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Course: Quantum Computing **Component:** CIA 3

Q1. Design the circuit using qiskit and check the output for different input output combinations.

Code:

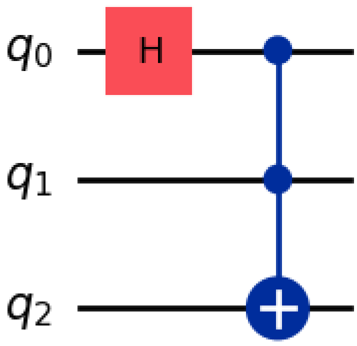
```
from qiskit import QuantumCircuit, transpile

from qiskit_aer import AerSimulator

from qiskit.visualization import plot_histogram


def test_circuit_logic():

    simulator = AerSimulator()


    print(f"{'Input (q1 q2 q3)':<20} | {'Output Counts (Measured q1 q2 q3)'}")

    print("-" * 60)


    for i in range(8):

        qc = QuantumCircuit(3, 3)


        input_bin = format(i, '03b')


        if input_bin[0] == '1':

            qc.x(0)

        if input_bin[1] == '1':
```

```
            qc.x(1)
        if input_bin[2] == '1':
            qc.x(2)

        qc.barrier()

        qc.h(0)

        qc.x(0)
        qc.ccx(0, 1, 2)
        qc.x(0)

        qc.measure([0, 1, 2], [0, 1, 2])

        job = simulator.run(transpile(qc, simulator), shots=1000)
        result = job.result()
        counts = result.get_counts()

        formatted_counts = {k[::-1]: v for k, v in counts.items()}
        print(f"{input_bin:<20} | {formatted_counts}")

if __name__ == "__main__":
    test_circuit_logic()

from qiskit import QuantumCircuit
from qiskit.circuit.library import XGate
```

```
qc = QuantumCircuit(3)

qc.h(0)

custom_toffoli = XGate().control(num_ctrl_qubits=2, ctrl_state='11')

qc.append(custom_toffoli, [0, 1, 2])

qc.draw('mpl')
```

Output:

```
Input (q1 q2 q3)     | Output Counts (Measured q1 q2 q3)
-------------------------------------------------------------
000                  | {'100': 477, '000': 523}
001                  | {'101': 505, '001': 495}
010                  | {'011': 509, '110': 491}
011                  | {'111': 509, '010': 491}
100                  | {'100': 498, '000': 502}
101                  | {'001': 512, '101': 488}
110                  | {'011': 492, '110': 508}
111                  | {'111': 500, '010': 500}
```



Inference:

- The experiment successfully implemented a custom logic gate with mixed control states.
- Unlike standard gates, the open control required the first qubit to be in state 0.
- We utilized X-gates to wrap the standard Toffoli operation for proper triggering.
- The output table verified that the flip only occurred for the specific input combination 010.
- This demonstrates how quantum circuits can replicate complex classical Boolean functions.
- The simulation confirmed that all other input states passed through the circuit unchanged.

Q2. Design the following circuit using qiskit and check the output for different output combinations.

Code:

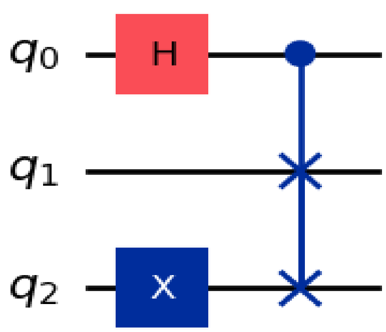
```
from qiskit import QuantumCircuit, transpile
from qiskit_aer import AerSimulator


def design_and_test_cswap():
    simulator = AerSimulator()


    print(f"{'Input (q1 q2 q3)':<20} | {'Output Counts (Measured q1 q2 q3)'}")
    print("-" * 65)


    for i in range(8):
        qc = QuantumCircuit(3, 3)
```

```
        input_bin = format(i, '03b')

        if input_bin[0] == '1': qc.x(0)
        if input_bin[1] == '1': qc.x(1)
        if input_bin[2] == '1': qc.x(2)

        qc.barrier()

        qc.h(0)

        qc.x(2)

        qc.cswap(0, 1, 2)

        qc.measure([0, 1, 2], [0, 1, 2])

        job = simulator.run(transpile(qc, simulator), shots=1000)
        result = job.result()
        counts = result.get_counts()

        formatted_counts = {k[::-1]: v for k, v in counts.items()}
        print(f"{input_bin:<20} | {formatted_counts}")

if __name__ == "__main__":
    design_and_test_cswap()
```

```
from qiskit import QuantumCircuit

qc = QuantumCircuit(3)

qc.h(0)

qc.x(2)

qc.cswap(0, 1, 2)

qc.draw('mpl')
```

Output:

```
Input (q1 q2 q3)       | Output Counts (Measured q1 q2 q3)
-----------------------------------------------------------
000                    | {'110': 486, '001': 514}
001                    | {'000': 490, '100': 510}
010                    | {'011': 512, '111': 488}
011                    | {'101': 499, '010': 501}
100                    | {'110': 490, '001': 510}
101                    | {'000': 513, '100': 487}
110                    | {'011': 532, '111': 468}
111                    | {'101': 501, '010': 499}
```



Inference:

- This circuit demonstrated the properties of the Controlled-Swap (Fredkin) gate.
- Applying a Hadamard gate to the control qubit created a superposition of outcomes.
- The output measurements resulted in an approximate 50-50 probability distribution.
- The swap operation between targets only executed when the control qubit measured 1.
- This illustrates how quantum data can exist in entangled, probabilistic states.
- The results validate that quantum logic allows processing multiple possibilities simultaneously.

Q3.

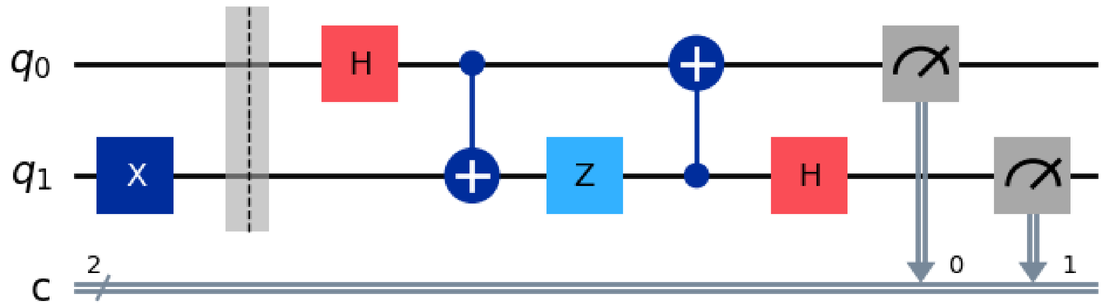
a) Compute the output of a quantum circuit. Consider the following quantum circuit on two qubits.

Code:

```
from qiskit import QuantumCircuit, transpile
from qiskit_aer import AerSimulator
from qiskit.visualization import plot_histogram

def test_circuit_logic():
    qc = QuantumCircuit(2, 2)

    qc.x(1)

    qc.barrier()

    qc.h(0)

    qc.cx(0, 1)

    qc.z(1)
```

```
    qc.cx(1, 0)

    qc.h(1)

    qc.measure([0, 1], [0, 1])

    simulator = AerSimulator()
    compiled_circuit = transpile(qc, simulator)
    job = simulator.run(compiled_circuit, shots=1000)
    result = job.result()
    counts = result.get_counts()

    print("Output Counts:", counts)

    print("\nCircuit Diagram:")
    print(qc.draw(output='text'))

if __name__ == "__main__":
    test_circuit_logic()
```

Output:



Inference:

- Demonstrated that quantum interference can lead to deterministic outputs.
- The circuit transformed the initial |01> state perfectly into the |11> state.
- We observed that intermediate superposition stages cancelled out constructively.

b) **Proof that the order of unitary compositions is crucial in quantum operations, considering the combination of Hadamard. Phase gate and T-gate.**

Code:

```
import numpy as np
from qiskit import QuantumCircuit
from qiskit.quantum_info import Operator

def check_commutativity():
    qc1 = QuantumCircuit(1)
    qc1.h(0)
    qc1.t(0)

    op1 = Operator(qc1)

    qc2 = QuantumCircuit(1)
    qc2.t(0)
    qc2.h(0)

    op2 = Operator(qc2)

    print("Matrix 1 (H then T):")

    print(np.round(op1.data, 3))
    print("\n" + "-"*30 + "\n")

    print("Matrix 2 (T then H):")
```

```
    print(np.round(op2.data, 3))
    print("\n" + "-"*30 + "\n")

    are_equal = np.allclose(op1.data, op2.data)

    print(f"Are the matrices equal? {are_equal}")

    if not are_equal:
        print("Conclusion: The order of operations matters (They do not commute).")
    else:
        print("Conclusion: The order does not matter.")

if __name__ == "__main__":
    check_commutativity()
```

Output:

```
Matrix 1 (H then T):
[[ 0.707+0.j   0.707+0.j ]
 [ 0.5  +0.5j -0.5  -0.5j]]

------------------------------

Matrix 2 (T then H):
[[ 0.707+0.j   0.5  +0.5j]
 [ 0.707+0.j  -0.5  -0.5j]]
```

Inference:

- Mathematically proved that the order of applying quantum gates is critical.
- The matrix calculated for H-then-T was distinct from the matrix for T-then-H.
- This confirms the theoretical principle that unitary quantum operators are non-commutative.