
IBM Q practice 1 : March 7, 2019
Hmw Quantum Computation

The goal of this first practice set is to get acquainted with **composer** (graphical interface) in the IBM Q experience. You will take into account geometrical constraints of the device in exercise 2. You are asked to : (i) first solve with pencil and paper, (ii) think carefully about your implementation on the composer, (iii) use the **simulate** button to reproduce pencil and paper results, (iv) use the **run** button to obtain an experimental (noisy) result. When you "run" in order not to spend credit units and/or wait in a queue you can **choose the cache option** which gives results of previously realised experiments when possible. **Those that already have some familiarity can directly go to exercise 2-c-d.**

Exercise 1 *Single qubit manipulations (use ibmqx2)*

- (a) Consider the following elementary single qubit operations : $|\text{output}\rangle = X|0\rangle$, $|\text{output}\rangle = H|0\rangle$, followed by a measurement operation in the computational basis. "simulate" and "run" and compare the histograms.
- (b) Consider the operations : $|\text{output}\rangle = XX|0\rangle$, $XXXX|0\rangle$, $XXXXXX|0\rangle$ followed by a measurement operation in the computational basis. "simulate" and "run" and compare the histograms. For qubit 1 on ibmqx2 you find results in the cache.
- (c) Consider the "Mach-Zehnder interferometer" operations : $|\text{output}\rangle = HXH|0\rangle$ followed by a measurement. "simulate" and "run" and compare histograms. Same questions with double and triple interfereometers. Use qubit 0 for cache results.

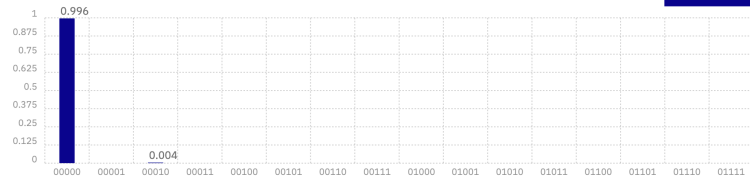
Exercise 2 *Two qubit manipulations (use ibmqx4)*

- (a) For the 5 qubit devices the CNOT gates are directional and denoted CX_{i-j} where i is the control and j the target bit. Get familiar with the CNOT gates : choose two qubits 1 and 0 and apply the CX_{1-0} gate. Simulate and run and compare histograms. For 1024 shots you should find cache results.
- (b) Think of a small circuit involving H and the directed CX_{1-0} gate to realize a CNOT where 0 is the *control* and 1 the *target* bit. First find such a circuit with pencil and paper. Then, simulate, run, compare histograms. For 1024 shots you should find cache results.
- (c) Choose the qubits 1 and 0 that are *connected* by a directed edge and realize the Bell state $\frac{1}{\sqrt{2}}(|0\rangle \otimes |0\rangle + |1\rangle \otimes |1\rangle)$ using the gates H and CX_{1-0} . Observe the histograms when you simulate and run. How would you proceed if 0 is the control bit and 1 the target bit ?
- (d) Now try to entangle qubits 0 and 3 (i.e., create a Bell pair) that are *not directly connected* by an edge. Involve only bits 0, 2, 3 in your circuit. You should first think carefully of a circuit design with pencil and paper. Then, simulate, run, produce histograms. Compare the quality of such Bell pairs with those in (c). If you use only bits 0, 2, 3 you might find the results in the cache.

Device: ibmqx2

Quantum State: Computation Basis

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Quantum Circuit

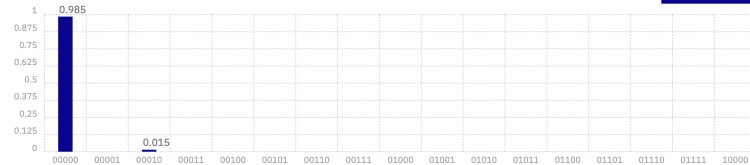


OPENQASM 2.0

```
1 include "qelib1.inc";
2
3 qreg q[5];
4 creg c[5];
5
6 measure q[1] -> c[1];
7
```

Quantum State: Computation Basis

[Download CSV](#)



Quantum Circuit



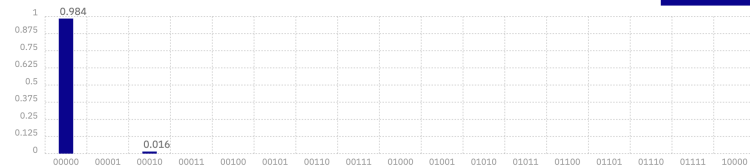
OPENQASM 2.0

```
1 include "qelib1.inc";
2
3 qreg q[5];
4 creg c[5];
5
6 x q[1];
7 x q[1];
8 measure q[1] -> c[1];
9
```

[Open in Composer](#)

Quantum State: Computation Basis

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Quantum Circuit



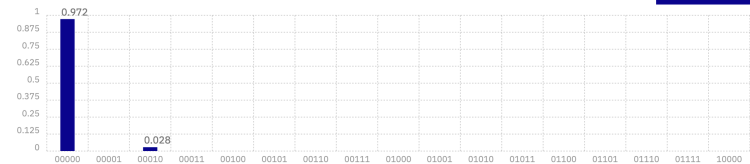
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3 qreg q[5];
4 creg c[5];
5
6 x q[1];
7 x q[1];
8 x q[1];
9
```

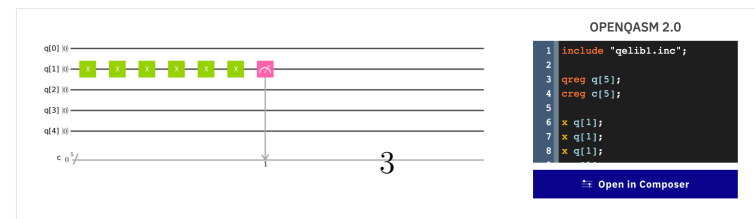
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Quantum State: Computation Basis

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Quantum Circuit



OPENQASM 2.0

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1 include "qelib1.inc";
2
3 qreg q[5];
4 creg c[5];
5
6 x q[1];
7 x q[1];
8 x q[1];
9
```

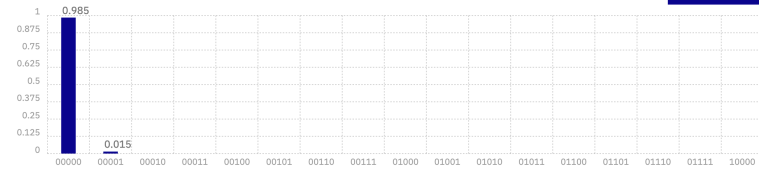
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FIGURE 2 – LOOKING HOW ERRORS ACCUMULATE (experiments with 1024 shots on 5 qubit device ibmqx2)

Device: ibmqx4

Quantum State: Computation Basis

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Quantum Circuit

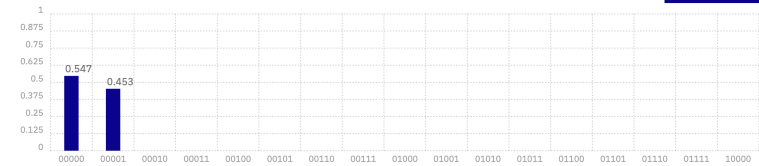


mach zehnder

Device: ibmqx4

Quantum State: Computation Basis

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Quantum Circuit



Device: Simulator

Quantum State: Computation Basis

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Quantum Circuit



Device: ibmqx4

Quantum State: Computation Basis

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Quantum Circuit

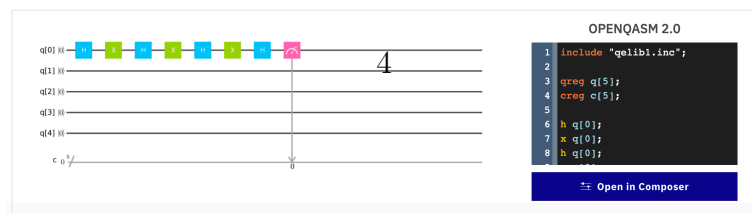
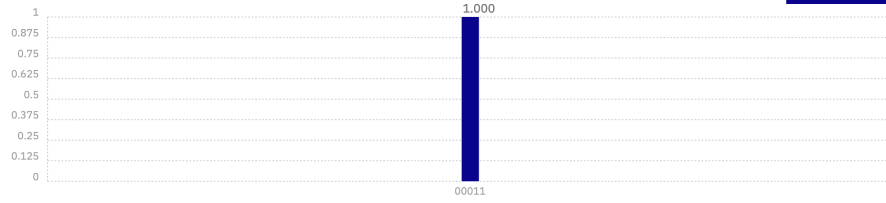


FIGURE 3 – MACH-ZEHNDER INTERFEROMETERS (experiments with 1024 shots on 5 qubit device ibmqx2).

Device: Simulator

Quantum State: Computation Basis

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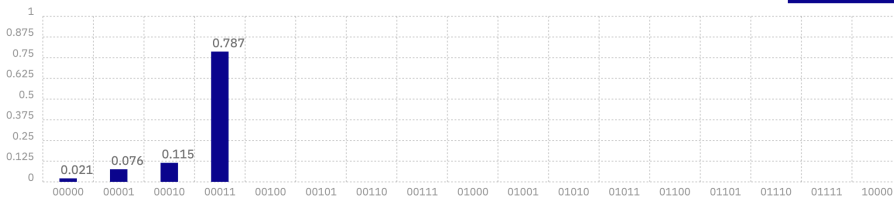
Quantum Circuit



Device: ibmqx4

Quantum State: Computation Basis

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Quantum Circuit

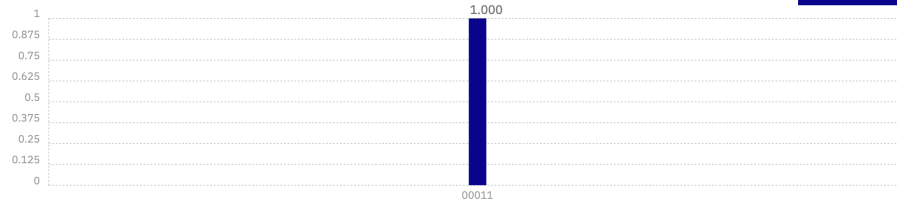


FIGURE 4 – DIRECT CNOT GATE (top= simulator 1024 shots; middle and bottom= experiment 1024 shots) on 5 qubit device ibmqx4.

Device: Simulator

Quantum State: Computation Basis

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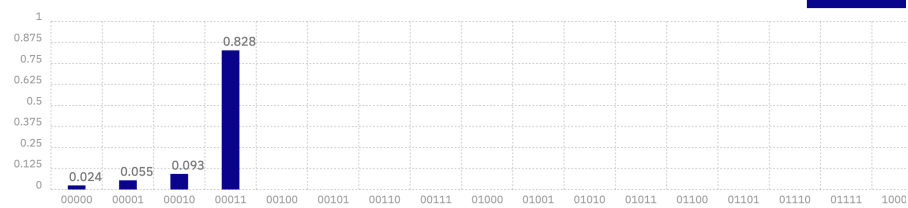
Quantum Circuit



Device: ibmqx4

Quantum State: Computation Basis

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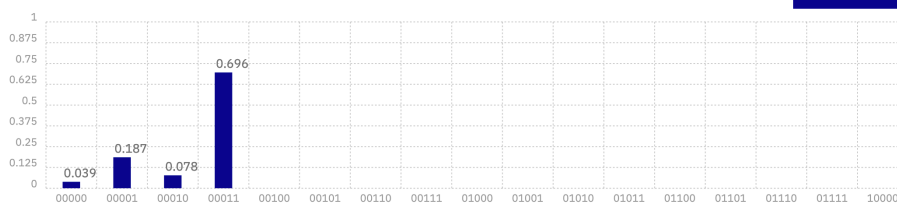
Quantum Circuit



Device: ibmqx4

Quantum State: Computation Basis

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Quantum Circuit



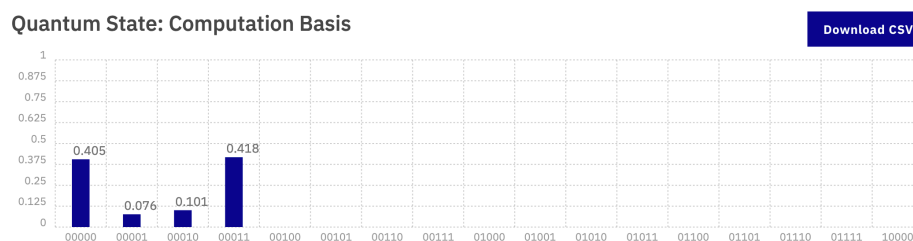
FIGURE 5 – INDIRECT CNOT GATE (top= simulator 1024 shots; middle and bottom= experiment 1024 shots) on 5 qubit device ibmqx4.



Quantum Circuit



Device: ibmqx4



Quantum Circuit

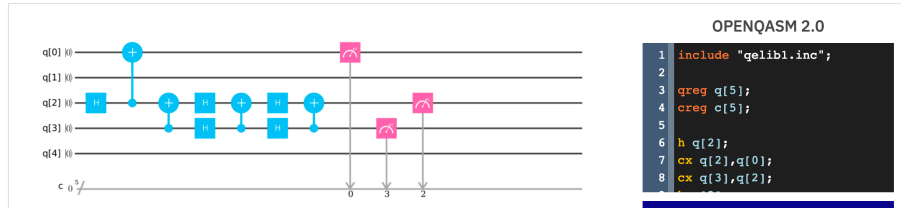


FIGURE 6 – BELL STATE FOR TWO CONNECTED QUBITS 0 and 1 (top= simulator 1024 shots; bottom= experiment 1024 shots) on 5 qubit device ibmqx4.

Quantum State: Computation Basis

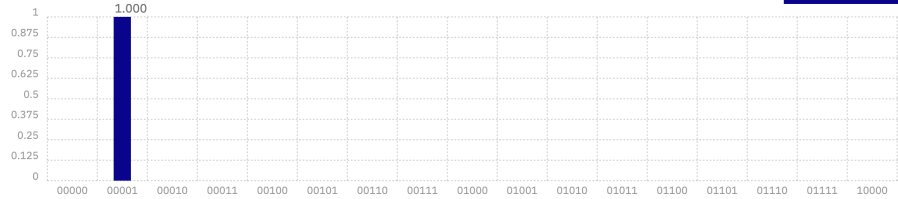
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Quantum Circuit

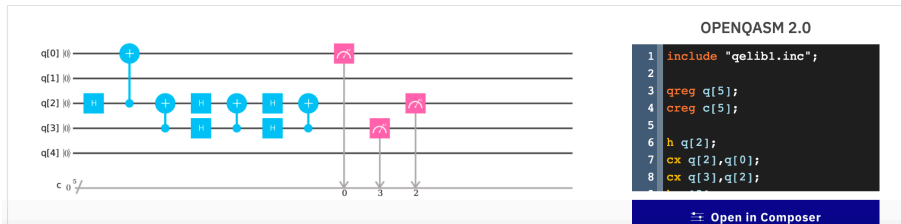


Device: ibmqx4

Quantum State: Computation Basis

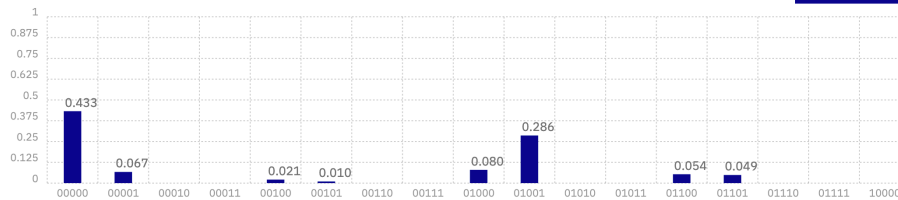
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Quantum Circuit



Device: ibmqx4

Quantum State: Computation Basis

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Quantum Circuit

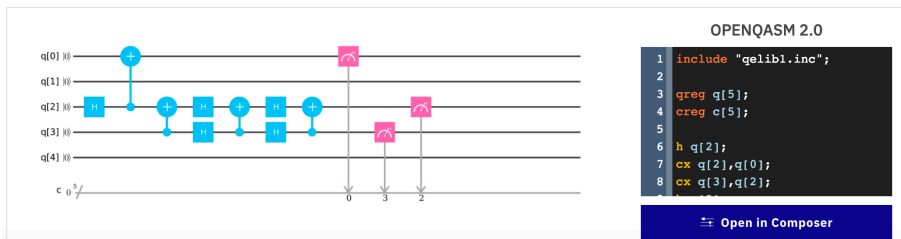


FIGURE 7 – BELL STATE FOR REMOTE QUBITS 0 and 3(top= simulator 1024 shots; middle= experiment 1 shot; bottom= experiment 1024 shots). Exps on 5 qubit device ibmqx4.