Experimental comparison of two superconducting quantum computers

Yulun Wang[1,2], Robert Harrison[1] and Predrag Krstić[1]

[1]Institute for Advanced Computational Science, Stony Brook University

[2]Department of Materials Science and Chemical Engineering, Stony Brook University

Abstract

Quantum computers as an emerging technology are promising to be vastly powerful at solving certain problems than any conventional computer. Two companies IBM and Rigetti based on the same architecture, superconducting transmon qubits, have reached a new level of maturity. With their public open access, we are able to implement Grover's algorithm to test and compare quantum computers irrespective of their hardware design logics.

Devices Topology

The IBM Q and Rigetti are quantum cloud services providing access to a set of IBM's or Rigetti's prototype quantum processors which are based on superconducting Josephson junctions. In this work, 5 qubit machine (***ibmqx4***), 14 qubit machine (***ibmq_16_melbourne***) and 16 qubit machine (Rigetti 16Q Aspen-1) are employed to implement Grover's search algorithm. The accuracy of the quantum results is compared with those simulated at classical machine.

The connection between qubits of superconducting machines have topological constraints. The arrows in topological map indicate the allowed CNOT operations and their preferred directions.

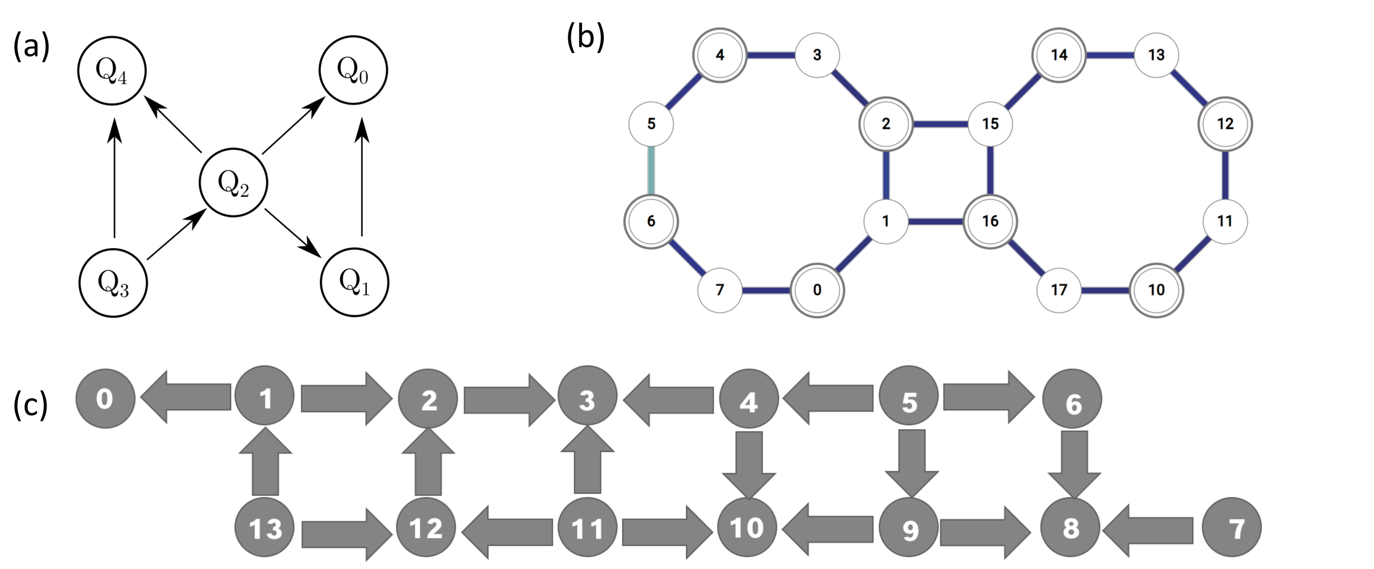


Fig. 1. Devices Topology: (a) ibmqx4; (b) Rigetti 16Q Aspen-1; (c) ibmq_16_melbourne.

Multi-qubit Gate Test

CNOT and Toffoli gate as key components building universal quantum circuits are tested before the implementation of algorithms. The algorithm success probability (**ASP**), which is the probability of measuring the expected state as the experimental outcome is used here to scale the performance.

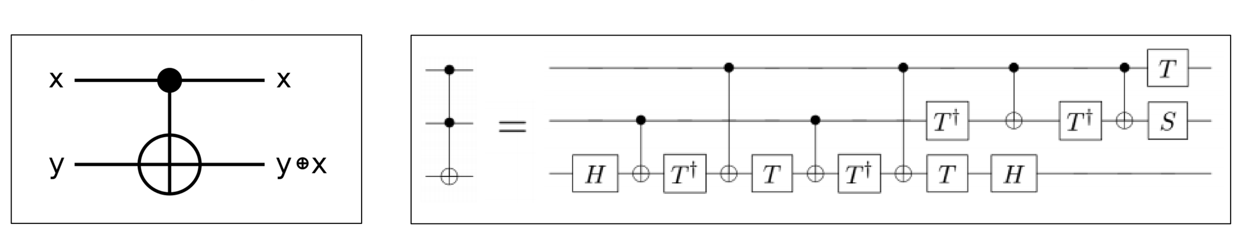


Fig. 2. CNOT gate(left), and Toffoli gate (right).

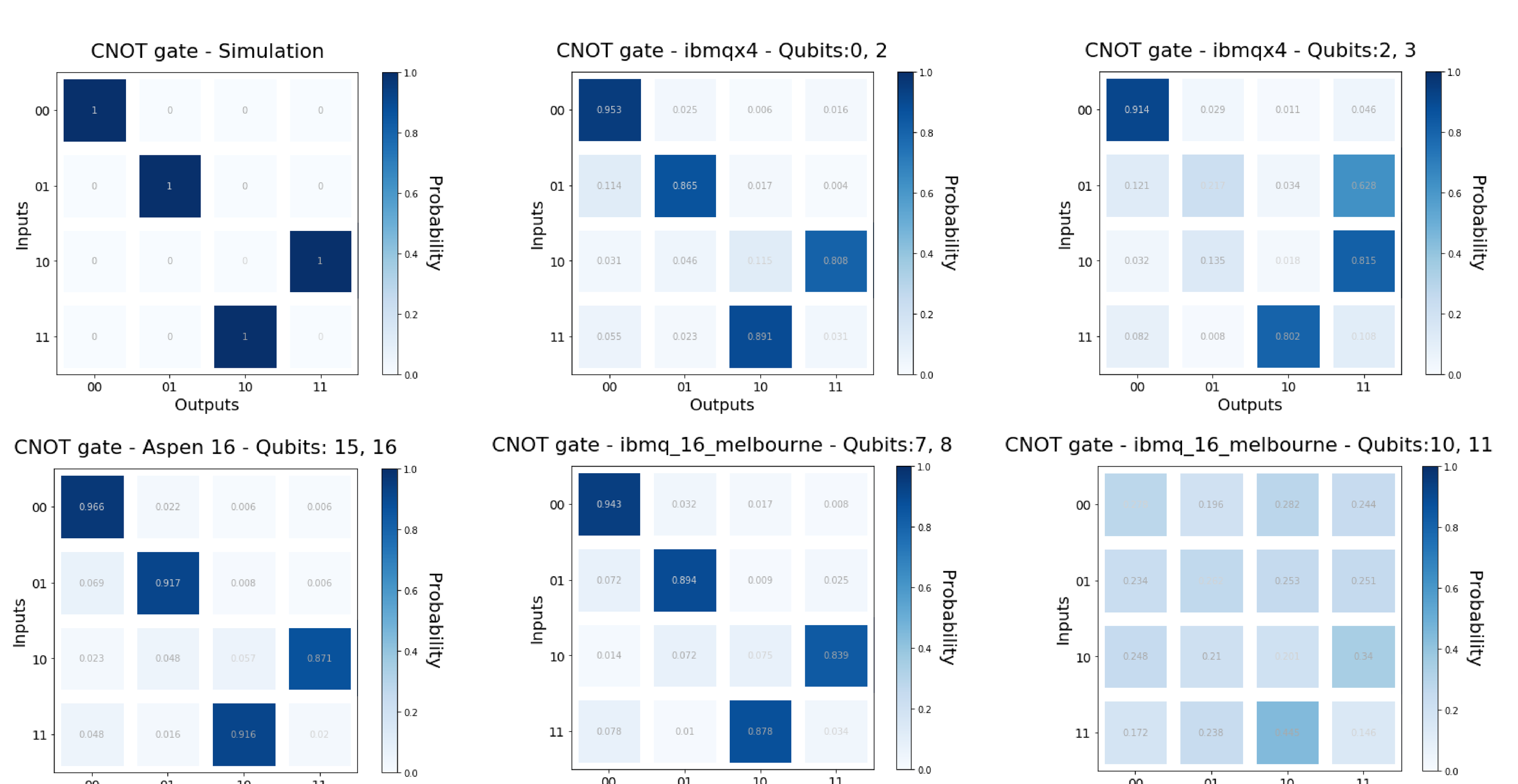


Fig. 3. CNOT gate test results.

CNOT operation were applied on different pairs of qubits on different machine. The fluctuated outcomes of different pairs on each machine revealed that the choice of physical qubits is important.

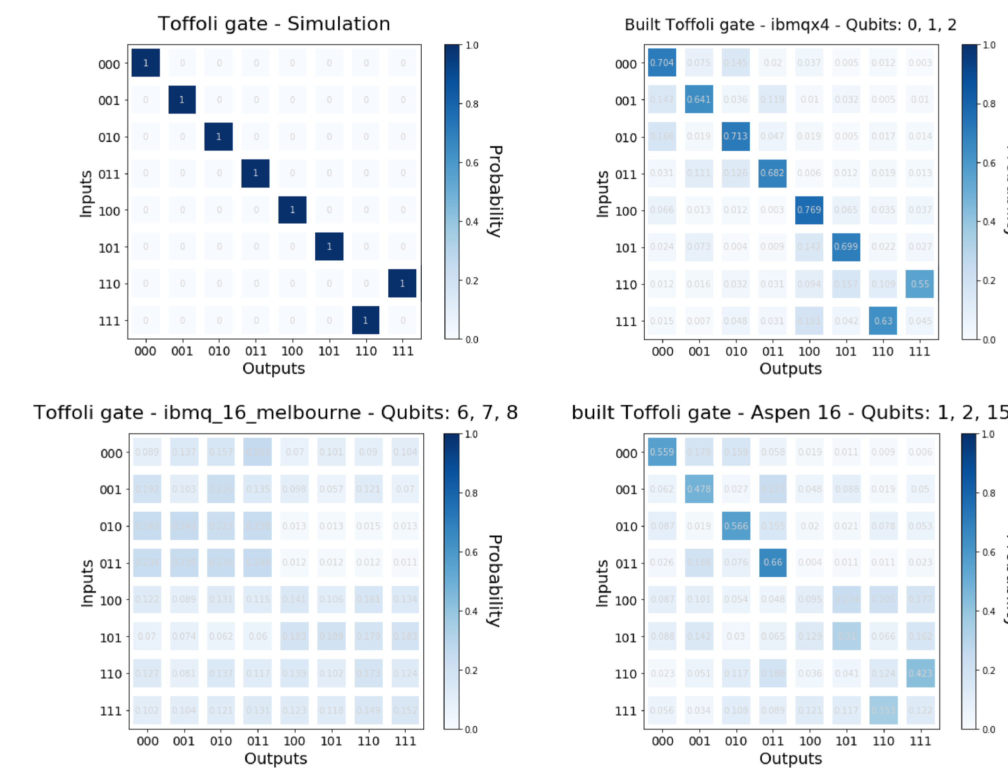
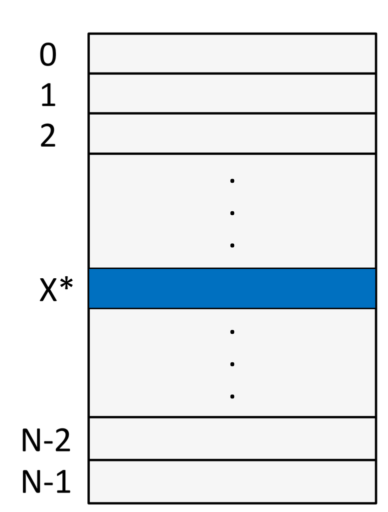


Fig. 4. Toffoli gate test results.

Toffoli gate as the key component of Grover's search algorithm are vital to overall algorithm performance. The testing results on different machines demonstrated that small quantum system works better. With more qubits, the controlling of quantum computer is harder to achieve and maintain a good level. And quantum computer is more likely to receive disturbance from environment with a large scale.

Grover's Algorithm

- Quantum computing relies on quantum superposition and entanglement of states, using quantum bits (**qubits**).
- Quantum computers would be able to efficiently solve problems not practically feasible on classical computers.
- One such problem is Grover's algorithm for unstructured search.



Problem: Given f: {0,1,…,N-1} → {0,1}, find x: f(x)=1
Hardest case: There is exactly one x: f(x)==1

On classical computer, unstructured search takes time ~ $O(N)$
Quantum algorithm applied to quantum computer is ~ $O(\sqrt{N})$

Principal steps of the algorithm:

- Initialization;
- Phase inversion;
- Inversion around the mean;
- Measurement.

Initialization

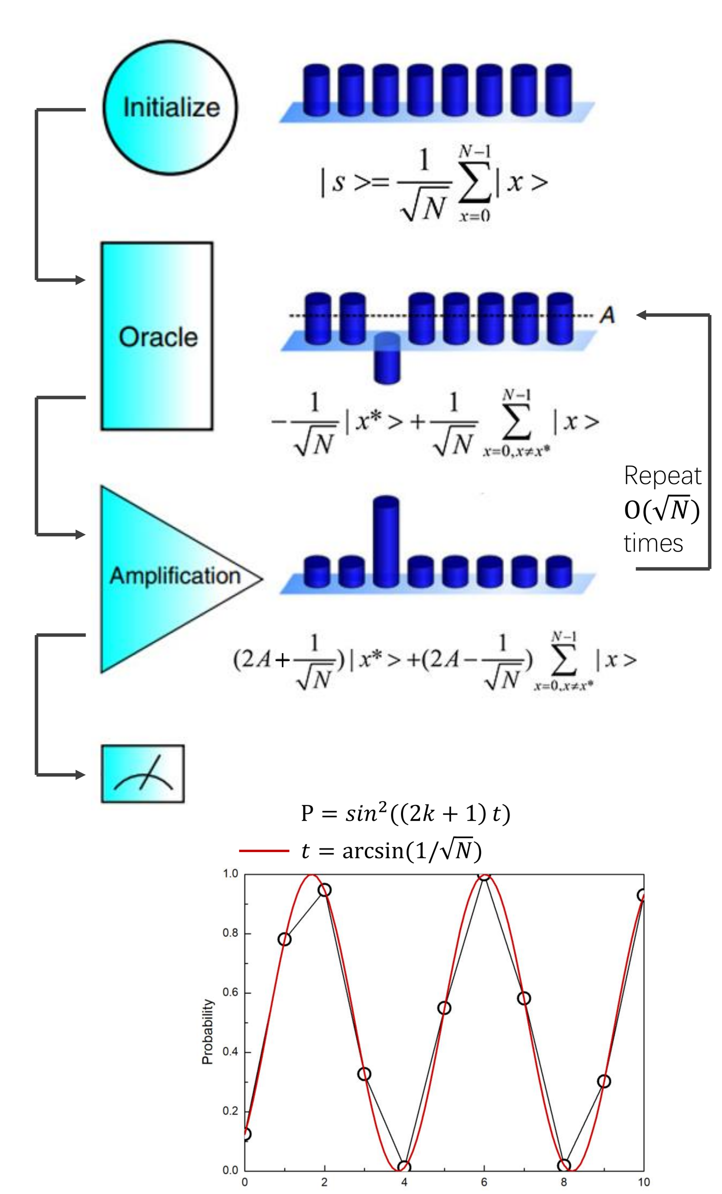
Initially is created a superposition of states of equal amplitudes $\frac{1}{\sqrt{N}}$. Among them is target state x*.

Phase Inversion (oracle)

Phase inversion marks the solution(s) by flipping the sign x*, lowering the mean a bit.

Inversion about mean (amplification)

This step performs a reflection about the mean, thus increasing the amplitude of the marked state x* by ~ $\frac{2}{\sqrt{N}}$ above where it was initially. The mean now goes up a bit (close to $\frac{1}{\sqrt{N}}$).



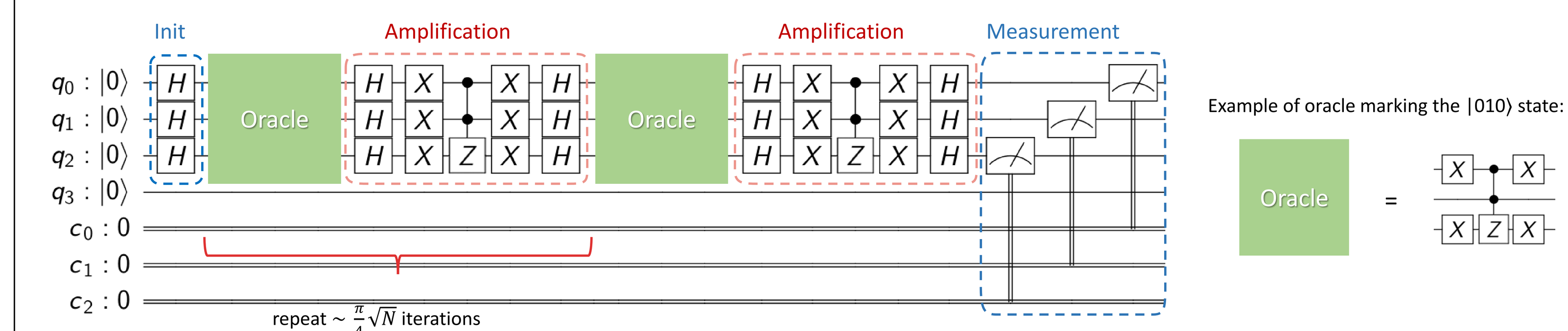


Fig. 5. Quantum circuit of Grover's search algorithm.

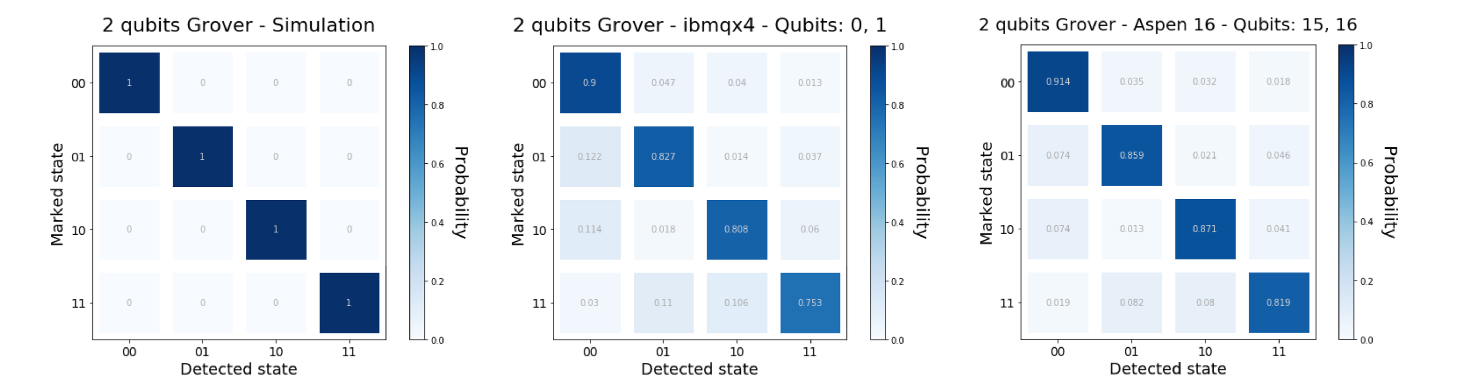


Fig. 6. 2 qubits Grover's search.

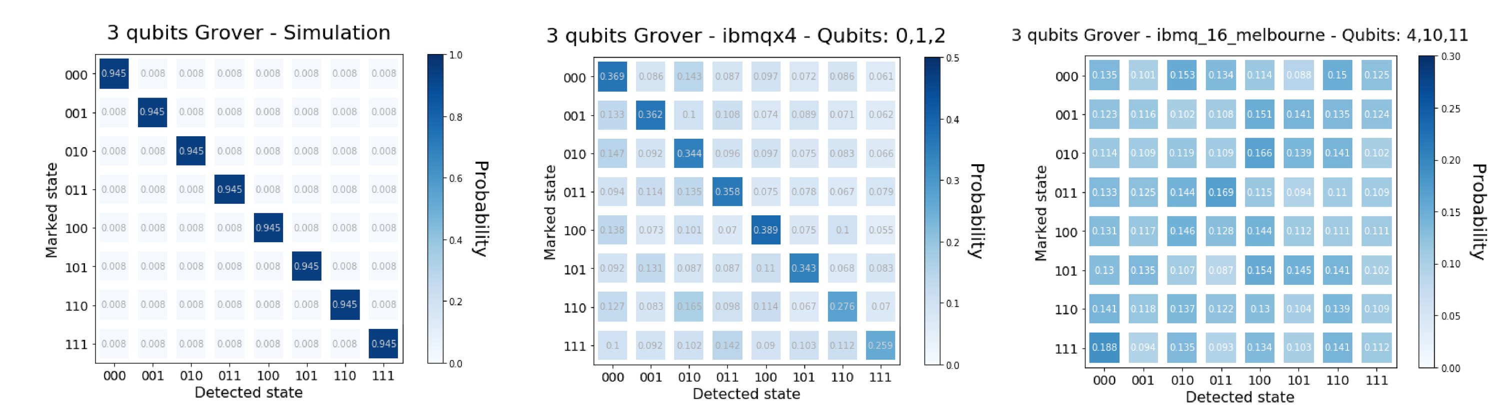


Fig. 7. 3 qubits Grover's search.

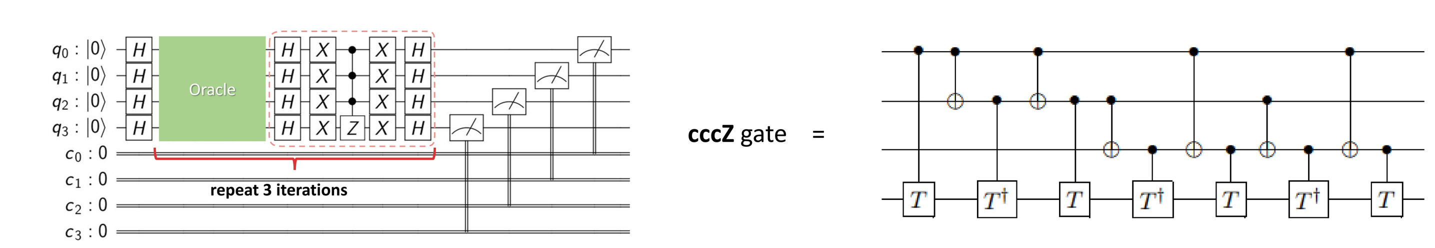


Fig. 8. Quantum circuit of 4 qubits Grover's search.

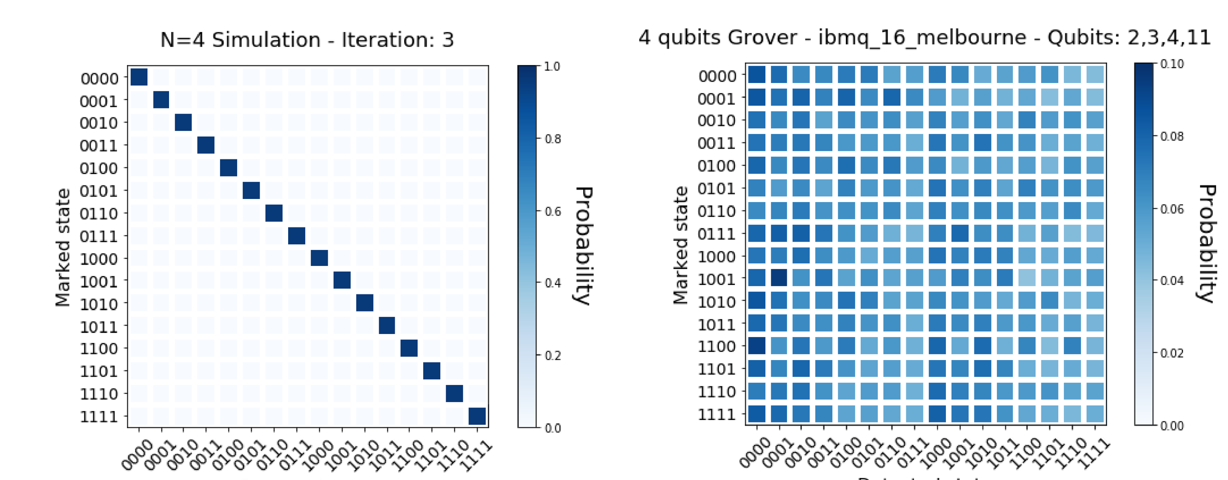


Fig. 9. 4 qubits Grover's search.

Conclusions

- Testing of multiple quantum gates and Grover's algorithm shows big errors, especially with a higher depth circuit, but with more expectations to the future.
- When working on a real quantum computer:
  - Recognition of different performance of different physical qubits is vital;
    - Hardware problem
  - Different system with different number qubits works differently.
    - Smaller system works much better
- Some error correction/mitigation strategies improve performance at single and double qubit gates.
  - Dynamic Decoupling
  - Dynamic Correcting
  - More research effort needed…