Quantum Error Correction

Particles, Fields, and Quanta Spring 2022

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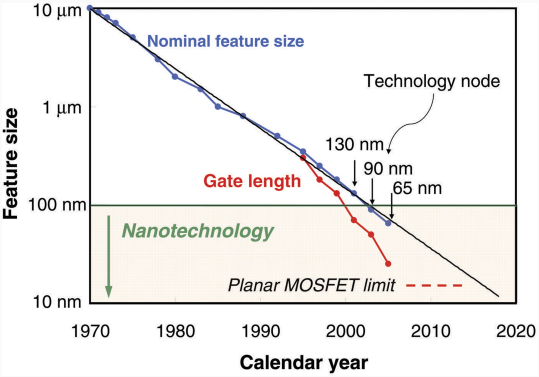
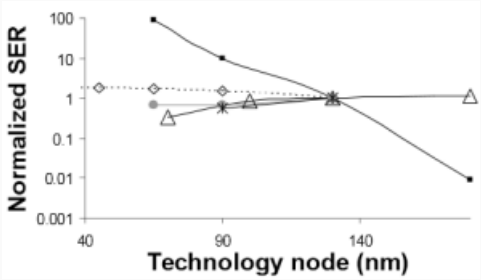
Motivation





Scott E. Thompson. *Moore's Law*. 2006. *Materials Today*
Nelson J Gaspard III. *Single-Event Upset Technology Scaling Trends.*. 2017. *Vanderbilt University PhD Thesis*

Motivation

➔ Current day microscale-devices error rates $< 1\%$

➔ Current day nanonscale devices error rates as high as 10%

Problem:

Energetic particles creating bit flip or voltage spike (Single Event Update)

D. Binder, E. C. Smith and A. B. Holman. *Satellite Anomalies from Galactic Cosmic Rays*. 1975. *IEEE*

Classical Solution

Repetition: make redundant copies of the original

Hamming: parity check, less redundant bits

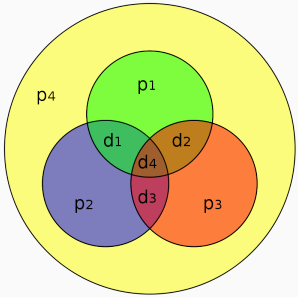
Original

00100100111011000001011101101

00100100110011000001011101101

00100100110011000001011101101

Redundant Copies



Hamming (7,4) code[1]

[1] Hamming (7,4). *User: Cburnett*, Wikipedia. CC-BY

Application in Quantum Information Theory

➔ Quantum systems are sensitive: *Decoherence*

➔ Today's Noisy Intermediate Scale Quantum *(NISQ)* era quantum computers, capable of only 50-100 qubits [1], are not suitable to implement algorithms like Shor's to break RSA encryption.[2]

[1] John Preskill. Quantum Computing in the NISQ Era and Beyond. 2018. *Quantum 2, 79*
[2] Frank Leymann and Johanna Barzen. 2020. *Quantum Sci. Technol.* 5 044007

Problems in Quantum Regime

Fundamental Problems

➔ No Cloning

$$|\psi\rangle \otimes |0\rangle \not\rightarrow |\psi\rangle \otimes |\psi\rangle$$

➔ Heisenberg Uncertainty Principle
Unknown quantum state cannot be completely measured, and if you measure the error, you disturb the state of the system.

Technical Problem

Requires 10-100 physical qubits to encode one fault tolerant qubit[1]

[1] Shalini Ghosh. *Low Density Parity Check Codes for Error Correction in Nanoscale Memory*. 2007. *Computer Science*

Quantum Error Correcting Codes

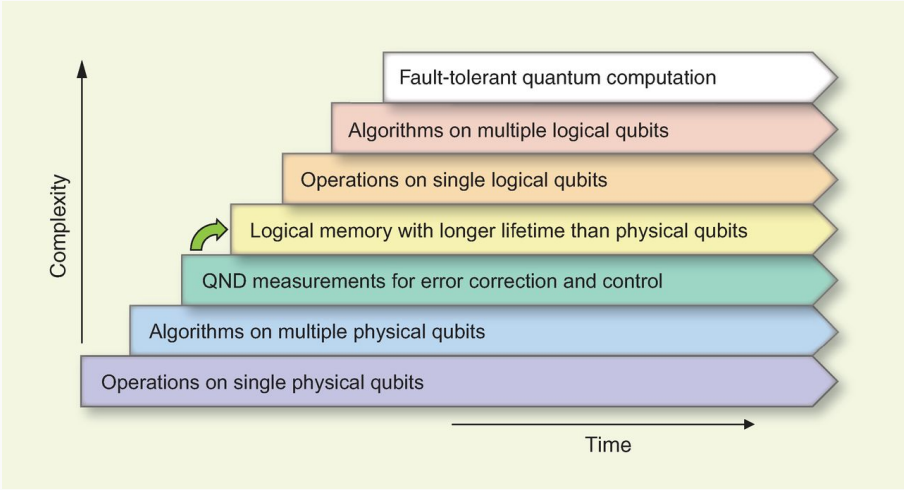
Error Correcting Codes

- ➔ 3-qubit code
- ➔ 9-qubit code
- ➔ Quantum Hamming Code
- ➔ Schrödinger Cat Code

Further

- ➔ LDPC code (small parity check)
- ➔ Topological quantum computation

Future in Quantum Error Correction



M.H. Devoret, R.J. Schoelkopf. *Superconducting Circuits for Quantum Information: An Outlook*. 2013. *Science*