QC IN ABSTRACT LECTURE 2

QUBIT X QUBIT

QUANTUM RESOURCES FOR COMPUTING

SUPERPOSITION
Quantum objects can be in two states at once. You won't know the state until you make a measurement.

ENTANGLEMENT
Is a quantum correlation between objects where the state of one quantum object depends on the state of the other.

INTERFERENCE
Two quantum objects can interact with each other or and either cancel each other out or amplify one another.

These three weird properties enable the design of quantum algorithms which can compute in ways classical computers cannot, making quantum computers more powerful for solving certain types of problems

QUANTUM BITS: QUBITS
"How quantum computers compute"

BIT to QUBIT

in	out
0	$\|0\rangle$
1	$\|1\rangle$

$|\ \rangle$ is a ket and it indicates that we are talking about quantum states.

WHY ARE QC FASTER

# OF QUBIT	# OF SUPERPOS. ST.
1	2 $(\|0\rangle, \|1\rangle)$
2	4 $(\|00\rangle, \|01\rangle, \|10\rangle, \|11\rangle)$
3	8 ...

n qubits $\longrightarrow$ 2^n superposition states

Each operation acts on all the elements of the superposition

TWO QUBITS
Let's say we have two qubits: A and B

$|00\rangle$ or $|0\rangle|0\rangle$ qubit A $\rightarrow |0\rangle$ qubit B $\rightarrow |0\rangle$

$|01\rangle$ or $|0\rangle|1\rangle$ qubit A $\rightarrow |0\rangle$ qubit B $\rightarrow |1\rangle$

$|10\rangle$ or $|1\rangle|0\rangle$ qubit A $\rightarrow |1\rangle$ qubit B $\rightarrow |0\rangle$

$|11\rangle$ or $|1\rangle|1\rangle$ qubit A $\rightarrow |1\rangle$ qubit B $\rightarrow |1\rangle$

QUANTUM SUPERPOSITION
"Quantum objects can be in two states at once"

SUPERPOSITION
SUPERPOSITION:

a qubit can be $|0\rangle$ and $|1\rangle$ at the same time

This is how we show it:

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

MEASUREMENT
MEASUREMENT:

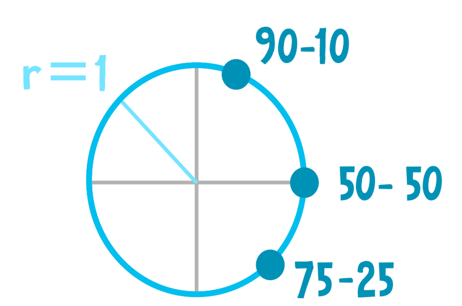
collapses the quantum state of the qubit $|\psi\rangle$ to either $|0\rangle$ or $|1\rangle$

probability of me. $|0\rangle$: $|\alpha|^2$

probability of me. $|1\rangle$: $|\beta|^2$

$$|\alpha|^2 + |\beta|^2 = 1$$

There are continuous set of superposition state



*Example

50- 50 superposition of 0 and 1

$|\psi\rangle = \sqrt{0.5}|0\rangle + \sqrt{0.5}|1\rangle$

$\alpha = \sqrt{0.5} = |\alpha|^2 = 0.5$

$\beta = \sqrt{0.5} = |\beta|^2 = 0.5$

75-25 superposition of 0 and 1

$|\psi\rangle = \sqrt{0.75}|0\rangle + \sqrt{0.25}|1\rangle$

$\alpha = \sqrt{0.75} = |\alpha|^2 = 0.75$

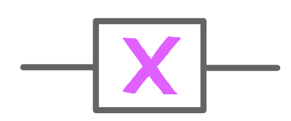
$\beta = \sqrt{0.25} = |\beta|^2 = 0.25$

QUANTUM GATES: SINGLE-QUBITS

X-GATE
bit-flip

$X|0\rangle \longrightarrow |1\rangle$

$X|1\rangle \longrightarrow |0\rangle$

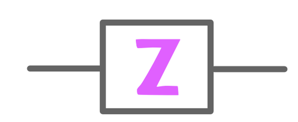


in	out
$\|0\rangle$	$\|1\rangle$
$\|1\rangle$	$\|0\rangle$

Z-GATE
phase gate

$Z|0\rangle \longrightarrow |0\rangle$

$Z|1\rangle \longrightarrow -|1\rangle$

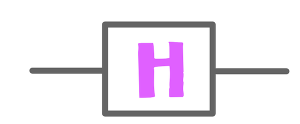


in	out
$\|0\rangle$	$\|0\rangle$
$\|1\rangle$	$-\|1\rangle$

HADAMARD
creates 50-50 superposition

$H|0\rangle \rightarrow \sqrt{0.5}|0\rangle + \sqrt{0.5}|1\rangle$

$H|1\rangle \rightarrow \sqrt{0.5}|0\rangle - \sqrt{0.5}|1\rangle$



in	out
$\|0\rangle$	$\frac{\|0\rangle+\|1\rangle}{\sqrt{2}}$
$\|1\rangle$	$\frac{\|0\rangle-\|1\rangle}{\sqrt{2}}$

QUANTUM GATES applied to superposition

Quantum gates apply to each state of the superposition

Separately

In parallel

$$X|\psi\rangle = X(\alpha|0\rangle + \beta|1\rangle)$$
$$= \alpha(X|0\rangle) + \beta(X|1\rangle)$$
$$= \alpha|1\rangle + \beta|0\rangle$$

What is the difference between a coin flip and quantum superposition

COIN FLIP

1 coin flip: 50%H 50%T

2 coin flip: 50%H 50%T

SUPERPOSITION

1 had gate: $\xrightarrow{\text{measu.}}$ 50%0 50%1

2 had gate: $\xrightarrow{\text{measu.}}$ 100%0

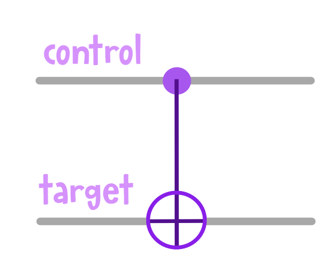
The states involved in quantum superposition can cancel or amplify

QUANTUM GATES: TWO QUBITS

CNOT gate (controlled not)

* If the control qubit is 0, does nothing
* If the control qubit is 1, flip the target qubit

in		out	
c	t	c	t
$\|0\rangle$	$\|0\rangle$	$\|0\rangle$	$\|0\rangle$
$\|0\rangle$	$\|1\rangle$	$\|0\rangle$	$\|1\rangle$
$\|1\rangle$	$\|0\rangle$	$\|1\rangle$	$\|1\rangle$
$\|1\rangle$	$\|1\rangle$	$\|1\rangle$	$\|0\rangle$



QUANTUM ENTANGLEMENT
"Quantum correlation between two qubits where the state of one qubit depends on the other qubit"

ENTANGLEMENT
Entangled state: $|\psi\rangle = \sqrt{0.5}|00\rangle + \sqrt{0.5}|11\rangle$

If we measure $|\psi\rangle$

* we get $|00\rangle$ with 50% probability
* we get $|11\rangle$ with 50% probability

What if we only measure qubit A?

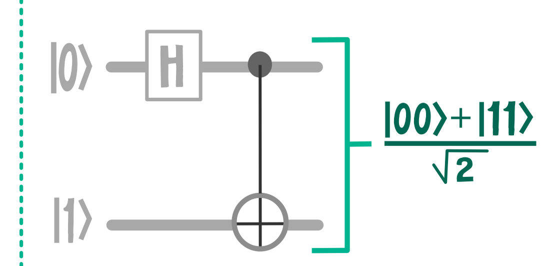
If qubit A is 0 the quantum state of qubit B is immediately set to $|0\rangle$

If qubit A is 1 quantum state qubit B set to $|1\rangle$

APPLICATIONS
* Quantum teleportation
* Quantum cryptography
* Superdense coding
* Quantum speedups

Q. TELEPORTATION
Transferring information or matter from one point to another without physically moving things!

HOW TO CREATE IT



Q. SUPREMACY
A programmable quantum device can solve a problem that no classical computer can solve in any feasible amount of time