QUANTUM TELEPORTATION ON THE IBM QUANTUM COMPUTER

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FINAL PRESENTATION
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BASICS OF QUANTUM COMPUTING

- THE QUBIT
- QUANTUM ENTANGLEMENT
- QUANTUM LOGIC GATES
THE QUBIT

- Known as the “quantum bit”
- Unlike a classical bit, it can simultaneously be 0 and 1—also known as “superposition” of states
- The qubit’s state is represented by any arbitrary point on the Bloch sphere (either inside or on the surface)

\[ \Psi = \cos \frac{\theta}{2} |0> + \sin \frac{\theta}{2} e^{i\phi} |1> \]

- A pure qubit state is a superposition of the basis states and can also be represented as:

\[ |\psi> = \alpha |0> + \beta |1> \]

where \( \alpha \) and \( \beta \) are probability amplitudes and can both be complex numbers
WHAT IS QUANTUM ENTANGLEMENT?

• **Quantum Entanglement** of two particles causes them to share a bond such that altering the state of one particle (spin) automatically alters the other’s state.

• Bell States / EPR states (Einstein, Podolsky, and Rosen)

  - Maximally entangled states
    \[
    |\beta_{00}\rangle = \frac{|00\rangle + |11\rangle}{\sqrt{2}}
    \]
    \[
    |\beta_{01}\rangle = \frac{|01\rangle + |10\rangle}{\sqrt{2}}
    \]
    \[
    |\beta_{10}\rangle = \frac{|00\rangle - |11\rangle}{\sqrt{2}}
    \]
    \[
    |\beta_{11}\rangle = \frac{|01\rangle - |10\rangle}{\sqrt{2}}
    \]
QUANTUM LOGIC
GATES

X GATE
HADAMARD GATE
CONTROLLED NOT GATE
WHAT ARE QUANTUM LOGIC GATES??

Quantum analog of Classical Logic Gates

Use polarizers to manipulate the spin or state of the photonic qubits
THE PAULI-X GATE (NOT GATE)

• Acts on a single qubit
• Quantum equivalent of the NOT gate
• Manipulates the state of a qubit through a “bit flip” or rotation around the x axis of the Bloch Sphere by $\pi$ radians
• Represented by the following

Matrix representation  Circuit representation

$X = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$  $X$

$X|0\rangle = |1\rangle$
$X|1\rangle = |0\rangle$

Fig1: Bloch Sphere Rotation for X Gate: $\pi$ radians
THE H-GATE (HADAMARD GATE)

• Acts on a single qubit

$H = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$

Circuit representation

Fig 2: Bloch Sphere
Rotation: H-Gate $\pi$ around Z axis and $\pi/2$ radians about Y axis

• Puts qubits in superposition of their states

$H|0\rangle = \frac{1}{\sqrt{2}} (|0\rangle + |1\rangle) = \frac{1}{\sqrt{2}} |0\rangle + \frac{1}{\sqrt{2}} |1\rangle$

$H|1\rangle = \frac{1}{\sqrt{2}} (|0\rangle - |1\rangle) = \frac{1}{\sqrt{2}} |0\rangle - \frac{1}{\sqrt{2}} |1\rangle$

$|\alpha_0|^2 = \frac{1}{2}$  $|\alpha_1|^2 = \frac{1}{2}$

Acting on pure states...

...gives a balanced superposition...
THE CNOT-GATE
(CONTROLLED NOT GATE)

• Acts on two qubits
• Used to generate entangled states
• First qubit is the control qubit, second is the target qubit
WHAT IS QUANTUM TELEPORTATION??

- DEFINITION
- PROTOCOL
- CIRCUIT
UNIDIRECTIONAL QUANTUM TELEPORTATION

• Data transmission (such as a state) from one location to another without physically transmitting the information

• Can be done through quantum entanglement
SIMULATING QUANTUM TELEPORTATION ON THE ACTUAL MACHINE

Figure 1: Traditional Unidirectional Quantum Teleportation Circuit

Figure 2: Modified Unidirectional Quantum Teleportation Circuit based on Principle of Deferred Measurement
SIMULATING QUANTUM TELEPORTATION ON THE ACTUAL MACHINE (CONT’D)

Qiskit

• A python package which provides tools for creating and manipulating quantum programs and running them on prototype quantum devices and simulators

• I used Qiskit Terra and Aer
IBM QUANTUM COMPUTER DIAGRAM

1. From the composer/Qiskit, the job is sent to the cloud where it is queued and then sent to a control/measurement computer.

2. Microwave electronics mix signal down to a frequency that can be digitized.

3. Measurement pulses go down the same coax after the control pulses.

4. Measurement pulses interact with qubits via readout resonators and are reflected back.

5. Measurement pulses are routed by circulators, and isolators prevent noise from getting to the qubits.

6. Amplifiers at 4K.

7. Microwave electronics mix signal down to a frequency that can be digitized.

8. Mixed-down signals are digitized by a classical computer and the result is classified as 0 or 1.

9. Results are sent back to you over the cloud.
TESTING FIDELITY OF TELEPORTATION ON VARIOUS QUANTUM COMPUTERS

• Pole States

(Surface of Bloch Sphere)

\[ |0> \]
\[ |1> \]
\[ |+> = \frac{1}{\sqrt{2}} ( |0> + |1> ) \]
\[ |-- = \frac{1}{\sqrt{2}} ( |0> - |1> ) \]
\[ |+i> = \frac{1}{\sqrt{2}} ( |0> + i|1> ) \]
\[ |-i> = \frac{1}{\sqrt{2}} ( |0> - i|1> ) \]

<table>
<thead>
<tr>
<th>Quantum Computer</th>
<th>Average Fidelity in Simulation (Noise Model) Shots: 10,000</th>
<th>Average Fidelity on Actual Machine Shots: 1024</th>
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<tbody>
<tr>
<td>IBMQX4</td>
<td>0.745616</td>
<td>0.735351</td>
</tr>
<tr>
<td>IBMQX2</td>
<td>0.889700</td>
<td>0.812825</td>
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<tr>
<td>IBMQ16 MELBOURNE</td>
<td>0.879033</td>
<td>0.785970</td>
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</table>
## Testing Fidelity of Arbitrary Quantum States on IBMQx2

### Fidelity of Quantum Teleportation of Arbitrary Quantum States Between 0 and 1

<table>
<thead>
<tr>
<th>Angle $\theta$ between 0 and 1</th>
<th>Fidelity without noise</th>
<th>Fidelity with noise</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi/18$</td>
<td>1.0</td>
<td>0.884765</td>
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<tr>
<td>$\pi/9$</td>
<td>1.0</td>
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<tr>
<td>$\pi/6$</td>
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<tr>
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<td>$\pi/3$</td>
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<tr>
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<tr>
<td>$4\pi/9$</td>
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<tr>
<td>$\pi/2$</td>
<td>1.0</td>
<td>0.796875</td>
</tr>
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FUTURE WORK

• Study Bidirectional Teleportation which involves both parties sending an arbitrary quantum state to the other party

Possible Directions:
  - Figure out what trigger qubits are for
  - Try to build a bidirectional super dense coding circuit
  - Try to remodel circuit using fewer qubits
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