

ECE 547/PHYS 581: Quantum Error Correction

Term: Spring 2025

Instructor: Milad Marvian (mmarvian@unm.edu)

Time: Tuesdays, Thursdays 13:30-14:45

Location: EECE-210

Credit hours: 3

Office hours: Mondays 5:00-6:00 pm; request additional hours by email.

Zoom: <https://unm.zoom.us/my/marvian>

My office: ECE 235-D

Course Description:

Quantum computers have the potential to be more powerful than classical computers. For example, they can solve particular computational problems, such as integer factoring, exponentially faster than classical computers. But quantum computers are also extremely susceptible to noise. Therefore any successful implementation of quantum algorithms needs to deal with the effect of noise. Currently, this is the major obstacle to engineering large-scale reliable quantum computers.

In this course, we will cover the fundamentals of noisy quantum processes and will see how genuine quantum effects, such as entanglement, can be utilized to reduce the effect of noise. We will introduce frameworks to take advantage of the extremely successful theory of classical error correction codes in designing quantum codes. We will explore techniques to mitigate the noise on the currently available small-scale quantum system. We will also explore techniques to make large-scale quantum computers, that will become available in the future, fault-tolerant.

Basic knowledge of (pure state) quantum computation is expected (e.g. at the level of ECE 445/545: An Introduction to Quantum Computing). No prior knowledge of classical error correction is assumed.

Course Goals: The course will introduce students to the fundamentals of quantum noise channels, and the theory of quantum error correction and fault-tolerance.

Course Outline:

- The fundamentals of the theory of open quantum systems, quantum noise, and decoherence. Density operator formalism; quantum channels
- Examples of noise channels; Markovian and non-Markovian noise; Distances on quantum states and channels
- The Knill-Laflamme quantum error correction conditions

- Classical error correction; linear codes
- Quantum error correcting codes; CSS codes; stabilizer codes; subsystem codes
- Error prevention and mitigation schemes
- Quantum fault tolerance theory
- Topological codes
- Final project presentations

We will follow the following two references closely:

- 1- Surviving as a Quantum Computer in a Classical World, Daniel Gottesman, Available here
- 2- “Quantum Computation and Quantum Information” by Michael Neilson & Isaac Chuang.

Links to other resources will be provided on the course website.

Grading:

- 60%: Problem sets
- 40%: Final project

Problem sets: Expect around 10 problem sets. The lowest grade is not counted in the final score. A clean presentation of the solutions is evaluated and is part of the grading. Both Latex generated PDF or a clean scan of handwritten solutions (in one PDF file) are accepted. Discussions on the problem sets are encouraged. The final solution must be written individually, and any collaboration/discussion on the problem set needs to be acknowledged in the returned solutions.

Final project: The final project consists of an oral presentation (30 minutes) to the class accompanied by a written report (6 to 8 pages). A list of suggested projects will be provided, but students are encouraged to suggest the topic of their interest. The chosen topic needs to be confirmed by the instructor.

The goal of the final project is to carefully read two or three key papers related to the topic of your choice and present them to your classmates. The expectation is to be able to digest the basic concepts and the main questions that are answered in the paper, critically examine the assumptions and limitations, compare and contrast them to each other, and effectively present them to your classmates by connecting to the topics that have been discussed in the class, both orally and in written form. There will be a mid-point check-in meeting, where we will meet one-on-one for 30 min to discuss the progress and your plans. This will contribute to the grade of the final project. The expectation for this meeting is to have a good understanding of the motivation and questions

that papers are trying to answer (without necessarily knowing the details of methods to answer them.)

A detailed feedback on both oral presentation and written report will be provided.

Grade distribution: Graduate students must earn a C or higher to earn credit for the course. Percentage breakdown to grading breakdown:

Score	>93	90-93	87-90	83-87	80-83	77-80	73-77	<73
Grade	A	A-	B+	B	B-	C+	C	F

COVID-19 Health and Awareness:

UNM is a mask friendly, but not a mask required, community. To be registered or employed at UNM, Students, faculty, and staff must all meet UNM's Administrative Mandate on Required COVID-19 vaccination. If you are experiencing COVID-19 symptoms, please do not come to class. If you have a positive COVID-19 test, please stay home for five days and isolate yourself from others, per the Centers for Disease Control (CDC) guidelines. If you do need to stay home, please communicate with me at mmarvian@unm.edu; I can work with you to provide alternatives for course participation and completion. UNM faculty and staff know that these are challenging times. Please let me, an advisor, or another UNM staff member know that you need support so that we can connect you to the right resources. Please be aware that UNM will publish information on websites and email about any changes to our public health status and community response.

Support:

Student Health and Counseling (SHAC) at (505) 277-3136. If you are having active respiratory symptoms (e.g., fever, cough, sore throat, etc.) AND need testing for COVID-19; OR If you recently tested positive and may need oral treatment, call SHAC.

LoboRESPECT Advocacy Center (505) 277-2911 can offer help with contacting faculty and managing challenges that impact your UNM experience.

Accommodation:

UNM is committed to providing equitable access to learning opportunities for students with documented disabilities. As your instructor, it is my objective to facilitate an inclusive classroom setting, in which students have full access and opportunity to participate. To engage in a confidential conversation about the process for requesting reasonable accommodations for this class and/or program, please contact Accessibility Resource Center at arcsrvs@unm.edu or by phone at 505-277-3506.

Support: Contact Accessibility Resource Center (<https://arc.unm.edu/>) at arcsrvs@unm.edu (505) 277-3506.

Credit hour statement:

This is a three credit-hour course. Class meets for two 65-minute sessions of direct instruction for fifteen weeks during the Spring 2023 semester. Please plan for a minimum of six hours of out-of-class work (or homework, study, assignment completion, and class preparation) each week.

Support: Center for Academic Program Support (CAPS). Many students have found that time management workshops can help them meet their goals (consult (CAPS) website under "services").

UAP 2720 and 2740:

Our classroom and university should always be spaces of mutual respect, kindness, and support, without fear of discrimination, harassment, or violence. If you ever need assistance or have concerns about incidents that violate this principle, please access campus support resources. These include confidential services at LoboRESPECT Advocacy Center, the Women's Resource Center, and the LGBTQ Resource Center. The University of New Mexico prohibits discrimination on the basis of sex (including gender, sex stereotyping, gender expression, and gender identity). UNM faculty and graduate teaching assistants are considered "responsible employees." "Responsible employees" must communicate reports of sexual harassment, sexual misconduct and sexual violence to Compliance, Ethics and Equal Opportunity. For more information on the campus policy regarding sexual misconduct, reporting, and reporting for "responsible employees," please see UAP 2720 and UAP 2740.

Citizenship and/or Immigration Status:

All students are welcome in this class regardless of citizenship, residency, or immigration status. Your professor will respect your privacy if you choose to disclose your status. As for all students in the class, family emergency-related absences are normally excused with reasonable notice to the professor, as noted in the attendance guidelines above. UNM as an institution has made a core commitment to the success of all our students, including members of our undocumented community. The Administration's welcome is found on our website: <http://undocumented.unm.edu/>.

Academic Integrity Statement:

Each student is expected to maintain the highest standards of honesty and integrity in academic and professional matters. The University reserves the right to take disciplinary action, up to and including dismissal, against any student who is found guilty of academic dishonesty or otherwise fails to meet the standards. Any student judged to have engaged in academic dishonesty in course work may receive a reduced or failing grade for the work in question and/or for the course. Academic dishonesty includes, but is not limited to, dishonesty in quizzes, tests, or assignments; claiming credit for work not done or done by others; hindering the academic work of other students; misrepresenting academic or professional qualifications within or without the University; and nondisclosure or misrepresentation in filling out applications or other University records.

Safety:

UNM offers several resources to help keep Lobos safe. LoboGuardian, <https://loboguardian.unm.edu>

is a mobile app that increases user safety by creating a virtual safety network of friends and family. The entire UNM campus has blue light emergency phones. UNM Police Department, tel.: (505) 277-2241, offers a free escort service for safety. Lobo Alerts <https://loboalerts.unm.edu> is UNM's emergency text messaging system that can inform you of any occurrences that impact safety. Get Help Now at <https://loborespect.unm.edu/Get%20Help%20now/index.html> LoboRespect Advocacy Center, for concerns such as sexual misconduct, hate/bias, bullying, hazing. Student Health Services <https://shac.unm.edu> provides counseling and health services to all students.