Intro to Quantum Computing

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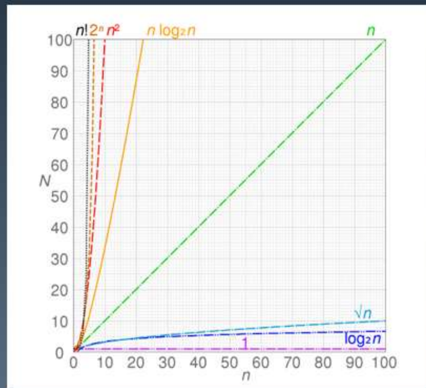
Contents

We will cover the following:

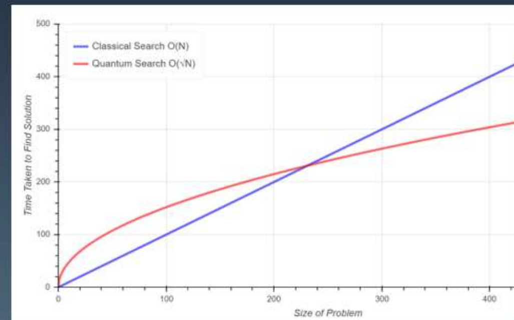
1. Introduction to Quantum Computing
2. Introduction to Quantinuum and TKET

1) Introduction to Quantum Computing

BIG O NOTATION



n is the number of input bits, and N is the number of operations required



The complexity for a classical search is O(N) for searching a database of N entries. Grover's algorithm could reduce to O($\sqrt{N}$).

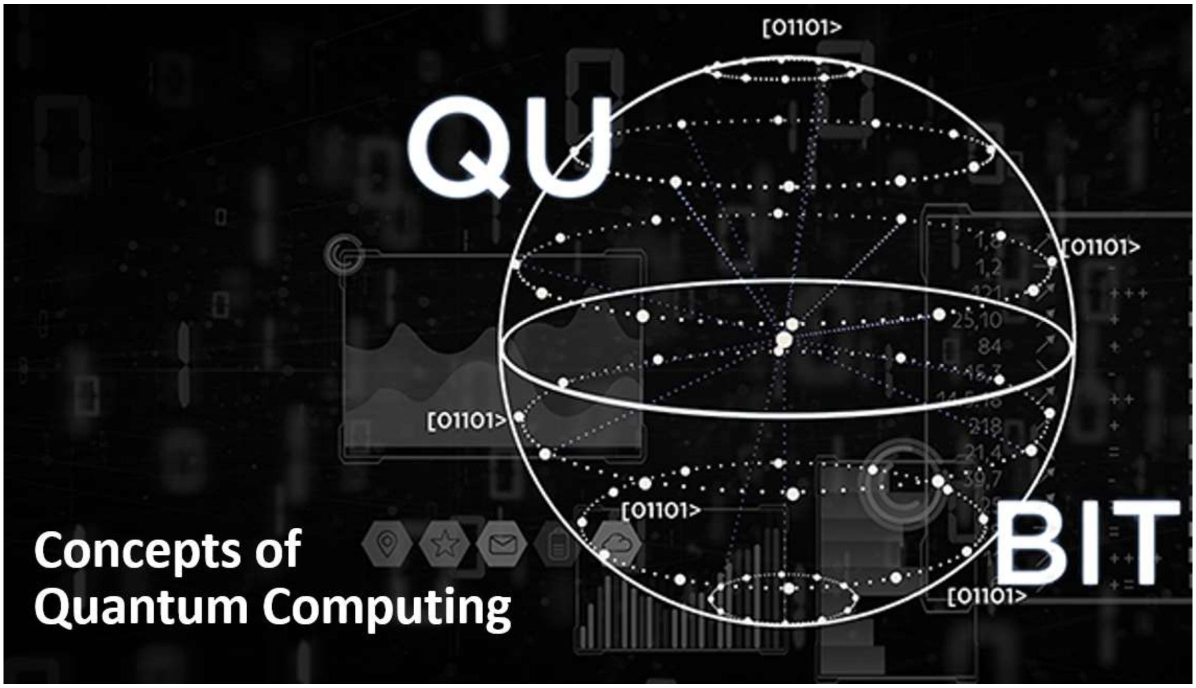
IT IS ANTICIPATED, QUANTUM COMPUTERS WILL ONE DAY SOLVE CERTAIN TYPES OF PROBLEMS THAT ARE INTRACTABLE FOR CLASSICAL COMPUTERS, SUCH AS:

Molecular Modeling

Optimization Applications

Data Encryption

Quantum computers will *complement*, not replace, classical computers.


[O1101>
QU
[O1101>
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BIT
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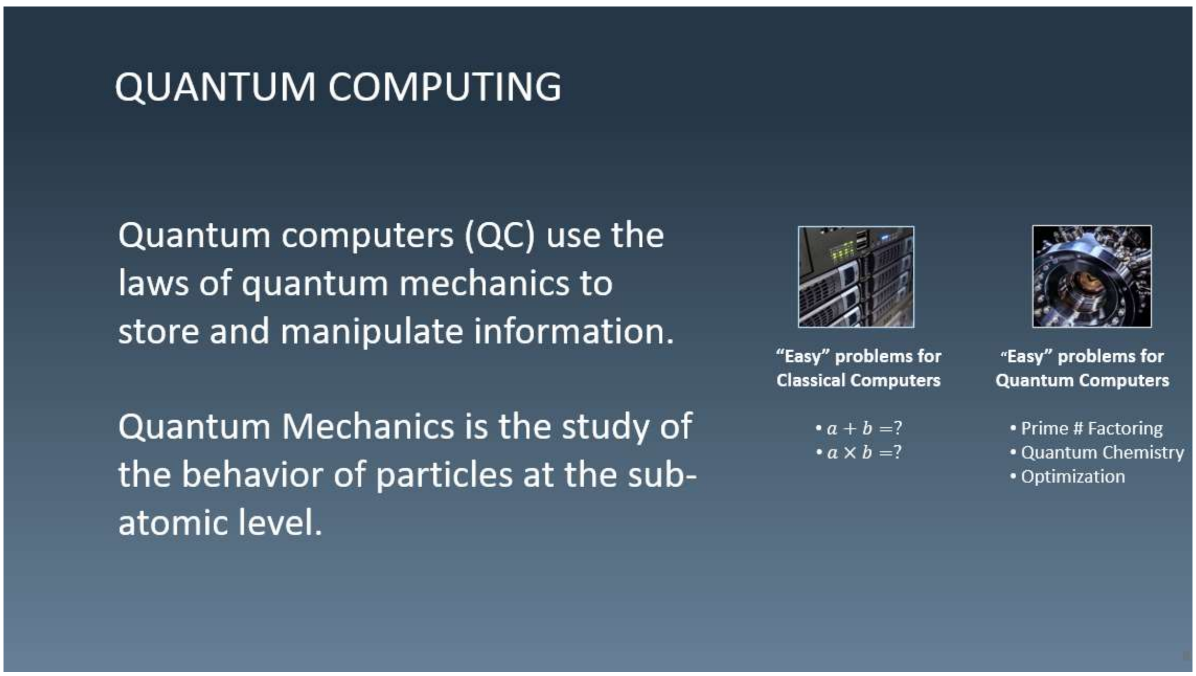
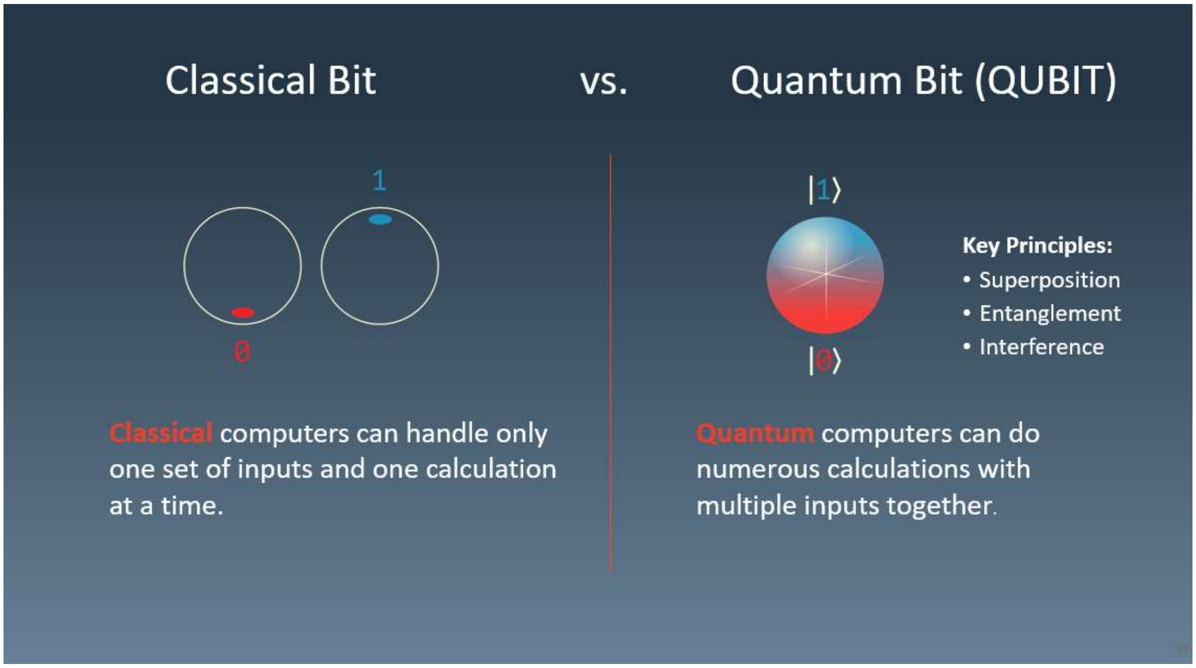
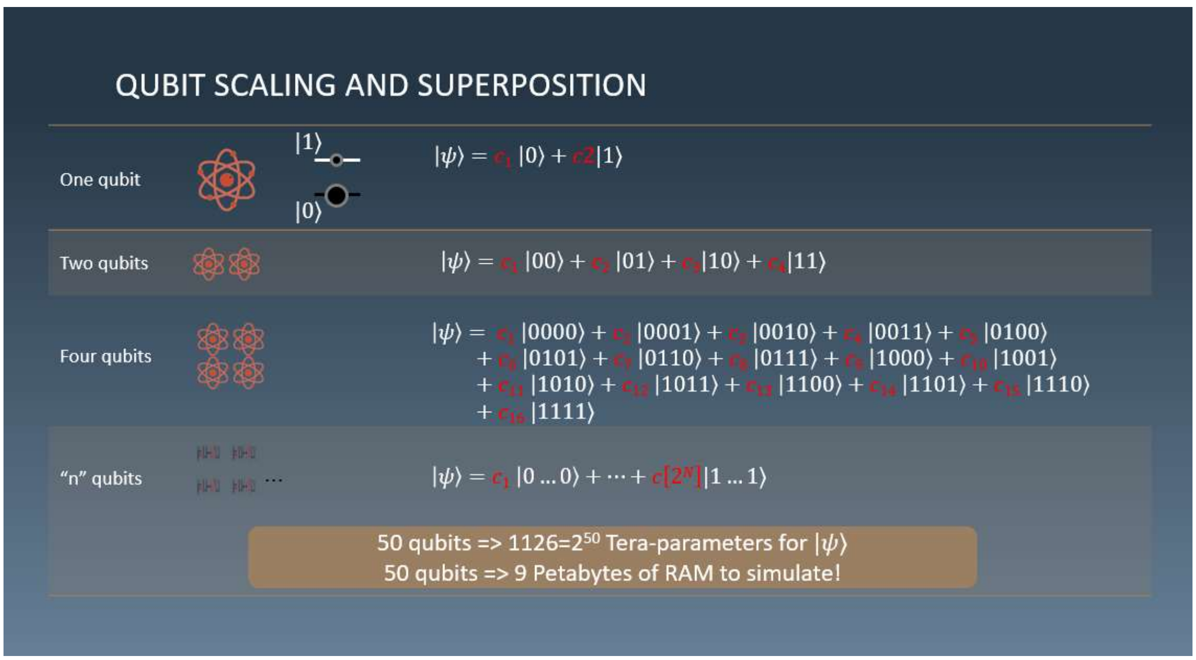
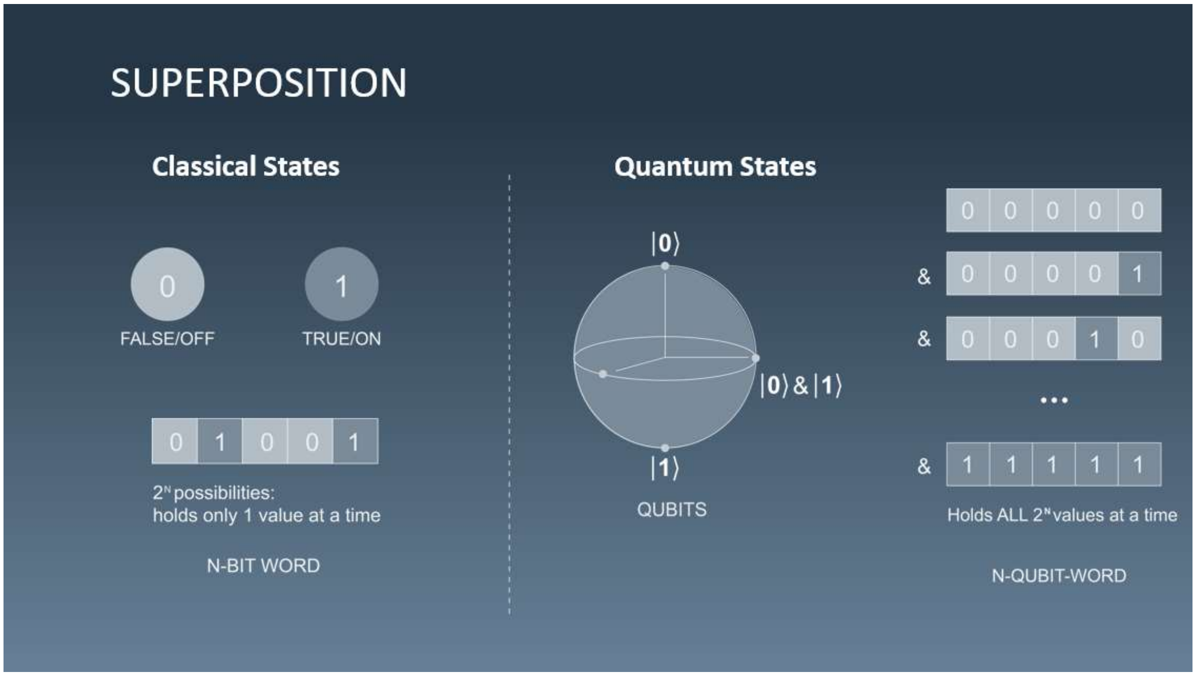
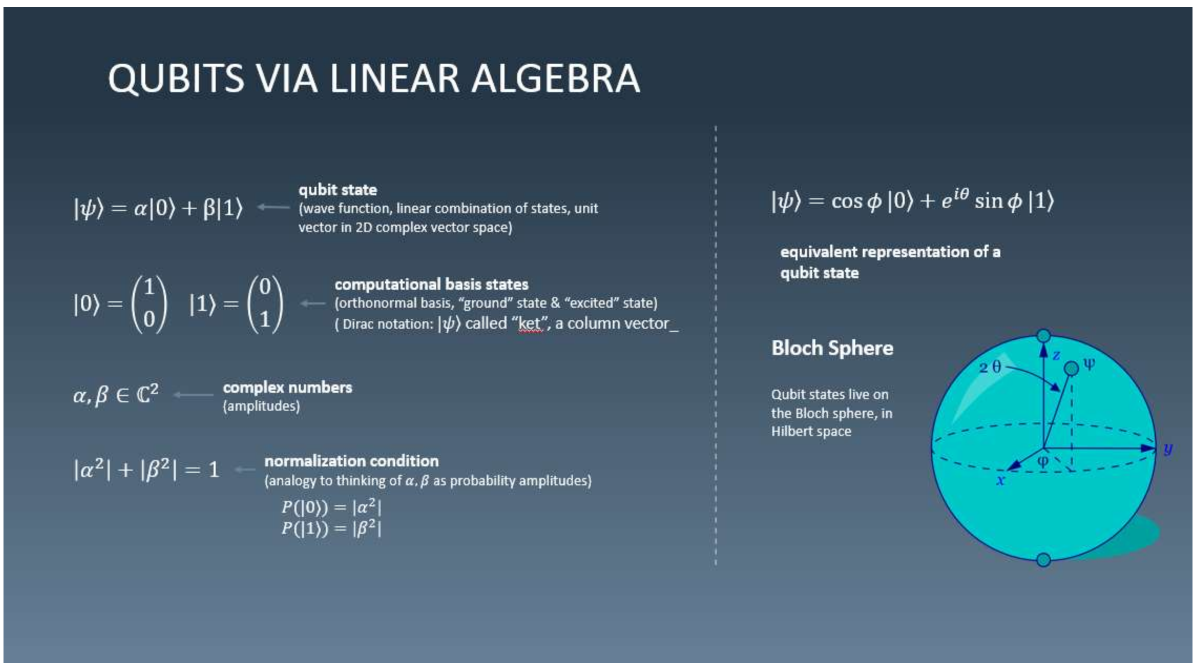
Concepts of
Quantum Computing


QUANTUM COMPUTING
Quantum computers (QC) use the laws of quantum mechanics to store and manipulate information.
Quantum Mechanics is the study of the behavior of particles at the sub-atomic level.
"Easy" problems for Classical Computers
• $a + b = ?$
• $a \times b = ?$
"Easy" problems for Quantum Computers
• Prime # Factoring
• Quantum Chemistry
• Optimization


Classical Bit
vs.
Quantum Bit (QUBIT)
1
0
|1⟩
|0⟩
Key Principles:
• Superposition
• Entanglement
• Interference
Classical computers can handle only one set of inputs and one calculation at a time.
Quantum computers can do numerous calculations with multiple inputs together.


QUBIT SCALING AND SUPERPOSITION
One qubit
|1⟩
|0⟩
$|\psi\rangle = c_1 |0\rangle + c2|1\rangle$
Two qubits
$|\psi\rangle = c_1 |00\rangle + c_2 |01\rangle + c_3|10\rangle + c_4|11\rangle$
Four qubits
$|\psi\rangle = c_1 |0000\rangle + c_2 |0001\rangle + c_3 |0010\rangle + c_4 |0011\rangle + c_5 |0100\rangle + c_6 |0101\rangle + c_7 |0110\rangle + c_8 |0111\rangle + c_9 |1000\rangle + c_{10} |1001\rangle + c_{11} |1010\rangle + c_{12} |1011\rangle + c_{13} |1100\rangle + c_{14} |1101\rangle + c_{15} |1110\rangle + c_{16} |1111\rangle$
"n" qubits
$|\psi\rangle = c_1 |0 \dots 0\rangle + \cdots + c[2^N]|1 \dots 1\rangle$
50 qubits => 1126=2^{50} Tera-parameters for $|\psi\rangle$
50 qubits => 9 Petabytes of RAM to simulate!

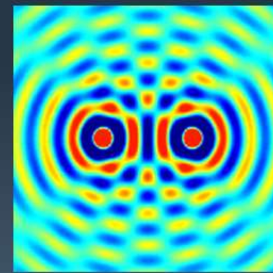


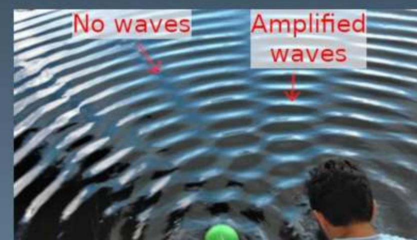


Euler's formula and polar coordinates ==> Bloch sphere

INTERFERENCE

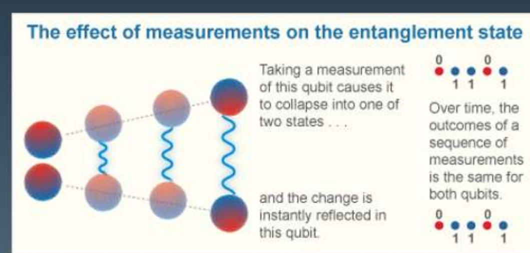
- Enables the quantum system to transform from one quantum state to another via the impact of individual particles interfering with one another.
- Analogy: noise-canceling headphones.
  - destructive and constructive
  - amplify the signals we care about and destroy all other signals

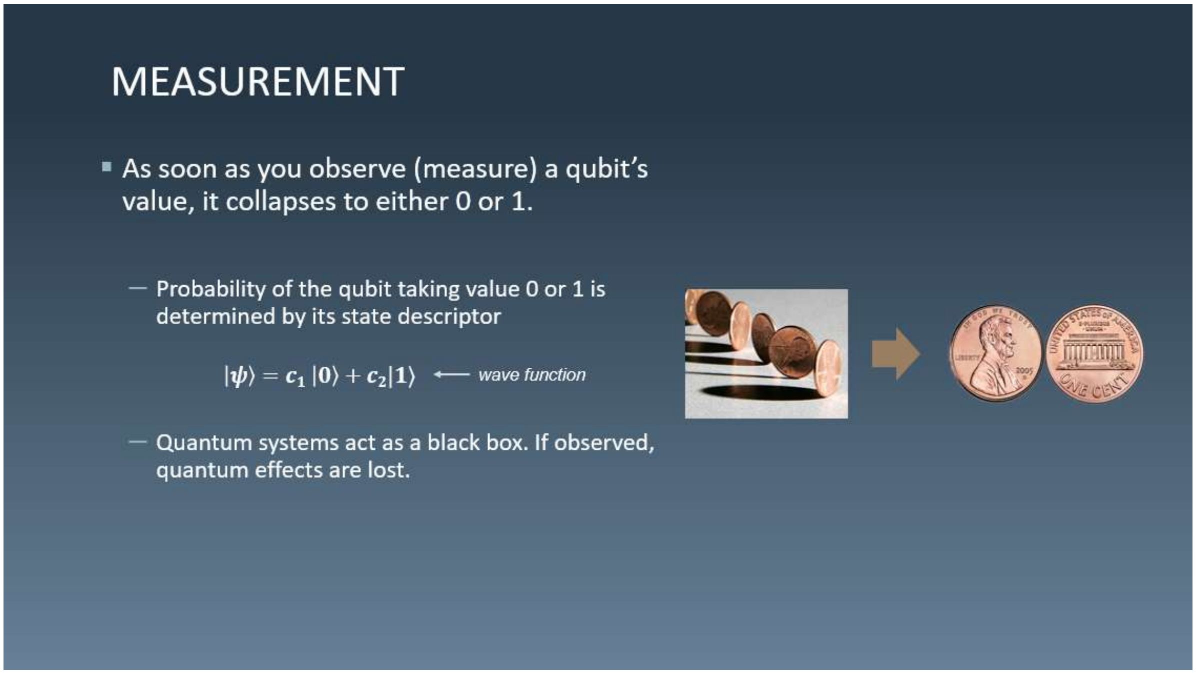


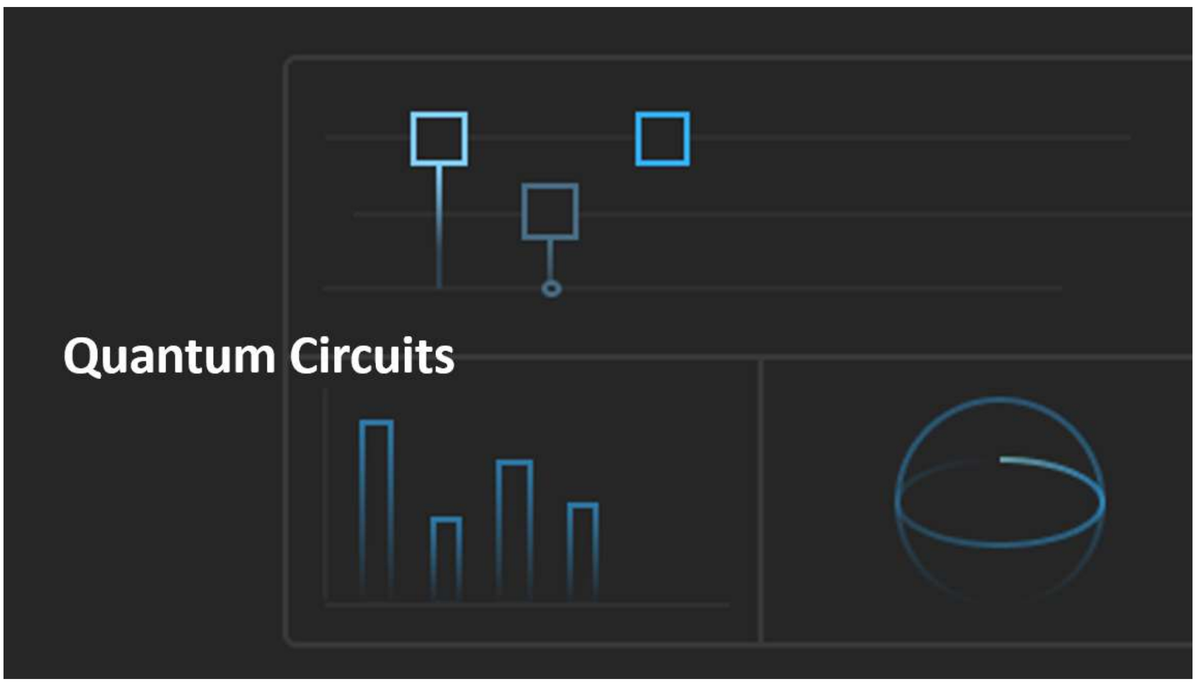


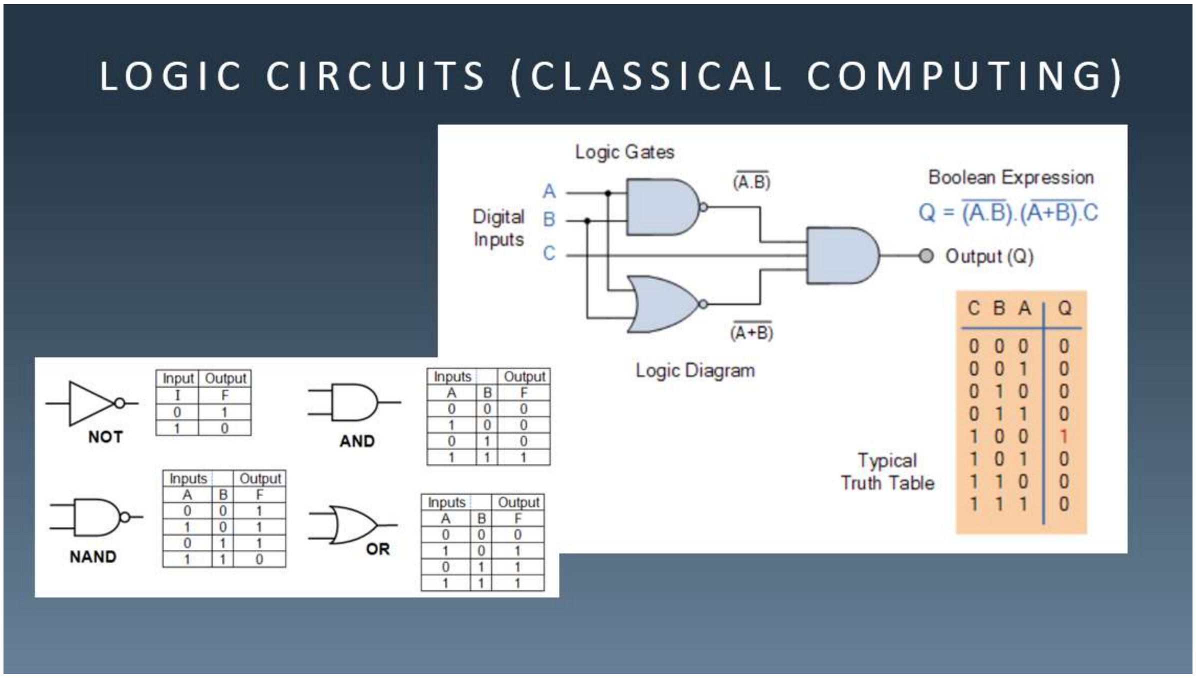
ENTANGLEMENT

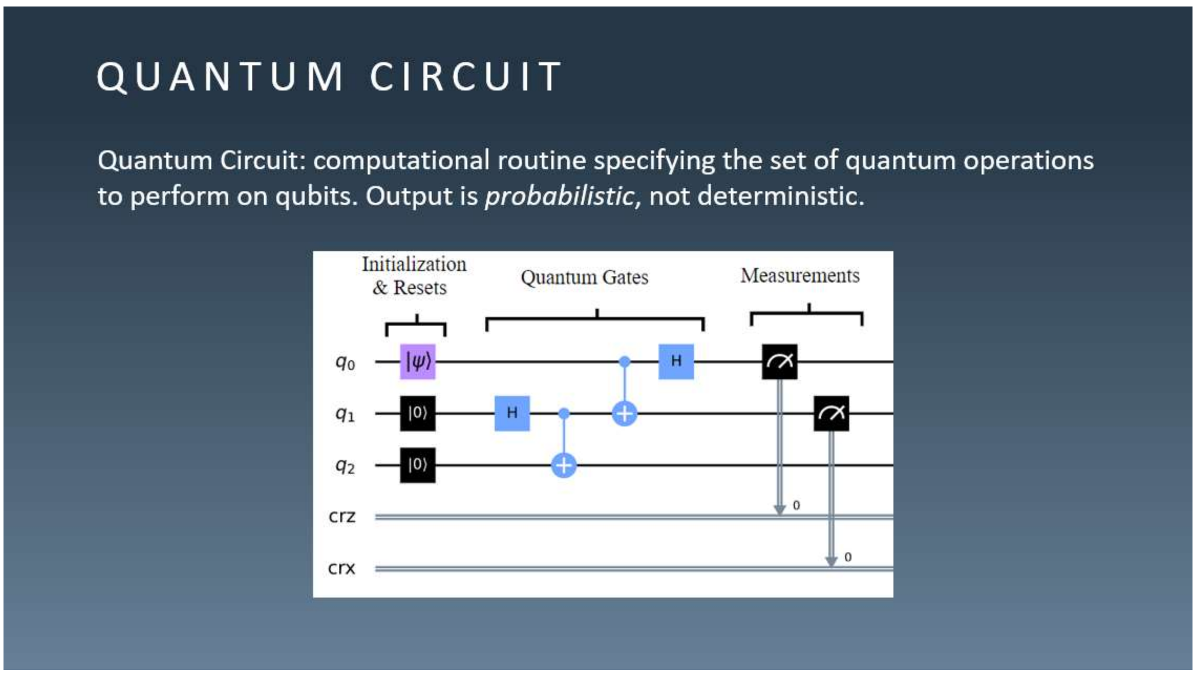
- Ability of quantum systems to exhibit correlations between states.
- When qubits are entangled, a change in one qubit impacts the state of another qubit.
- Deduce the property of other qubits without "looking" (measuring) those qubits.




MEASUREMENT
As soon as you observe (measure) a qubit's value, it collapses to either 0 or 1.
— Probability of the qubit taking value 0 or 1 is determined by its state descriptor
$|\psi\rangle = c_1\,|0\rangle + c_2|1\rangle \longleftarrow$ *wave function*
— Quantum systems act as a black box. If observed, quantum effects are lost.

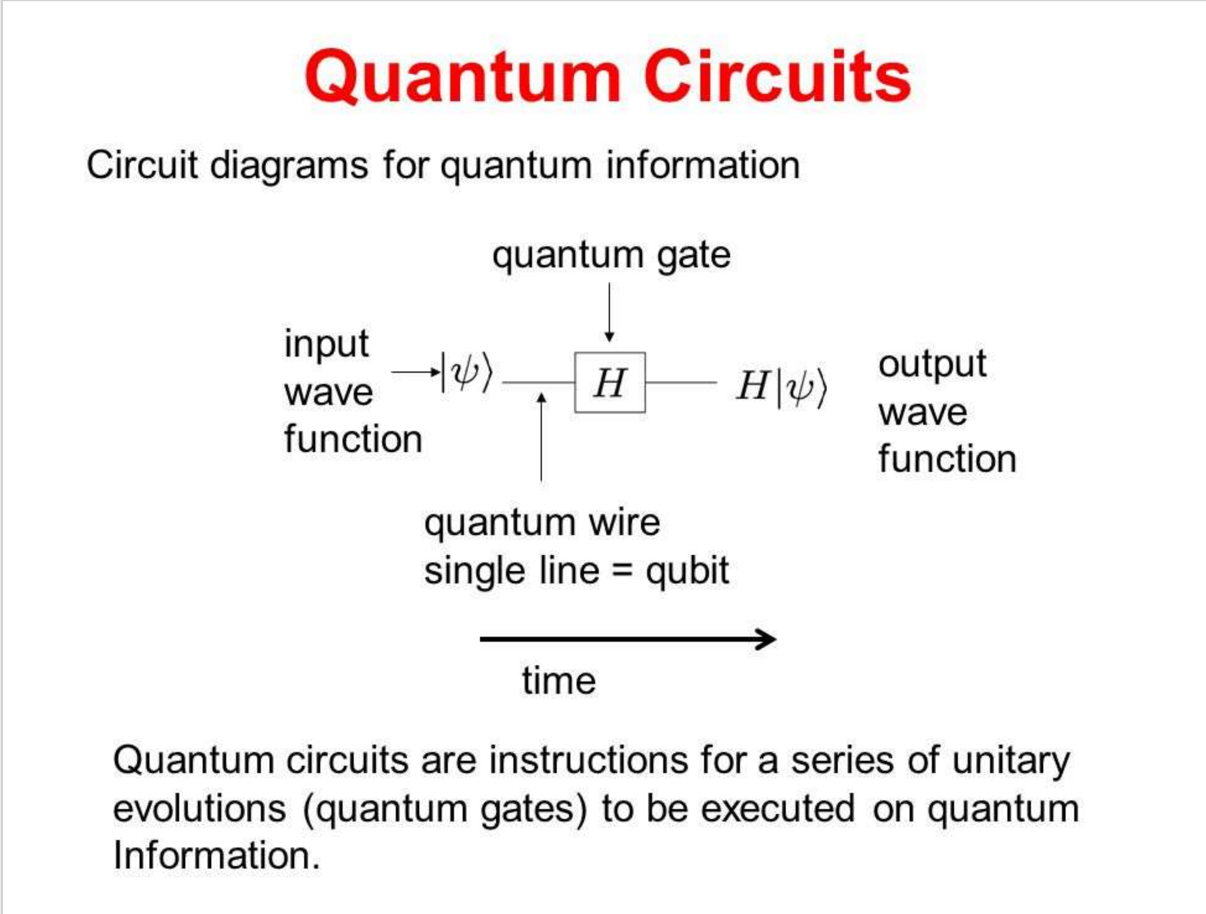

Quantum Circuits





- Used to describe a series of operations on a quantum computer
- Each row (wire) represents a bit (either classical or quantum)
- The operations in the circuit performed in order on each qubit from left to right
- Shoes dependency of operation with no implicit timing information

Here we can see some quantum gates on qubit 0 and qubit 1 and then we have two measurement operations which measure the state of the qubit which collapses it to a 0 or 1 and writes those out to a classical bit which is C0 and C1.



In bra-ket notation for fully entangled Bell state:

$$\text{CX}(\text{H} \otimes \text{I})\,|00\rangle = \text{CX}\frac{1}{\sqrt{2}}(|0\rangle + |1\rangle)\,|0\rangle = \frac{1}{\sqrt{2}}(|00\rangle + |11\rangle)$$

where:

$$\text{CX} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix} \quad \text{and} \quad \text{H} = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$$

Quantum Gates

- Quantum gates are the operations perforemd on qubits
- Gates are reversible
- Each gate is represented as a unitary matrix

Some Quantum Gates

Gate	Symbol	Unitary
Pauli X	X	$\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$
Pauli Y	Y	$\begin{bmatrix} 0 & -i \\ i & 0 \end{bmatrix}$
Pauli Z	Z	$\begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$
Hadamard	H	$\frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$
CNOT		$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}$

Gate	Symbol	Unitary
U1	$U1(\lambda)$	$\begin{bmatrix} 1 & 0 \\ 0 & e^{i\lambda} \end{bmatrix}$
U2	$U2(\phi, \lambda)$	$\frac{1}{\sqrt{2}}\begin{bmatrix} 1 & -e^{i\lambda} \\ e^{i\phi} & e^{i(\phi+\lambda)} \end{bmatrix}$
U3	$Rz(\phi)$	$U(\theta, \phi, \lambda)$
Z Rotation	$Rz(\phi)$	$\begin{bmatrix} e^{-\frac{i\phi}{2}} & 0 \\ 0 & e^{\frac{i\phi}{2}} \end{bmatrix}$
SWAP		$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

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This example here is a block sphere and it's very useful to think about operations on single qubits as rotations on the sphere. The Bloch sphere is a geometric representation for a quantum state you can think of it as that vector that red vector and you apply a quantum gate to a qubit and that vector rotates around. You can think of the operations on a single qubit as just rotating that vector around in 3d space. It's a very helpful model to conceptualize what's going on it gets a
little bit more complicated when you involve multiple qubits.
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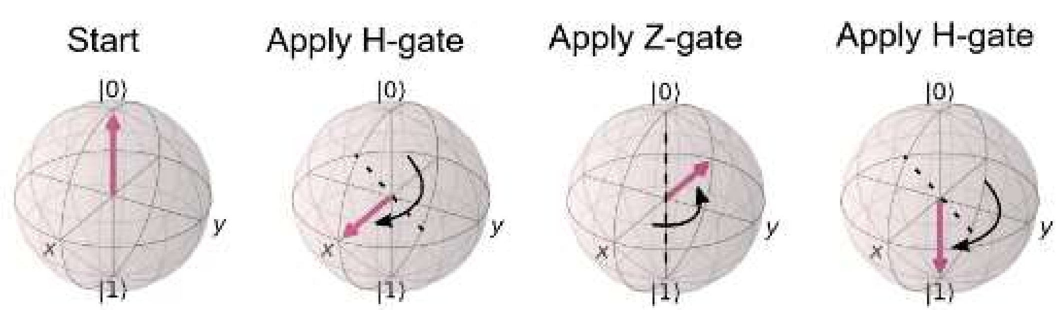
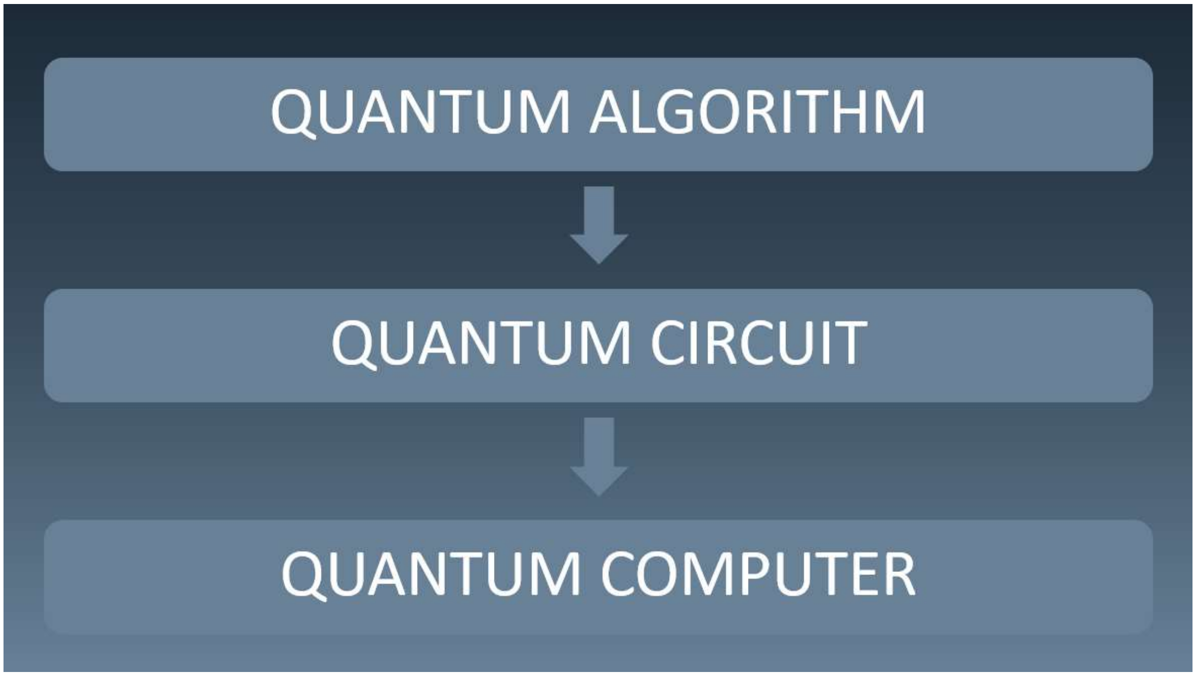
Example

HZH operated on the |0> state looks as follows on the Bloch sphere:



2) Introduction to Quantinuum and TKET



QUANTUM COMPUTERS

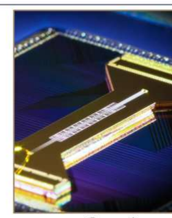
Trapped Ions
Quantinuum, IonQ, AQT, …..

Superconducting
IBM, Google, Rigetti, OQC, ….

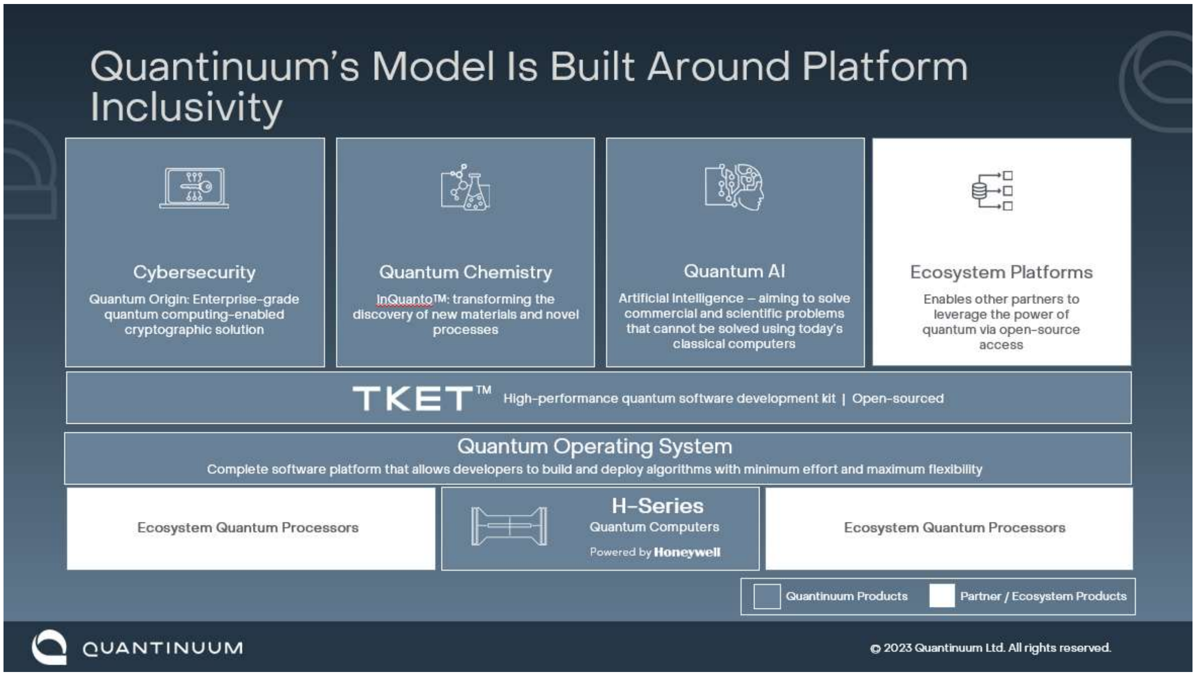
Neutral atoms
Cold Quanta, Pasqal, Atom Computing,….

Photonic
Psi Quantum, ORCA, Xanadu, Quandela, ….

Silicon Spin / Quantum Dots
Intel, Quantum Motion, Diraq, ….


Quantinuum


ETH Zürich


Quantinuum's Model Is Built Around Platform Inclusivity
Cybersecurity
Quantum Origin: Enterprise-grade quantum computing-enabled cryptographic solution
Quantum Chemistry
InQuanto™: transforming the discovery of new materials and novel processes
Quantum AI
Artificial Intelligence – aiming to solve commercial and scientific problems that cannot be solved using today's classical computers
Ecosystem Platforms
Enables other partners to leverage the power of quantum via open-source access
TKET™ High-performance quantum software development kit | Open-sourced
Quantum Operating System
Complete software platform that allows developers to build and deploy algorithms with minimum effort and maximum flexibility
Ecosystem Quantum Processors
H-Series
Quantum Computers
Powered by Honeywell
Ecosystem Quantum Processors
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