Investigation Into the Visualization of Quantum Computing Algorithms

Authors: Vaibhav Santurkar, Hans-Peter Bischof

Presenter: Vaibhav Santurkar, Graduate Student at Rochester Institute of Technology

Presenter E-mail: vs4503@g.rit.edu

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Vaibhav Santurkar

- Hello everyone! I am a graduate student at Rochester Institute of Technology. Currently, I am working towards completing my Master's degree in Computer Science with an advanced specialization in Big Data Analytics. My interests include Web Services and Service-Oriented Computing, Database System Implementation, and Quantum Computing. In my spare time, I enjoy collecting model aircraft and flying their virtual counterparts in Microsoft Flight Simulator.

Research Topics

- We have chosen quantum computing as our research topic as it is a relatively unexplored field of computer science.
- Specifically, we chose to focus on the visualization of quantum algorithms as quantum visualization tools are limited in their capabilities.
- Building multi-purpose tools for quantum visualization and quantum algorithms has considerable potential as a research topic.

Project Rationale

- Despite the complexity of quantum mechanics and computing, is the visualization of quantum programs comprehensive?
- Multiple visualization tools work in multiple scenarios based on the algorithm.
- A visualization framework is required to illustrate some popular quantum algorithms.

Goals

- Apply visualization framework to algorithms with multiple qubits.
- Namely, Deutsch-Jozsa, Bernstein-Vazirani, Shor's, and Grover's algorithms.
- Analyze the results of the framework and determine the interpretability of the graphs generated.

What is Quantum Computing?

- Quantum computing is a field of computer science that utilizes quantum concepts to build algorithms.
- By making use of some fundamental quantum concepts, we can design simple solutions to once-complicated problems.
- Qubits, superposition, entanglement, and interference are the concepts used to design quantum programs.

Fundamental Concepts of Quantum Computing

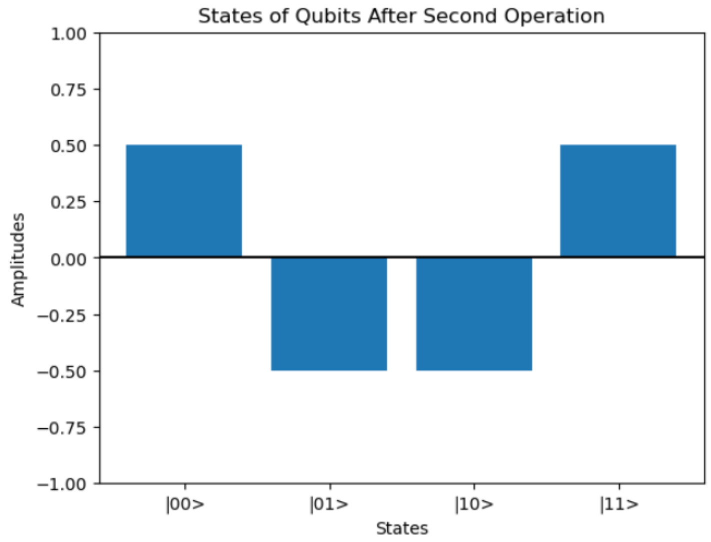
- Qubits: The quantum equivalent of a bit. A qubit exists between multiple basis states at the same time.
- Superposition: When a quantum state is a combination of multiple states at the same time.
- A qubit '|q>' is of the form "α|0> + ß|1>" where α and ß are the amplitudes of the basis states |0> and |1>.

Fundamental Concepts of Quantum Computing

- Entanglement: 2 qubits can be correlated in a quantum sense, iff the changes made to one qubit are reflected in the second qubit.
- Interference: The concept that 2 qubits of the same amplitude and basis state reinforce each other and vice versa.

Dump Machine and Amplitude Visualization

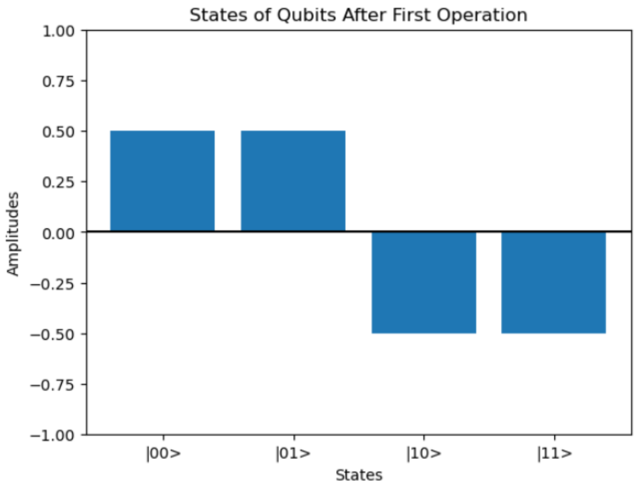
- For multi-qubit systems, visualizing the probability amplitudes of the qubits is the best way to explain the steps of an algorithm.
- The 'DumpMachine' function in Q#, when called, records all the data related to the state of the qubits in a program.
- At certain intervals in the program, the 'DumpMachine' function was applied and the generated JSON data was collected.
- By isolating the amplitude data, a bar graph was drawn for each step, which depicts the state of the qubits at that point in the algorithm.
- These graphs efficiently show how the algorithm manipulates the qubits.

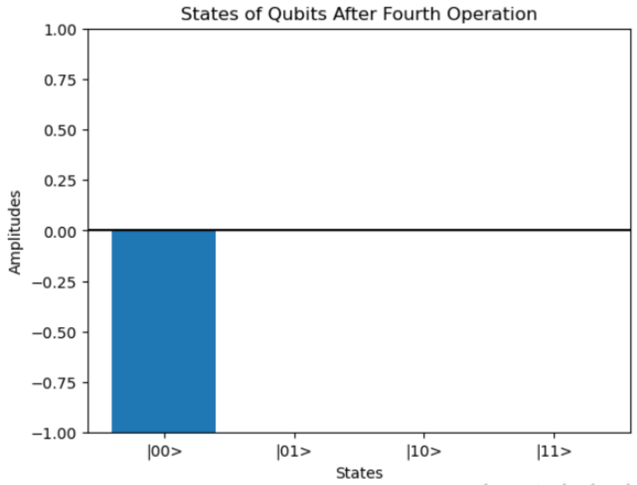


Quantum Algorithms

- Idea: To test if a function is constant (f(0) = f(1)) or balanced (f(0) ≠ f(1)) / To guess an integer string in a single computation.
- Uses the concepts of superposition, X (bitflip), CNOT (XOR), and H gates.
- Classical algorithms will take ‘n’ computations to reach an answer, while quantum algorithms will take only 1 computation.
- The steps performed in these algorithms are:

1) Apply the H gate to all qubits.
2) Apply Oracle transformation U_f to all qubits.
3) Apply the H gate to a subset of qubits and measure the result.



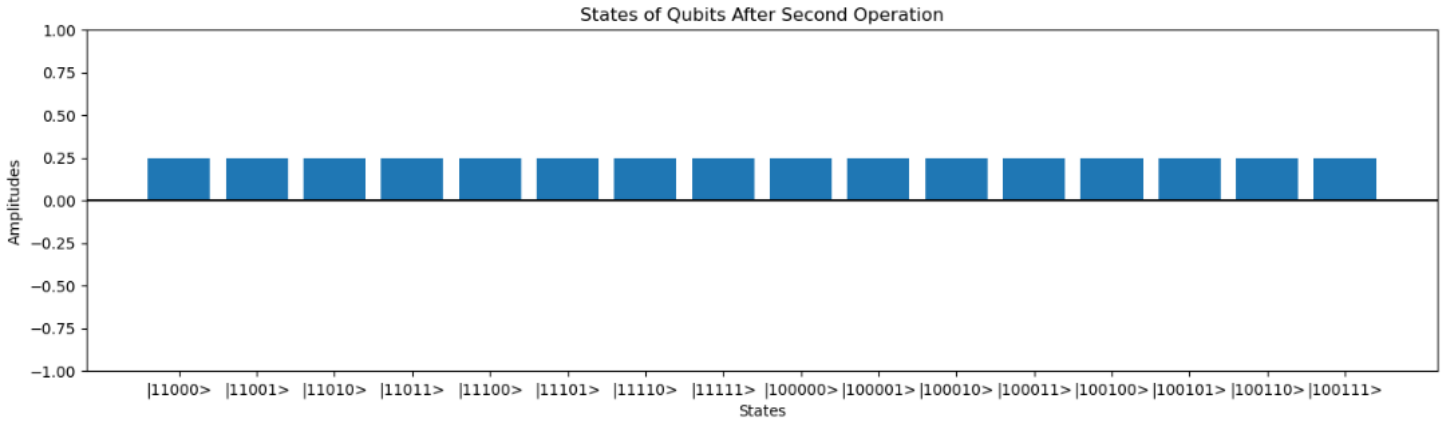


Testing if a function is constant/balanced. Output: Balanced function.

Shor's Algorithm

- Idea: The application of quantum principles to find the answer to the following problem:
- a^x mod N is cyclic (periodic) for 'x' by remainder cycle, where 'a' and 'N' are co-primes.
- In other words, when we take increasing powers of 'a' and then apply mod N to each of these, the remainders obtained start repeating and form a cycle.
- For example, if a = 2, N = 3 the cycle is 2:

  2 mod 3 = 2, 2^2 mod 3 = 1, 2^3 mod 3 = 2, 2^4 mod 3 = 1
- We use the same steps as before, but we apply Quantum Fourier Transformation (QFT) instead of the oracle U_f.
- Using QFT, we can create quantum adder and multiplier functions, comparable to their classical counterparts.
- These functions transform the qubits' states from |y> to |a^x mod N>.
- By applying superposition to the above states we can test multiple values of 'x' in one computation.
- Measuring the resulting states, will yield the period of the 2 co-primes.

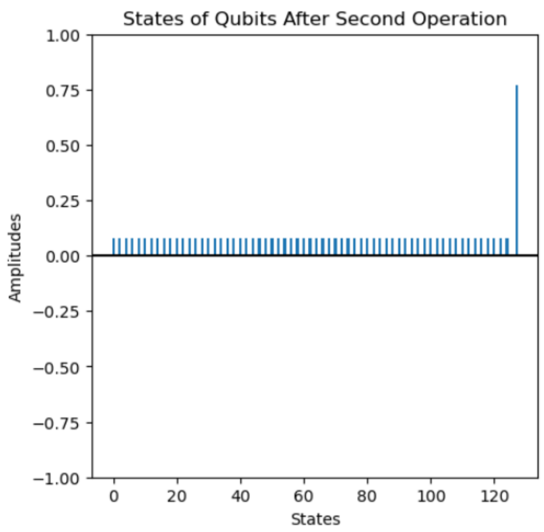


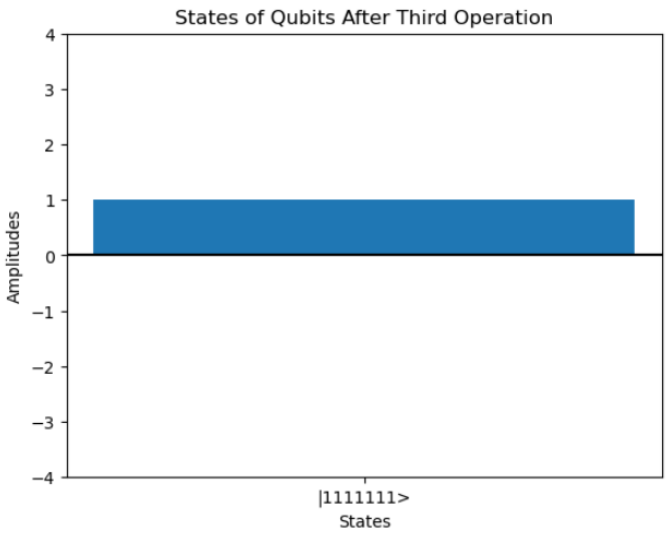
Grover's Algorithm

- Idea: The quantum equivalent of any classical search algorithm, i.e., searching a minimum spanning tree or finding the shortest path.
- Any x, where x satisfies f(x) = 1, is considered a solution, and any other value of x is considered a fail.
- This algorithm can be applied to multiple scenarios and hence has 'template states' which can be modified based on the scenario.
- Here, qubits states are reflected through 2 operations, namely:

1. Through a rotational unitary matrix of the form: $H R_0 H$ where H is the Hadamard transform, and R is a rotational transform.
2. Through a 'good'/'bad' template state. The resulting states and their amplitudes represent possible solutions to the search problem.

- Upon measuring the final states, if we get 1, the algorithm has found a solution to the problem, else it ignores the state.





Conclusion and Future Work

- Quantum algorithms and states can be visualized in an unambiguous way, through the proposed framework.
- Current visualization tools have scope for improvement, as quantum algorithms are commonly multi-qubit algorithms.
- The framework should be extended to automatically accept any quantum algorithm and display the quantum states.

Thank You!

Please feel free to email me any questions you have about my presentation!