quantum devices. Special focus will be on the physical method of operation of current and proposed quantum devices, explained with the mathematical structure of quantum information, rather than theoretical physics.

Pre- &/or Co-Requisites

This is a graduate-level course that assumes familiarity with college level calculus, complex numbers, and linear algebra topics including vector spaces, inner product spaces, matrix manipulation, diagonalization and eigenvalues/vectors. Prior exposure to quantum computing topics, such as quantum algorithms, provides useful background but is not strictly required. No prior knowledge of physics is assumed.

Course Goals and Learning Outcomes

By the end of this course, students will:

(1) Become familiar with the dominant qubit technologies and understand their relative advantage and disadvantages in terms of scalability, including the following platforms:
   a. Superconducting circuits (transmons)
   b. Trapped ions
   c. Trapped neutral atoms
   d. Semiconductor quantum dots

(2) Become familiar with how different single and multi-qubit operations are performed physically, including:
   a. ISWAP gate (superconducting circuit)
   b. Cirac-Zoller gate (ion trap)
   c. Mølmer-Sørensen gate (ion trap)
   d. Geometric phase gate (ion trap)
   e. Rydberg blockade gate (neutral atom)

(3) Understand how to create quantum superposition and entangle qubits at the hardware level for quantum algorithms
(4) Understand the problem of quantum noise, its origin, and schemes to benchmark quantum error
(5) Become familiar with advanced/exploratory qubit concepts, including photonic quantum computing and topological qubits
(6) Understand the critical challenges for scaling up quantum computers from a system-level hardware perspective
(7) Write code using IBM's qiskit platform using expanded Hilbert spaces to simulate a more complete description of quantum platforms

Course Requirements & Grading

The course is organized as a series of modules featuring pre-recorded lecture videos. Following the lecture videos there will be short checkpoint quizzes. Additionally, each module will have a longer programming assignment.

Assignment	Date	Weight (Percentage, points, etc)
Video Checkpoints	Course end	25%
Programming Assignments	Course end	75%

Description of Graded Components

Video checkpoint quizzes will contain 2-4 questions and be multiple choice. Programming assignments should be done with Python and qiskit, and will be graded automatically based on whether the submitted program meets the stated requirements in the assignment description. Programming assignments should take between 1-4 hours to complete.

Grading Scale

Your final grade will be assigned as a letter grade according to the following scale:

A	90-100%
B	80-89%
C	70-79%
D	60-69%
F	0-59%

Course Materials

Course Text

Recommended reference: "Quantum Computing and Quantum Information" by Nielsen and Chuang

Additional Materials/Resources

H. Häffner, C.F. Roos, and R. Blatt, "Quantum computing with trapped ions", Physics Reports **469** (4) 155-203 (2008) https://doi.org/10.1016/j.physrep.2008.09.003

M. Saffman, T. G. Walker, and K. Mølmer, "Quantum information with Rydberg atoms", Rev. Mod. Phys. **82** (3) 2313-2363 (2010) https://doi.org/10.1103/RevModPhys.82.2313

Alexandre Blais, Arne L. Grimsmo, S. M. Girvin, and Andreas Wallraff, "Circuit quantum electrodynamics", Rev. Mod. Phys. **93** (2) 025005 (2021) https://doi.org/10.1103/RevModPhys.93.025005

Guido Burkard, Thaddeus D. Ladd, Andrew Pan, John M. Nichol, and Jason R. Petta, "Semiconductor spin qubits", Rev. Mod. Phys. **95** (2) 025003 (2023) https://doi.org/10.1103/RevModPhys.95.025003

"Atomic Physics" by Christopher Foot (Oxford University Press, 2004) https://doi.org/10.1093/oso/9780198506959.001.0001

"Introduction to Superconductivity" by Michael Tinkham (Dover publications, 2004 ISBN:9780486435039)

"Introduction to Quantum Computing" by Hiu Yung Wong (Springer Nature, 2024) https://doi.org/10.1007/978-3-031-36985-8

"Quantum Computing Architecture and Hardware for Engineers" by Hiu Yung Wong (Spring Nature, 2025) https://doi.org/10.1007/978-3-031-78219-0

Course Website and Other Classroom Management Tools

Course materials are available on Canvas. Programming assignments can be submitted in Gradescope, which is linked from Canvas.

Course Policies, Expectations, & Guidelines

Academic Integrity

Georgia Tech aims to cultivate a community based on trust, academic integrity, and honor. Students are expected to act according to the highest ethical standards. Review Georgia Tech's Honor Code and the student Code of Conduct.

Any student suspected of cheating or plagiarizing on a quiz, exam, or assignment will be reported to the Office of Student Integrity, who will investigate the incident and identify the appropriate penalty for violations.

Accommodations for Students with Disabilities

If you are a student with learning needs that require special accommodation, contact the Office of Disability Services (404-894-2563) as soon as possible to make an appointment to discuss your special needs and to obtain an accommodations letter. Please also e-mail me as soon as possible in order to set up a time to discuss your learning needs.

Collaboration & Group Work

Students may discuss assignments with other students, but checkpoint quizzes and submitted programming assignments must be completely original work.

Extensions, Late Assignments, & Re-Scheduled/Missed Exams

All assignments for all modules must be completed by the course deadline.

Student-Faculty Expectations Agreement

At Georgia Tech, we believe that it is important to strive for an atmosphere of mutual respect, acknowledgement, and responsibility between faculty members and the student body. The Student-Faculty Expectations articulate some basic expectations that you can have of me and that I have of you. In the end, simple respect for knowledge, hard work, and cordial interactions will help build the environment we seek. Therefore, I encourage you to remain committed to the ideals of Georgia Tech while in this class.

Graduate Student Academic and Professional Success Resources: A list of resources for graduate students is given on the Office of Graduate and Postdoctoral Education website. Specific information for current graduate students includes

- Academic Resources such as the Communications Center, Language Institute, Library, Catalog, Registrar, resources for conducting research, Advocacy and Conflict Resolution resources, and how to manage unexpected situations that may impact your academic performance;
- Student Resources such as Campus Services, Child Care/Family programs, Health & Wellness, Career Services, and the Student Resource Guide

Student Well-Being: At Georgia Tech, we are concerned about your overall physical, social, and mental well-being. A comprehensive list of wellness related resources has been compiled and maintained by the Office of the Vice President for Student Engagement and Well-being.