ECE 595: Quantum Error Correction

Term: Spring 2022
Instructor: Milad Marvian (mmarvian@unm.edu)
Office: ECE 235-D
Zoom: https://unm.zoom.us/my/marvian
Time: MW 11:00-12:20
Location: EECE-215
Credit hours: 3
Office hours: Fridays 4:45-5:30 pm; request additional hours by email.

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, such as the IBM Quantum device that we have access to at UNM. 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.

The recommended textbooks will be “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.

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

<table>
<thead>
<tr>
<th>Score</th>
<th>97-100</th>
<th>93-97</th>
<th>90-93</th>
<th>87-90</th>
<th>83-87</th>
<th>80-83</th>
<th>77-80</th>
<th>73-77</th>
<th>&lt;73</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade</td>
<td>A+</td>
<td>A</td>
<td>A-</td>
<td>B+</td>
<td>B</td>
<td>B-</td>
<td>C+</td>
<td>C</td>
<td>F</td>
</tr>
</tbody>
</table>
**UNM Administrative Mandate on Required Vaccinations**

UNM requires COVID-19 vaccination and a booster for all students, faculty, and staff, or an approved exemption (see: [UNM Administrative Mandate on Required Vaccinations](#)). Proof of vaccination and booster, or a medical, religious, or online remote exemption, must be uploaded to the UNM vaccination verification site. Failure to provide this proof may result in a registration hold and/or disenrollment for students and disciplinary action for UNM employees.

**Booster Requirement:** Individuals who received their second dose of a Pfizer or Moderna vaccine on or before June 15, 2021, or their single dose of a Johnson & Johnson vaccine on or before October 15, 2021, must provide documentation of receipt of a booster dose no later than January 17, 2022. Individuals who received their second dose of a Pfizer or Moderna vaccine after June 15, 2021 or who received their single dose of Johnson & Johnson after November 15, 2021 must provide documentation of receipt of a booster within four weeks of eligibility, according to the criteria provided by the FDA (6 months after completing an initial two-dose Moderna vaccine, 5 months after completing the Pfizer sequence, and 2 months after receiving a one-dose Johnson and Johnson vaccine).

International students: Consult with the Global Education Office.

**Exemptions:** Individuals who cannot yet obtain a booster due to illness should request a medical, religious, or online remote exemption (which may have an end date) and upload this to the vaccination verification site. Medical and religious exemptions validated in Fall 2021 (see your email confirmation) are also valid for Spring 2022 unless an end date was specified in the granting of a limited medical exemption. Students must apply for a remote online exemption every semester.

**UNM Requirement on Masking in Indoor Spaces**

All students, staff, and instructors are required to wear face masks in indoor classes, labs, studios and meetings on UNM campuses, see [the masking requirement](#). Students who do not wear a mask indoors on UNM campuses can expect to be asked to leave the classroom and to be dropped from a class if failure to wear a mask occurs more than once in that class. Students and employees who do not wear a mask in classrooms and other indoor public spaces on UNM campuses are subject to disciplinary actions. Medical/health grade masks are the best protection against the omicron variant and these masks should be used, rather than cloth.

**COVID-19 Symptoms and Positive Test Results:**

Please do not come to a UNM campus if you are experiencing symptoms of illness, or have received a positive COVID-19 test (even if you have no symptoms). Contact your instructors and let them know that you should not come to class due to symptoms or diagnosis. Students who need support addressing a health or personal event or crisis can find it at the Lobo Respect Advocacy Center.

**Accommodation Statement:**

In accordance with University Policy 2310 and the Americans with Disabilities Act (ADA), aca-
ademic accommodations may be made for any student who notifies the instructor of the need for an accommodation. It is imperative that you take the initiative to bring such needs to the instructor’s attention, as I am not legally permitted to inquire. Students who may require assistance in emergency evacuations should contact the instructor as to the most appropriate procedures to follow. Contact Accessibility Resource Center at 277-3506 or arc.unm.edu for additional information.

Credit hour statement
Federal Credit Hour Definition: A credit hour is an amount of work represented in intended learning outcomes and verified by evidence of student achievement that is an institutionally-established equivalency that reasonably approximates not less than: (1) one hour of classroom or direct faculty instruction and a minimum of two hours of out-of-class student work each week for approximately fifteen weeks for one semester or trimester hour of credit, or ten to twelve weeks for one quarter hour of credit, or the equivalent amount of work over a different amount of time; or (2) at least an equivalent amount of work as required in paragraph (1) of this definition for other activities as established by an institution, including laboratory work, internships, practica, studio work, and other academic work leading toward the award of credit hours. 34CFR 600.2 (11/1/2010)

Title IX Statement:
Title IX prohibitions on sex discrimination include various forms of sexual misconduct, such as sexual assault, rape, sexual harassment, domestic and dating violence, and stalking. Current UNM policy designates instructors as required reporters, which means that if I am notified (outside of classroom activities) about any Title IX violations, I must report this information to the Title IX coordinator. If you or someone you know has been harassed or assaulted and would like to receive support and academic advocacy, there are numerous confidential routes available to you. For example, you can contact the Women’s Resource Center, the LGBTQ Resource Center, Student Health and Counseling (SHAC), or LoboRESPECT. LoboRESPECT can be contacted on their 24-hour crisis line, (505) 277-2911 and online at loborespect@unm.edu. You can receive non-confidential support and learn more about Title IX through the Title IX Coordinator at (505) 277-5251 and http://oeo.unm.edu/title-ix/. Reports to law enforcement can be made to UNM Police Department at (505) 277-2241.

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 Student Health Services https://shac.unm.edu provides counseling and health services to all students.