FIRE: THE FIRST-YEAR INNOVATION & RESEARCH EXPERIENCE

QUANTUM MACHINE LEARNING

Quantum Error Correction
A Telephone Game

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Introduction

Quantum computing is one of the most vibrant fields at this time and is considered revolutionize data science in the near future. With the rise of quantum computing and the importance of making sure that quantum systems are error free, new algorithms have been created to correct for errors in a quantum circuit. Just like how traditional computing has error correction algorithms to keep a system and their conditions within the expected threshold of answers, QC has a similar concept.

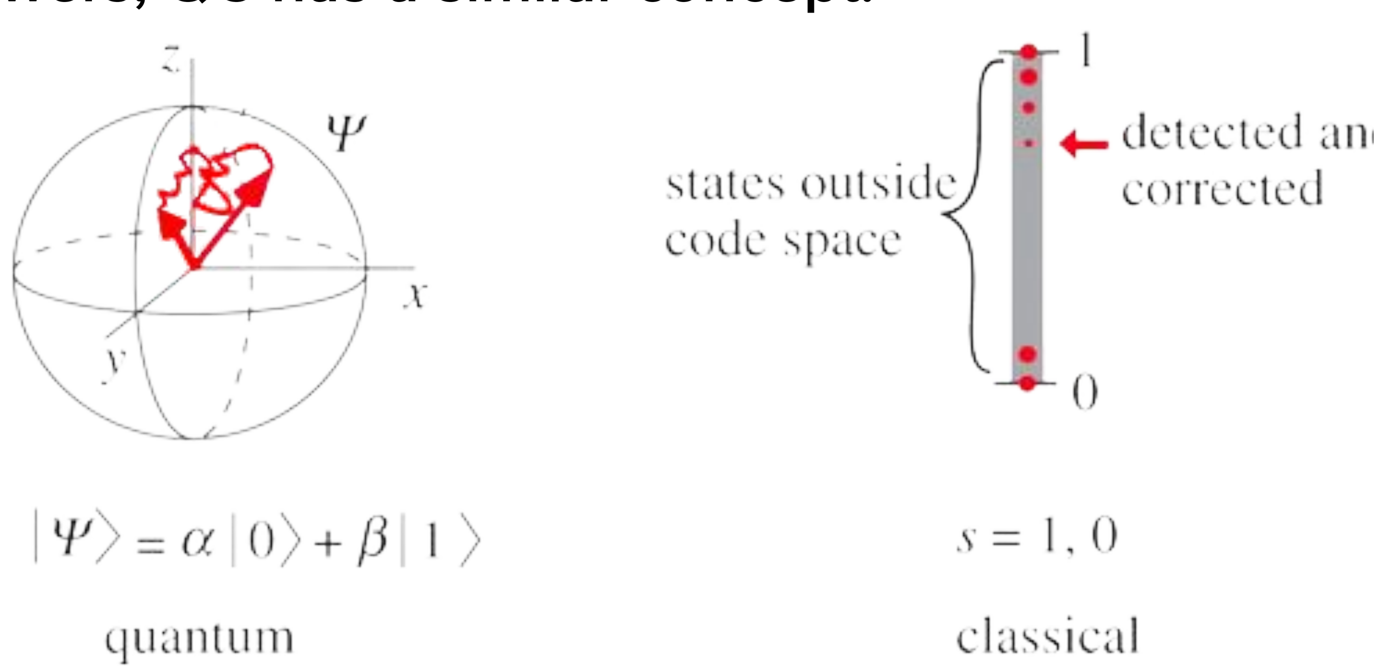

Figure 1. Quantum errors are far more complex than classical errors. To understand the difference between classical errors(right) and quantum errors(left) you should think of a classical bit as a light switch and a qubit as a dimmer.

Quantum Error Correction

QEC is a process where the state and phase of one qubit gets mapped onto multiple qubits to help combat decoherence or noise in a system. The basic process of it is by mapping and modulating the state and phase of a qubit onto a group of qubits, you could in turn return a qubit back to its intended state. This process is really powerful because information about a qubit can be retrieved without destroying any of the already encoded information. There have been many different processes for QEC created but the most popular are the bit flip, phase flip, and Shor code.

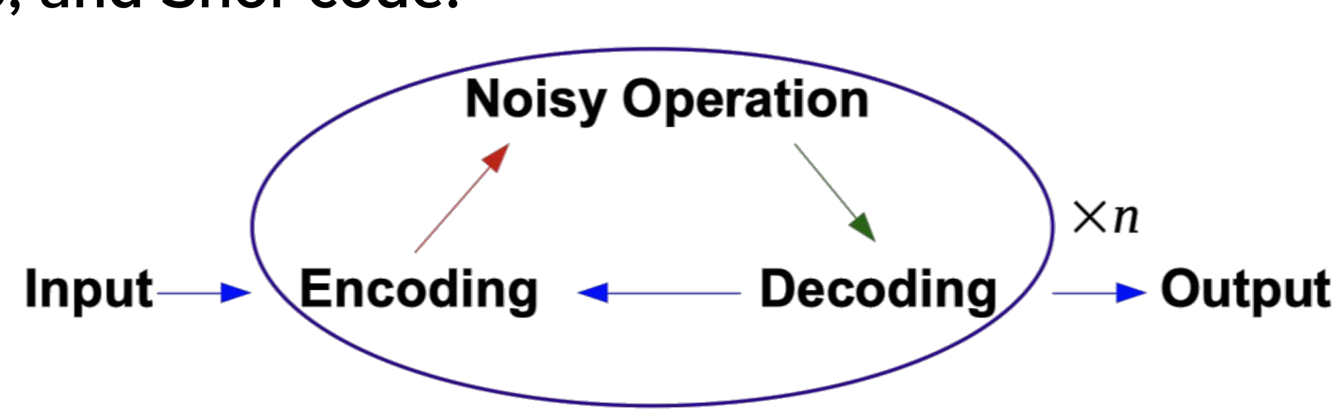

Figure 2. The cyclical nature for how QEC works. A cycle of encoding and decoding around noise with an expected output helps revert an error back to its expected state

Noise and Noise Model

If we run an algorithm, say Grover's, on quantum simulator and on one of the real IBM quantum computers, the results would be very different, as shown in Fig.3. Even though the probability of the two correct states is still the highest, it is not 100% as in the case of perfect simulation.

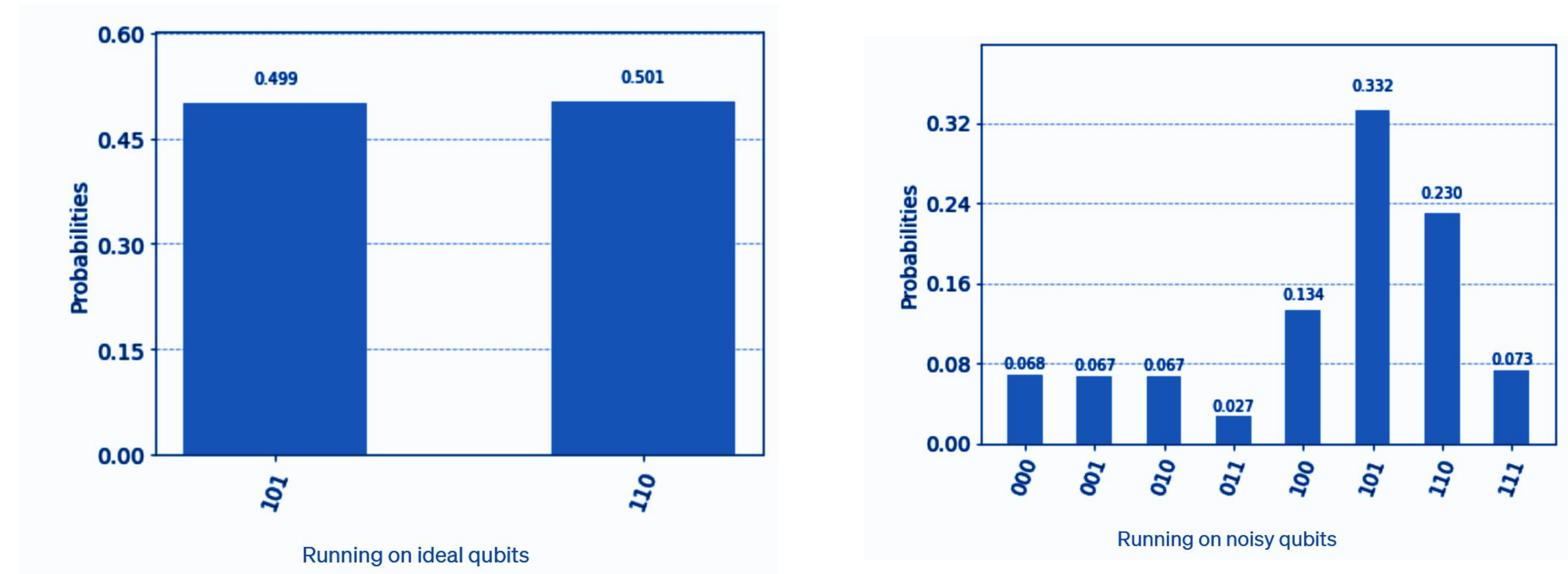

Figure 3. Left, Grover's algorithm searching for states 101 and 110, when run on a simulator with perfect qubits; Right: .same algorithm run on noisy qubits of a real quantum computer.

For our study, we simulated the noise model in a quantum circuit based on two factors: pgate and pmeas, the threshold for error from gate operation and from measurement, respectively. They both represent the probability to replace the state of any qubit to any random state(?) during any operation/measurement.

If we create a 3 qubit circuit, and apply flip all three qubit states from |0> to |1> (x-gate application), we get the distributions in Fig.4 for different error probabilities in the noise model.

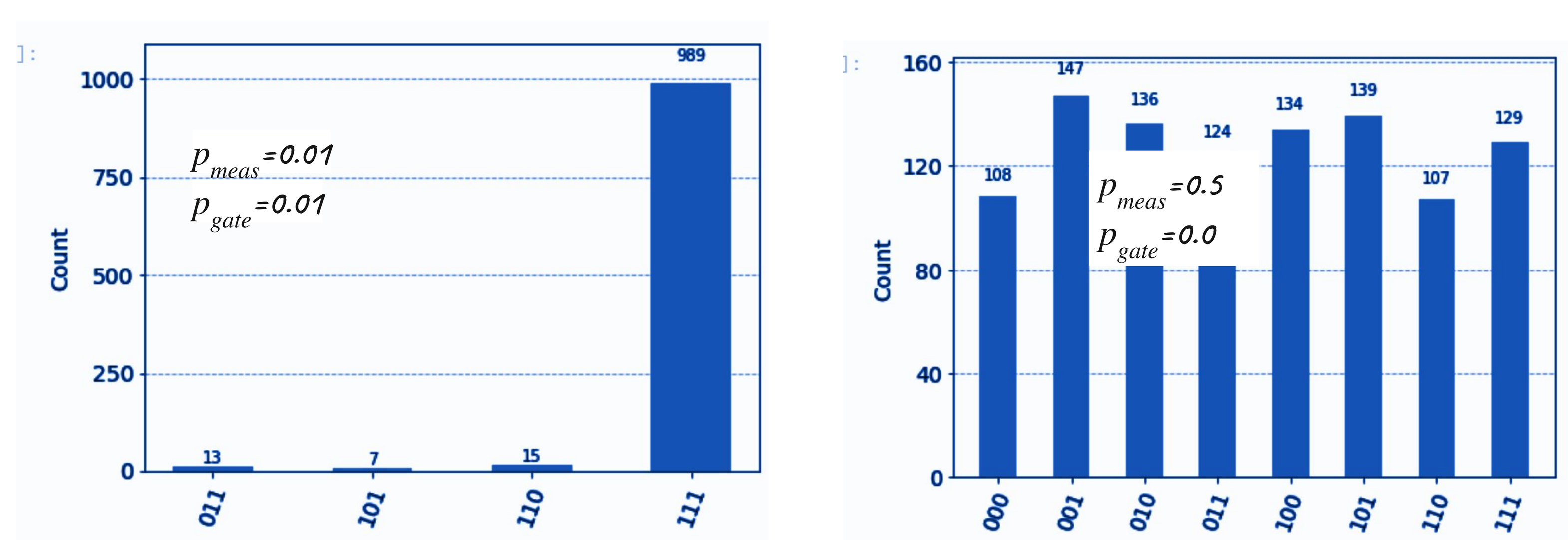

Figure 4. By creating a three qubit circuit and applying a flop to all three qubit states we are able to get the distributions for each error probability in the noise model.

References

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https://qiskit.org/textbook/ch-quantum-hardware/error-correction-repetition-code.html

QEC Using Repetition

Error correction using repetition is one of the most basic error-correcting methods. You can think of it like the game telephone. Where a message is sent n times along a line but along the way this message gets disrupted. In this game of telephone the message is repeatedly sent along an ordered line until the last person gets it right. This approach is essentially brute force but it has shown to work.

As in classical computing, we define a logical qubit to comprise of multiple physical qubits. We use "syndrom" measurement, that is, a multi-qubit measurement that does not collapse the quantum state of the multi-qubit system to get information about the error..

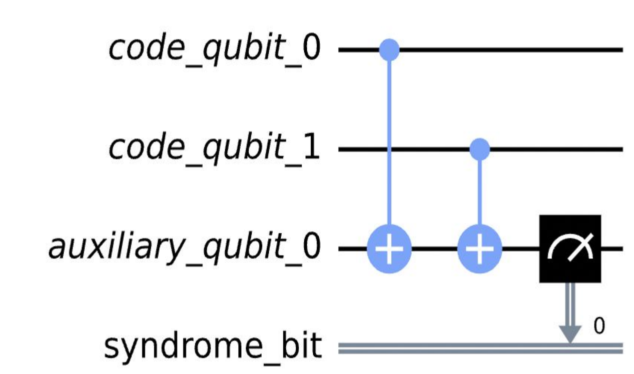

Figure 5: Both the qubits are either 0 or 1, then the output is 0. Otherwise the output is 1 which can be used to verify the state of the inputs.

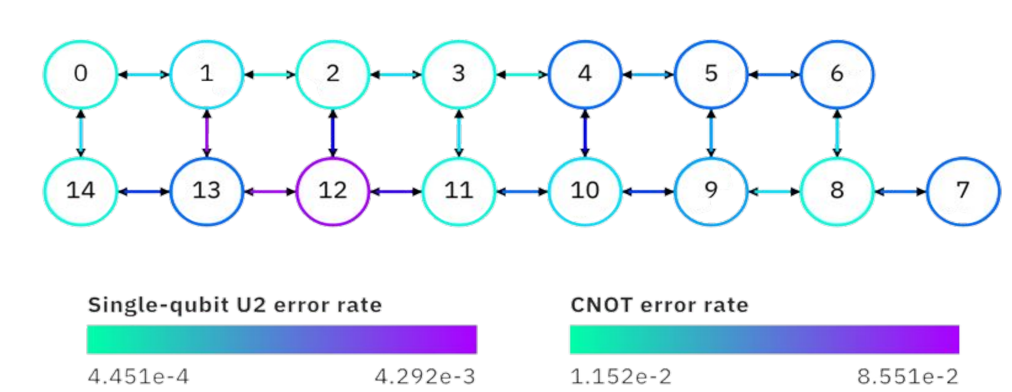

Figure 6: Tests of the repetition code require qubits to be effectively ordered along a line.

Conclusion/Future Work

Qubits will always be imprecise and imperfections can never be removed entirely. Quantum error correction research has made progress over the last few years, but there's still much left to accomplish to achieve this goal. Companies are working with the broader quantum community to thoughtfully bring about practical quantum computing as soon as possible. The ultimate challenge is to design quantum error correction technologies that enable the construction of fault tolerant quantum computers, which are quantum computers capable of detecting and correct errors faster than errors occur.