Source: IBM

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ENTC
Electronic and Telecommunication Engineering

University of British Columbia
QUANTUM CLUB

IEEE
Sri Lanka Section

QUANTUM COMPUTING WITH IBM QISKIT

WORKSHOP SESSION 2: January 21, 2023

About Me

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Cornell University

Outline

- Qiskit and IBM Quantum experience
- First circuit in Qiskit
- Quantum speedups-- Deutsch-Jozsa Algorithm
- Quantum Teleportation and Entanglement

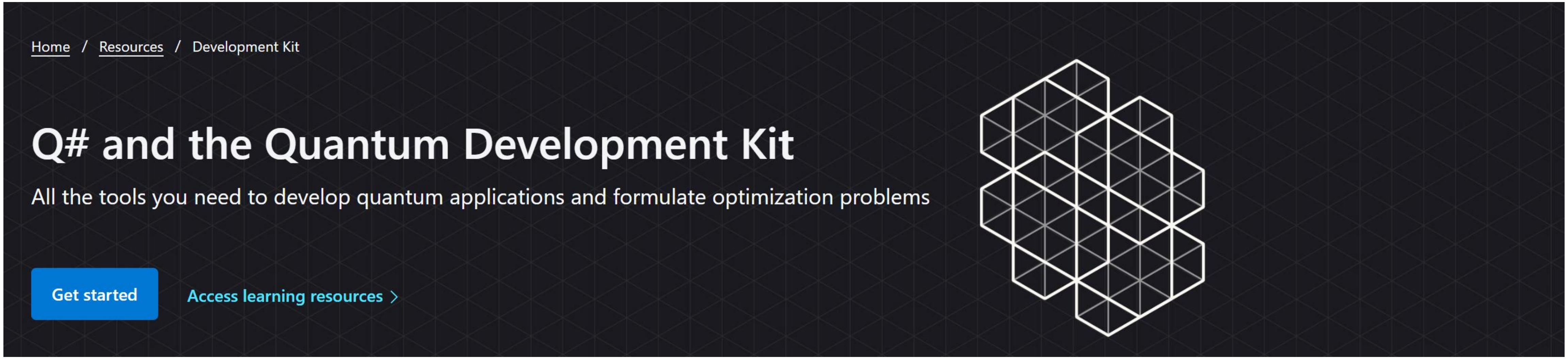
Open-source python-based frameworks for quantum computing

https://qiskit.org/

https://pennylane.ai/

https://quantumai.google/cirq

Microsoft



https://azure.microsoft.com/en-us/resources/development-kit/quantum-computing/

What is Qiskit?

- IBM’s Quantum computer programming language
- Open-source quantum computing software development framework

IBM Quantum experience

Graphically build circuits with

IBM Quantum Composer

Launch Composer

Develop quantum experiments in

IBM Quantum Lab

Launch Lab

- Simulator to debug and validate circuits
- Quantum computing resources of IBM

Name	Qubits	QV	CLOPS	Status	Total pending jobs	Processor type	Plan	Features
ibm_nairobi	7	32	2.6K	Online	18	Falcon r5.11H	open	OpenQASM 3
ibm_oslo	7	32	2.6K	Online	5	Falcon r5.11H	open	OpenQASM 3
ibmq_manila	5	32	2.8K	Online	17	Falcon r5.11L	open	OpenQASM 3
ibmq_quito	5	16	2.5K	Online	17	Falcon r4T	open	
ibmq_belem	5	16	2.5K	Online - Queue paused	24	Falcon r4T	open	
ibmq_lima	5	8	2.7K	Online - Queue paused	29	Falcon r4T	open	

ibm_oslo

OpenQASM 3

Details

7 Qubits	Status:	Online	Median CNOT Error:	8.573e-3
32 QV	Total pending jobs:	6 jobs	Median Readout Error:	1.990e-2
2.6K CLOPS	Processor type:	Falcon r5.11H	Median T1:	141.48 us
	Version:	1.0.16	Median T2:	45.11 us
	Basis gates:	CX, ID, IF_ELSE, RZ, SX, X	Providers with access:	2 Providers
	Your usage:	8 jobs		

Calibration data

Last calibrated: 14 minutes ago

Map view | Graph view | Table view

Qubit:

Readout assignment error

Median 1.990e-2

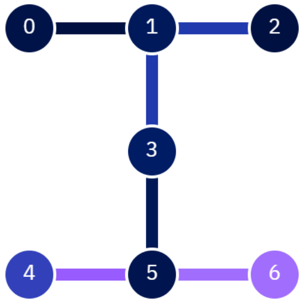
min 1.110e-2 max 1.431e-1

Connection:

CNOT error

Median 8.573e-3

min 5.996e-3 max 1.256e-2



One of the IBM quantum computers

Resources shared

- Creating an account– IBMid
- Uploading Jupyter Notebook to Quantum Lab
- How to configure API to run algorithms on real quantum devices of IBM

QUBIT X QUBIT

ENTC Electronic and Telecommunication Engineering

Skill Surf

<Coding School/>

IBM Quantum Experience Guide

Introduction to Quantum Computing Free Workshop

Dept. of Electronic & Telecommunication Engineering, University of Moratuwa (ENTC, UoM)

Last Modified - 15/01/2023

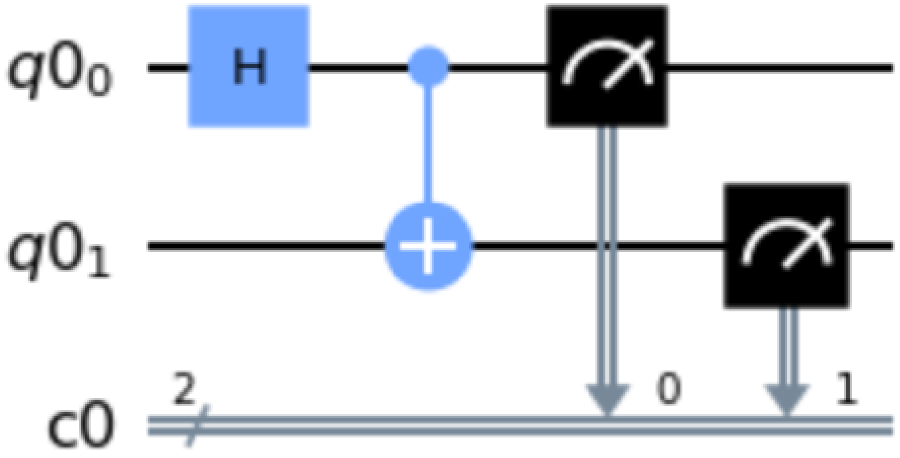
Table of Contents

HelloWorld with Qiskit

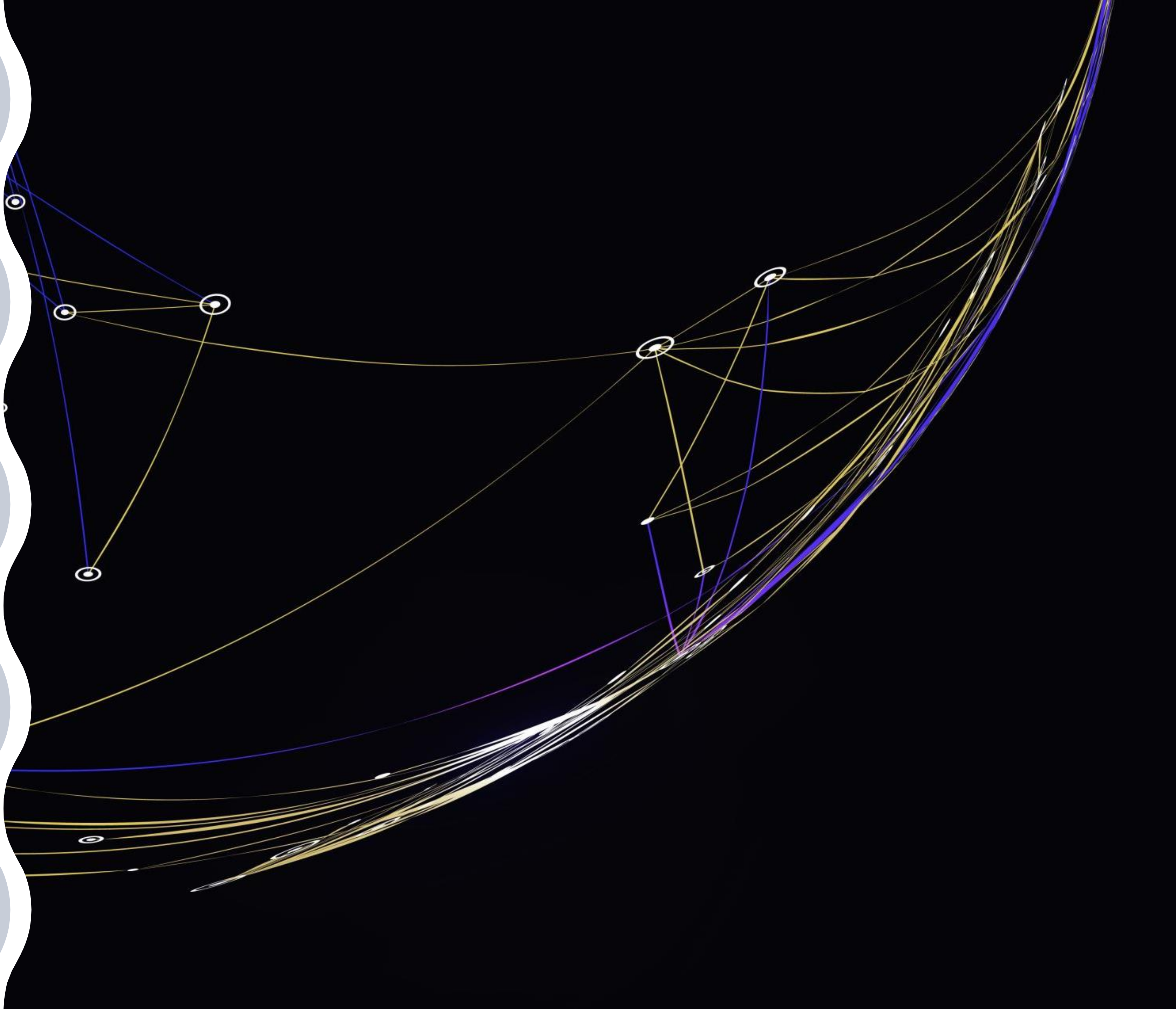
- Let's implement our first circuit in Qiskit

Notebook: FirstCircuit.ipynb

- Hadamard gate
- CNOT gate
- Then measure the qubits
- Run the circuit in quantum simulator
- Run the circuit in IBM quantum devices



Quantum Speedups



Deutsch-Jozsa Algorithm

- Goal: Given a function $f: \{0,1\}^n \rightarrow \{0,1\}^m$, finding whether that function f is balanced or constant

Input	Output
0	1
1	0

Balanced

Input	Output
0	0
1	0

Constant

How many times that we have to access this function to determine this?

For a classical computer, we need 2 queries

Input	Output
0	1
1	0

- Claim: Quantum computer needs only one query

For a classical computer, we need 3 queries

Input		Output
0	0	1
0	1	1
1	0	1
1	1	1

- Claim: Quantum computer needs only one query

Let's justify the claim!

Setup

- $f: \{0,1\} \quad \rightarrow \{0,1\}$
- How many such functions? 4!
- What are they?

Input	Output
0	0
1	0

Input	Output
0	1
1	1

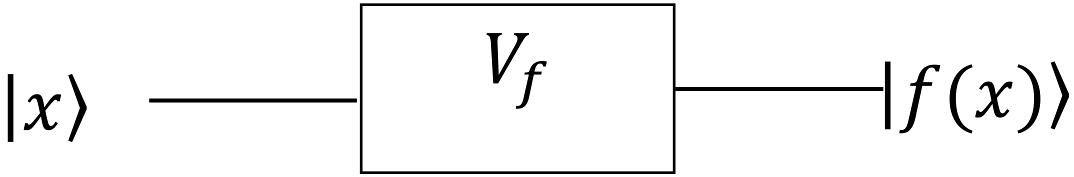
Input	Output
0	0
1	1

Input	Output
0	0
1	0

How to implement these functions in a quantum computer?

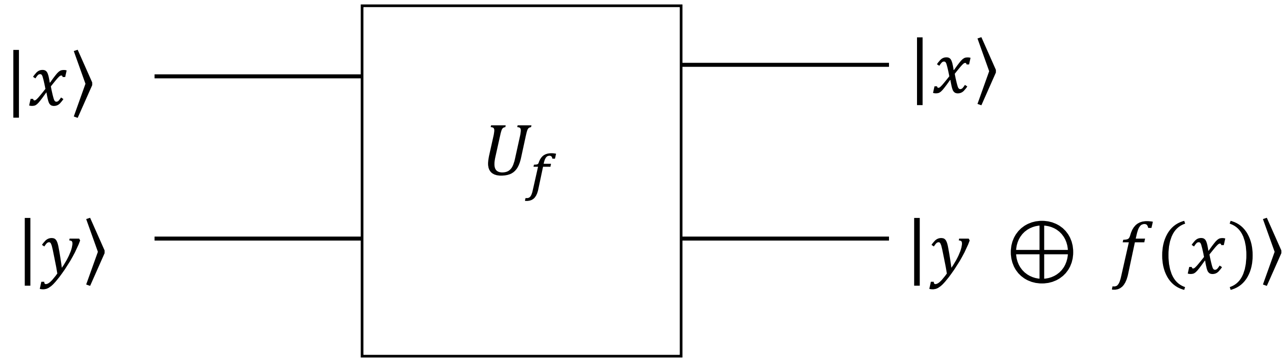
Oracle Implementation

- Quantum circuits that we want to implement should be unitary and reversible.
- Let $0 \rightarrow |\,0\,\rangle, 1 \rightarrow |\,1\,\rangle$
- $x, y \in \{0,1\}$



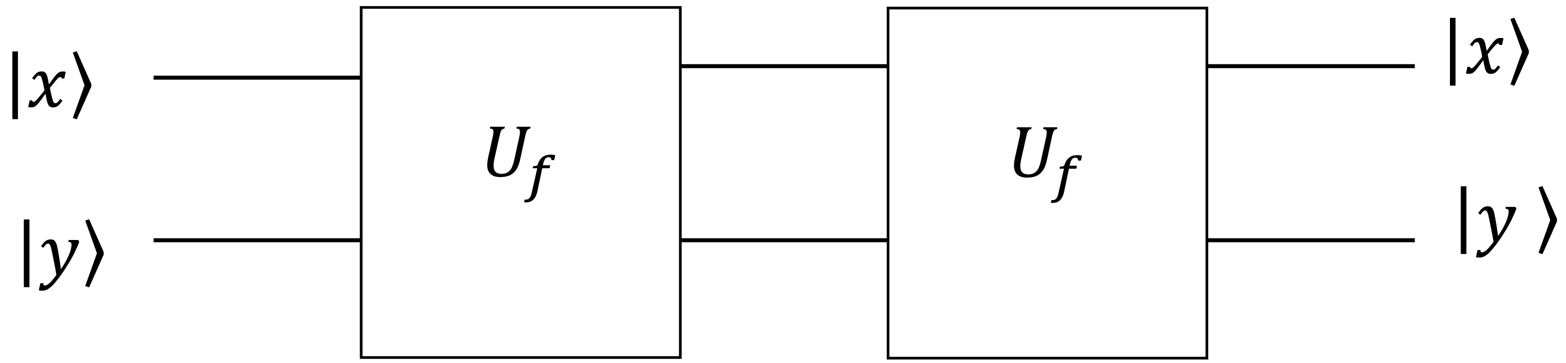
Is this reversible?

Oracle Implementation



Is this reversible?

Why is it reversible?

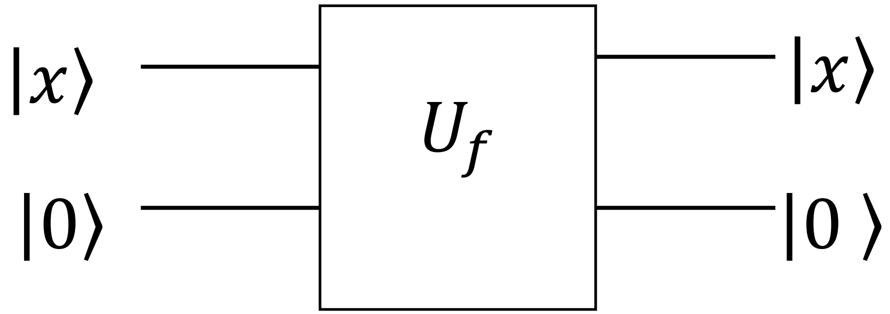


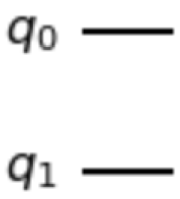
Property 1: $|y \oplus y\rangle = |0\rangle$

Property 2: $|y \oplus 0\rangle = |y\rangle$

Oracle for constant 0 function

Input	f
0	0
1	0

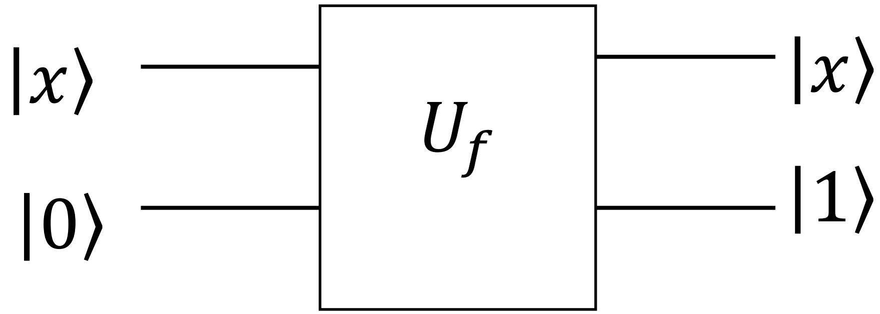


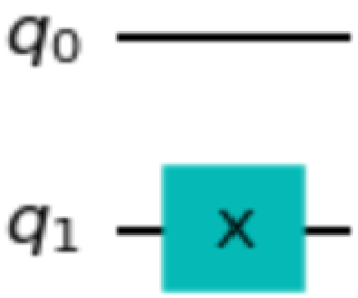


Input to q_0 qubit and ancillary qubit to q_1

Oracle for constant 1 function

Input	f
0	1
1	1

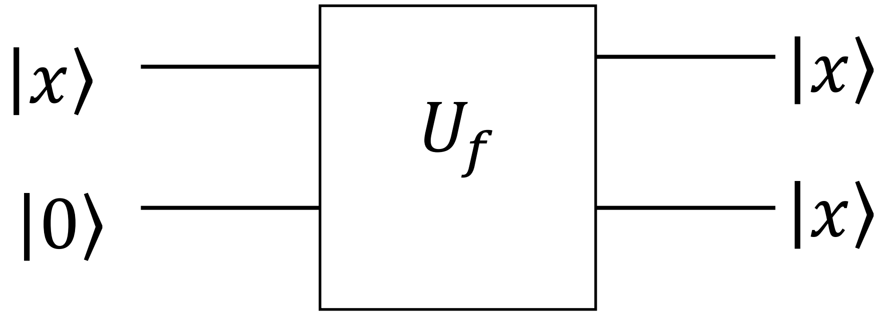


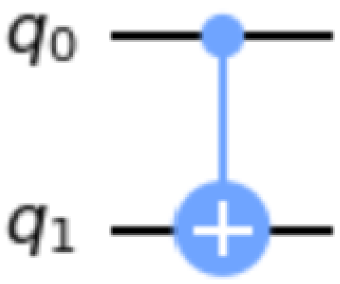


Input to q_0 qubit and ancillary qubit to q_1

Oracle for balanced function 1

Input	f
0	0
1	1

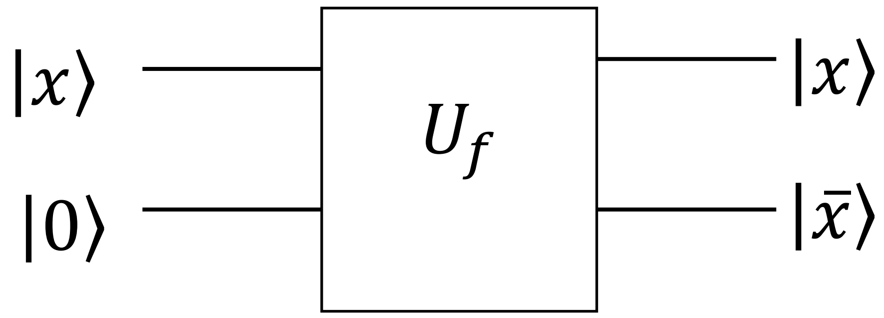


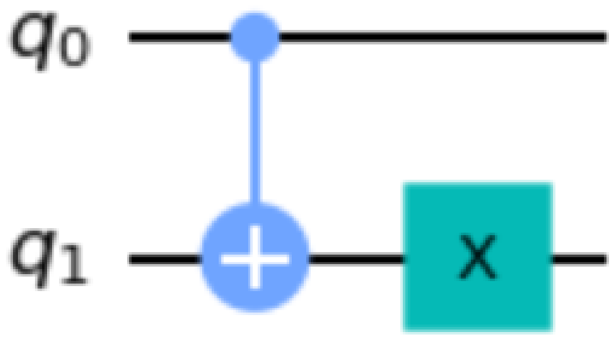


Input to q_0 qubit and ancillary qubit to q_1

Oracles for balanced function 2

Input	f
0	1
1	0





Input to q_0 qubit and ancillary qubit to q_1

Summary: Oracles for each function

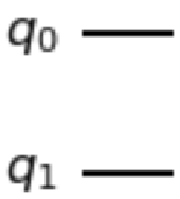
Input to q_0 qubit and ancillary qubit to q_1

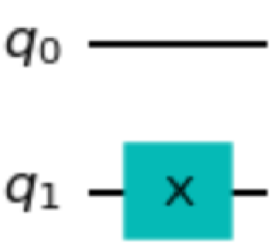
Input	f
0	0
1	0

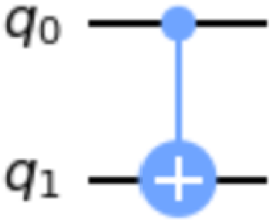
Input	f
0	1
1	1

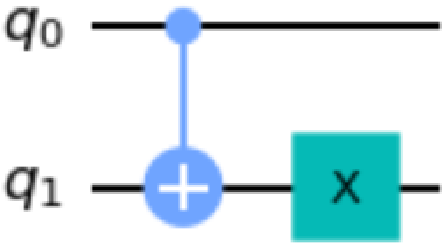
Input	f
0	0
1	1

Input	f
0	1
1	0

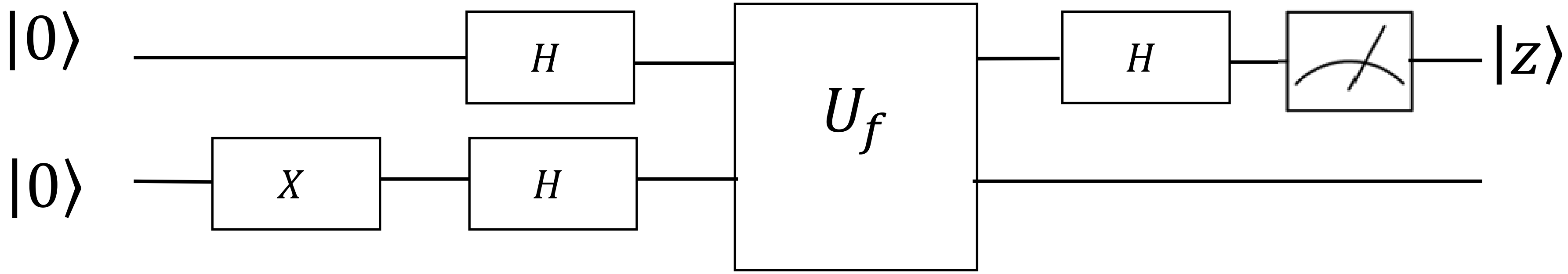








Quantum circuit

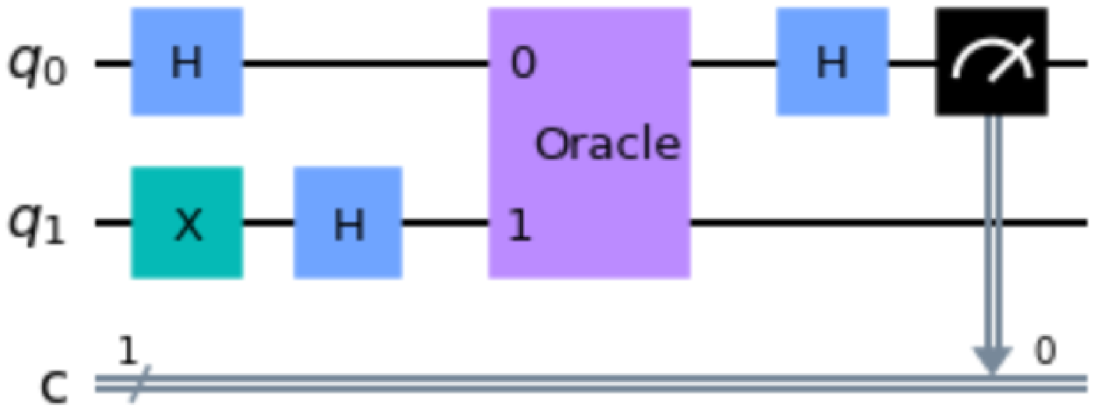


How to decide?

If $z = 0$: Constant function
If $z = 1$: Balanced function

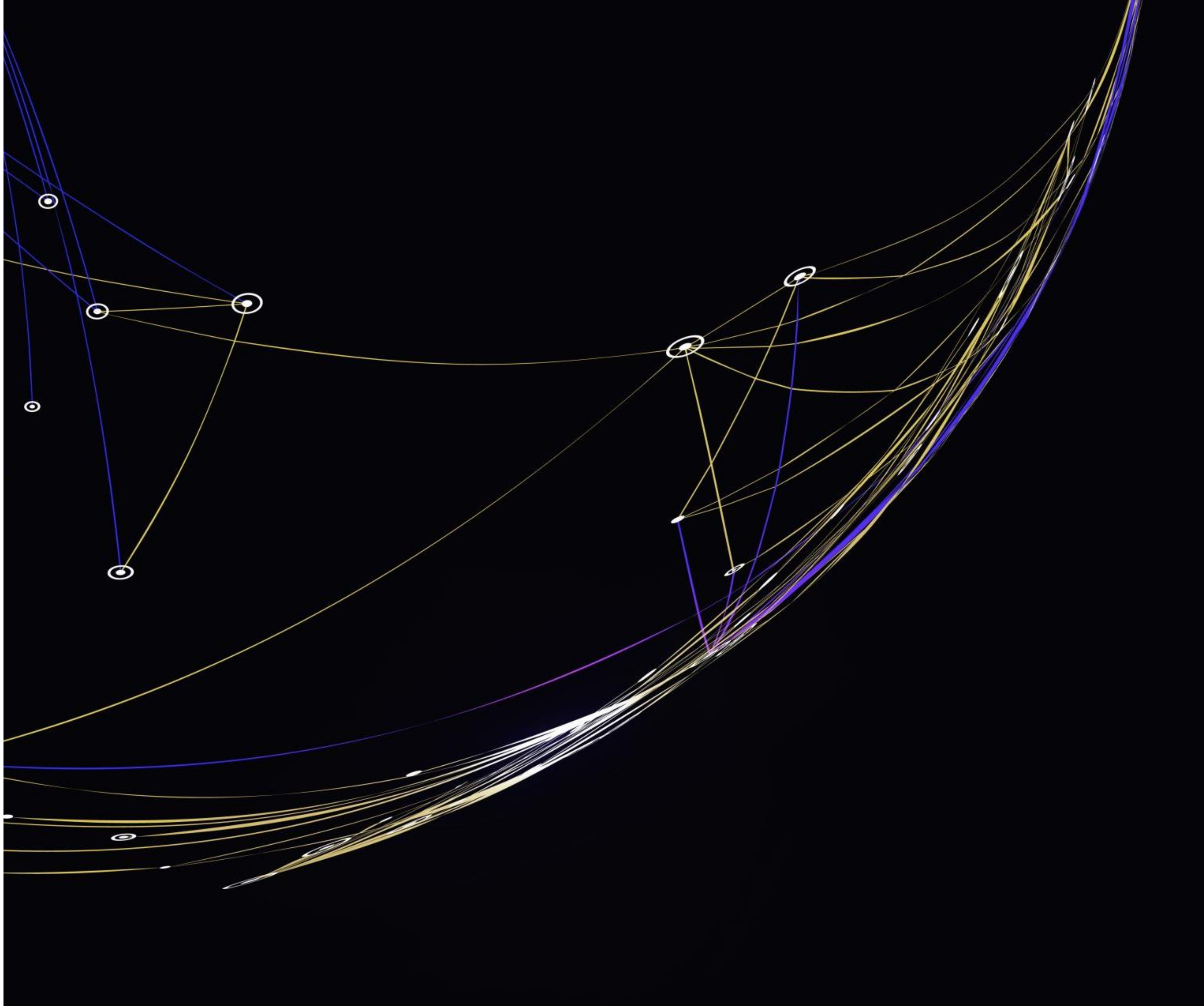
Back to implementation

- Let's look at a Qiskit implementation of this quantum circuit now!



Notebook: Demo_Deutsch_Jozsa.ipynb

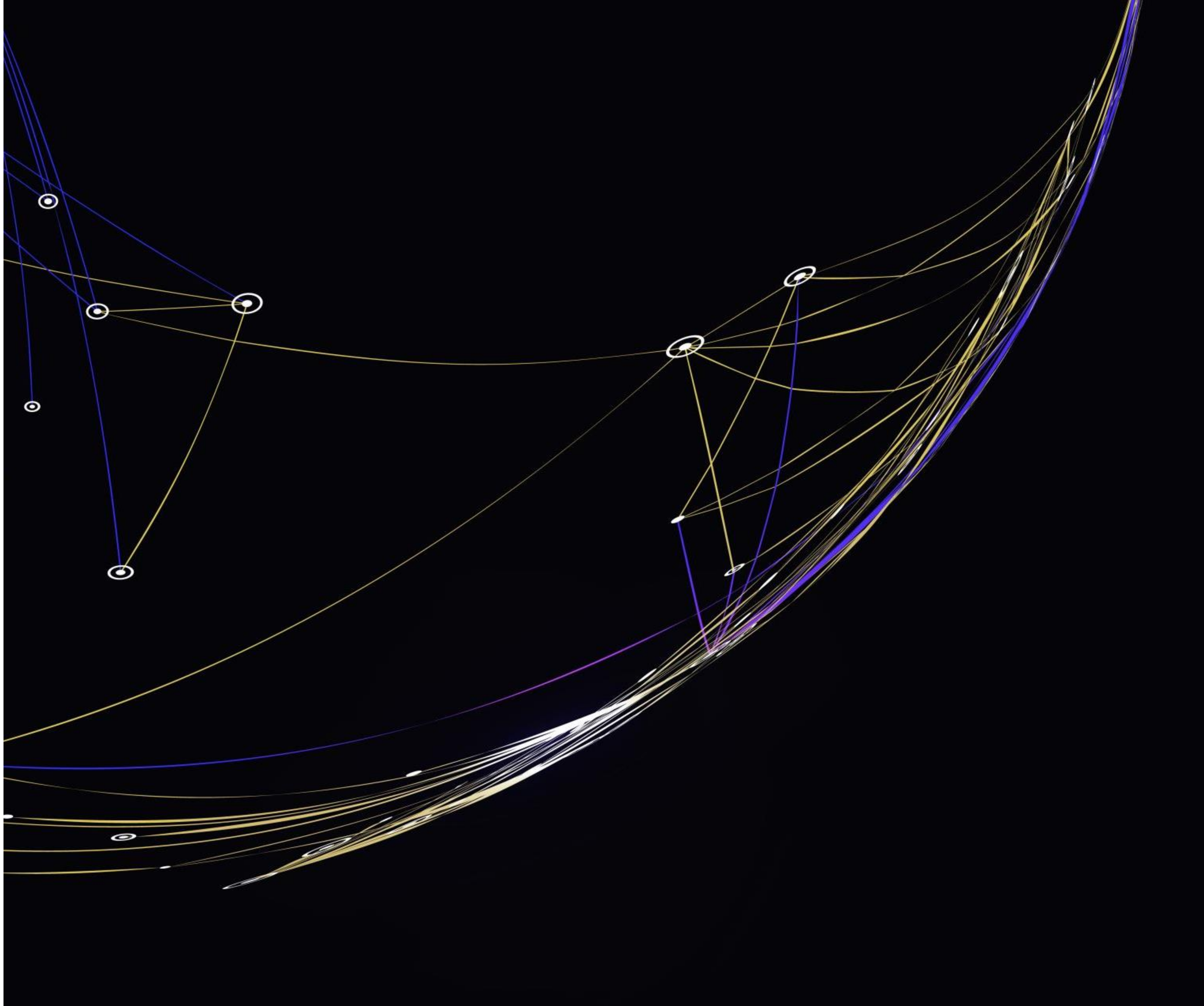
Quantum Speedups



Quantum speedups

- Deutsch-Josza algorithm for n-bit functions
  - Classically $2^{n-1} + 1$ queries to the oracle (worst case)
  - Quantum– only 1 query
- This algorithm leads to more advanced algorithms to identify interesting properties
  - Period finding--- Simon’s algorithm
  - Factoring algorithm---Shor’s algorithm
- Speed up provided for factoring --- Breaking down RSA encryption

Quantum Properties



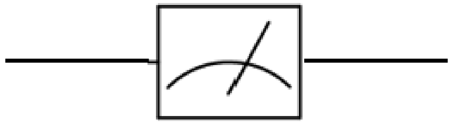
No-cloning Theorem

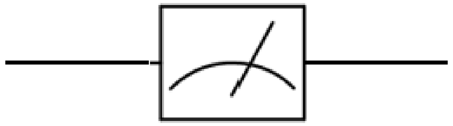
- What is that?
  - Classical data can be copied and duplicated
  - Can’t copy, duplicate quantum states
- Interesting property for security applications

Destructiveness of measurements

- Once the measurement is done, original state may “collapses”

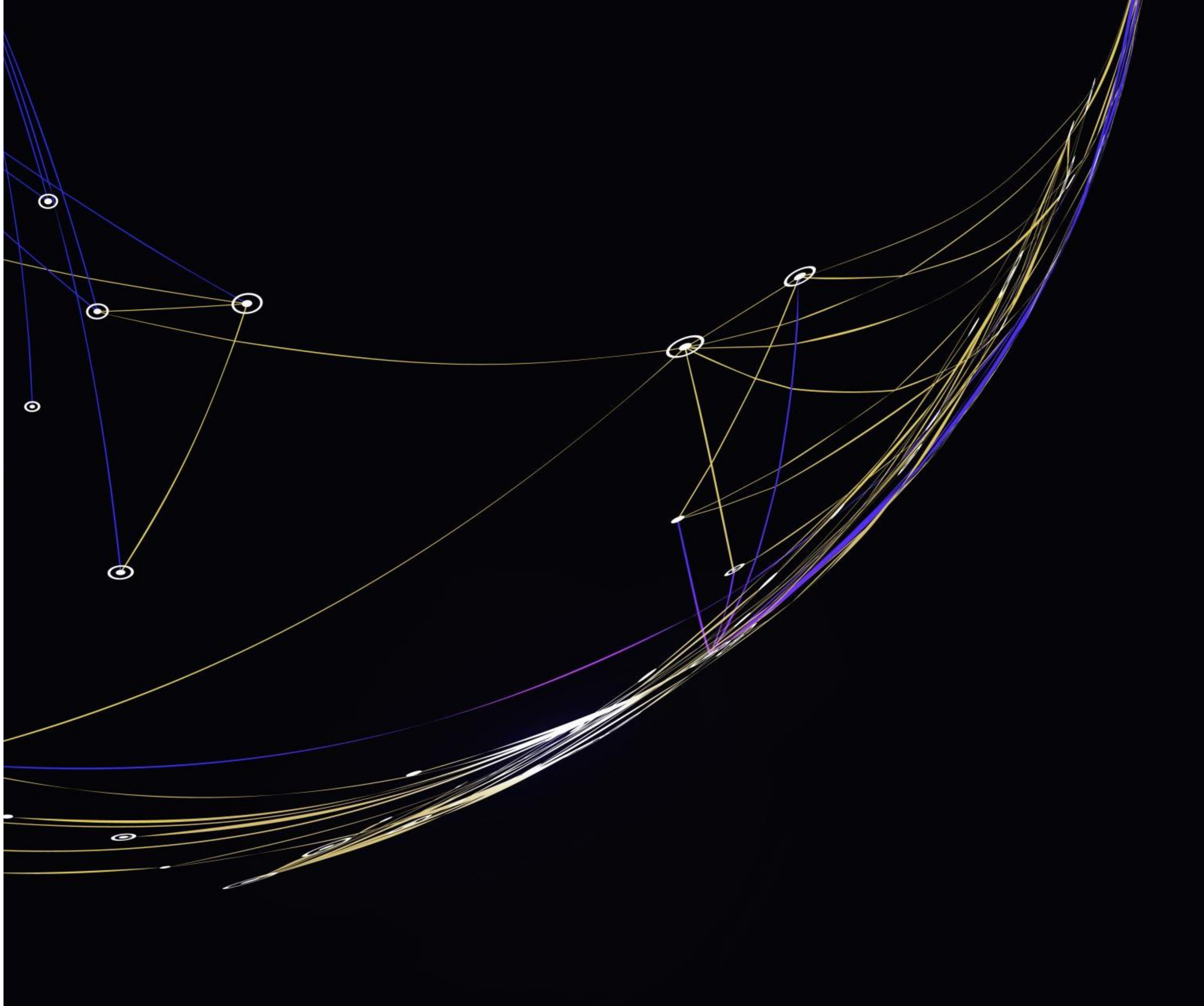
Example:

$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$  $|0\rangle$ With probability $|\alpha|^2$

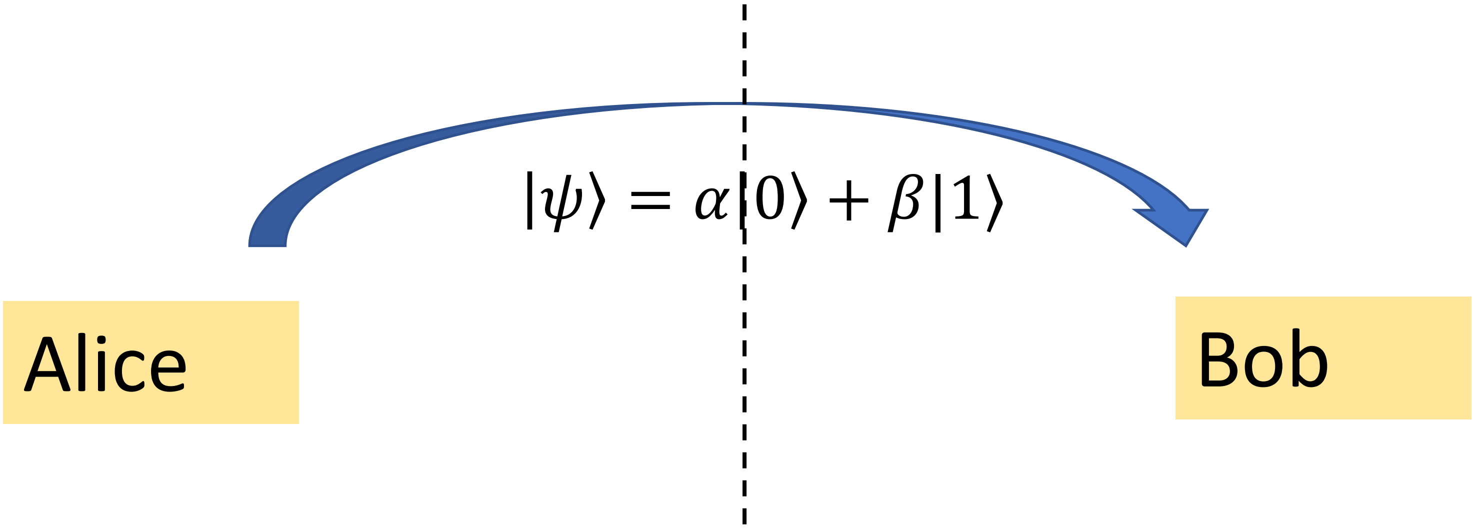
$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$  $|1\rangle$ With probability $|\beta|^2$

Post-measurement state

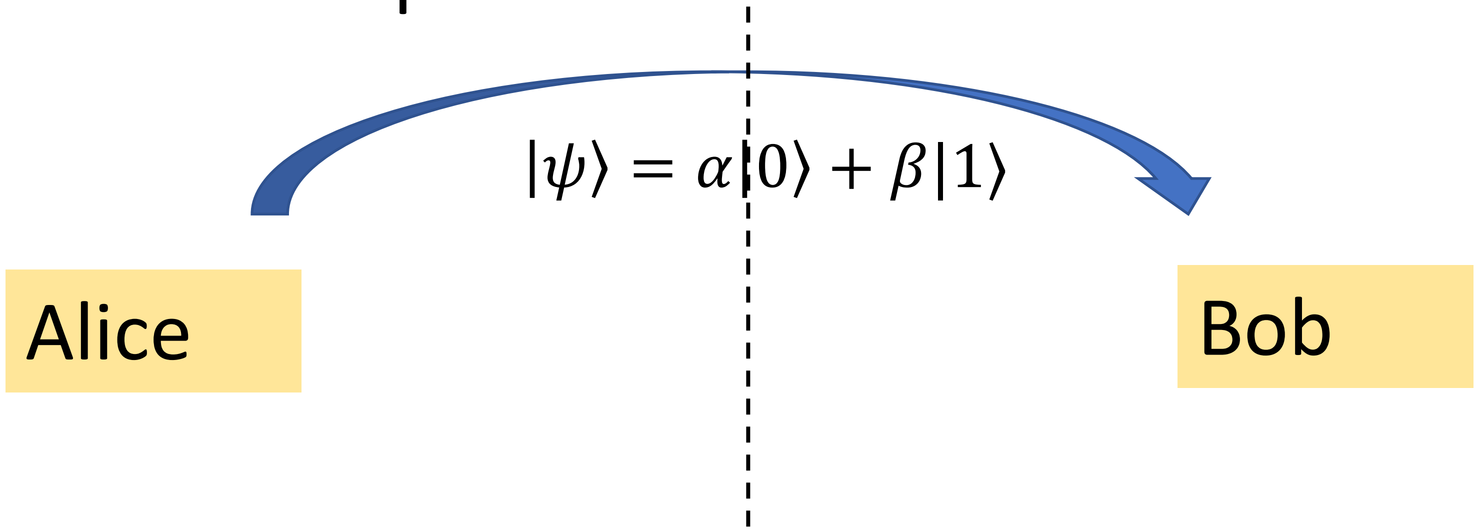
Quantum Teleportation



Quantum Teleportation

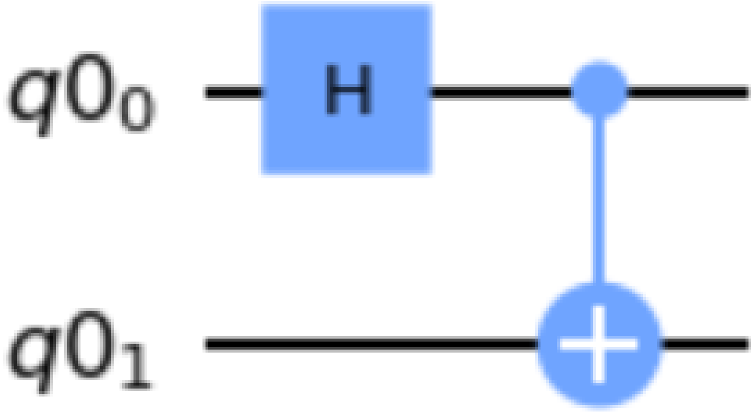


Quantum Teleportation



- From No-Cloning theorem, quantum states can’t be copied or duplicated.
- How to transmit the quantum information without destroying the superposition of quantum states?

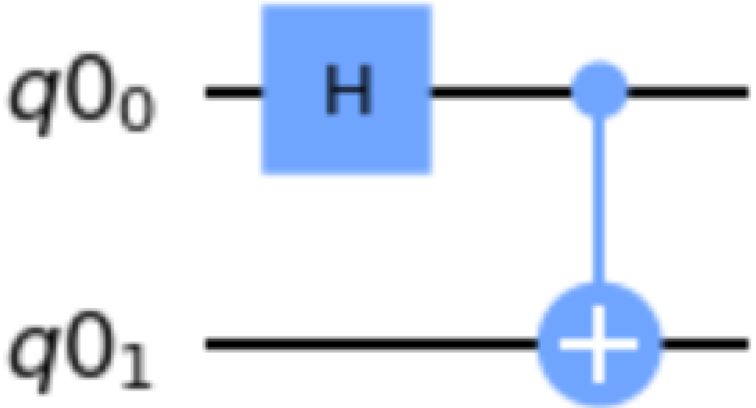
Back to our first circuit in Qiskit

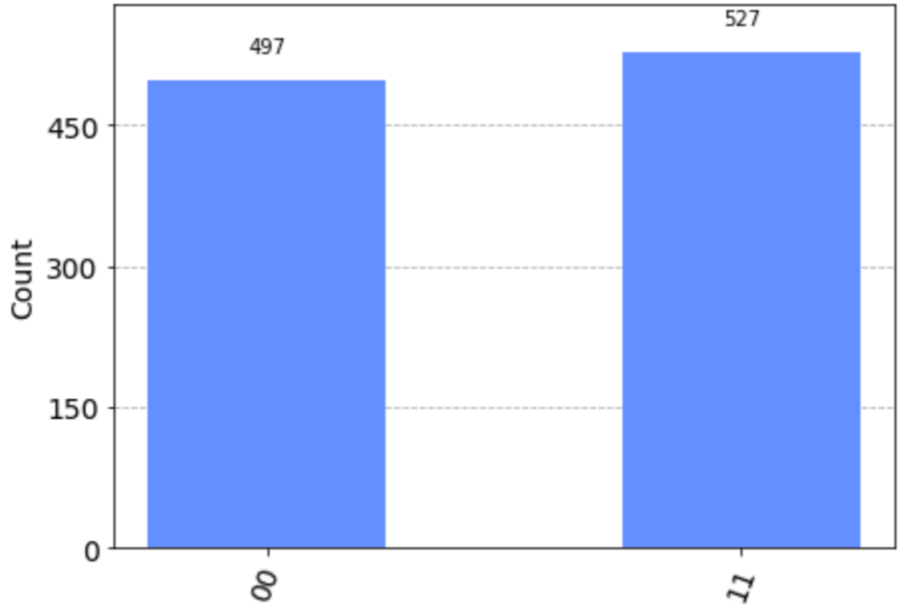


Output state of this circuit: $|\psi\rangle = \frac{1}{\sqrt{2}}(|00\rangle + |11\rangle)$

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

Back to our first circuit in Qiskit





Exists Correlations!

Output state of this circuit: $|\psi\rangle = \frac{1}{\sqrt{2}}(|00\rangle + |11\rangle)$

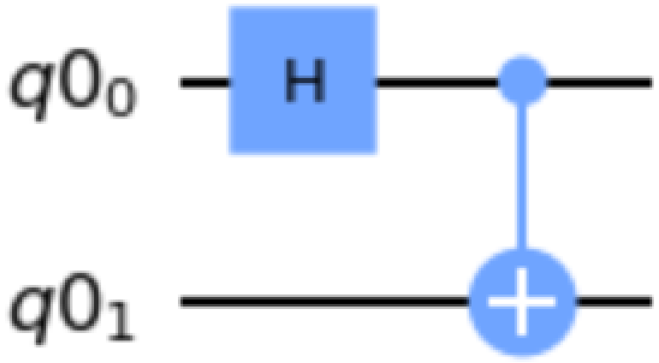
$= \frac{1}{\sqrt{2}}(|0\rangle \otimes |0\rangle + |1\rangle \otimes |1\rangle)$

Bell states

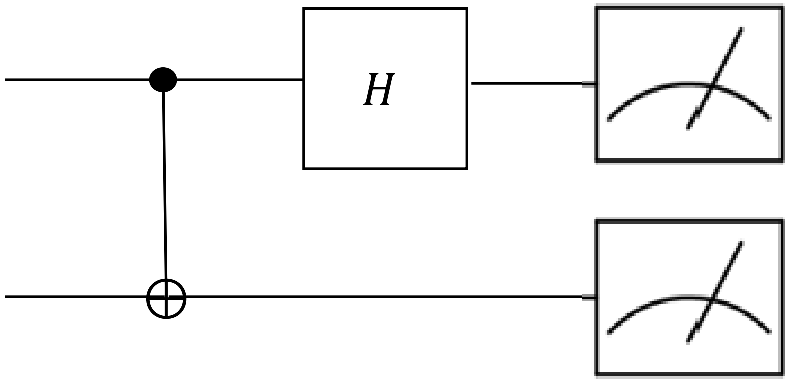
- Bell states are entangled states

$$|\psi\rangle = \frac{1}{\sqrt{2}}(|00\rangle + |11\rangle)$$

- How to create the following Bell state



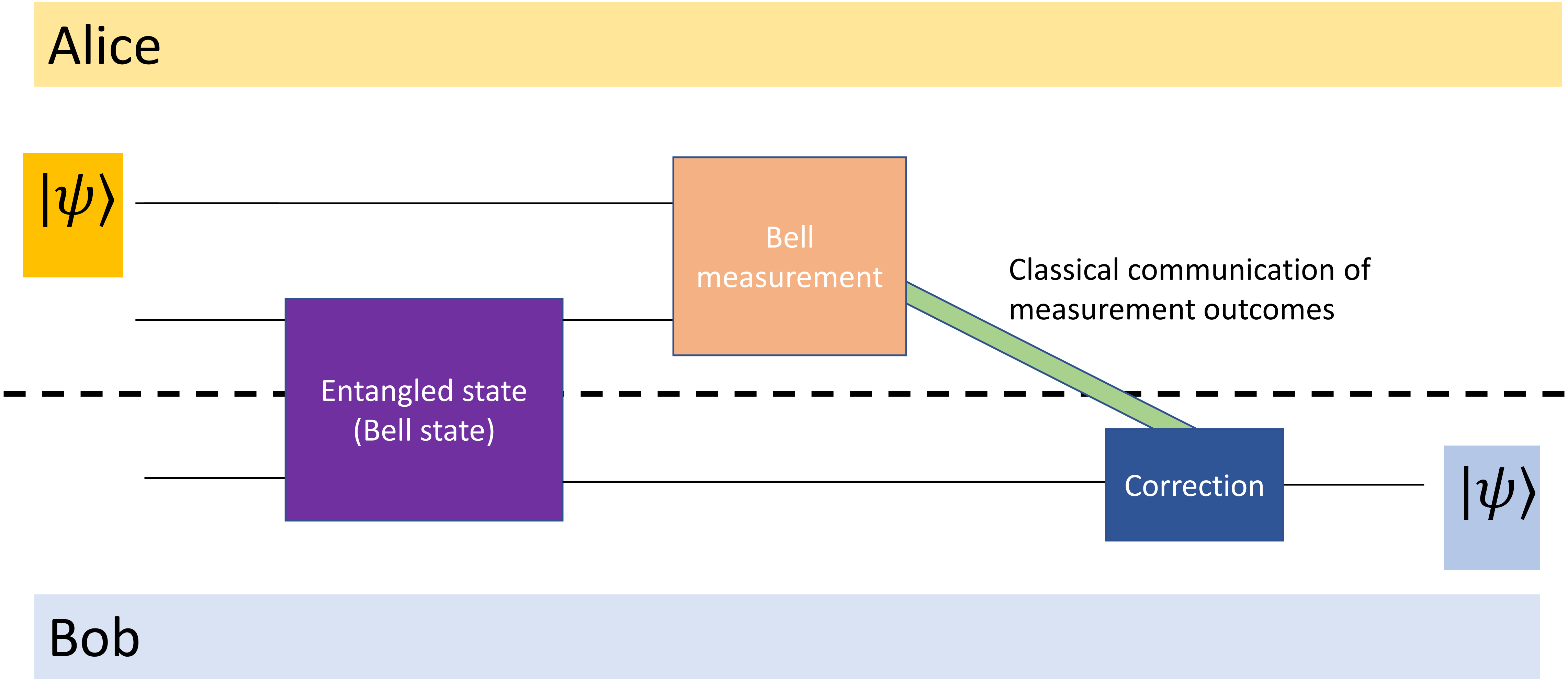
Bell measurement



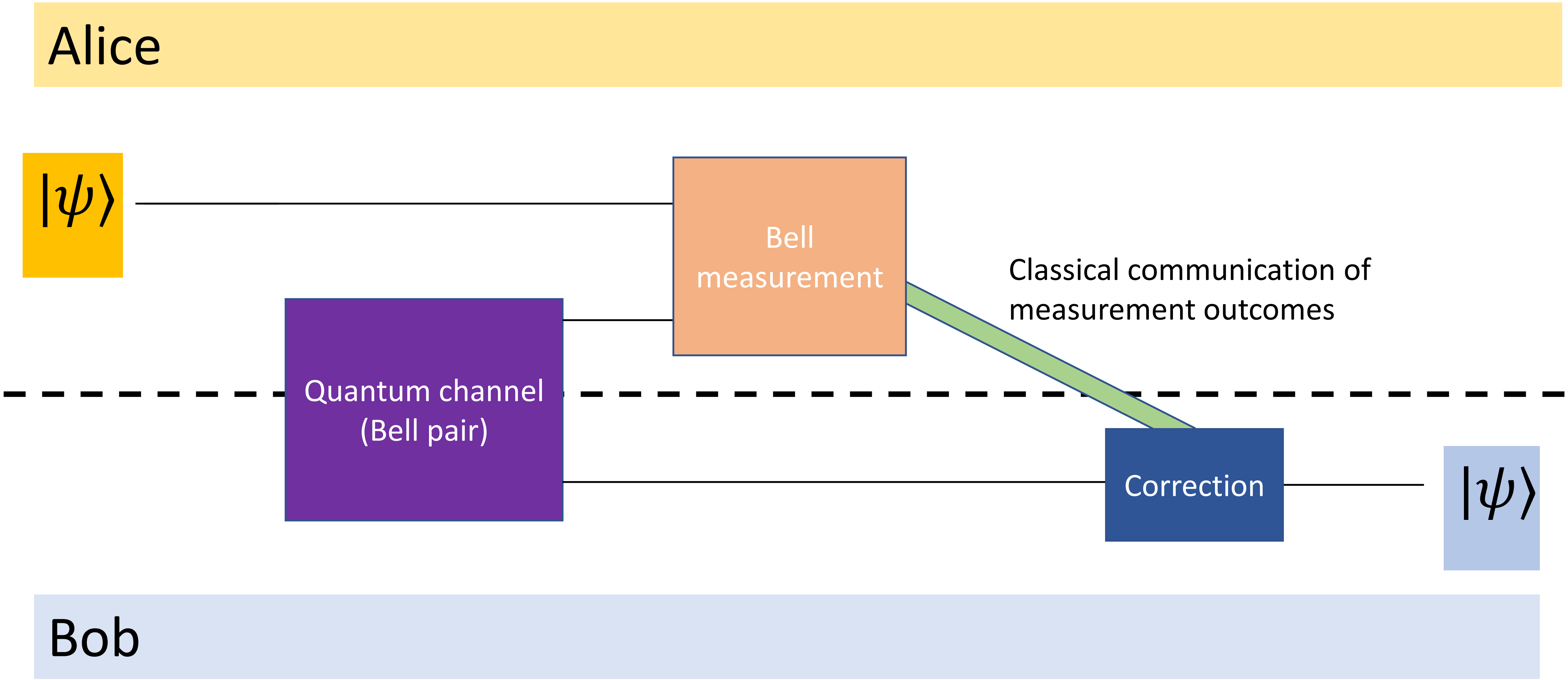
Entanglement and measurement

Steps

- Alice has one qubit with state $|\psi\rangle$
- Alice and Bob share an entangled state--- Bell pair
- Alice apply a Bell measurement to his two qubits
- Then Alice send the outcomes of those measurements to Bob through a classical channel
- Bob does the correction circuit
- Now Bob has the state $|\psi\rangle$--- Teleportation

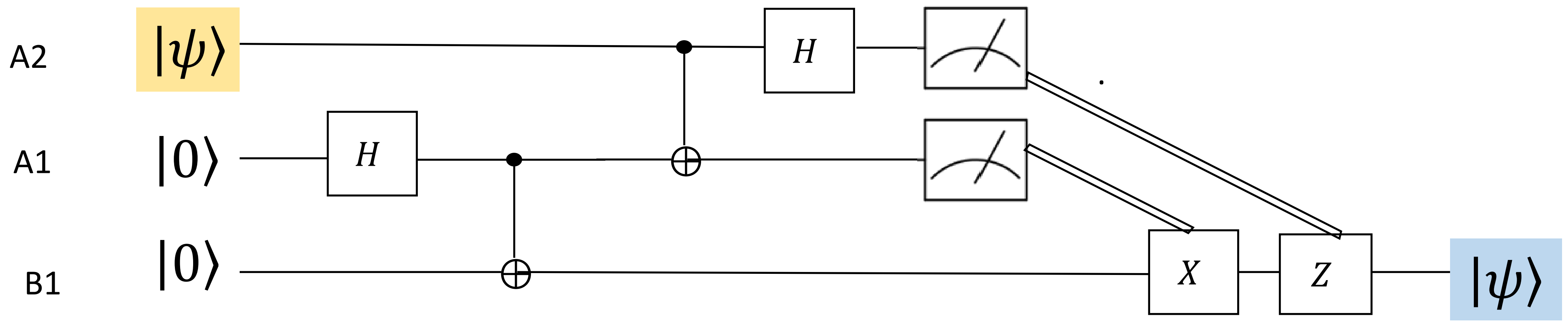


Alice
$|\psi\rangle$
Bell
measurement
Classical communication of
measurement outcomes
Entangled state
(Bell state)
Correction
$|\psi\rangle$
Bob



This protocol destroys the quantum state in one location and recreates at a distant location

Quantum circuit



$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$

What is Bob’s correction?

Measurement outcomes of Alice	00	01	10	11
Bob’s qubit	$\alpha\|0\rangle + \beta\|1\rangle$	$\alpha\|1\rangle + \beta\|0\rangle$	$\alpha\|0\rangle - \beta\|1\rangle$	$\alpha\|1\rangle - \beta\|0\rangle$

- Without knowing measurement outcomes, all these states are equiprobable
- Thus, can’t do teleportation violating the speed of light – Need to send the outcomes through a classical channel

Corrections- 00

Measurement outcomes of Alice	**00**	**01**	**10**	**11**
Bob's qubit	$\alpha\|0\rangle + \beta\|1\rangle$	$\alpha\|1\rangle + \beta\|0\rangle$	$\alpha\|0\rangle - \beta\|1\rangle$	$\alpha\|1\rangle - \beta\|0\rangle$

$$\downarrow$$

$$|\psi\rangle$$

$$X|0\rangle = |1\rangle$$
$$X|1\rangle = |0\rangle$$
$$\mathrm{Z}|0\rangle = |0\rangle$$
$$Z|1\rangle = -|1\rangle$$

Corrections- 01

Measurement outcomes of Alice	**00**	**01**	**10**	**11**
Bob's qubit	$\alpha\|0\rangle + \beta\|1\rangle$	$\alpha\|1\rangle + \beta\|0\rangle$	$\alpha\|0\rangle - \beta\|1\rangle$	$\alpha\|1\rangle - \beta\|0\rangle$

$$X|0\rangle = |1\rangle$$
$$X|1\rangle = |0\rangle$$
$$\mathrm{Z}|0\rangle = |0\rangle$$
$$Z|1\rangle = -|1\rangle$$

Apply X

Corrections- 10

Measurement outcomes of Alice	**00**	**01**	**10**	**11**
Bob's qubit	$\alpha\|0\rangle + \beta\|1\rangle$	$\alpha\|1\rangle + \beta\|0\rangle$	$\alpha\|0\rangle - \beta\|1\rangle$	$\alpha\|1\rangle - \beta\|0\rangle$

Apply Z

$$X|0\rangle = |1\rangle$$
$$X|1\rangle = |0\rangle$$
$$\mathrm{Z}|0\rangle = |0\rangle$$
$$Z|1\rangle = -|1\rangle$$

Corrections- 11

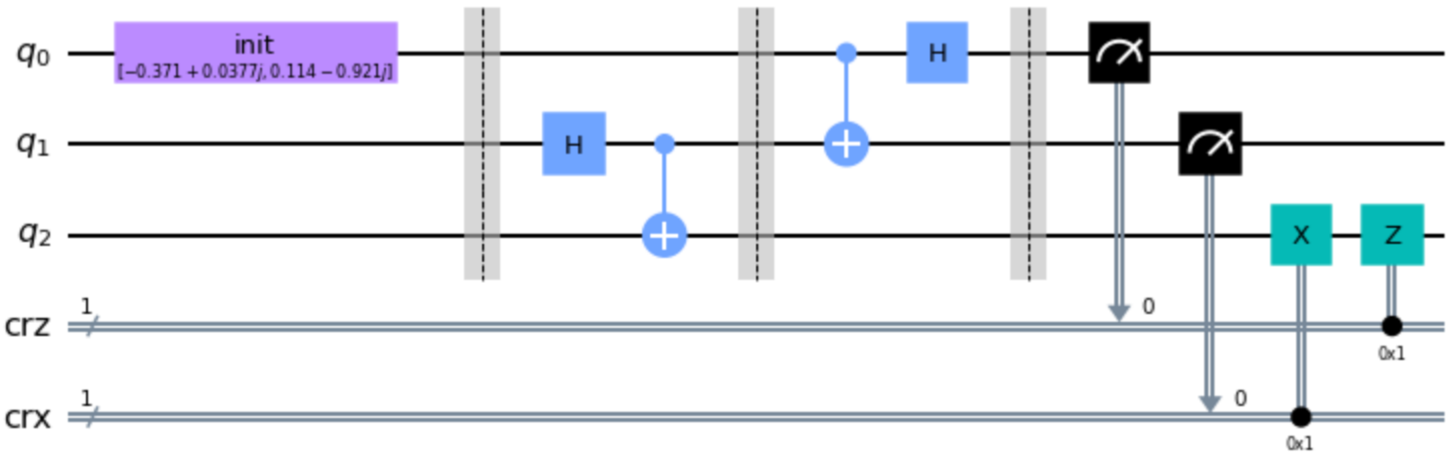
Measurement outcomes of Alice	**00**	**01**	**10**	**11**
Bob's qubit	$\alpha\|0\rangle + \beta\|1\rangle$	$\alpha\|1\rangle + \beta\|0\rangle$	$\alpha\|0\rangle - \beta\|1\rangle$	$\alpha\|1\rangle - \beta\|0\rangle$

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

Apply ZX

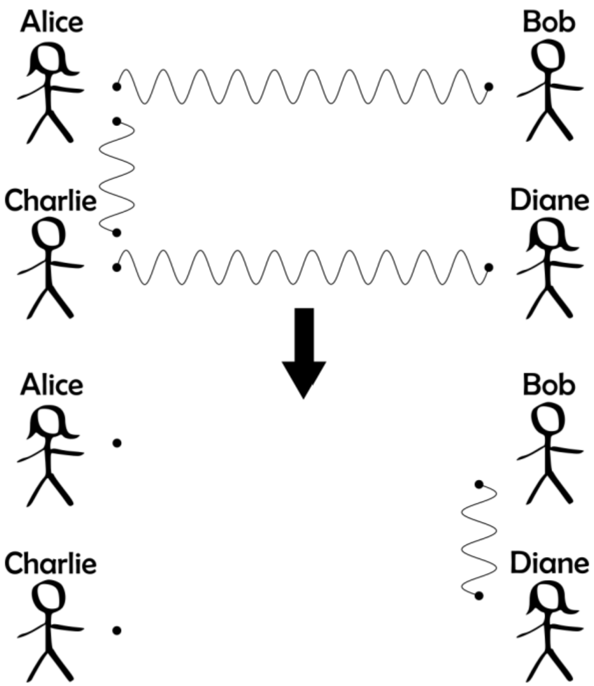
Quantum Teleportation circuit with Qiskit

- Let's implement this quantum circuit and see how it works



Notebook: Demo_Quantum_Teleportation

Entanglement swapping



- Alice and Bob share a Bell pair
- Charlie and Diane share a Bell pair
- Teleportation from Alice to Charlie
- Teleportation from Charlie to Diane
- Bob and Diane share a Bell pair

Bob and Diane didn’t interact directly

Image Source: Scott Aaronson’s notes

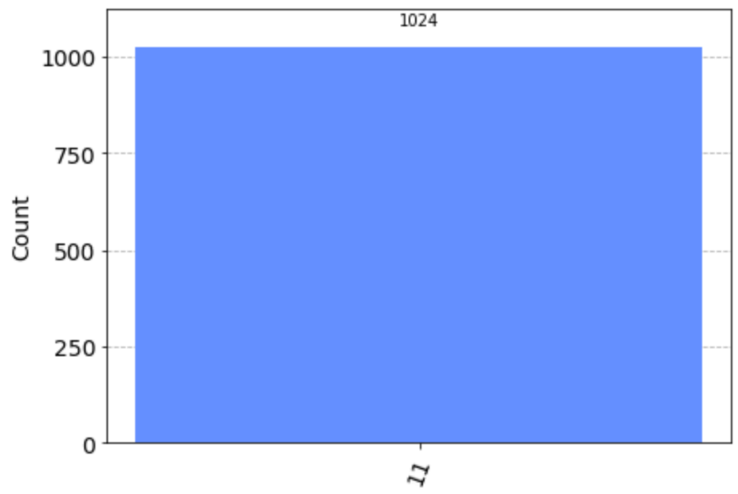
Back to Outline

- Qiskit and IBM Quantum experience
- First circuit in Qiskit
- Quantum speedups-- Deutsch-Jozsa Algorithm
- Quantum correlations--Entanglement
- Quantum Teleportation

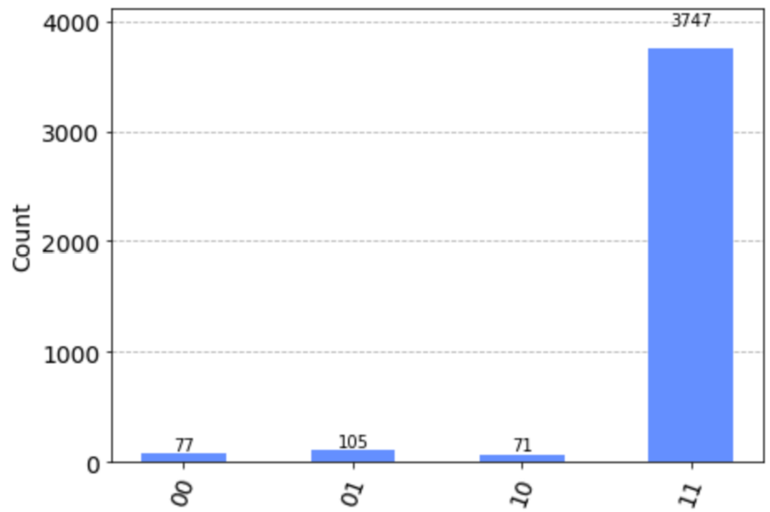
Questions?

Challenges in Quantum computing

- Errors



Ideal quantum computer



Available quantum devices

- Scalability
- Connectivity