UNIVERSITY OF SOUTHERN CALIFORNIA
MING HSIEH DEPARTMENT OF ELECTRICAL ENGINEERING

EE 599 Special Topic: Quantum Information Theory, Spring 2014

Instructor: Prof. Todd A. Brun **Phone:** (213) 740-3503
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Office hours: Mon 2-4 pm, Thu 10:30 am -12 noon

Lectures: Tu-Thu 3:30-4:50 pm

Text: *Quantum Information Theory,* Mark M. Wilde (Cambridge, 2013); Lecture Notes.

Supplemental Text: *Quantum Computation and Quantum Information*, Michael A. Nielsen and Isaac L. Chuang (Cambridge, 2000).

Homework: Eight problem sets will be assigned at 2-3 week intervals

Exams: There will be one midterm exam (given in class) and one final exam. The exams will be open book/open notes.

Midterm Exam: Date and Time to be determined

Final exam: Thu 8 May 2013, 2-4 pm

Course Grade:

Problem Sets	20%
Midterm	30%
Final Exam	50%

Course Description: This class will give a one-semester graduate-level introduction to Quantum Information Theory: Shannon Theory and its extension to the quantum domain, including quantum communication channels (noiseless and noisy), different resources for communication (e.g., quantum communication, classical communication, and shared entanglement), basic families of quantum communication protocols, the definition of various channel capacities, quantum error-correcting codes, experimental implementations, and open questions.

Required Preparation: A strong knowledge of complex linear algebra and probability theory, such as that obtained from EE 441 and EE 464. Prior knowledge of quantum information, such as from EE 520, and of information theory, such as EE 565a, is strongly encouraged.

Learning Objectives

Students who complete this class will learn the basic concepts and mathematical techniques of Quantum Shannon Theory. They will learn the fundamental protocols of quantum information theory: direct coding, entanglement distribution, superdense coding and quantum teleportation. The various mathematical tools--including various distance measures and entropic quantities will be defined and explained. They will learn the resources used in quantum protocols: quantum and classical channels (noiseless and noisy), shared entanglement, shared randomness and private communication. They will also learn the trade-offs among these resources, and the definitions of the various channel capacities in quantum information theory. They will also learn about the computational difficulties surrounding many of these capacities, and open problems in our current understanding of quantum information theory.

Course Outline

Week	Subjects	Text pages & Homework
1	Introduction; Classical Shannon Theory: compression and source coding; Shannon entropy; noisy channels and channel capacities; coding; mutual information.	Chapters 1 and 2
2	Review of Quantum theory: state vectors, qubits, the Bloch sphere, Pauli matrices, unitary transformations, measurement, composite systems and tensor products, quantum gates and circuits, entanglement and Bell inequalities.	Chapter 3
3	Noisy quantum states: ensembles and density matrices, evolution of density matrices, POVMs and generalized measurements, separability and entanglement, Kraus maps and quantum instruments, noisy quantum channels, purifications.	Chapters 4 and 5 HW 1 due
4	Unit quantum protocols: entanglement distribution, elementary encoding, superdense coding, quantum teleportation. Resource inequalities.	Chapter 6 HW 2 due
5	Coherent protocols. Capacity regions.	Chapters 7 and 8
6	Tools of Quantum Shannon Theory: distance measures, classical information and entropies, quantum information and entropies.	Chapters 9, 10 and 11 HW 3 due

Week	Subjects	Text pages & Homework
7	Classical typicality: typical sets, typical sequences, Shannon compression, weak and strong typicality, joint typicality, conditional typicality.	Chapter 13 HW 4 due
8	Quantum typicality: typical subspaces, bipartite and multipartite states, conditional quantum typicality, weak and strong quantum typicality, joint and conditional quantum typicality.	Chapter 14
9	Schumacher compression. **Midterm Exam.**	Chapter 17
Spring Break, 17-21 March 2014.		
10	The method of types for classical and quantum systems. Types, type classes and typical type classes.	Chapters 13 and 14
11	Entanglement concentration.	Chapter 18 HW 5 due
12	Classical communication over noisy quantum channels. Holevo information, and classical capacity. Examples of quantum channels. Superadditivity of classical capacity.	Chapter 19 HW 6 due
13	Classical communication over entanglement-assisted quantum channels. Capacity theorem.	Chapter 20
14	Coherent communication with noisy resources: entanglement-assisted quantum communication; quantum communication.	Chapter 21 HW 7 due
15	Noisy superdense coding; resource trade-offs and trade-off coding. Open problems.	Chapter 21 HW 8 due

Academic Integrity

"The University, as an instrument of learning, is predicated on the existence of an environment of integrity. As members of the academic community, faculty, students, and administrative officials share the responsibility for maintaining this environment. Faculties have the primary responsibility for establishing and maintaining an atmosphere and attitude of academic integrity such that the enterprise may flourish in an open and honest way. Students share this responsibility for maintaining standards of academic performance and classroom behavior conducive to the learning process. Administrative officials are responsible for the establishment and maintenance of procedures to support and enforce those academic standards. Thus, the entire University community bears

the responsibility for maintaining an environment of integrity and for taking appropriate action to sanction individuals involved in any violation. When there is a clear indication that such individuals are unwilling or unable to support these standards, they should not be allowed to remain in the University." (Faculty Handbook, 1994:20)

Academic dishonesty includes: (Faculty Handbook, 1994: 21-22)
Examination behavior – any use of external assistance during an examination shall be considered academically dishonest unless expressly permitted by the teacher.
Fabrication – any intentional falsification or invention of data or citation in an academic exercise will be considered a violation of academic integrity.
Plagiarism – the appropriation and subsequent passing off of another's ideas or words as one's own. If the words or ideas of another are used, acknowledgment of the original source must be made through recognized referencing practices.
Other Types of Academic Dishonesty – submitting a paper written by or obtained from another, using a paper or essay in more than one class without the teacher's express permission, obtaining a copy of an examination in advance without the knowledge and consent of the teacher, changing academic records outside of normal procedures and/or petitions, using another person to complete homework assignments or take-home exams without the knowledge or consent of the teacher.

The use of unauthorized material, communication with fellow students for course assignments, or during a mid-term examination, attempting to benefit from work of another student, past or present and similar behavior that defeats the intent of an assignment or mid-term examination, is unacceptable to the University. It is often difficult to distinguish between a culpable act and inadvertent behavior resulting from the nervous tensions accompanying examinations. Where a clear violation has occurred, however, the instructor may disqualify the student's work as unacceptable and assign a failing mark on the paper.

Students with Disabilities

Any student requesting academic accommodations based on a disability is required to register with Disability Services and Programs (DSP) each semester. A letter of verification for approved accommodations can be obtained from DSP. Please be sure the letter is delivered to me as early in the semester as possible. Your letter must be specific as to the nature of any accommodations granted. DSP is located in STU 301 and is open 8:30 am to 5:30 pm, Monday through Friday. The telephone number for DSP is (213) 740-0776.