

Quantum Error Correction

Louis Golowich Wenjie Gong Ari Hatzimemos
Dylan Li Dylan Zhou

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Harvard University

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Table of Contents

- 1 Introduction and Review of Quantum Error Correction
- 2 The 3-Qubit Codes
- 3 The Shor Code
- 4 The 7-Qubit Code

“To be an Error and to be Cast out is part of God’s Design.”

William Blake

- Noise as a longstanding problem in information processing systems
 - e.g., classical computers, modems, CD players, etc.
- Noise is still a problem in quantum information
- Key idea: to protect a message against noise, *encode* the message by adding redundant information; even if some information is corrupted, redundancy allows us to *decode* and recover the original message

Project Framework

- Goals:
 - to implement various quantum error-correcting codes
 - we chose the 3-qubit, 9-qubit, 7-qubit codes
 - to analyze and compare their performances
 - *when are they effective?*
 - *when should we use error-correcting codes?*
- Tools:
 - Python's Qiskit package
 - IBM's quantum machines

Classical Inspiration

- Encoding by *repetition codes*:

$$0 \rightarrow 000$$

$$1 \rightarrow 111.$$

- Decoding by *majority voting*:

$$\text{Ex.: } 001 \rightarrow 0.$$

- Analysis: Let p be the probability that a bit is flipped. This method fails when 2 or more bits are flipped, which occurs with probability $3p^2(1-p) + p^3$, so the probability of error is $p_e = 3p^2 - 2p^3$. Then this method is preferred when $p_e < p$, or $p < 1/2$.

The Quantum Version: 3-Qubit Bit Flip Code

- Encoding:

$$|0\rangle \rightarrow |0_L\rangle \equiv |000\rangle$$

$$|1\rangle \rightarrow |1_L\rangle \equiv |111\rangle .$$

The Shor Code

7-Qubit Code