Implementation of Grover's Algorithm with Qiskit tool

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Let's remind iterative Grover's algorithm

$$G = Z_f \, Z_A.$$

In Qiskit, operations are performed from left to right, unlike traditional matrix calculations done in Matlab.

Here operator Z_f changes the signs of the amplitudes if the oracle function has the value $f(x) = 1$

$$Z_f : \quad |x\rangle \quad \rightarrow \quad (-1)^{f(x)} \, |x\rangle \, ,$$

Z_A performs an inversion transformation with respect to the mean value

$$|\psi\rangle = \sum_{x=0}^{N-1} \alpha_x \, |x\rangle \, , \quad A = \frac{1}{N} \sum_{x=0}^{N-1} \alpha_x ,$$

$$Z_A \, |\psi\rangle = \sum_{x=0}^{N-1} (2A - \alpha_x) \, |x\rangle \, .$$

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Let me remind that in Lecture 5 we showed that the inversion transformation with respect to the mean value can also be written as follows (all operators are unitary):

$$Z_A = H^{\otimes n}\, Z_{OR}\, H^{\otimes n}, \quad n = \log N,$$

$$Z_{OR}: \quad |x\rangle \;\rightarrow \begin{cases} |x\rangle, & x = 0^n, \\ -|x\rangle, & x \neq 0^n. \end{cases}$$

Let's consider the first practical problem. We have two qubits q_0 and q_1 (i.e. $|q_1, q_0\rangle$), such a system can be in four states

$$|00\rangle, \quad |01\rangle, \quad |10\rangle, \quad |11\rangle.$$

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$$|00\rangle, \quad |01\rangle, \quad |10\rangle, \quad |11\rangle.$$

Using Grover's search algorithm, let's find the element "11"

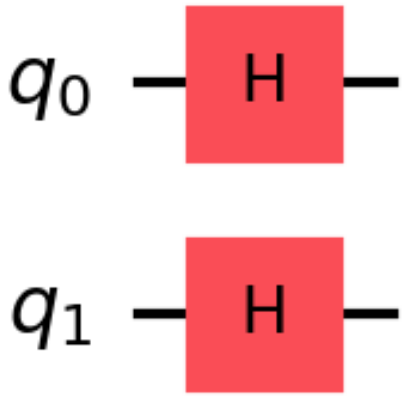
```
#Required imports

from qiskit import QuantumCircuit

from qiskit import transpile

circuit = QuantumCircuit(2)
circuit.h(0)
circuit.h(1)
```

Visualization of circuit construction



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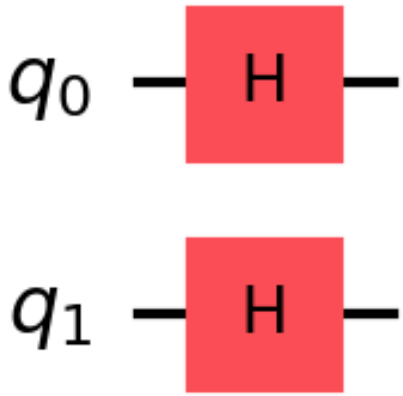
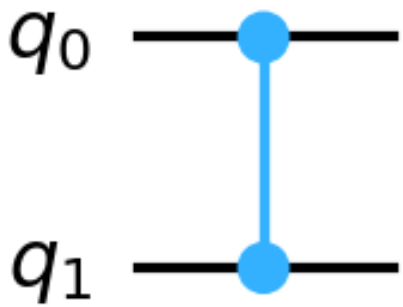


We obtain the following initial state of the two-qubit chain: a superposition of four base states with equal coefficients

$$|\psi\rangle = \frac{1}{2}\sum_{x=0}^{3}|x\rangle = \frac{1}{2}\big(\,|00\rangle + |01\rangle + |10\rangle + |11\rangle\,\big).$$

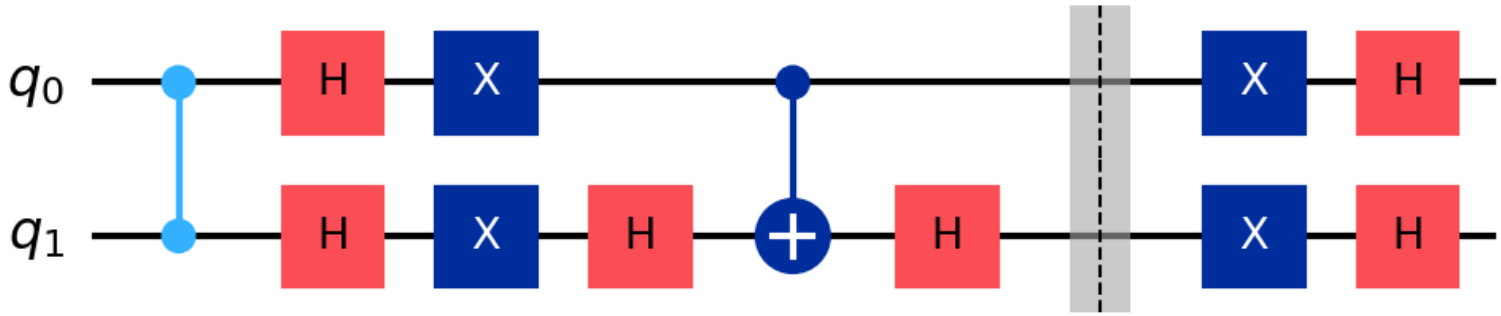
#We generate an oracle operator Z_f that recognizes the state "11".
#We describe it as a separate quantum circuit that uses
#the same two qubits q_0, q_1:

```
oracle = QuantumCircuit(2)
oracle.cz(0, 1)
```



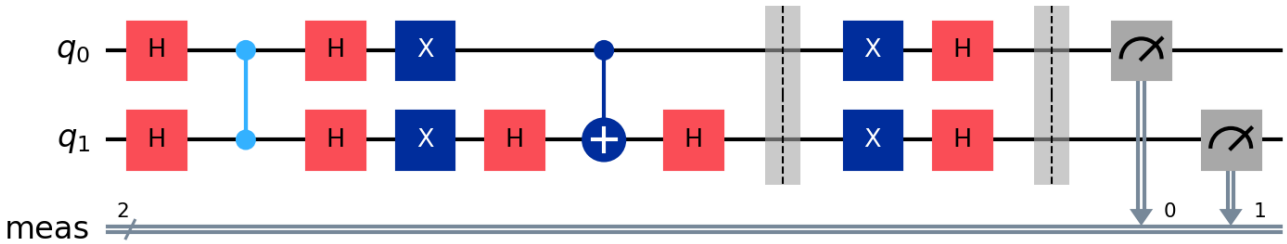
#Generate Grover's operator: add Z_A transformation:

```
grover = oracle
grover.h(0)
grover.h(1)
grover.x(0)
grover.x(1)
grover.h(1)
grover.cx(0, 1)
grover.h(1)
grover.x(0)
grover.x(1)
grover.h(0)
grover.h(1)
```


q_0
q_1
H
H
X
X
H
H
X
X
H
H

#We perform one Grover iteration and measure the result:

circuit.measure_all()



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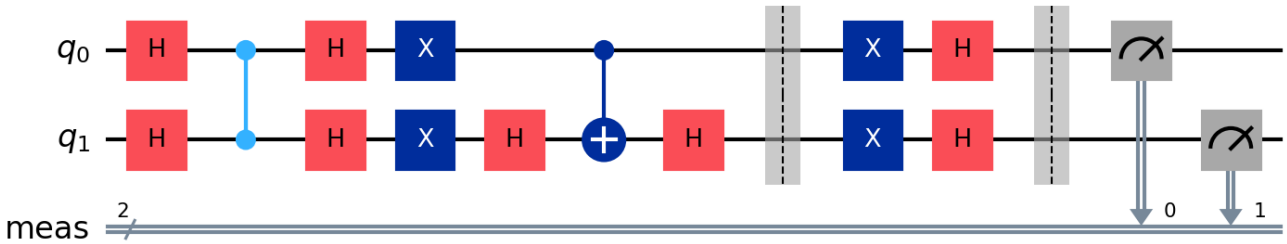

simulator = AerSimulator()
circuit2 = transpile(circuit, simulator)
job = simulator.run(circuit2, shots=200)
result = job.result()
counts = result.get_counts(circuit2)
print(counts)

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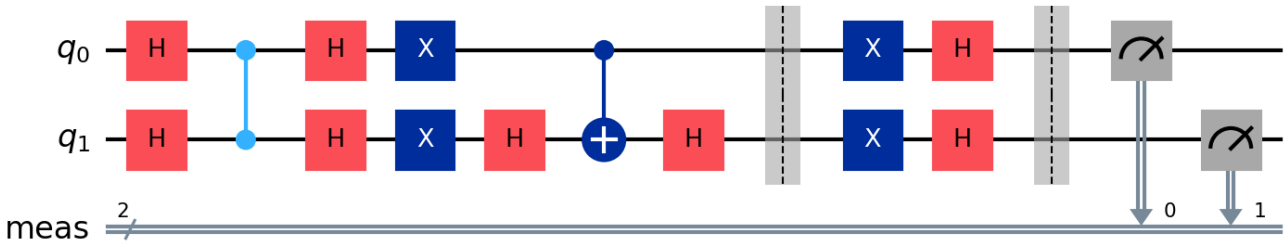

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Results:

{'11': 200}

Do two iterations of the Grover algorithm:

Add the second iteration to the circuit:

circuit = circuit.compose(grover)

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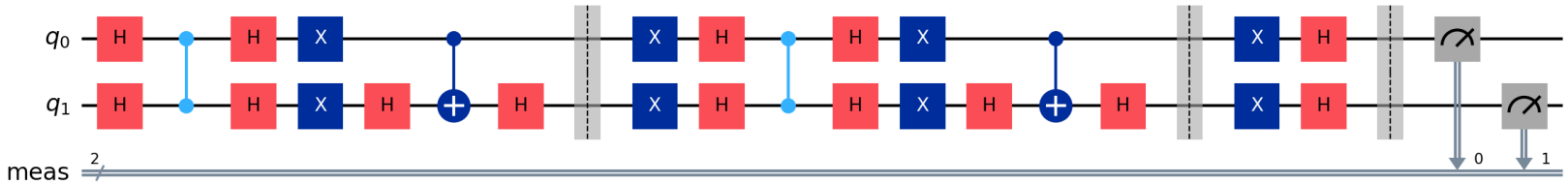

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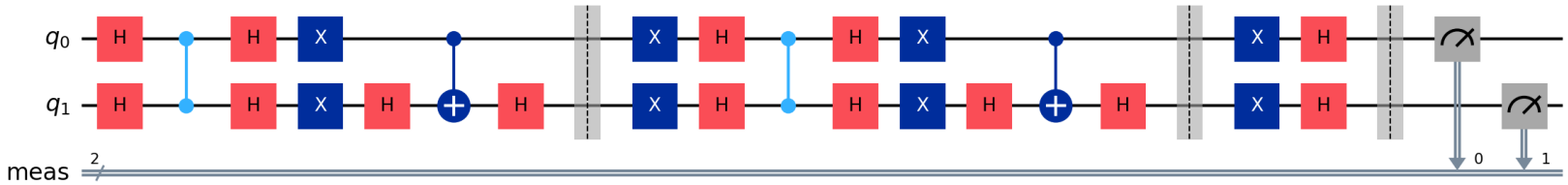

Results:

{'11': 44, '10': 52, '00': 44, '01': 60}

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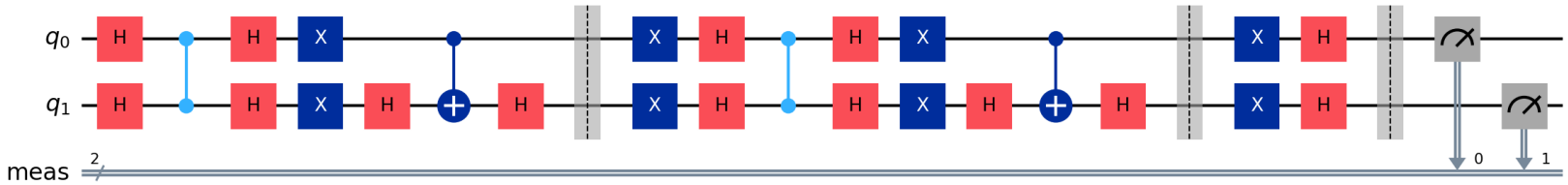

Results:

{'11': 44, '10': 52, '00': 44, '01': 60}

Remind that from theoretical estimates it also follows that one iteration is optimal for two qubits.

Let's change our target and make a search for the element "01".

It is enough to change only the oracle part.

oracle.x(1)
oracle.cz(0, 1)
oracle.x(1)

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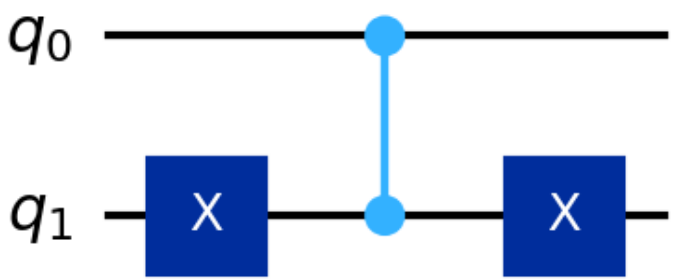
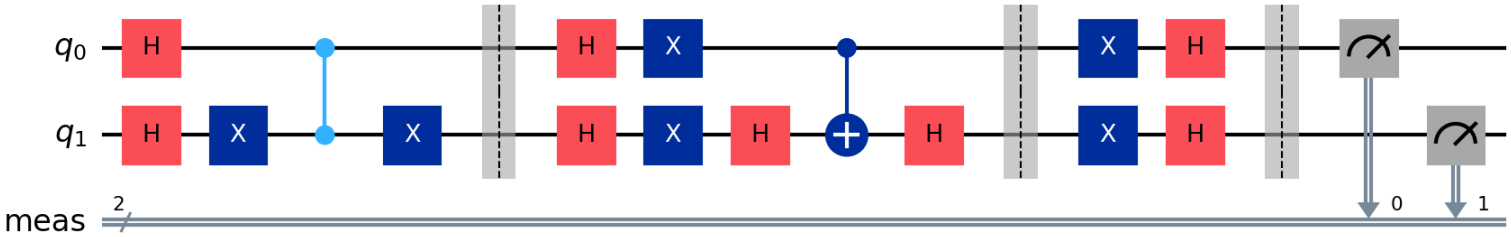


We perform one iteration of Grover's algorithm



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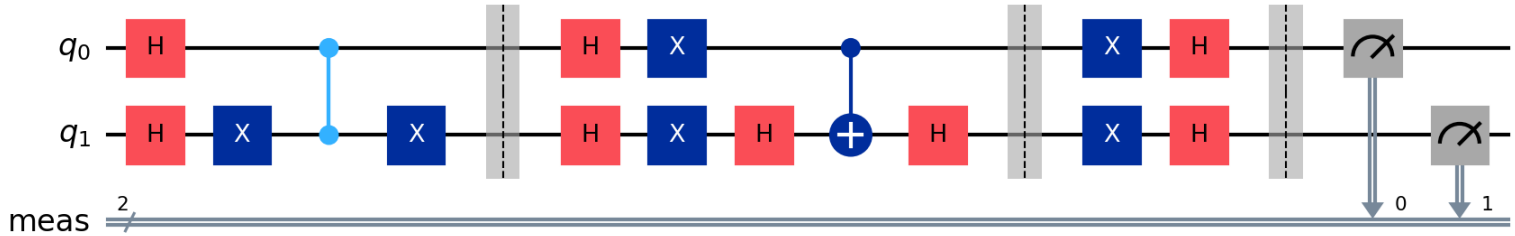

We obtain the following results from a series of experiments:

{'01': 200}

Next we take a system of three qubits and generate a superposition of eight quantum states:

$$|\psi\rangle = \frac{1}{2\sqrt{2}}(|000\rangle + |001\rangle + |010\rangle + |011\rangle + |100\rangle + |101\rangle + |110\rangle + |111\rangle).$$

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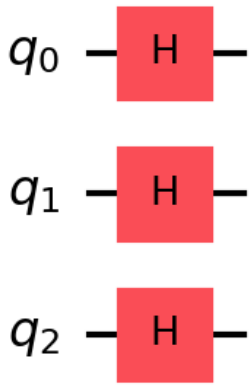
Initial distribution is generated by the following circuit

```
init = QuantumCircuit(3)
init.h(0)
init.h(1)
init.h(2)
```




```
circuit = QuantumCircuit(3)
circuit = circuit.compose(init)
```

```
# Define the Oracle to find a state "110"
oracle = QuantumCircuit(3)
oracle.x(0)
oracle.ccz(0, 1, 2)
oracle.x(0)
```

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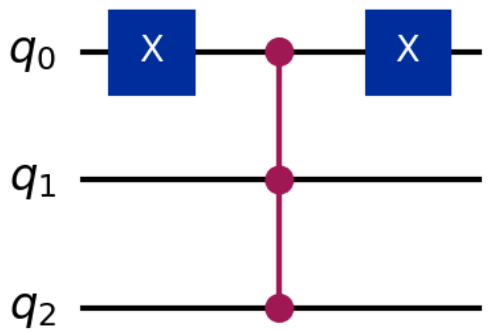

```
# Generate Grover's operator:
grover = oracle

grover.barrier()
grover.h(0)
grover.h(1)
grover.h(2)
grover.x(0)
grover.x(1)
grover.x(2)
grover.h(2)
grover.ccx(0, 1, 2)
grover.h(2)
```

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grover.x(1)
grover.x(2)
grover.h(0)
grover.h(1)
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```

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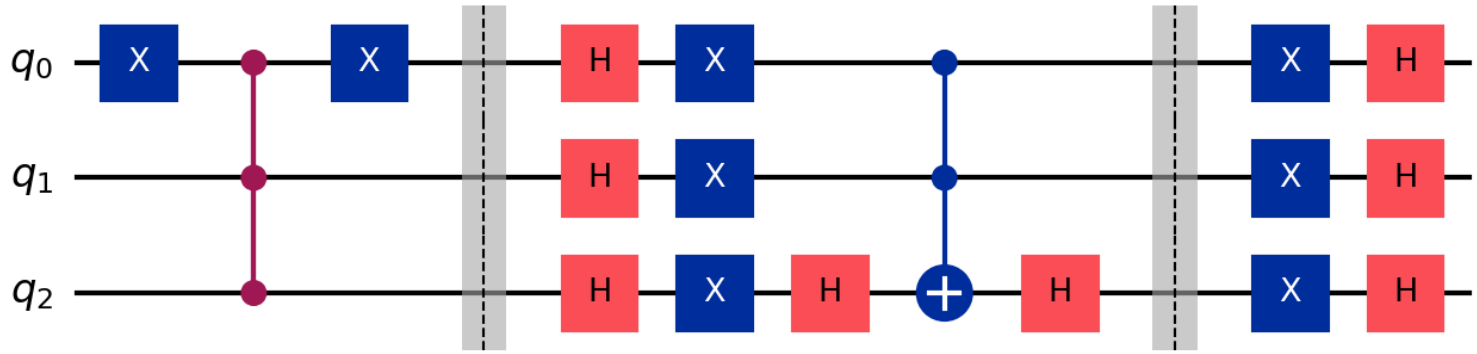
grover.x(1)
grover.x(2)
grover.h(0)
grover.h(1)
grover.h(2)
```



```
#Generate a circuit with two Grover's iterations
#and make measurements
circuit = circuit.compose(grover)
circuit = circuit.compose(grover)
circuit.measure_all()
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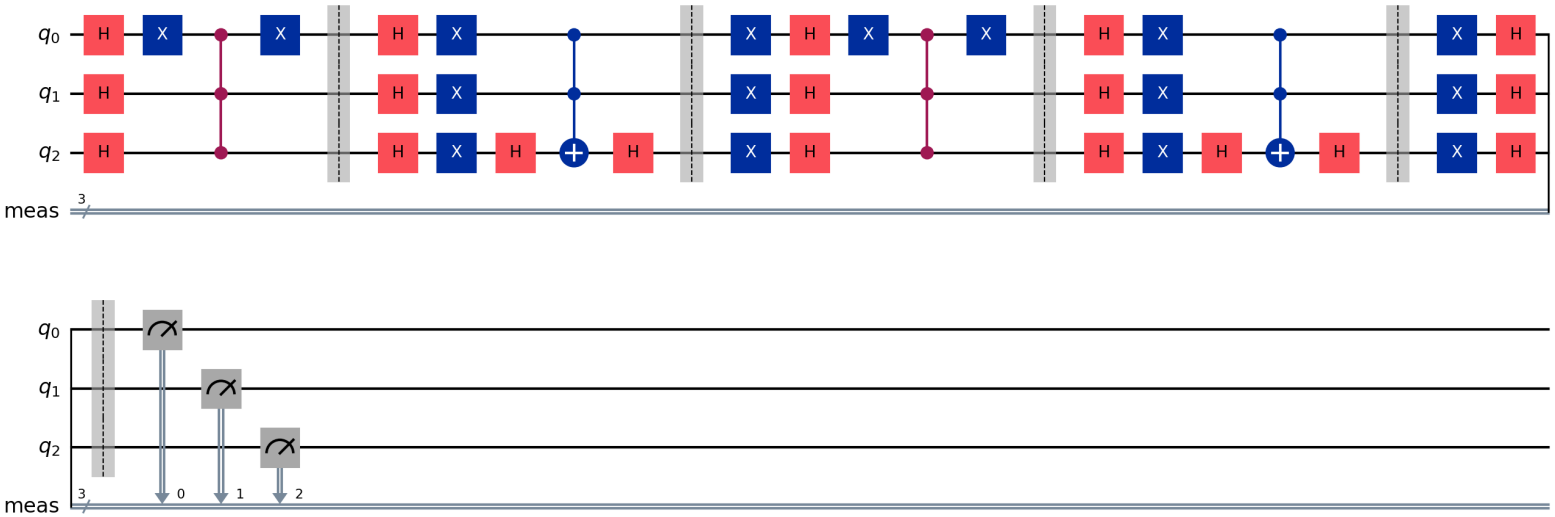

Results of two experimental series of 100 trials each:

{'111': 1, '101': 1, '000': 1, '100': 1, '001': 1, '110': 95 }

{'100': 1, '001': 1, '010': 1, '101': 1, '011': 1, '111': 2, '110': 93 }