Joint Science and Technology Institute

Entangling Qubits on IBM Quantum Computers

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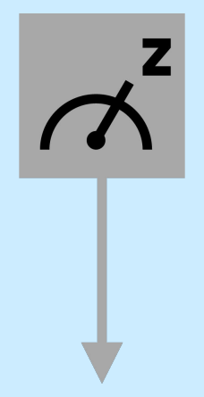
Introduction

Small, bizarre, and not fully understood -- yet with the potential to unlock complex scientific mysteries -- this is the quantum particle. With the power to harness quantum particles, scientists are able to better understand complex systems that the best supercomputers could not process. Despite being in their infancy, quantum computers have progressed massively since their introduction. Quantum computers are an undeniably complex beast that will certainly yield vastly valuable insights into the nature of the universe itself. Learning about the basics of the quantum particles' strange properties, then designing circuits to test remotely on IBM's quantum computers provided a better understanding of how a quantum computer works.

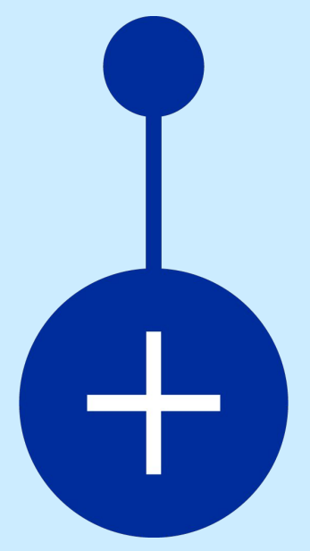
Background

- The qubit (quantum-bit) stores information as a 0 signal, a 1 signal, or both simultaneously, in what is called superposition.
- Measuring a qubit in superposition causes the superposition to collapse and gives a definite output.
- Quantum computing uses multiple qubits and interdependent operations (called logic gates) on these qubits to compute:
  - Some logic gates use classical methods, and take an input to give a definite output. (See NOT and CNOT gates)
  - Other logic gates rely on quantum mechanics, and take an input to give an output in superposition. (See HADAMARD gate)
  - When classical gates have inputs in superposition, the output is the superposition of all possible corresponding outputs of the inputs.

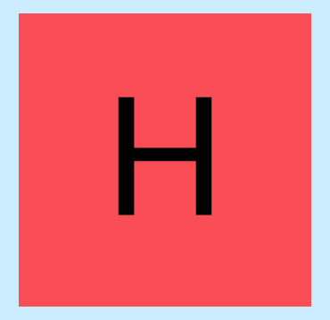
NOT gate
Returns opposing variable, 1 to 0; vice versa



Measurement
Provides outcome of variable from circuit.



CNOT gate
One variable passes through control, and may flip output from target



HADAMARD gate
Output is equally likely to be one of two variables
Two gates in a row returns the input

- Measurements of qubits are only executed at the end of computation to avoid collapsing any qubits in superposition.
- In some (but not all) cases, the measurement of a single qubit in a multi-qubit superposition is enough to completely collapse the superposition of those qubits, forcing them into a definite state.
  - This is an instantaneous phenomenon called entanglement, and occurs over any physical distance separating the qubits.

Materials and Methods

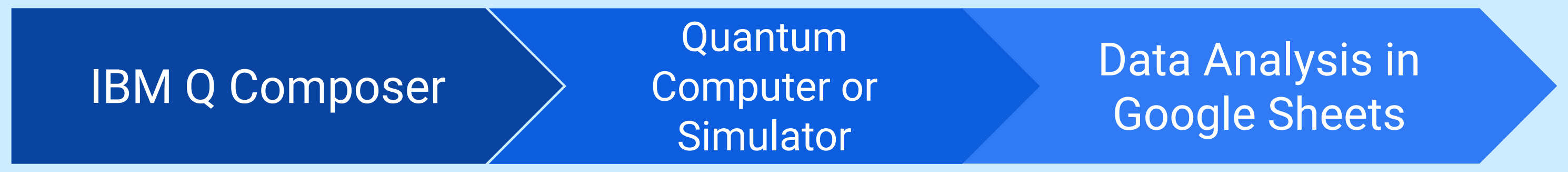
IBM Q - Online resource that gave us direct access to quantum computers around the world in addition to being able to use Logic and Quantum Gates to design our own circuits

Data Analysis Methods

Mean - The mean is a type of average. It is the sum of all the values in a set of data, such as numbers or measurements, divided by the number of values on the list.

Standard Deviation -The Standard Deviation is a measure of how spread out numbers are.

Variance - The variance is the average of the squared differences from the mean. To figure out the variance, first calculate the difference between each point and the mean; then, square and average the results.



IBM Q Composer

Composition of circuits with specific logic and quantum gates.

Quantum Computer or Simulator

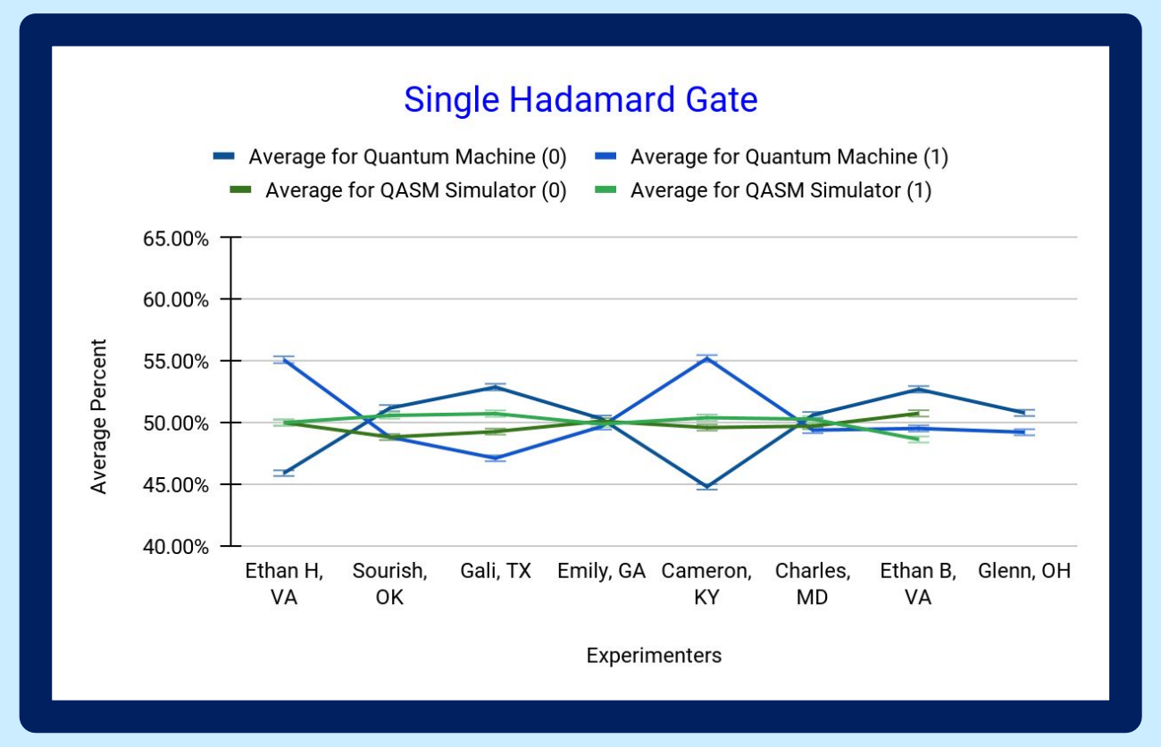
1. Choosing the best Quantum Computer - This was heavily based on its performance in terms of T1 and T2 time and CNOT error.
2. T1 and T2 are both decoherence times, which describe the length of time that the qubit stays in its excited state.
3. CNOT error describes the probability of an error occurring in a CNOT gate

Data Analysis in Google Sheets

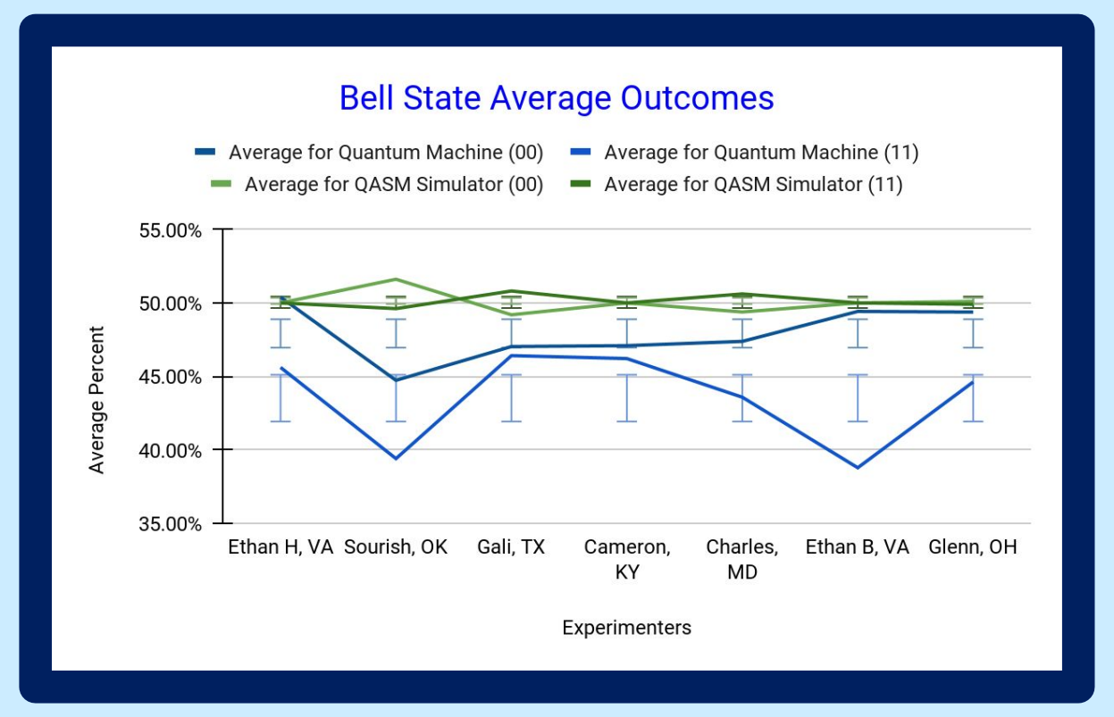
Once run in IBM Q, the differing Means, Variances, and Standard Deviations of the Simulator and Computer were compared to measure the accuracy of the Quantum Computers

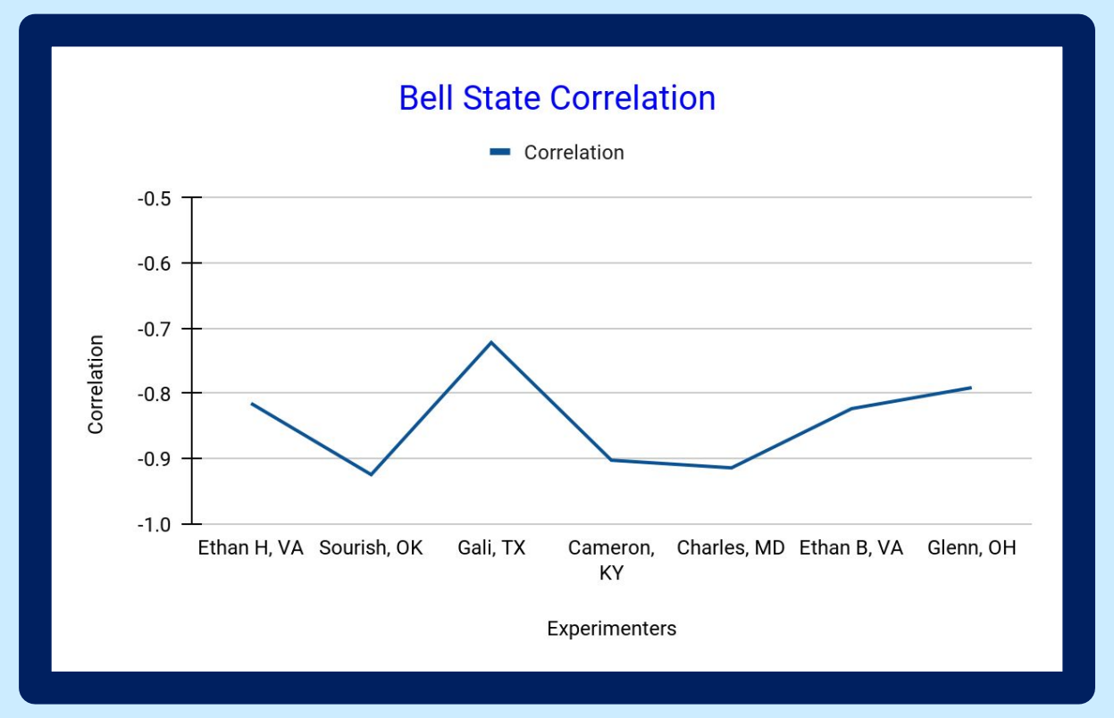
Results

Single Qubit Circuit
On average, the simulator results are split more evenly than the quantum computer results.

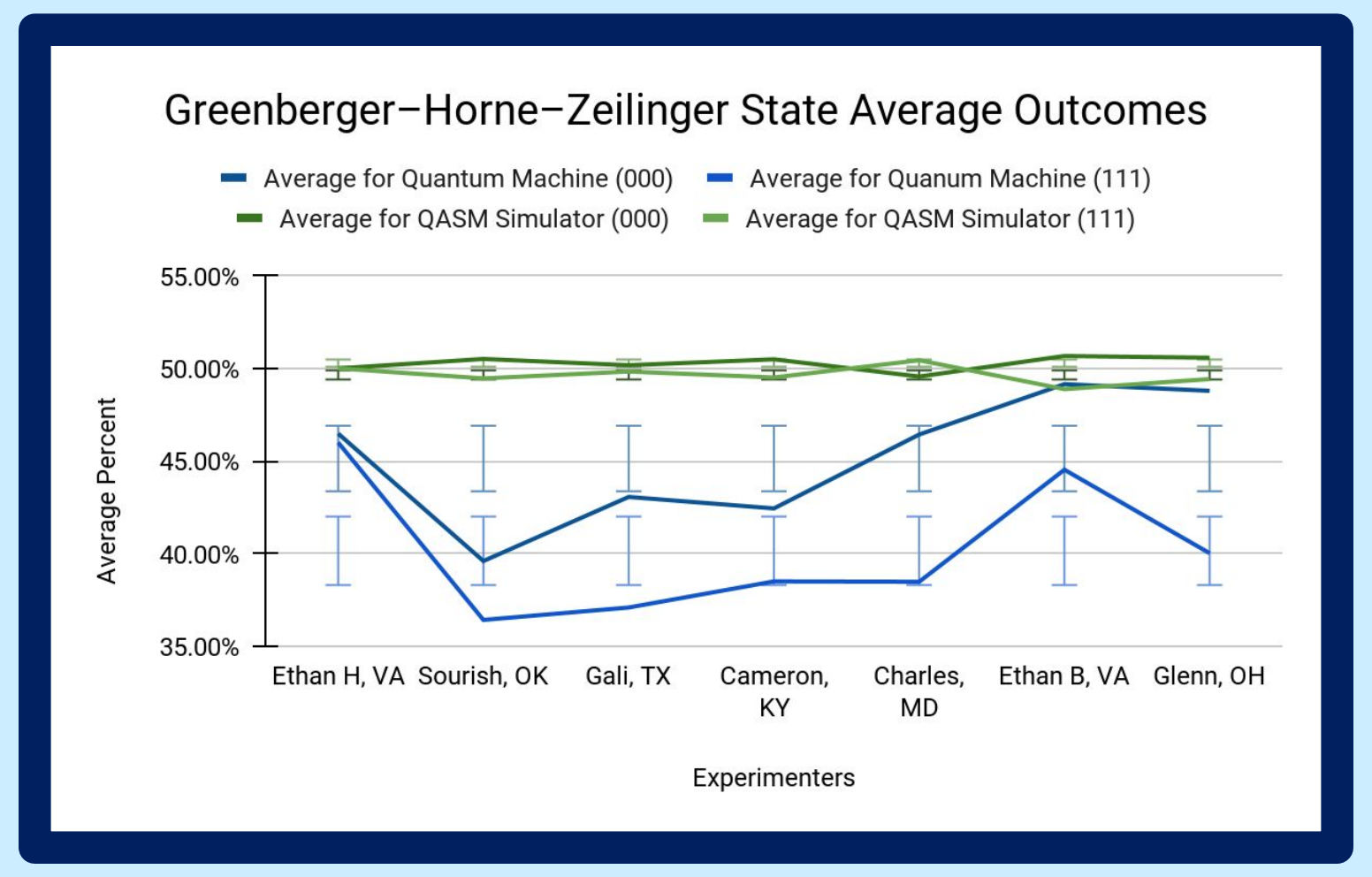


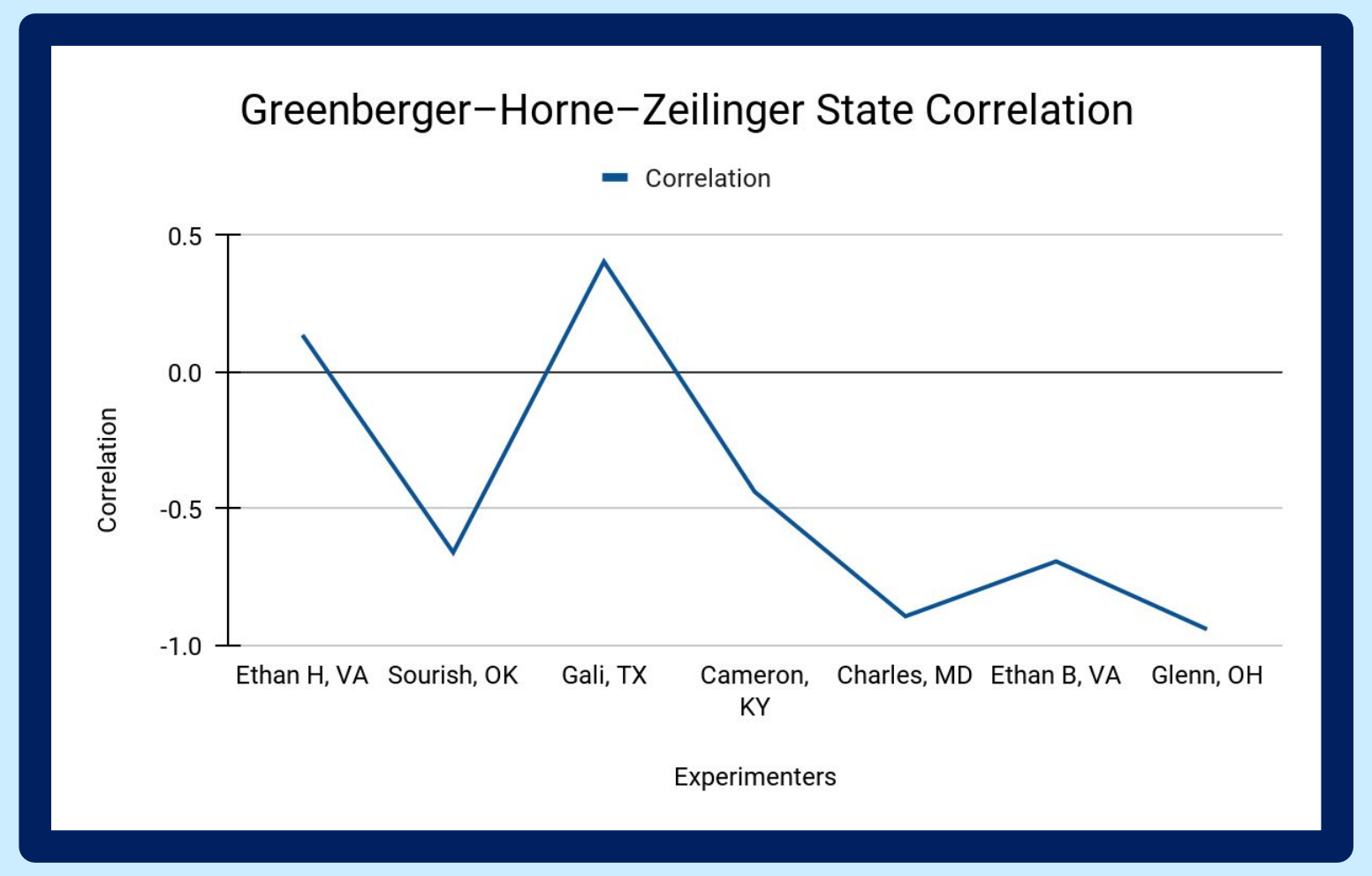
Double Qubit Circuit
The averages for the quantum machines are lower than on the simulator because some outputs are miscalculated as 01 or 10, both of which are incorrect outputs for the circuit. Additionally, the strong correlation(close to -1) shows that qubits are likely to be entangled.





Triple Qubit Circuit
Similarly, the averages for the quantum machines are lower than the simulator because some outputs on the quantum machines are miscalculated as 010, 100, or 110, which, again, are incorrect outputs for this circuit. Although there are a few outliers in the correlation data, the majority of the data points to an entanglement between qubits.





Conclusions

When comparing the results of the two and identifying quantum entanglement, it was found that the simulation had the best performance because it provided more accurate results when a Hadamard Gate was involved. The quantum computers can not provide a way for electrons to stay in a constant state long enough for their data to be as accurate.

- When comparing a quantum simulator and quantum hardware, there will be some limitations to the extent of the results on a quantum simulator because of the ideal possibility.
- On a quantum simulator, the results are more absolute with defined calculations while the actual quantum hardware does not propose perfect functionality according to the simulation since the number of qubits and their characteristics interact with physical circuits and gates that cause differentiations in the entanglement.

Acknowledgements

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