Quantum Error-Correction Codes: How to deal with uncertainty when reliability is crucial.

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1 Introduction

2 General Objective

To develop a guide for Error Correcting Codes in quantum computing, accompanying it with computational and theoretical error analysis for determining its improvements based on the noise and parameters. There will be minimal use of physical quantum computers given the necessity of encodings for augmenting the amount of qubits, resulting prohibitive for frequent use.

3 Specific Objectives

1. To establish the theoretical foundations of Quantum Error Correction and Quantum Error Correcting Codes.
2. To design, implement, and analyze classical simulations of representative QECCs using quantum computing frameworks.
3. To perform a comparative error analysis of the implemented QECCs quantifying their quality.
4. To synthesize the theoretical and computacional results into a comprehensive guide.

4 Metodology

This project will be divided into three different departments corresponding to the first three specific objectives. The last objective runs throughout the project, combining and compiling the knowledge obtained from every other one.

4.1 Theoretical Foundations

This section will rely on bibliographic study and reproduction of proofs, meaning that it would result in a document explaining and proving keystone theorems in the QEC field and theoretical explanations of representative codes.

Topics Included:

- Hamming Bound.
- Quantum Linear Error Accumulation.
- Discretization of the errors.
- Independent Error Models.
- Shor Code.
- Calderbank-Shor-Steane Codes.
- Stabilizer Codes.

4.2 Computational Simulations

Following the recommendations made in (McGeoch, 2012), the simulation environment will be designed to separate parameters either in the QECC itself—for example, the number of qubits in the encoding—and the specific noise—for example, the probability of noise taking effect. This will improve correspondence and interpretability between parameters and results. It will also be foundational to compare and contrast computational simulations with theoretical error analysis.

The test suite itself will be created with Qiskit, which is a framework for quantum computing. As stated previously, it will be used—as long as it's possible—the simulation feature for reducing costs and accelerating development. However, after the testing phase, the results will benefit from checking with real hardware for accuracy in results. This last check with real hardware will depend on the availability of computers and the cost of accessing them.

4.3 Error Analysis

Quality in QECCs is measured by the number of errors correctable in the presence of arbitrary interactions (Knill, 2000). In this section, the quality of each code will be quantified by analyzing its structure and theoretically obtaining a relationship between its parameters and how many errors can be corrected.

5 Ethical Considerations

This project will not employ any methodology involving vulnerable populations or living subjects. Furthermore, it will not utilize any form of confidential or sensitive data for its processing or results. Any information or data external to the authors will be properly cited and accredited in accordance with the specifications provided by the university. Consequently, no phase of this study requires explicit approval from an ethics committee, and thus, submission to such a committee is deemed unnecessary.

6 Schedule

Tasks \ Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	X	X	X	X						X	X	X	X			
2	X	X	X			X	X		X	X						
3			X			X			X		X					
4				X	X		X	X				X	X			
5					X	X		X	X				X	X		
6	X	X	X	X	X		X	X		X	X					
7										X	X	X	X	X	X	X

- Task 1: Literature Review, retrieving information crucial to the field.
- Task 2: Test suite design and recalibration.
- Task 3: Code Description, explaining how a code works.
- Task 4: Code Simulation, testing the code to check its quality and performance.
- Task 5: Error Analysis, for quality measurement.
- Task 6: Present advances in simulations, theoretical definitions, and analysis (30%).
- Task 7: Synthesis of knowledge acquired, writing of the final document, and preparation for the final defense.

7 Subject Matter Expert

- Cesar Neyit Galindo Martinez (Universidad de los Andes)
- Alonso Botero Mejia (Universidad de los Andes)
- Nombre de profesor 3 (Instituto o Universidad de afiliación 3)

References

[1] McGeoch, Catherine C. A Guide to Experimental Algorithmics. Cambridge University Press, 2012.

[2] Knill, Emanuel, Raymond Laflamme, and Lorenza Viola. Theory of Quantum Error Correction for General Noise. Physical Review Letters 84, no. 11 (2000): 2525-28. https://doi.org/10.1103/PhysRevLett.84.2525.

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