



Quantum Computing Profiling

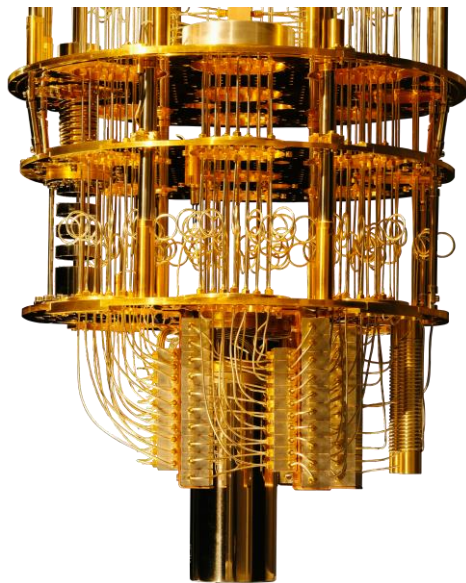
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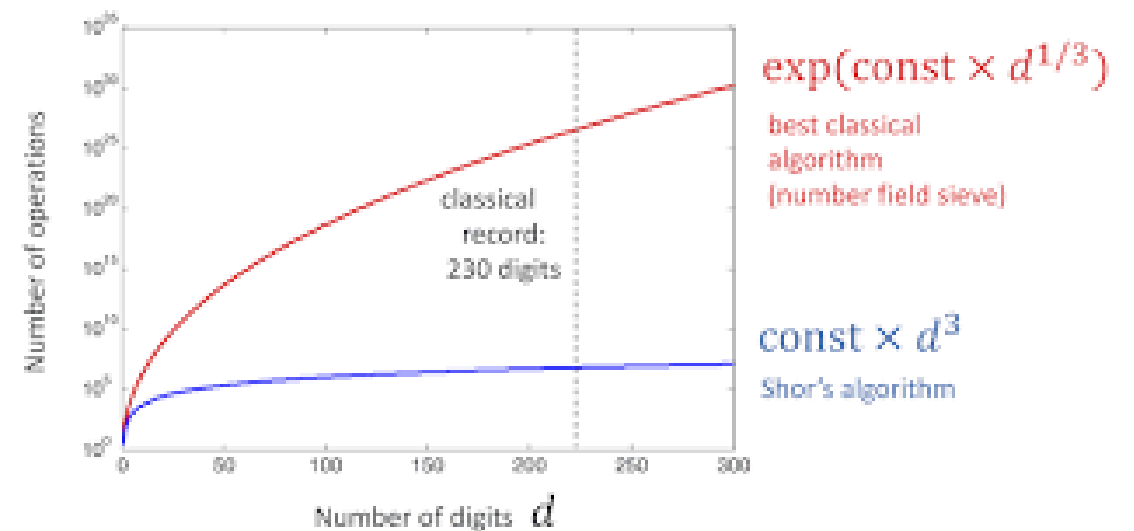
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Quantum Computers & Quantum Supremacy

“A **Quantum Computer** is a device that leverages specific properties described by quantum mechanics to perform computations” [1]



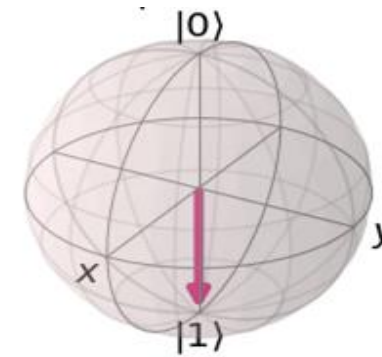
When field ready, Quantum Computers will be able to solve problems that classical computers cannot. For example, the integer factorization problem that is at the foundation of current encryption standards.



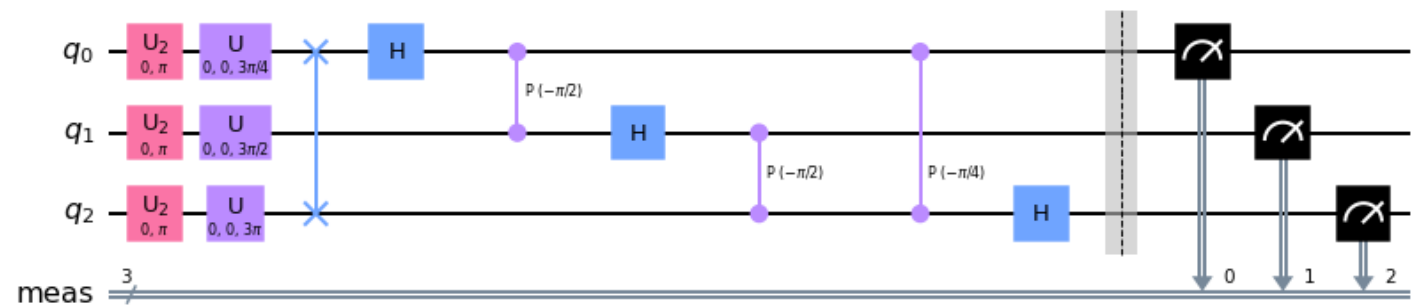
This research focuses on the programming aspects of quantum machines

How do we program a Quantum Computer

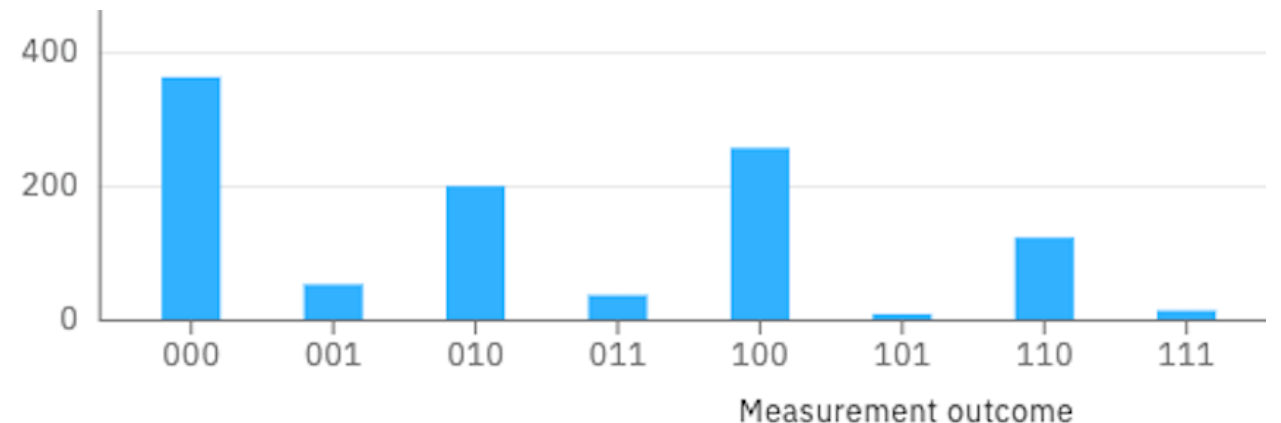
Prepare the Data: data in Quantum computers are stored in Qubits which are entities that can be in State 0 or 1 (like classical bits) but also in any superposition of the two.



Create a Circuit: currently, to run a quantum algorithm we need to create a circuit that implements the steps in the algorithm as gates.

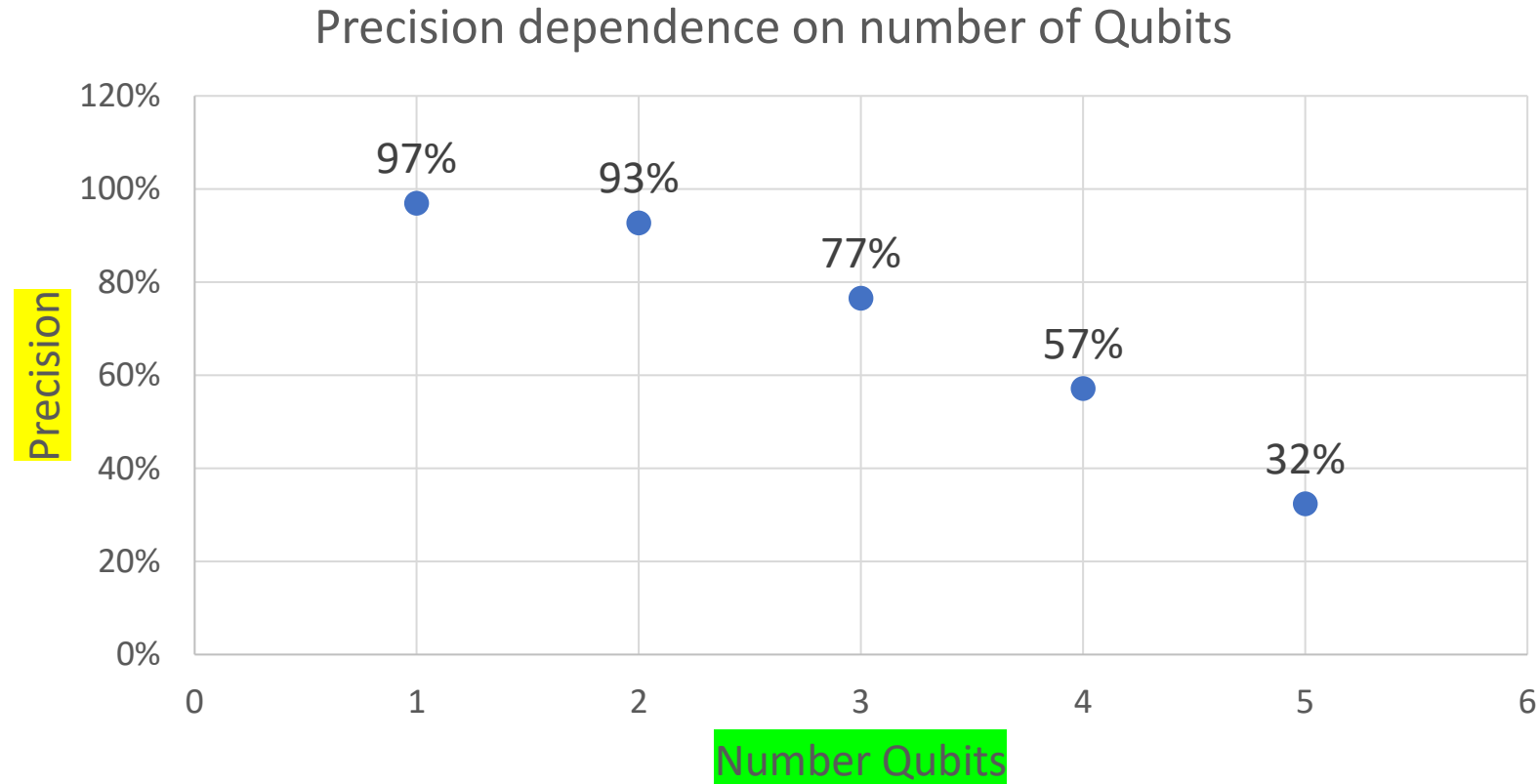


Analyze and Interpret the results: since they are provided as final 0/1 qubits states and are susceptible to random errors due to decoherence.



The need for our study in one image

Current Quantum Computers are still grappling with decoherence issues. These issues can be summarized in a decrease in **precision** as the **number of Qubits** increases



We created the above results by running our code on the IBM Falcon r4T quantum computer “imbq_lima” using the Qiskit programming language.

Research Proposal

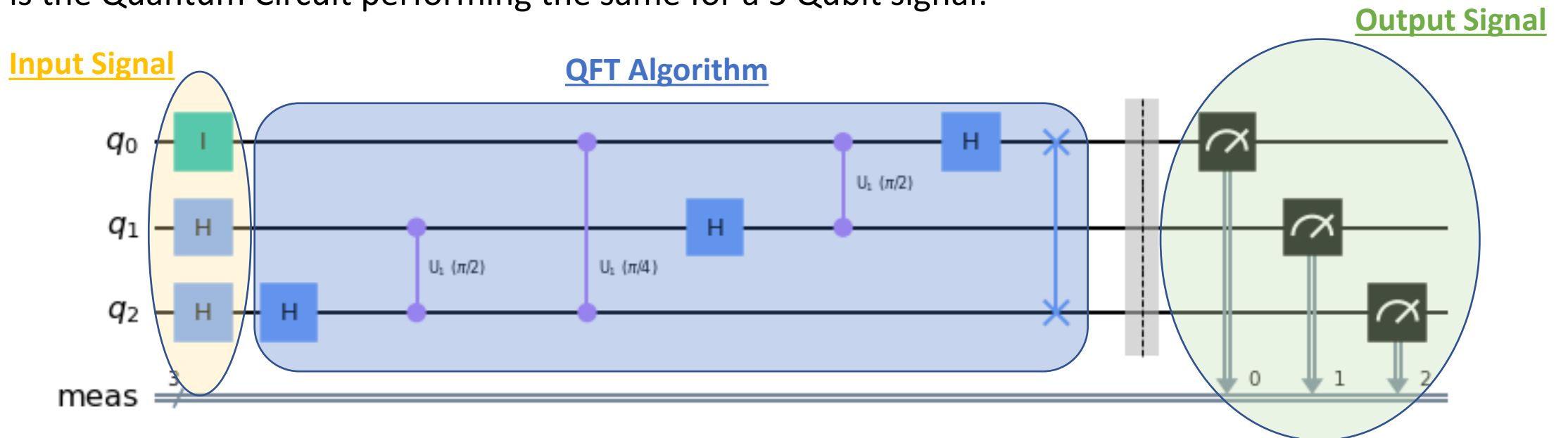
- Create a “Sample Code” that is relevant to the field of Quantum Computing to be used to profile current Quantum Computers and their Simulators.
- Run the sample code in the following systems:
 - IBM
 - Amazon
 - Google
- Study and report the results to establish performance benchmarks, code portability among platforms and future directions

Sample Code Choice & Implementation

For our code we choose the application of the Quantum Fourier Transform (QFT) Algorithm to a periodic signal of which we knew the outcome (from Matlab)

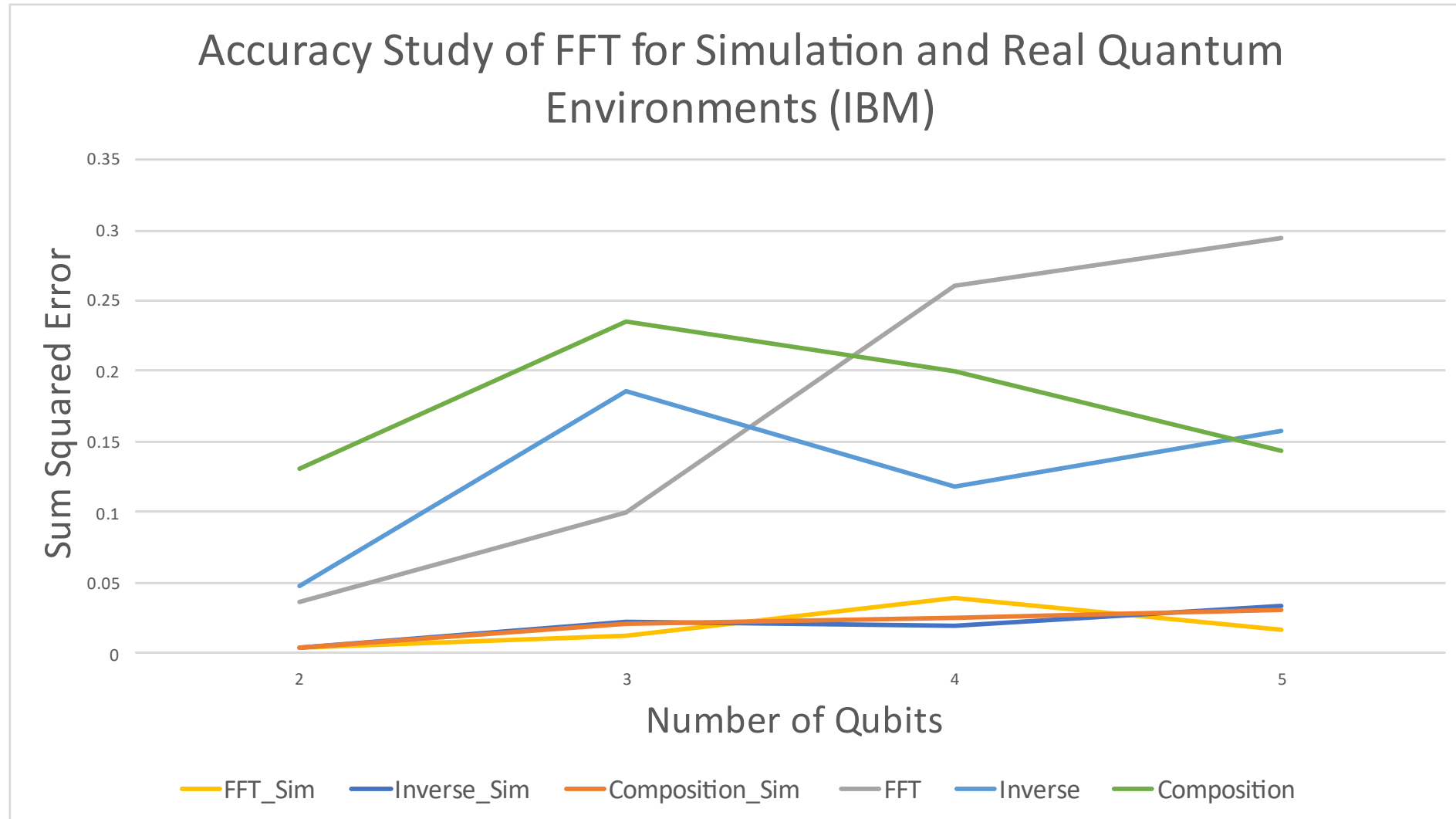


Here is the Quantum Circuit performing the same for a 3 Qubit signal:



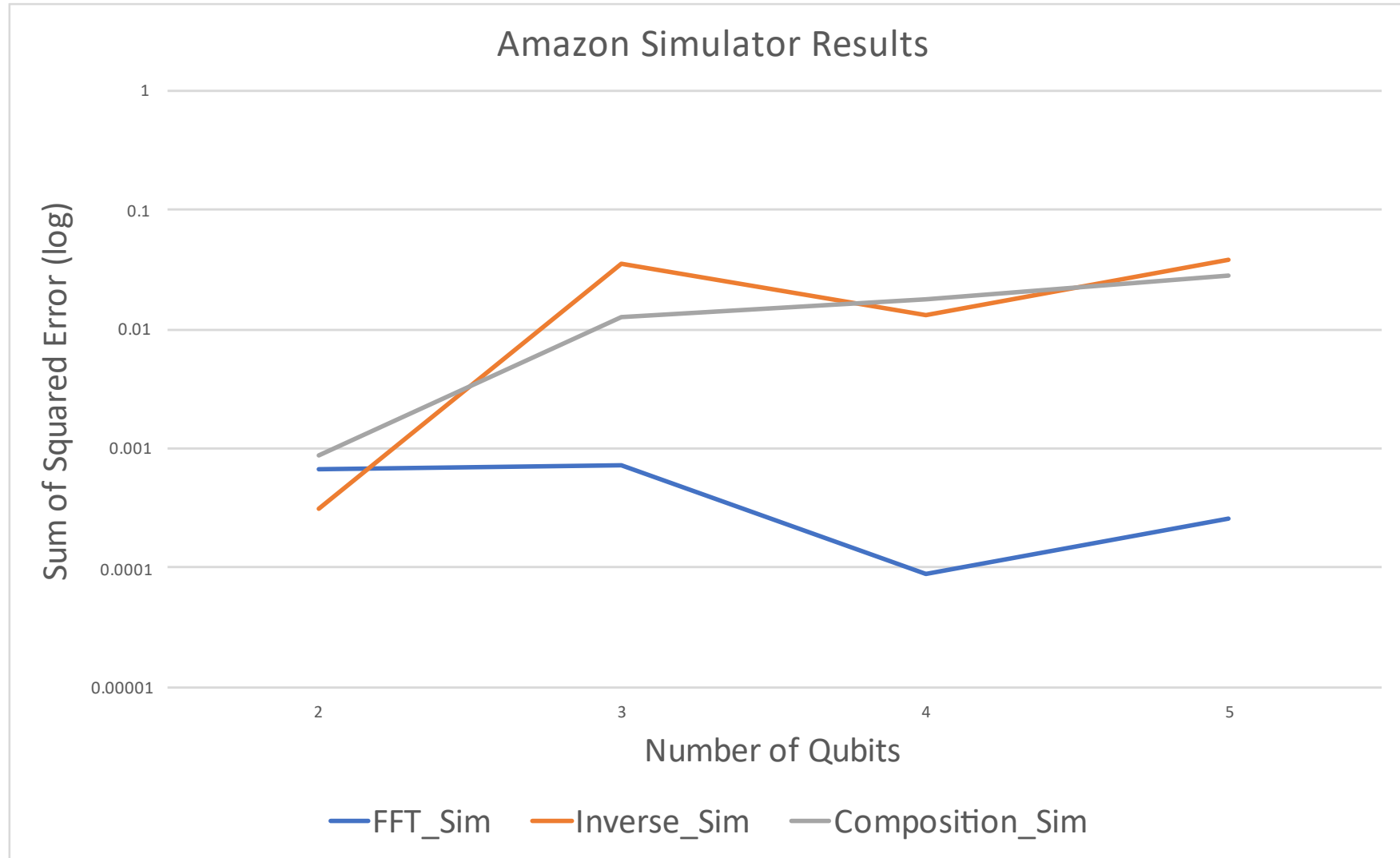
IBM Qiskit Results

- The graph shows QFT simulations on IBM Simulator and Real Quantum Machine (*ibmq_quito*)
- The error grows as the number of Qubits is added.
- Real QCs are not as reliable as the simulators predict.
- The simulators introduce some error and allow us to study what would happen when QCs will be reliable enough.



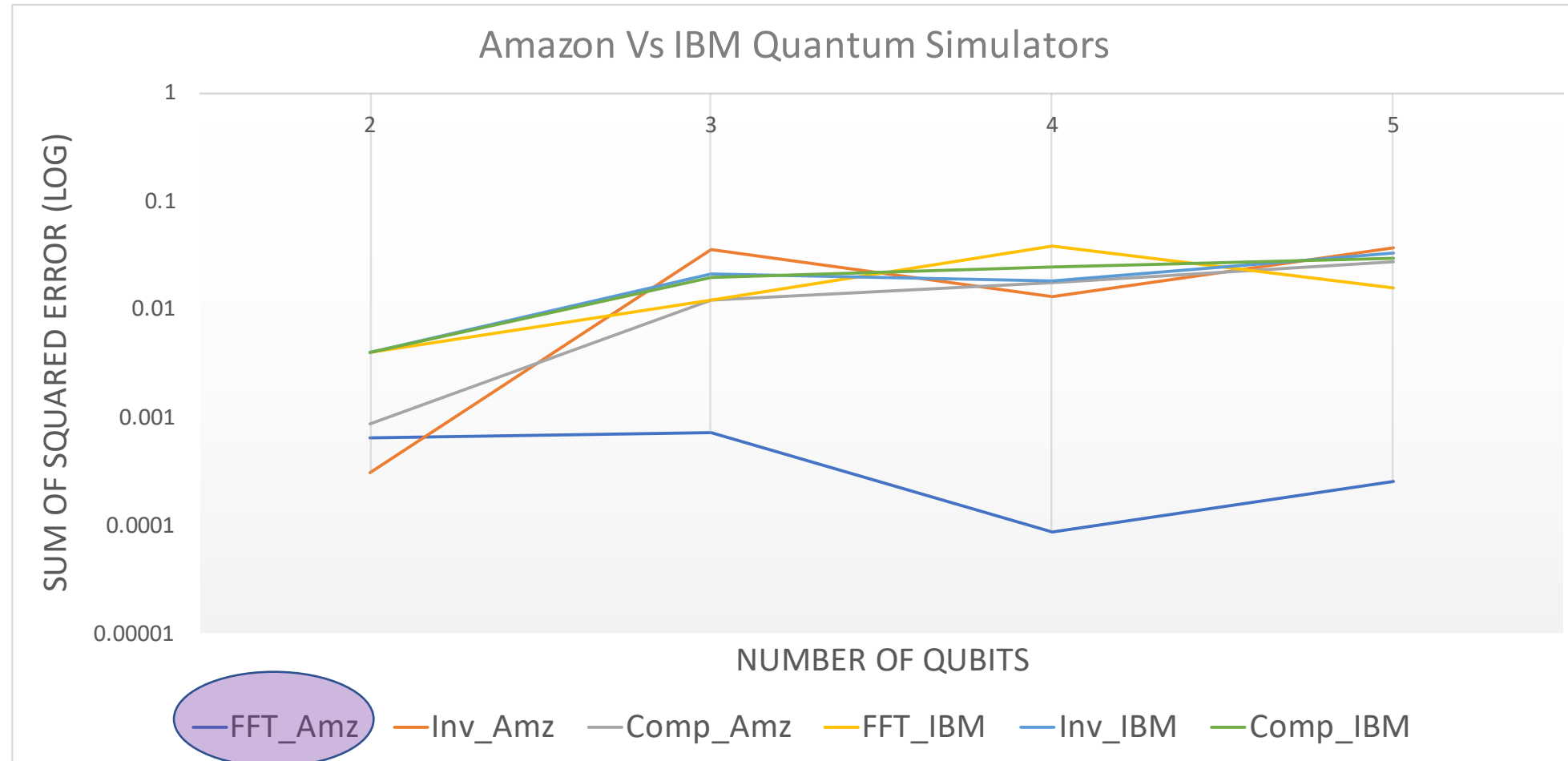
Amazon Braket Results (Simulators only)

- This figure shows how the error changes as the number of qubits is added for the Amazon Braket simulator.
- We still observe error growth as the number of Qubits increases.
- Interestingly, the QFT gives a better result than the inverse.



Amazon Braket Vs IBM Qiskit

- Comparison among the two simulator does not highlight any significant differences except for the QFT precision advantage for Amazon Braket.

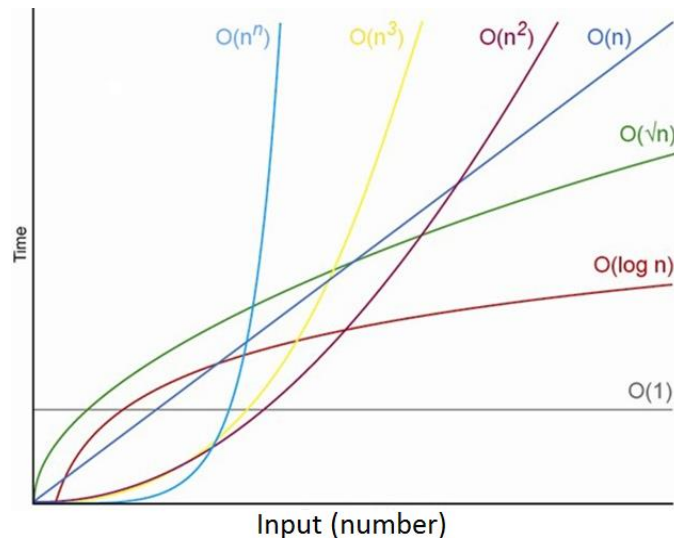


Research Next Steps

- Study the code with Amazon Braket Real QCs
- Study the code with Google Cirq
- Explore execution time and breakdown of gate error (are certain gates better implemented than others?)
- State vectors are ways that simulator can simplify coding by allowing programmers to initialize a system to a specific Qubits configuration. How do these system handle statevector?

Lesson Plan: Quantum Algorithm Complexity

Summary: Introduce the idea of time/space complexity for algorithms and how it is computed. I explain the computation by using Big-O notation as well as counting principles that have been used since the beginning of the course. The learners work in groups to find the complexity of two algorithms a min/max algorithm and a mean finding algorithm. We discuss the findings. I introduce Machine Learning ideas and present the difficulty to establish the complexity of algorithms that do not have a set number of steps due to their nondeterministic nature. Student work in groups to study a non-linear regression algorithm that will be the foundation for an individual take-home assessment



Summative Assessment

This assignment focuses on how you can apply algorithm complexity to Machine Learning.

The last digit on your MEID determines which algorithm you will be studying for this assignment.

Last # of MEID	Machine Learning Algorithm
0 or 5	Logistic Regression
1 or 6	K-Means
2 or 7	Support Vector Machine
3 or 8	Quadratic Least Square Regression
4 or 9	Decision Tree

For the algorithm that matches the last digit on your MEID perform the following:

- Research the algorithm (cite your sources!).
- State the scenario that you will analyze (regression/classification, size of the data). Choose something simple with one-dimensional independent variable and one-dimensional dependent variable.
- Study time/space complexity for the algorithm. Make sure to describe in detail your approach. You might need to sketch how the algorithm works and state your choices for the operations that mostly affect time complexity.

Reflection on RET experience

Training: I found it very fulfilling to participate to the lectures and I have learned a lot about ML and how it is used with data and in embedded sensors. The end of the week requirements are enough to give me a chance to reflect on our work but not enough to stress me.

Research: my research was on a field at its early stages (Quantum Computing). QC requires a lot background information before delving into the coding, but the support team did a great job on supporting me. I wish I had a chance to do some ML but there is still time 😊

Lesson Plan: I was able to come up with a lesson plan that fits one of my classes that needs the most hands-on material. The meetings were very useful although the breakout sessions were a bit hard to take advantage of given the online format.

Networking with other participants: I did not really interact with anybody else aside from a few chat messages and the breakout sessions. I think it's due to the format that does not fit my personality and that if we were in-person I would have been able to create more networking opportunities.

Some References

1. *J. Hidary, Quantum Computing: An Applied Approach. Champ: Springer, 2019.*
2. *Devitt, Simon J. "Performing quantum computing experiments in the cloud." Physical Review A 94.3 (2016): 032329.*
3. *Weinstein, Yaakov S., et al. "Implementation of the quantum Fourier transform." Physical review letters 86.9 (2001): 1889.*
4. *Terhal, Barbara M. "Quantum supremacy, here we come." Nature Physics 14.6 (2018):530-531.*
5. *Qiskit Development Team "Learn quantum Computing Using Qiskit". URL: <https://qiskit.org/textbook/preface.html> (last accessed June, 2021).*

Questions?