



**EE 599 Quantum Information Theory**

**Units: 4**

**Spring 2019, Tue-Thu 2:00-3:50 pm**

**Location:** VKC 261

**Instructor: Todd Brun**

**Office:** EEB 502

**Office Hours:** Mon 2-4 pm, Thu 10:30 am-12 noon

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

## 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.

## 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.

**Recommended Preparation:** A strong knowledge of complex linear algebra and probability theory is required, such as that obtained from EE 510 and EE 503. Prior knowledge of quantum information, such as from EE 520 or EE 514, and of information theory, such as EE 565, is helpful but not required.

## 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

The required textbook for this course is the second edition of Mark Wilde's *Quantum information Theory* (Cambridge, 2017). Readings and exercises will be assigned out of this textbook. As supplemental references I recommend *Quantum Computation and Quantum Information* by Michael A. Nielsen and Isaac L. Chuang (Cambridge, 2000) and *The Theory of Quantum Information* by John Watrous (Cambridge, 2018). The lecture notes will be made available to the students as the course goes on. Some supplementary readings may also be provided at the instructor's discretion.

## Description and Assessment of Assignments

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

**Midterm Exam Date:** Tuesday 5 March 2019, in class

**Final Exam Date:** Thursday 2 May 2019, 2-4 pm

## Grading Breakdown

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

## Course Schedule: A Weekly Breakdown

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

## 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](http://policy.usc.edu/scampus-part-b). Other forms of academic dishonesty are equally unacceptable. See additional information in *SCampus* and university policies on scientific misconduct, <http://policy.usc.edu/scientific-misconduct>.

### Support Systems:

*Student Counseling Services (SCS) – (213) 740-7711 – 24/7 on call*

Free and confidential mental health treatment for students, including short-term psychotherapy, group counseling, stress fitness workshops, and crisis intervention. [engemannshc.usc.edu/counseling](http://engemannshc.usc.edu/counseling)

*National Suicide Prevention Lifeline – 1 (800) 273-8255*

Provides free and confidential emotional support to people in suicidal crisis or emotional distress 24 hours a day, 7 days a week. [www.suicidepreventionlifeline.org](http://www.suicidepreventionlifeline.org)

*Relationship and Sexual Violence Prevention Services (RSVP) – (213) 740-4900 – 24/7 on call*

Free and confidential therapy services, workshops, and training for situations related to gender-based harm. [engemannshc.usc.edu/rsvp](http://engemannshc.usc.edu/rsvp)

*Sexual Assault Resource Center*

For more information about how to get help or help a survivor, rights, reporting options, and additional resources, visit the website: [sarc.usc.edu](http://sarc.usc.edu)

*Office of Equity and Diversity (OED)/Title IX Compliance – (213) 740-5086*

Works with faculty, staff, visitors, applicants, and students around issues of protected class. [equity.usc.edu](http://equity.usc.edu)

*Bias Assessment Response and Support*

Incidents of bias, hate crimes and microaggressions need to be reported allowing for appropriate investigation and response. [studentaffairs.usc.edu/bias-assessment-response-support](http://studentaffairs.usc.edu/bias-assessment-response-support)

*The Office of Disability Services and Programs*

Provides certification for students with disabilities and helps arrange relevant accommodations. [dsp.usc.edu](http://dsp.usc.edu)

*Student Support and Advocacy – (213) 821-4710*

Assists students and families in resolving complex issues adversely affecting their success as a student EX: personal, financial, and academic. [studentaffairs.usc.edu/ssa](http://studentaffairs.usc.edu/ssa)

*Diversity at USC*

Information on events, programs and training, the Diversity Task Force (including representatives for each school), chronology, participation, and various resources for students. [diversity.usc.edu](http://diversity.usc.edu)

*USC Emergency Information*

Provides safety and other updates, including ways in which instruction will be continued if an officially declared emergency makes travel to campus infeasible. [emergency.usc.edu](http://emergency.usc.edu)

*USC Department of Public Safety – UPC: (213) 740-4321 – HSC: (323) 442-1000 – 24-hour emergency or to report a crime.*

Provides overall safety to USC community. [dps.usc.edu](http://dps.usc.edu)