WORKSHOP

Quantum Computing

From Zero to Quantum Hero

7 notebooks | ~100 minutes | Hands-on learning

PPSP Laboratory

Overview

My First Qubit
Circuit, X gate, Measurement, Bloch sphere

Superposition
Hadamard, Probabilities, H dot H = I

Rotations & Interference
Pauli gates, RX/RY/RZ, Phase, H-Z-H

Two Qubits & CNOT
CNOT, Bell states, Correlations

Entanglement
Quantum correlations, CHSH inequality

Deutsch's Algorithm
Oracle, Quantum advantage, 1st algorithm

Teleportation
Full protocol, No-cloning, Fidelity

Prerequisites: Basic Python
Framework: Qiskit (IBM)

My First Qubit

The Analogy

Classical bit = light switch

ON or OFF, never both

Qubit = spinning coin

Heads AND tails until you look

The Bloch Sphere

Geometric representation of a qubit:

- North pole = |0>
- South pole = |1>
- Equator = superposition

Key Concepts

- **Quantum circuit**
- Program = qubits + gates + measurement
  X gate (quantum NOT)
- |0> becomes |1> and vice-versa
  Measurement
- Collapses the state, gives 0 or 1
  Reversibility
  X applied twice = identity

```
qc = QuantumCircuit(1, 1)
 qc.x(0)
# X gate
 qc.measure(0, 0)
```

Superposition

Classical vs Quantum

CLASSICAL COIN

In the air: we don't know

On the ground: heads OR tails

Always in ONE state, just unknown

QUBIT IN SUPERPOSITION

Before measurement: 0 AND 1 simultaneously

After measurement: collapses to 0 or 1

TRULY in both states at once

Born Rule

P(outcome) = |amplitude|^2

The Hadamard Gate (H)

Creates a perfect 50/50 superposition

H|0> = (|0> + |1>) / sqrt(2)

This is the |+> state, located on the equator of the Bloch sphere (positive X axis)

Amplitude |0>

1/sqrt(2)

Amplitude |1>

1/sqrt(2)

Key point: Superposition is not classical uncertainty. The qubit IS in both states at once.

Rotations & Interference

Pauli Gates (180 deg rotations)

X
X axis
|0> and |1>

Y
Y axis
+ phase

Z
Z axis
phase flip

Arbitrary Rotations

RX(theta), **RY(theta)**, **RZ(theta)**
Rotation by any angle around chosen axis

Quantum Phase

Relative sign between amplitudes.
Invisible to direct measurement, but crucial for interference.

Quantum Interference

Like waves meeting in the ocean:

CONSTRUCTIVE
Amplitudes add up

DESTRUCTIVE
Amplitudes cancel

Key demo: H-H = Identity

```
|0> --[H]--> |+> --[H]--> |0>
```

Interference reconstructs |0> with 100% certainty!

With Z between the two H:

```
|0> --[H]--> |+> --[Z]--> |-> --[H]--> |1>
```

The phase flip changes the interference!

Two Qubits & CNOT

The CNOT Gate

Controlled-NOT: applies X on target IF control is |1>

```
|00> --> |00>
|01> --> |01>
|10> --> |11> # flip!
|11> --> |10> # flip!
```

State space: exponential growth

2 qubits	50 qubits
4 states	10^15

Bell States

H + CNOT creates entangled pairs:

|Phi+> (|00>+|11>)/sqrt2	|Phi-> (|00>-|11>)/sqrt2
|Psi+> (|01>+|10>)/sqrt2	|Psi-> (|01>-|10>)/sqrt2

No-Cloning Theorem

Impossible to copy an arbitrary unknown quantum state. CNOT only clones basis states!

Entanglement

Einstein's Gloves Analogy

CLASSICAL VIEW

Left glove in one box, right glove in the other.
Opening one box, you "know" what's in the other.
Values were predetermined.

QUANTUM REALITY

The "gloves" have no defined hand before measurement.
Yet they ALWAYS match.
"Spooky action at a distance" - Einstein

Measuring in different bases:
H before measurement = X basis instead of Z basis

CHSH Inequality (Bell)

Parameter S measuring correlations:

CLASSICAL	QUANTUM
$S \leq 2$	$S = 2.828$
Hidden variables	= 2 sqrt(2)

Bell Inequality Violation

S > 2 proves nature is NOT classical.
No predetermined hidden variables.
Einstein was wrong on this point.

Nobel Prize 2022: Aspect, Clauser, Zeilinger

Deutsch's Algorithm

The Problem

A function f(x) is hidden. It is either:

CONSTANT	BALANCED
f(0)=f(1)	f(0) != f(1)

CLASSICAL	QUANTUM
2	1
queries	query

Quantum Oracle

U_f |x>|y> = |x>|y XOR f(x)>

The Algorithm

```
|0>|1> -- initial
[H][H] -- superposition
[U_f ] -- oracle (1 query!)
[H][ ] -- interference
measure
```

Result: Measure 0 = constant, Measure 1 = balanced

Why does it work?

Parallelism: evaluates f(0) AND f(1)
Interference: reveals the global property

Quantum Teleportation

The Protocol

Alice wants to send |psi> to Bob without sending the qubit:

- Share a Bell pair between Alice and Bob
- Alice performs Bell measurement on |psi> and her qubit
- Alice sends 2 classical bits to Bob
- Bob applies correction (X and/or Z)
- Bob now has exactly |psi>

Fidelity: 100% (in ideal conditions)
Original state is DESTROYED at Alice's side (no-cloning)

Key Points

Not faster than light

Bob must receive Alice's 2 classical bits to complete the transfer. Without this info, his qubit is random.

Entanglement as a resource

The Bell pair is "consumed" by the protocol. Entanglement is a one-time-use quantum channel.

Bob's Corrections

`00: I` `01: X` `10: Z` `11: ZX`

"The most famous protocol in quantum computing"

What You've Learned

Fundamentals
Circuits, gates, measurements, Bloch

Multi-qubits
CNOT, Bell, exponential

Superposition
Hadamard, Born, 0 AND 1

Entanglement
Non-classical, CHSH

Interference
Phase, constructive/destructive

Algorithms
Deutsch, quantum advantage

Going Further

Grover, Shor, Error correction
learn.qiskit.org

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