



EE 589 Quantum Information Theory

Units: 4

Spring 2023, Mon-Wed 12-1:50 pm

Location: GFS 223

Instructor: Todd Brun

Office: EEB 502

Office Hours: Mon 2:30-4, Tue 1-3

Contact Info: Email: tbrun@usc.edu; phone (213) 740-3503

TA: Juan Garcia Nila

Office: EEB 527

Office hours: Wed 10-11, Fri 12-2

Contact Info: Email: jgarcian@usc.edu

Course Description

Quantum Shannon theory: quantum channels and entanglement; dense coding, teleportation, quantum compression, and quantum capacity theorems. Open problems in quantum communication.

Learning Objectives

Students who complete this class will know the basic concepts and mathematical techniques of Quantum Shannon Theory. They will know 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 know the resources used in quantum protocols: quantum and classical channels (noiseless and noisy), shared entanglement, shared randomness and private communication. They will also know the trade-offs among these resources, and the definitions of the various channel capacities in quantum information theory. They will learn about the computational difficulties surrounding many of these capacities, and open problems in our current understanding of quantum information theory.

Recommended Preparation: A strong working knowledge of complex linear algebra and probability theory is required, such as that obtained from an advanced undergraduate course (at the level of MATH 225, MATH 307, EE 364, etc.). Prior knowledge of quantum information, such as from EE 520 or EE 514, is helpful.

Course Notes

All lecture notes for this class, assignments, and any suggested additional reading will be posted on the Blackboard site.

Required Readings and Supplementary Materials

Required readings:

- *Quantum information Theory* (2nd edition), Mark Wilde (Cambridge University Press, 2017). ISBN 9781107176164.
- Instructor's lecture notes.

Supplementary references:

- *Quantum Computation and Quantum Information*, Michael A. Nielsen and Isaac L. Chuang (Cambridge University Press, 2000). ISBN 9781107002173.
- *The Theory of Quantum Information*, John Watrous (Cambridge University Press, 2018). ISBN 9781107180567.

Description and Assessment of Assignments

Nine problem sets will be assigned at 1-2 week intervals. These will include both exercises from the textbook and additional problems, and will be handed in in class and returned approximately one week later. Late assignments will not be accepted except with a medical excuse. The problems will include mathematical derivations and proofs. There will be one midterm exam (given in class) and one final exam. The exams will be open book/open notes.

Grading Breakdown

Assignment	% of Grade
Problem Sets	20%
Midterm Exam	30%
Final Exam	50%

Course Schedule: A Weekly Breakdown

	Topics/Daily Activities	Readings	Deliverables
Week 1	Introduction; Classical Shannon Theory: compression and source coding; Shannon entropy; noisy channels and channel capacities; coding; mutual information.	Chapters 1-2	HW 1 assigned
Week 2	Review of Quantum theory: state vectors, qubits, Pauli matrices, unitary transformations, measurement.	Chapter 3	
Week 3	Review of Quantum theory continued: composite systems and tensor products, quantum gates and circuits, entanglement and Bell inequalities.	Chapter 3	HW 1 due HW 2 assigned
Week 4	Noisy quantum states: ensembles and density matrices, POVMs and generalized measurements.	Chapter 4	HW 2 due HW 3 assigned
Week 5	Noisy quantum theory continued: separability and entanglement, Kraus maps and quantum instruments, noisy quantum channels, purifications.	Chapters 4-5	HW 3 due HW 4 assigned
Week 6	Unit quantum protocols: entanglement distribution, elementary encoding, superdense coding, teleportation.	Chapter 6	HW 4 due HW 5 assigned
Week 7	Resource inequalities. Coherent protocols. Capacity regions.	Chapters 7-8	HW 5 due HW 6 assigned
Week 8	Tools of Quantum Shannon Theory: distance measures, classical information and entropies, quantum information and entropies.	Chapters 9-11	
Week 9	Classical typicality: typical sets, typical sequences, Shannon compression, weak and strong typicality, joint typicality, conditional typicality.	Chapter 14	Midterm Exam
	Spring Break		
Week 10	Quantum typicality: typical subspaces, bipartite and multipartite states, conditional quantum typicality, weak and strong quantum typicality, joint and conditional quantum typicality.	Chapters 14-15	HW 6 due HW 7 assigned
Week 11	Schumacher compression. The method of types for classical and quantum systems. Types, type classes and typical type classes. The Packing Lemma.	Chapters 16, 18	HW 7 due HW 8 assigned
Week 12	Entanglement manipulation and LOCC. Classical communication over noisy quantum channels. Holevo information, and classical capacity. Examples of quantum channels.	Chapters 19-20	HW 8 due HW 9 assigned
Week 13	Superadditivity of classical capacity. Classical communication over entanglement-assisted quantum channels. Capacity theorem.	Chapter 21	
Week 14	Coherent communication with noisy resources: entanglement-assisted quantum communication; private classical communication.	Chapters 22-23	HW 9 due
Week 15	Quantum communication. The quantum capacity theorem. Resource trade-offs and trade-off coding. Nonadditivity and other open problems.	Chapters 24-25	
FINAL	Date: For the date and time of the final for this class, consult the USC <i>Schedule of Classes</i> at classes.usc.edu .		Final Exam

Statement on Academic Conduct and Support Systems

Academic Integrity:

The University of Southern California is a learning community committed to developing successful scholars and researchers dedicated to the pursuit of knowledge and the dissemination of ideas. Academic misconduct, which includes any act of dishonesty in the production or submission of academic work, comprises the integrity of the person who commits the act and can impugn the perceived integrity of the entire university community. It stands in opposition to the university's mission to research, educate, and contribute productively to our community and the world.

All students are expected to submit assignments that represent their own original work, and that have been prepared specifically for the course or section for which they have been submitted. You may not submit work written by others or "recycle" work prepared for other courses without obtaining written permission from the instructor(s).

Other violations of academic integrity include, but are not limited to, cheating, plagiarism, fabrication (e.g., falsifying data), collusion, knowingly assisting others in acts of academic dishonesty, and any act that gains or is intended to gain an unfair academic advantage.

The impact of academic dishonesty is far-reaching and is considered a serious offense against the university. All incidences of academic misconduct will be reported to the Office of Academic Integrity and could result in outcomes such as failure on the assignment, failure in the course, suspension, or even expulsion from the university.

For more information about academic integrity see [the student handbook](#) or the [Office of Academic Integrity's website](#), and university policies on [Research and Scholarship Misconduct](#).

Please ask your instructor if you are unsure what constitutes unauthorized assistance on an exam or assignment, or what information requires citation and/or attribution.

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

Free and confidential mental health treatment for students, including short-term psychotherapy, group counseling, stress fitness workshops, and crisis intervention.

[988 Suicide and Crisis Lifeline](#) - 988 for both calls and text messages – 24/7 on call

The 988 Suicide and Crisis Lifeline (formerly known as the National Suicide Prevention Lifeline) provides free and confidential emotional support to people in suicidal crisis or emotional distress 24 hours a day, 7 days a week, across the United States. The Lifeline is comprised of a national network of over 200 local crisis centers, combining custom local care and resources with national standards and best practices. The new,

shorter phone number makes it easier for people to remember and access mental health crisis services (though the previous 1 (800) 273-8255 number will continue to function indefinitely) and represents a continued commitment to those in crisis.

[Relationship and Sexual Violence Prevention Services \(RSVP\)](#) - (213) 740-9355(WELL) – 24/7 on call
Free and confidential therapy services, workshops, and training for situations related to gender- and power-based harm (including sexual assault, intimate partner violence, and stalking).

[Office for Equity, Equal Opportunity, and Title IX \(EEO-TIX\)](#) - (213) 740-5086
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
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 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) 740-0411
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
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
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) 442-1200 – 24/7 on call
Non-emergency assistance or information.

[Office of the Ombuds](#) - (213) 821-9556 (UPC) / (323-442-0382 (HSC)
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) 442-2850 or otfp@med.usc.edu
Confidential Lifestyle Redesign services for USC students to support health promoting habits and routines that enhance quality of life and academic performance.