V.V. Sangha's
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Department of Computer Science & Engineering
2024-25

Game's Using Quantum Computing

Batch Number: B1

by,

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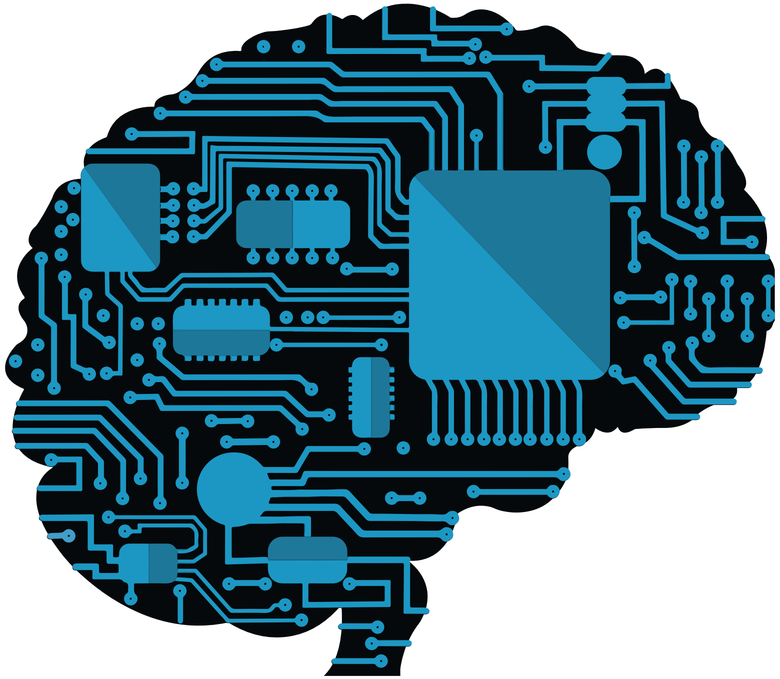


Quantum Computing Games

- ➢ Quantum Computer
  - ➢ A computer that uses laws of quantum mechanics to perform massively parallel computing through superposition, entanglement, and decoherence.
- ➢ Classical Computer
  - ➢ A computer that uses voltages flowing through circuits and gates, which can be controlled and manipulated entirely by classical mechanics.

Classical Bit vs. Quantum Bit

CLASSICAL BITS:

- can be in two distinct states, 0 and 1
- can be measured completely
- are not changed by measurement
- can be copied
- can be erased

QUANTUM BITS:

- can be in state |0> or in state |1> or in any other state that is a linear combination of the two states
- can be measured partially with given probability
- are changed by measurement
- cannot be copied
- cannot be erased

Evolution of Quantum Theory & Quantum Technology

The Foundations

From Theory to Practice

Commercialization & Application

1900's

1925: Schrödinger Equation proposed

1929: Dirac, one of the founders of quantum physics writes that physicists now know all laws necessary to simulate chemical systems

1935: The **EPR paradox** is a thought experiment intended to demonstrate an inherent paradox in the early formulations of quantum theory; it is among the best-known examples of quantum entanglement

1965: Feynman's theories of quantum-electro-dynamics

1980

1981: Feynman proposes quantum phenomenon to perform computations

1984: Quantum cryptography (IBM)

1994: **Shor's Algorithm** for finding prime factors sparks huge interest in quantum computing

1996: Grover's database search algorithm

1998: **First working 2-qubit quantum computer** demonstrated

2001: Using a 7-qubit computer researchers at IBM/Stanford factor the number 15

2004/5: First photon entanglement + **first quantum byte** (qubyte)

2010

2010: D-Wave announces **first commercially available QC**

2016: IBM makes a 5-qubit QC available to developers & researchers for experimentation via its **cloud** portal

Jan 2017: D-Wave makes 2000Q system commercially available

May 2017: IBM announces 16-qubit machine available in the cloud

Sep 2017: Microsoft reveals quantum programming language

Oct 2017: Google announces OpenFermion: Open source chemistry package for QC

Nov 2017: IBM announces 20-qubit machine available in cloud & first working 50-qubit processor

2018: Intel confirms development of 49-qubit chip

2019: Google claims to have reached **quantum supremacy** for the first time

2019: IBM launches first commercial 20-qubit QC

2020: Chinese scientists claimed 100 trillion faster of quantum supremacy

2021

Brief History of Quantum Computers

- 1981: Richard Feynman proposed to use quantum computing to model quantum systems. He also describe theoretical model of quantum computer
- 1985: David Deutsch described first universal quantum computer
- 1994: Peter Shor developed the first algorithm for quantum computer (factorization into primes)
- 1995 Schumacher proposed “Quantum bit” or “qubit” as physical resource
- 1996: Lov Grover developed an algorithm for search in unsorted database
- 1998: the first quantum computers on two qubits, based on NMR (Oxford; IBM, MIT, Stanford)
- 2000: quantum computer on 7 qubits, based on NMR (Los-Alamos)
- 2001: 15 = 3 x 5 on 7- qubit quantum computer by IBM
- 2005-2006: experiments with photons; quantum dots; fullerenes and nanotubes as "particle traps"

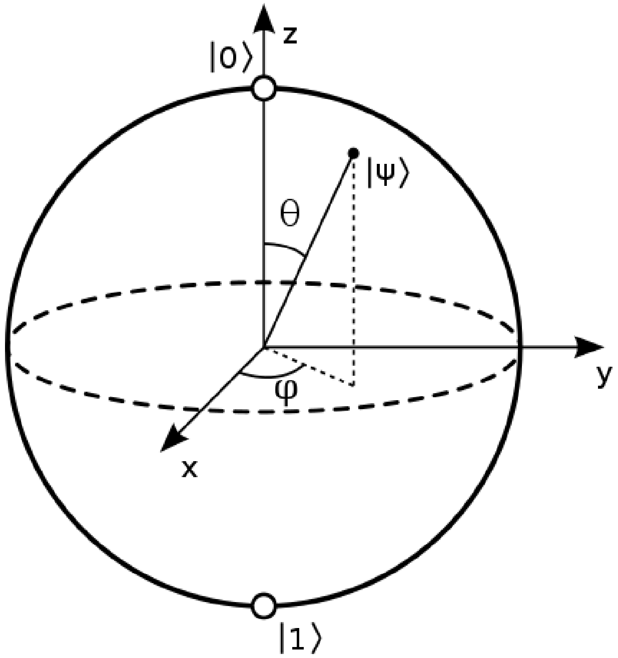
Brief History of Quantum Computers

- 2007: D-Wave announced the creation of a quantum computer on 16 qubits
- 2012: D-Wave claimed a quantum computation using 84 qubits
- 2017: D-Wave Systems Inc. announced the D-Wave 2000Q quantum annealer with 2000 qubits
- 2017: Microsoft revealed Q Sharp with 32 qubits
- 2018: Google announced the creation of a 72-qubit quantum chip
- 2019: Google claimed quantum supremacy with 54 qubits to perform operations in 200 seconds that would take a supercomputer about 10,000 years to complete
- 2019: IBM revealed 53 qubits
- 2020: Chinese researchers claimed to have achieved quantum supremacy using a photonic 76-qubit system at 100 trillion times the speed of classical supercomputers
- 2020: IBM will build 1121-qubit quantum computer in 2023, and 1 million-qubit quantum computer in 2030.

Qubits

Classical bits are either 0 or 1, quantum bits have been described as being 0 and 1

A more mathematical definition would be that the condition of n qubits is like a vector in a 2^n dimensional Hilbert space



Why Quantum?

Because quantum solutions perform better at certain tasks

Quantum Superposition

Quantum Entanglement

Qubits scale exponentially (2^n)

Quantum algorithms

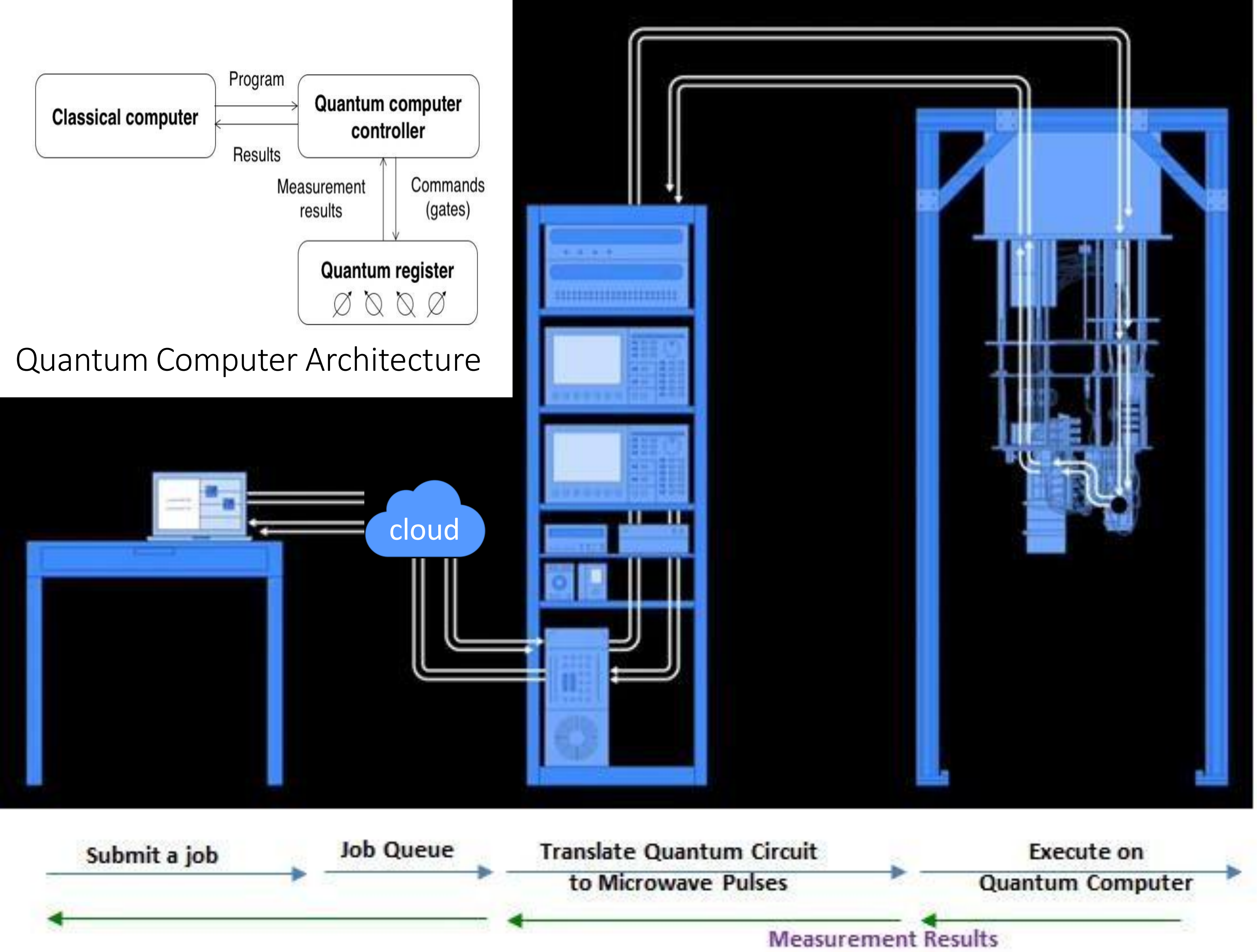
Moore's Law failing, Neven's law succeeding

Success of Rose's Law

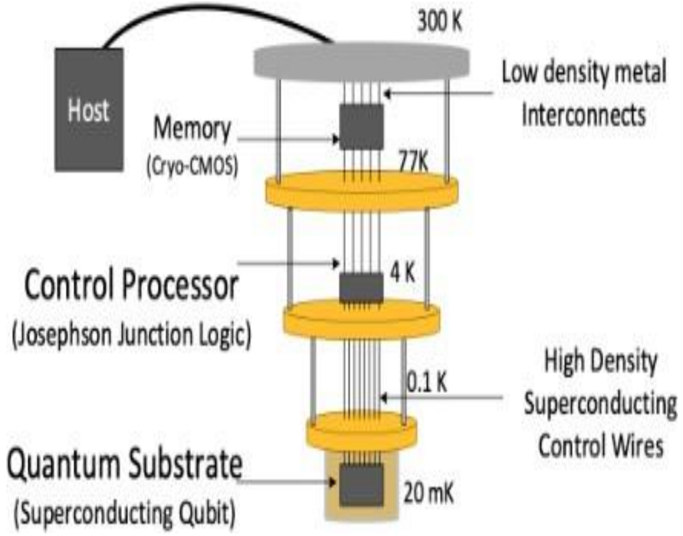
Quantum solutions scale much more easily

Amount of data is increasing exponentially, classical algorithms cannot keep up

How does a quantum computer work?



Quantum Computer Architecture



The flow of submitting a job from a classical computer to a quantum computer, executing the job, and returning quantum measurement results to the classical computer.

Superposition

- Every quantum state can be represented as a sum of two or more other distinct states. Mathematically, it refers to a property of solutions to the Schrödinger equation; since the Schrödinger equation is linear, any linear combination of solutions will also be a solution.
- A single qubit can be forced into a superposition of the two states denoted by the addition of the state vectors:

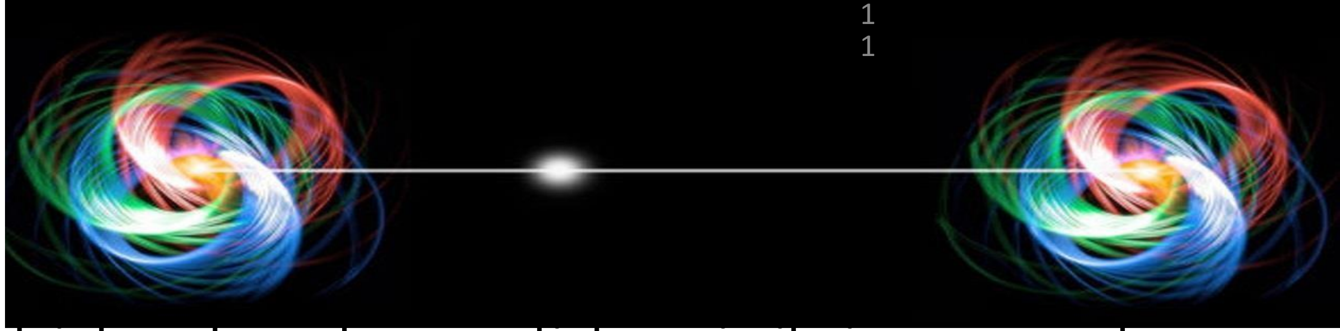
$$|\psi\rangle = \alpha_0\, |0\rangle + \alpha_1\, |1\rangle$$

Where α_0 and α_1 are complex numbers and $|\alpha_0|^2 + |\alpha_1|^2 = 1$

- A qubit in superposition is in both of the states |1> and |0 at the same time
- If this state is measured, we see only one or the other state (live or dead) with some probability.
- The classic example of superposition is Schrödinger's Cat in a black box. Since both a living and dead cat are obviously valid solutions to the laws of quantum mechanics, a superposition of the two should also be valid. Schrödinger described a thought experiment that could give rise to such a state.
- Consider a 3-qubit register. An equally weighted superposition of all possible states would be denoted by:

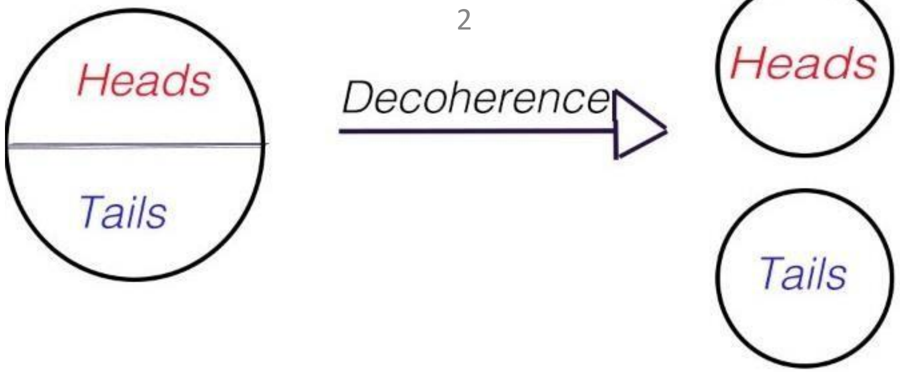
$$|\psi\rangle = \frac{1}{\sqrt{8}}|000\rangle + \frac{1}{\sqrt{8}}|001\rangle + \ldots + \frac{1}{\sqrt{8}}|111\rangle$$

Entanglement



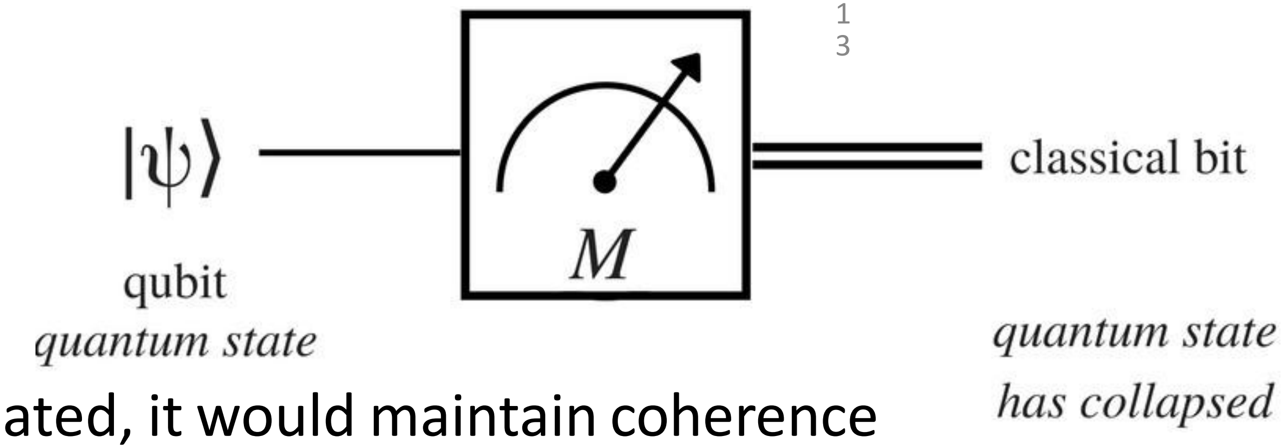
- When a pair or group of particles is generated, interact, or share spatial proximity in a way such that the quantum state of each particle of the pair or group cannot be described independently of the state of the others, even when the particles are separated by a large distance.
- An entangled pair is a single quantum system in a superposition of equally possible states. The entangled state contains no information about the individual particles, only that they are in opposite states.
- If the state of one is changed, the state of the other is ***instantly*** adjusted to be consistent with quantum mechanical rules.
- If a measurement is made on one, the other will ***automatically*** collapse.
- Quantum entanglement is at the heart of the disparity between classical and quantum physics: *entanglement is a primary feature of quantum mechanics lacking in classical mechanics*.
- Entanglement is a joint characteristic of two or more quantum particles.
- Einstein called it "**spooky actions at a distance**"

Decoherence



- Quantum decoherence is the loss of superposition, because of the spontaneous interaction between a quantum system and its environment.
- Decoherence can be viewed as the loss of information from a system into the environment.
- The reason why quantum computers still have a long way to go because superposition and entanglement are extremely fragile states.
- Preventing decoherence remains the biggest challenge in building quantum computers.

Measurement



- If a quantum system were perfectly isolated, it would maintain coherence indefinitely, but it would be impossible to manipulate or investigate it.
- A quantum measure is a decoherence process.
- When a quantum system is measured, the wave function $|\psi\rangle$ collapses to a new state according to a probabilistic rule.
- If $|\psi\rangle = \alpha_0 |0\rangle + \alpha_1 |1\rangle$, after measurement, either $|\psi\rangle = |0\rangle$ or $|\psi\rangle = |1\rangle$, and these alternatives occur with certain probabilities of $|\alpha_0|^2$ and $|\alpha_1|^2$ with $|\alpha_0|^2 + |\alpha_1|^2 = 1$.
- A quantum measurement never produces $|\psi\rangle = \alpha_0 |0\rangle + \alpha_1 |1\rangle$.
- <u>*Example*</u>: Two qubits: $|\psi\rangle = 0.316|00\rangle + 0.447|01\rangle + 0.548|10\rangle + 0.632|11\rangle$

  The probability to read the rightmost bit as 0 is $|0.316|^2 + |0.548|^2 = 0.4$

The problem - Sudoku

It's a combinatorial, number placing puzzle

The objective is to place numbers from 1 through 9, exactly once in each column, row and 3x3 subgrid

Gets easier as the number of digits already filled increases

5	3			7				
6			1	9	5			
	9	8					6	
8				6				3
4			8		3			1
7				2				6
	6					2	8	
			4	1	9			5
				8			7	9

Qubit modelling

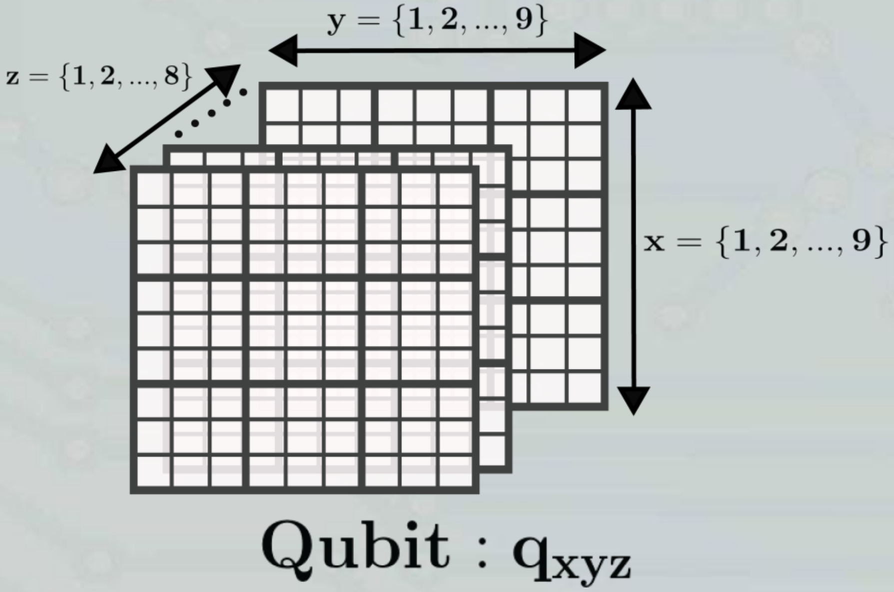
Each square has one digit from 1 through 9.

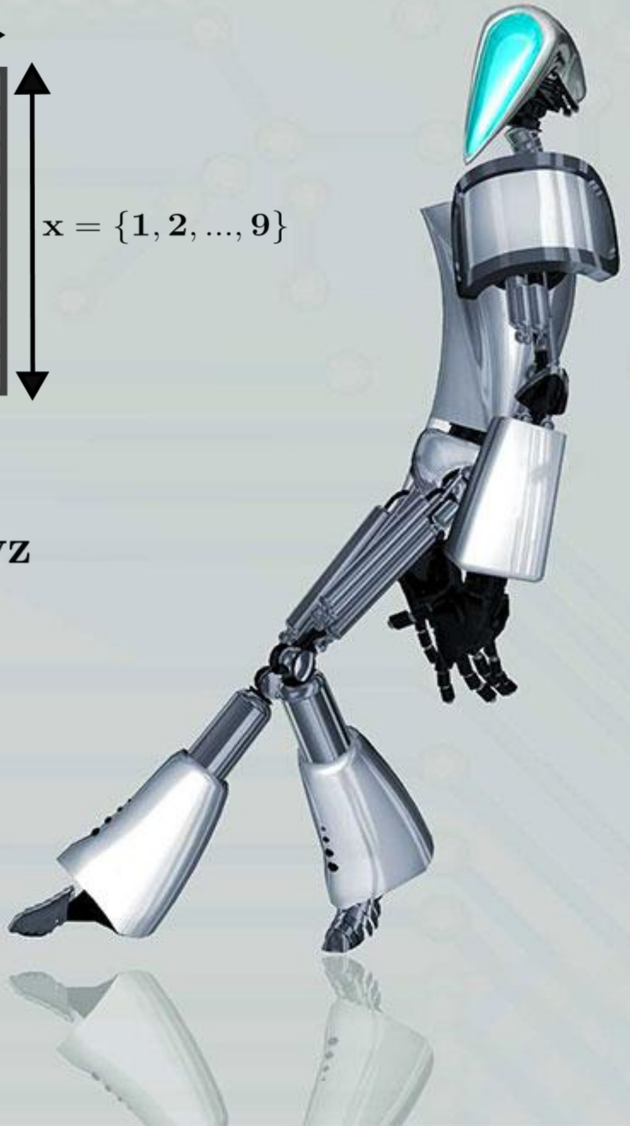
We model those 9 numbers with 8 qubits.

(call it an 8-group)

This can be called 'one-hot and zero' encoding

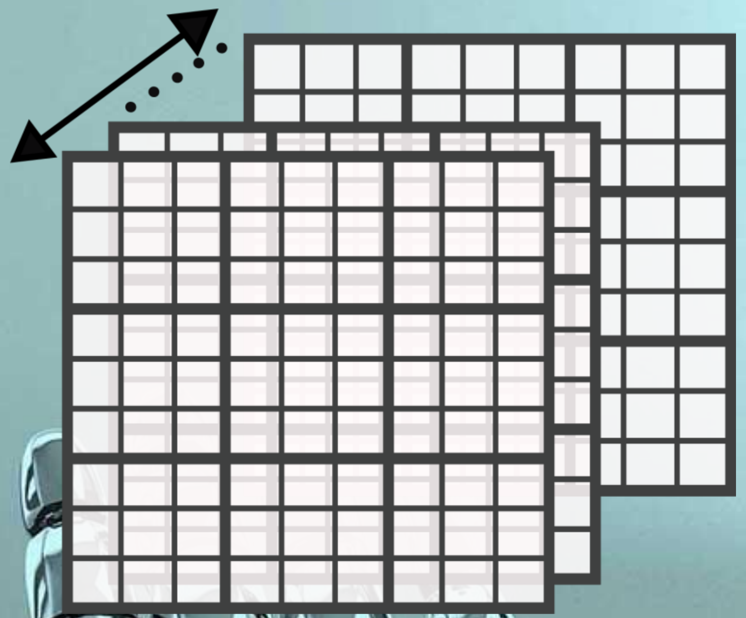
That makes 648 such qubits





Constraints

1. Each 8-group should have at most one qubit in the '1' state, all the others in '0' state
2. Each row has all 9 digits appearing only once
3. Each column has all 9 digits appearing only once
4. Each 3x3 subgrid has all 9 digits appearing only once



Solution Presented

High level Algorithm for our solution

- Initialize and Set Up the Sudoku Game
- Validate Player Moves
- Map Player Moves to Quantum Circuit
- Implement Undo Functionality
- Check for Completed Sub-Grids (Boxes)
- Track Player Progress
- Combine Quantum Circuits
- Validate and Analyze the Solution

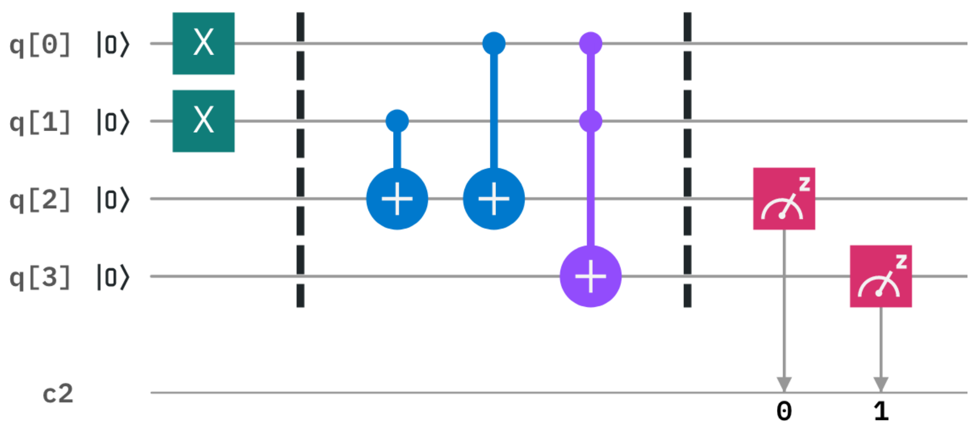
Qiskit

Elements for building a quantum future

Quantum Programming

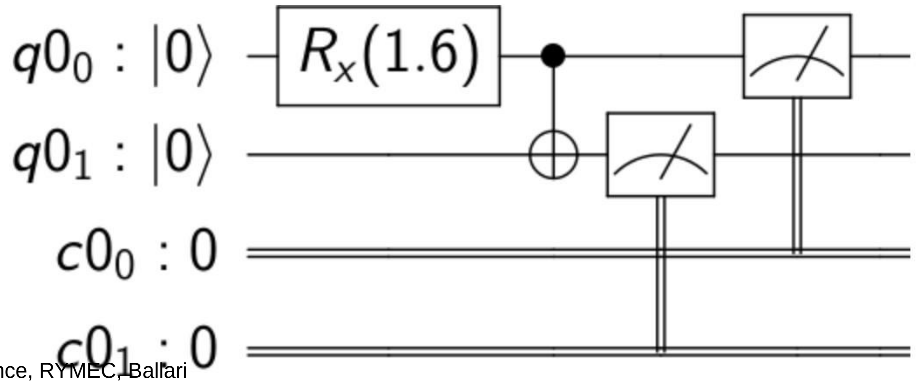
- **QISKit** (**Q**uantum **I**nformation **S**cience **Kit**)

Qiskit is an open-source framework for quantum computing. It provides tools for creating and manipulating quantum programs and running them on prototype quantum devices on IBM Quantum Experience over Cloud-based access



In [7]:
```
from qiskit import QuantumRegister, ClassicalRegister, QuantumCircuit
from qiskit.tools.visualization import circuit_drawer
import numpy as np

qr = QuantumRegister(2)
cr = ClassicalRegister(2)
qp = QuantumCircuit(qr,cr)

qp.rx( np.pi/2,qr[0])
qp.cx(qr[0],qr[1])

qp.measure(qr,cr)

circuit_drawer(qp)
```

Out[7]:



In [1]:
```
from qiskit import *
```

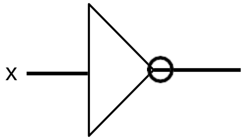
In [2]:
```
qr = QuantumRegister(2)
cr = ClassicalRegister(2)
```

In [3]:
```
c = QuantumCircuit(qr, cr)    # c = QuantumCircuit(2,2)
```

Quantum vs. Classic Gates

Operator	Gate(s)		Matrix
Pauli-X (X)	X	$\oplus$	$\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$
Pauli-Y (Y)	Y		$\begin{bmatrix} 0 & -i \\ i & 0 \end{bmatrix}$
Pauli-Z (Z)	Z		$\begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$
Hadamard (H)	H		$\frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$
Phase (S, P)	S		$\begin{bmatrix} 1 & 0 \\ 0 & i \end{bmatrix}$
$\pi/8$ (T)	T		$\begin{bmatrix} 1 & 0 \\ 0 & e^{i\pi/4} \end{bmatrix}$
Controlled Not (CNOT, CX)			$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix}$
Controlled Z (CZ)	Z		$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \end{bmatrix}$
SWAP			$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$
Toffoli (CCNOT, CCX, TOFF)			$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}$

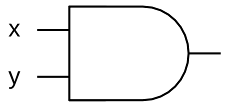
NOT gate



y = NOT(x)

x	y
0	1
1	0

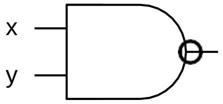
AND gate



z = (x) AND (y)

x	y	z
0	0	0
0	1	0
1	0	0
1	1	1

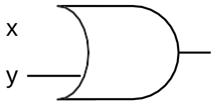
NAND gate



z = (x) NAND (y)

x	y	z
0	0	1
0	1	1
1	0	1
1	1	0

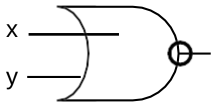
OR gate



z = (x) OR (y)

x	y	z
0	0	0
0	1	1
1	0	1
1	1	1

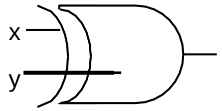
NOR gate



z = (x) NOR (y)

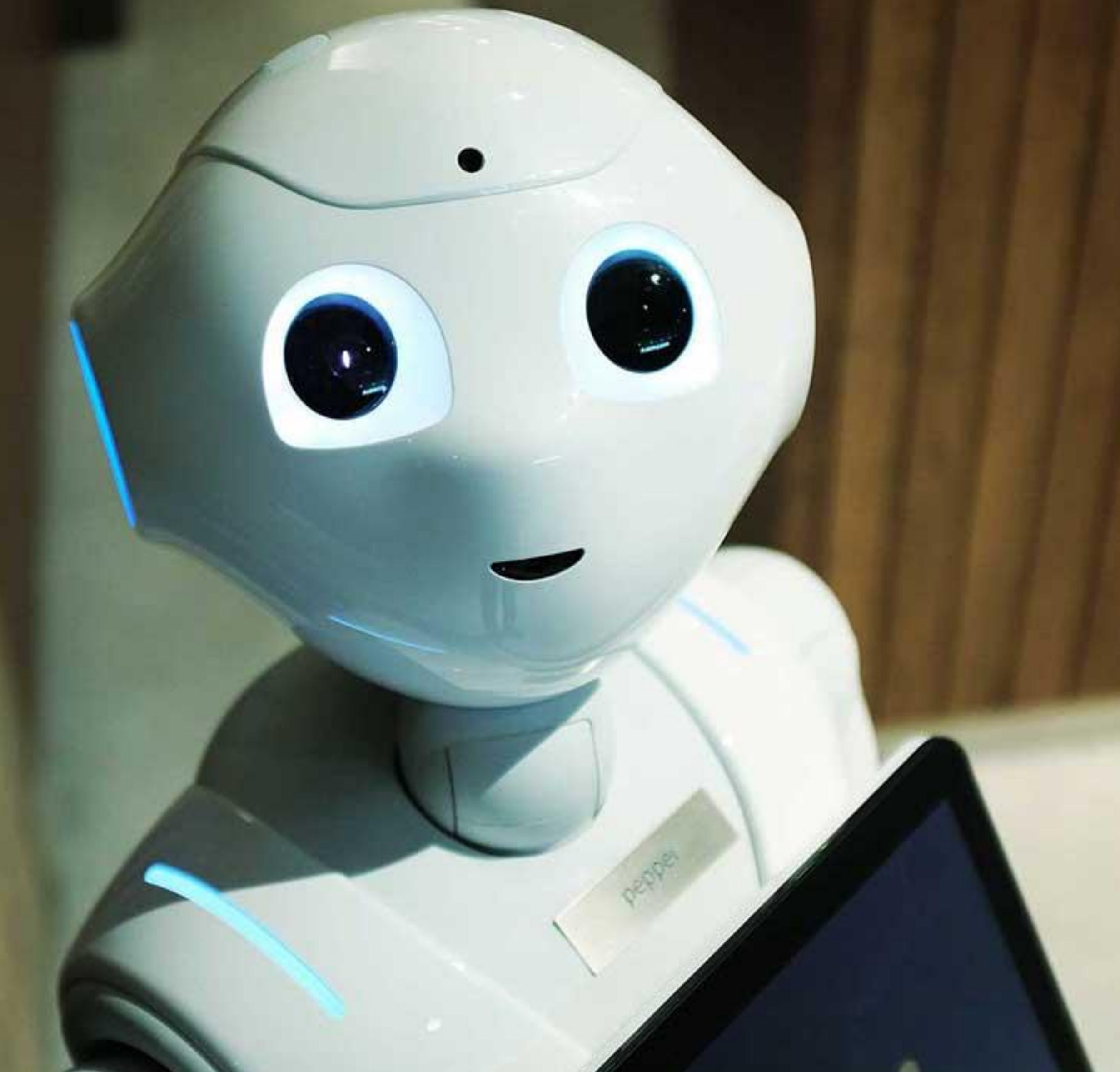
x	y	z
0	0	1
0	1	0
1	0	0
1	1	0

XOR gate



z = (x) XOR (y)

x	y	z
0	0	0
0	1	1
1	0	1



CODE

Language used :- Python 3.7.1

Librarie’s used :- NumPy, Qiskit, Matplotlib, pygame, time

1	4		7	9	2		8	5
2		8	3	4	6	7	9	1
3	7	9			1	4		2
4	3	7	9	1	5	8	2	
5		1	6		7	9	3	4
6	9	2	4	3	8	1	5	7
7			2	6	9		4	8
8	2	4	1	5	3	6	7	9
9		5	8	7		2	1	3

Original Puzzle

1	4	6	7	9	2	3	8	5
2	5	8	3	4	6	7	9	1
3	7	9	5	8	1	4	6	2
4	3	7	9	1	5	8	2	6
5	8	1	6	2	7	9	3	4
6	9	2	4	3	8	1	5	7
7	1	3	2	6	9	5	4	8
8	2	4	1	5	3	6	7	9
9	6	5	8	7	4	2	1	3

Solved Puzzle

Quantum Computing Highlights:

1. **Google's Willow Chip**: With 105 qubits, it reduces errors and solves tasks billions of times faster than classical supercomputers.

2. **Entanglement Record**: 24 logical qubits were entangled, advancing scalable, fault-tolerant quantum systems.

3. **IBM's Progress**: Focused on healthcare, climate, and materials science, IBM plans a fully error-corrected quantum system by 2029.

THANK YOU