EE 599 Quantum Fault Tolerance

Units: 4
Fall 2022—4-5:50 TTh

Location: GFS 222

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IT Help: NA
Hours of Service:
Contact Info:

Course Description

An accurate quantum computer can be built using noisy components. This course will cover noise models, quantum error-correcting codes, and methods for computing with encoded states. The aim is to cover both theoretical threshold theorems and practical problems remaining to overcome for implementations. Topics include stabilizer, subsystem, self-correcting and surface codes, threshold lower and upper bounds, and engineering and optimization techniques.

Learning Objectives

Students will learn how to evaluate fault-tolerance schemes, how to design new schemes, and how to deploy them in experiments. Students will be brought up to current frontiers of fault-tolerance research. They will learn how to demonstrate fault-tolerant error correction and computation on current and near-future small-scale quantum devices. They will also learn engineering techniques for the architecture of future large-scale quantum computers using 2D topological codes, block codes, or low-density parity-check codes.

Prerequisite(s): NA
Co-Requisite(s): EE 520 Intro. Quantum information processing
Concurrent Enrollment: NA
Recommended Preparation: NA

Course Notes

Letter grades. We will try to simulcast the class on Zoom. Even for remote students, class participation is still required.

Technological Proficiency and Hardware/Software Required

Mathematical maturity and basic programming skills. Python is the preferred language.

Required Readings and Supplementary Materials

Supplementary materials will include and freely available research papers and lecture notes.
Optional textbooks:
"Quantum Error Correction and Fault Tolerant Quantum Computing" by Frank Gaitan
"Quantum Computing for Computer Architects" (2nd ed.), by Metodi, Faruque and Chong

Description and Assessment of Assignments

Participation grade will be based on in-class discussions of required readings.
Homeworks will include both theory, computer-assisted combinatorial analysis, computer simulations, and running quantum circuits in hardware.
The quizzes will focus primarily on the theoretical background.
The final project will involve reading research papers and developing or implementing a fault tolerance technique at least through to simulation.

Grading Breakdown

Assessment Tool (assignments)	% of Grade
Participation	5
Homeworks	35
Quizzes (2)	40
Final project	20
TOTAL	100

Assignment Submission Policy

New homeworks will be assigned every one to two weeks.

Grading Timeline

They will be returned on a similar timeline.

Additional Policies

NA

Course Schedule: A Weekly Breakdown

	Topics/Daily Activities	Readings/Preparation	Deliverables
Week 1	Quantum error-correcting codes (QECCs) - Stabilizer codes		
Week 2	- Existence of good codes (random codes) - Limits of QECCs (Hamming bound, etc.)		HW 1 due

Week 3	- Subsystem codes
	  - Surface codes
	  - Self-correcting codes
			HW 2 due

Week 4	Quantum fault tolerance
	  - Clifford algebra
	  - Encoding and decoding QECCs		

Week 5	- Fault-tolerant universality (Shor's construction and magic states distillation)		**Quiz 1** HW 3 due

Week 6	Fault-tolerance threshold theorems
	  - AGP threshold theorem
	  - Specialized threshold theorems
			HW 4 due

Week 7	Optimized fault-tolerance schemes
	  - Teleportation-based schemes
	  - Postselection-based schemes		

Week 8	- Optimized syndrome extraction methods		HW 5 due
Week 9	Physical considerations (efficiency/threshold tradeoff, locality, gate parallelism, ancilla factories, memory, biased noise, system case studies)		
Week 10	Simulation techniques		**Quiz 2**

			HW 6 due
Week 11	Tailored error-reduction methods - Dynamical decoupling - Decoherence-free subspaces - Error mitigation		
Week 12	Anyonic computation		HW 7 due
Week 13	Fault tolerance on small and NISQ quantum devices		HW 8 due
Week 14	Fault-tolerance architectures for large-scale quantum computers		
Week 15	Summary and research opportunities		
FINAL	Final projects		Refer to the final exam schedule in the USC *Schedule of Classes* at classes.usc.edu.

Statement on Academic Conduct and Support Systems

Academic Conduct:

Plagiarism – presenting someone else's ideas as your own, either verbatim or recast in your own words – is a serious academic offense with serious consequences. Please familiarize yourself with the discussion of plagiarism in SCampus in Part B, Section 11, "Behavior Violating University Standards" policy.usc.edu/scampus-part-b. Other forms of academic dishonesty are equally unacceptable. See additional information in SCampus and university policies on Research and Scholarship Misconduct.

Students and Disability Accommodations:

USC welcomes students with disabilities into all of the University's educational programs. The Office of Student Accessibility Services (OSAS) is responsible for the determination of appropriate accommodations for students who encounter disability-related barriers. Once a student has completed the OSAS process (registration, initial appointment, and submitted documentation) and accommodations are determined to be reasonable and appropriate, a Letter of Accommodation (LOA) will be available to generate for each course. The LOA must be given to each course instructor by the student and followed up with a discussion. This should be done as early in the semester as possible as accommodations are not retroactive. More information can be found at osas.usc.edu. You may contact OSAS at (213) 740-0776 or via email at osasfrontdesk@usc.edu.

Support Systems:

Counseling and Mental Health - (213) 740-9355 – 24/7 on call
studenthealth.usc.edu/counseling
Free and confidential mental health treatment for students, including short-term psychotherapy, group counseling, stress fitness workshops, and crisis intervention.

National Suicide Prevention Lifeline - 1 (800) 273-8255 – 24/7 on call
suicidepreventionlifeline.org
Free and confidential emotional support to people in suicidal crisis or emotional distress 24 hours a day, 7 days a week.

Relationship and Sexual Violence Prevention Services (RSVP) - (213) 740-9355(WELL), press "0" after hours – 24/7 on call
studenthealth.usc.edu/sexual-assault
Free and confidential therapy services, workshops, and training for situations related to gender-based harm.

Office for Equity, Equal Opportunity, and Title IX (EEO-TIX) - (213) 740-5086
eeotix.usc.edu
Information about how to get help or help someone affected by harassment or discrimination, rights of protected classes, reporting options, and additional resources for students, faculty, staff, visitors, and applicants.

Reporting Incidents of Bias or Harassment - (213) 740-5086 or (213) 821-8298
usc-advocate.symplicity.com/care_report
Avenue to report incidents of bias, hate crimes, and microaggressions to the Office for Equity, Equal Opportunity, and Title for appropriate investigation, supportive measures, and response.

The Office of Student Accessibility Services (OSAS) - (213) 740-0776
osas.usc.edu
OSAS ensures equal access for students with disabilities through providing academic accommodations and auxiliary aids in accordance with federal laws and university policy.
USC Campus Support and Intervention - (213) 821-4710
campussupport.usc.edu
Assists students and families in resolving complex personal, financial, and academic issues adversely affecting their success as a student.

Diversity, Equity and Inclusion - (213) 740-2101
diversity.usc.edu
Information on events, programs and training, the Provost's Diversity and Inclusion Council, Diversity Liaisons for each academic school, chronology, participation, and various resources for students.

USC Emergency - UPC: (213) 740-4321, HSC: (323) 442-1000 – 24/7 on call
dps.usc.edu, emergency.usc.edu
Emergency assistance and avenue to report a crime. Latest updates regarding safety, including ways in which instruction will be continued if an officially declared emergency makes travel to campus infeasible.

USC Department of Public Safety - UPC: (213) 740-6000, HSC: (323) 442-120 – 24/7 on call
dps.usc.edu
Non-emergency assistance or information.

Office of the Ombuds - (213) 821-9556 (UPC) / (323-442-0382 (HSC)
ombuds.usc.edu
A safe and confidential place to share your USC-related issues with a University Ombuds who will work with you to explore options or paths to manage your concern.

*Occupational Therapy Faculty Practice - (323) 442-33*40 or otfp@med.usc.edu
chan.usc.edu/otfp

Confidential Lifestyle Redesign services for USC students to support health promoting habits and routines that enhance quality of life and academic performance.