Future of AI with Quantum Computing

A CS-664 project by
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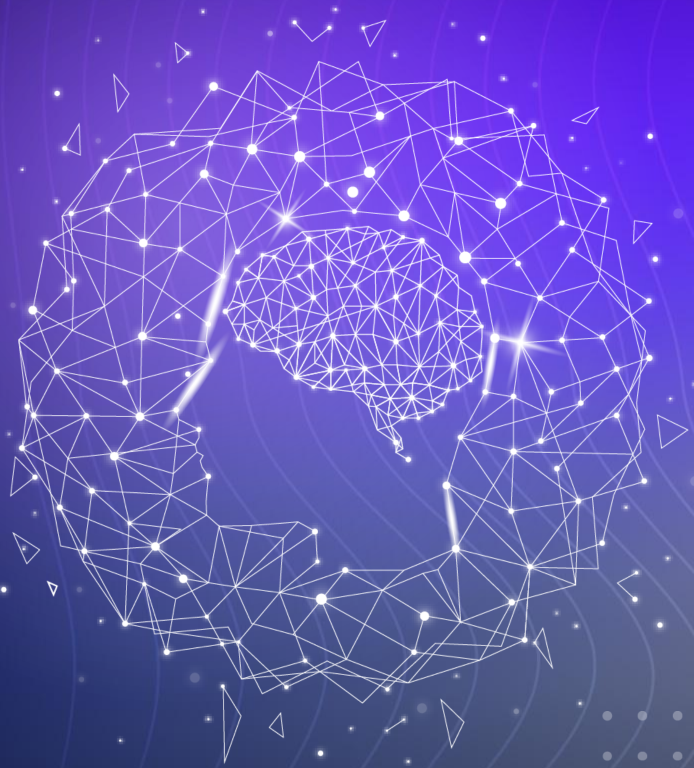
An Overview

AI and Quantum computing are both developing domains that have shown a lot of promise in terms of changing the way we view computers. Most of us seem to look at them as independent entities moving towards their own paths to success. But what happens when these 2 emerging giants are combined? Let's find out.

01 Introduction



Say hello to the Future

The future of AI with quantum computing is an exciting and rapidly evolving field, with many possibilities yet to be explored. Together, they could unlock new capabilities and lead to breakthroughs in areas such as materials science, cryptography, and finance.

The 2 emerging Giants

AI

The human species with superhuman powers

QC

Computers that don't follow your conventional rules

Artificial Intelligence

A branch of computer science that aims to develop intelligent machines that can perform tasks that typically require human intelligence, such as perception, reasoning, learning, and decision-making.

A Well known Example

Evolution of AI

1943

Warren McCulloch and Walter Pitts published a paper on "A Logical Calculus of Ideas Immanent in Nervous Activity," which proposed a mathematical model for artificial neurons.

1965

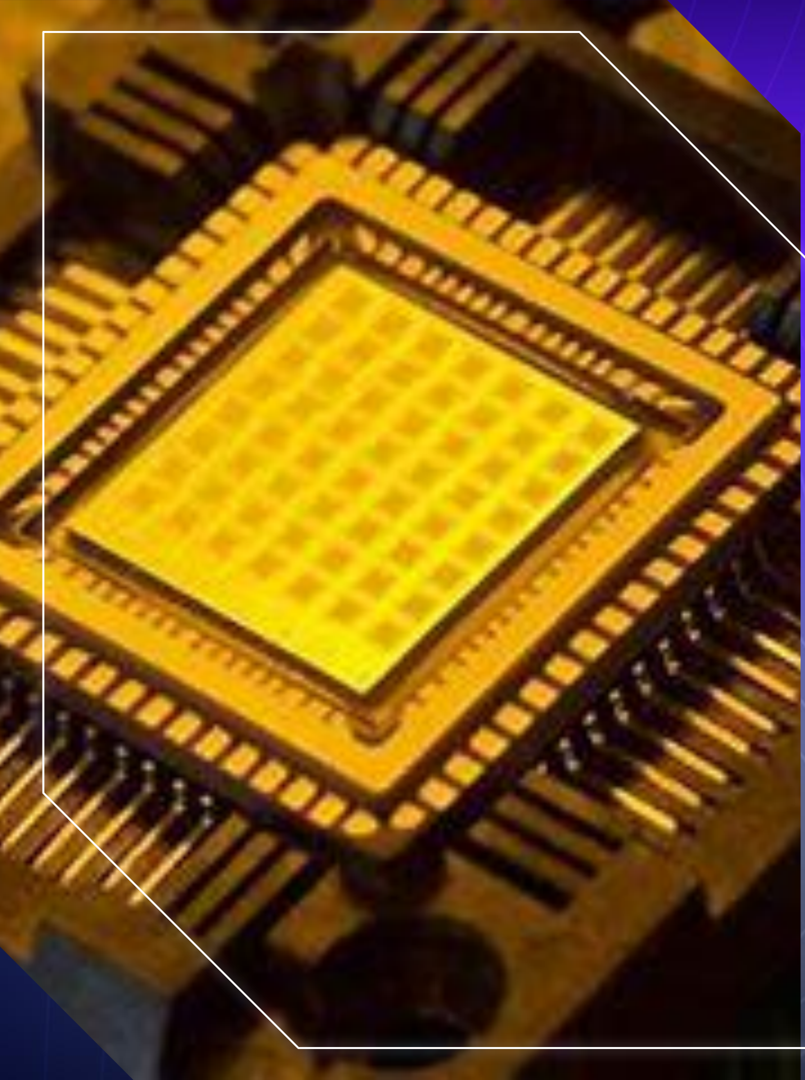
Joseph Weizenbaum developed the ELIZA program, which used natural language processing to simulate a psychotherapist.

1990s

The field of AI saw renewed interest and progress due to advances in computing power and the availability of large datasets, leading to breakthroughs in areas such as machine learning and natural language processing.

2010

Deep learning, a subfield of machine learning, became increasingly popular and has led to significant advances in areas such as image and speech recognition.



Quantum Computing

Quantum computing is a type of computing that uses quantum-mechanical phenomena, such as superposition and entanglement, to perform operations on data

Evolution of QC

1981 Richard Feynman proposes the concept of a quantum computer.

1998 Isaac Chuang and his colleagues at IBM build the first two-qubit quantum computer.

2010 D-Wave Systems claims to have built the first commercially available quantum computer, although the system's quantumness is disputed by some researchers.

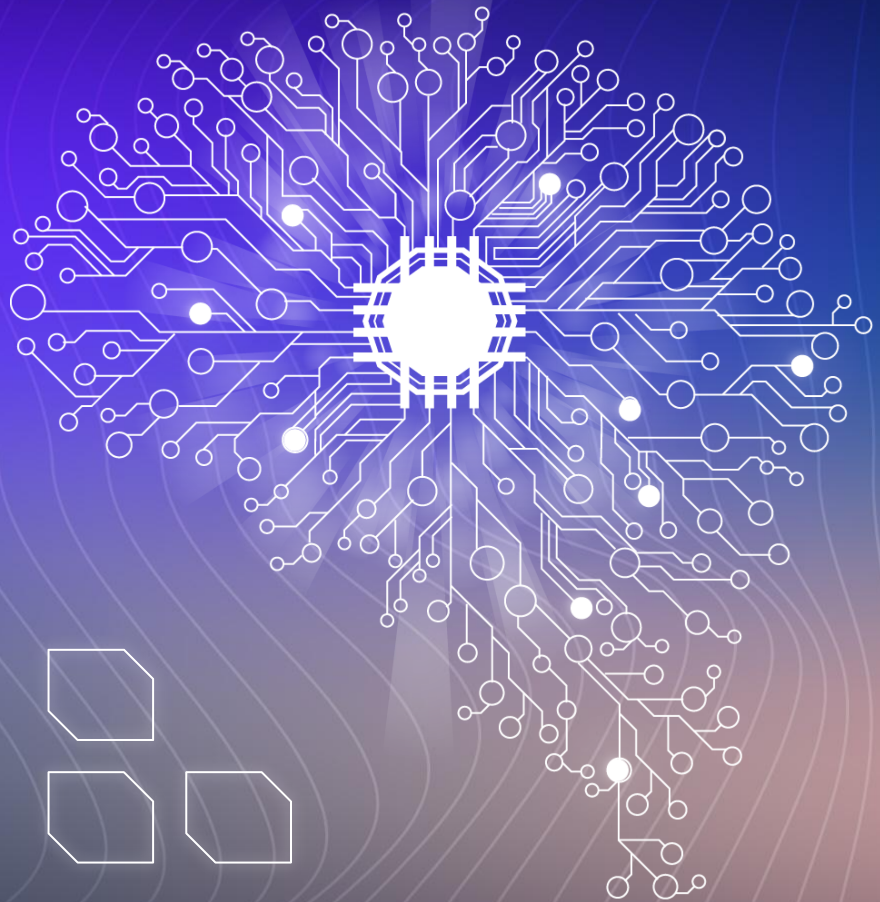
2017 Google claims to have achieved "quantum supremacy," demonstrating that a quantum computer can solve a problem that would take a classical computer an impractically long time.

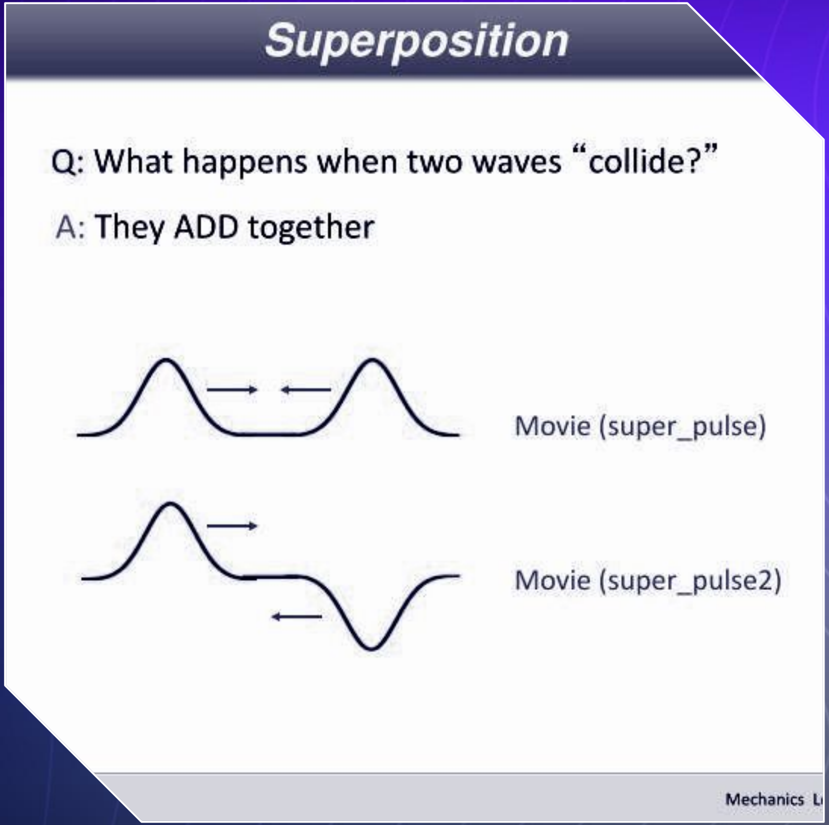
Benefits of Combining Both

1. Parallel Processing
2. Optimization
3. Quantum ML
4. Quantum Encryption

Parallel Processing

Quantum computers can perform certain types of calculations exponentially faster than classical computers by exploiting the principles of quantum mechanics.



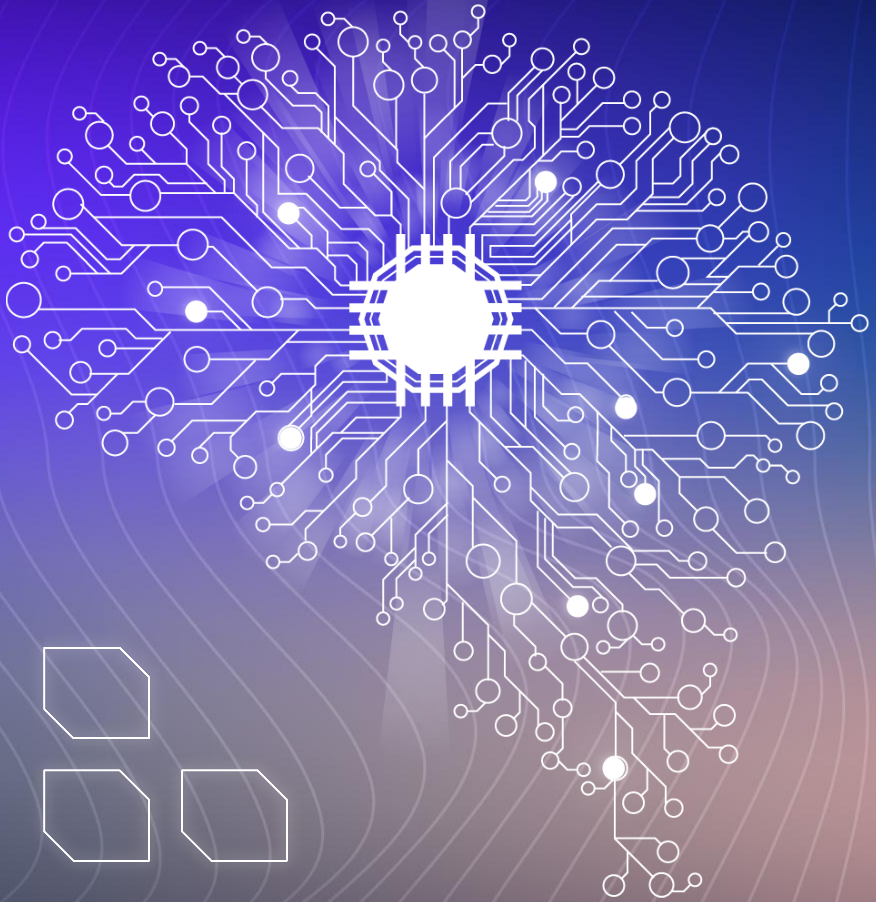


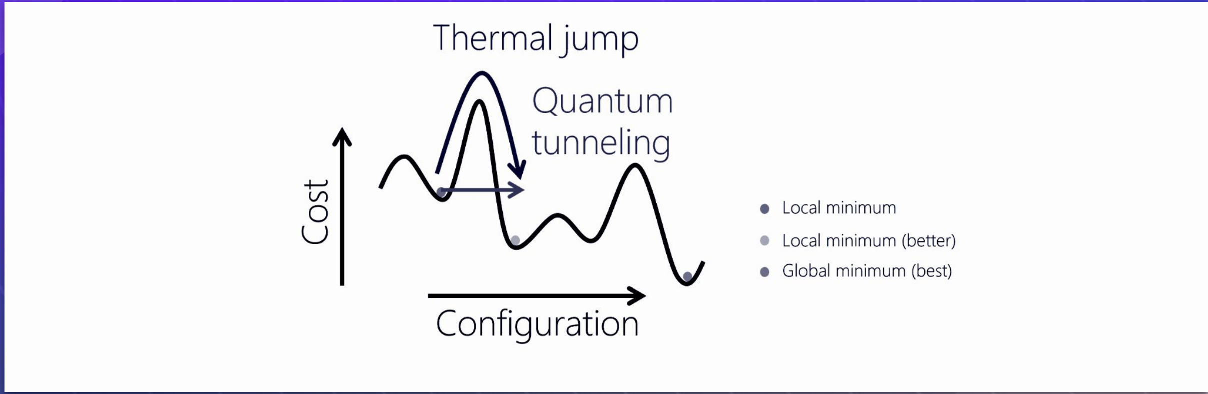
Superposition

The image beside shows a simple depiction of superposition

Optimization

Optimization is the process of finding the best solution to a problem from a set of possible options, given its desired outcome and constraints.

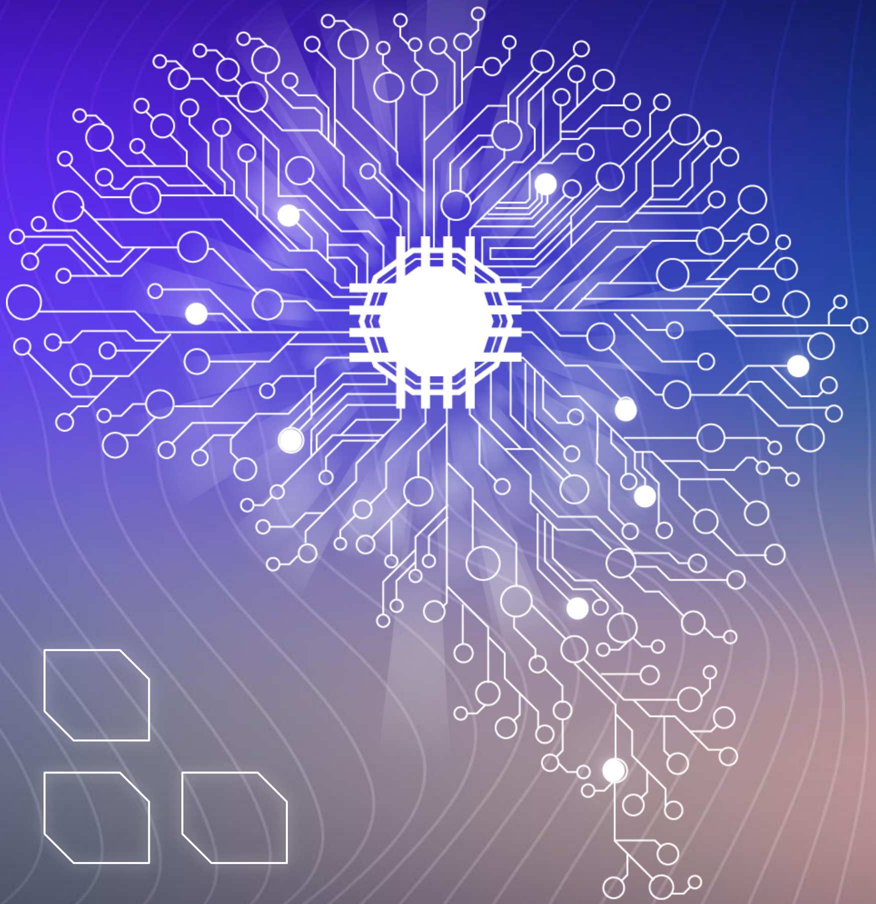


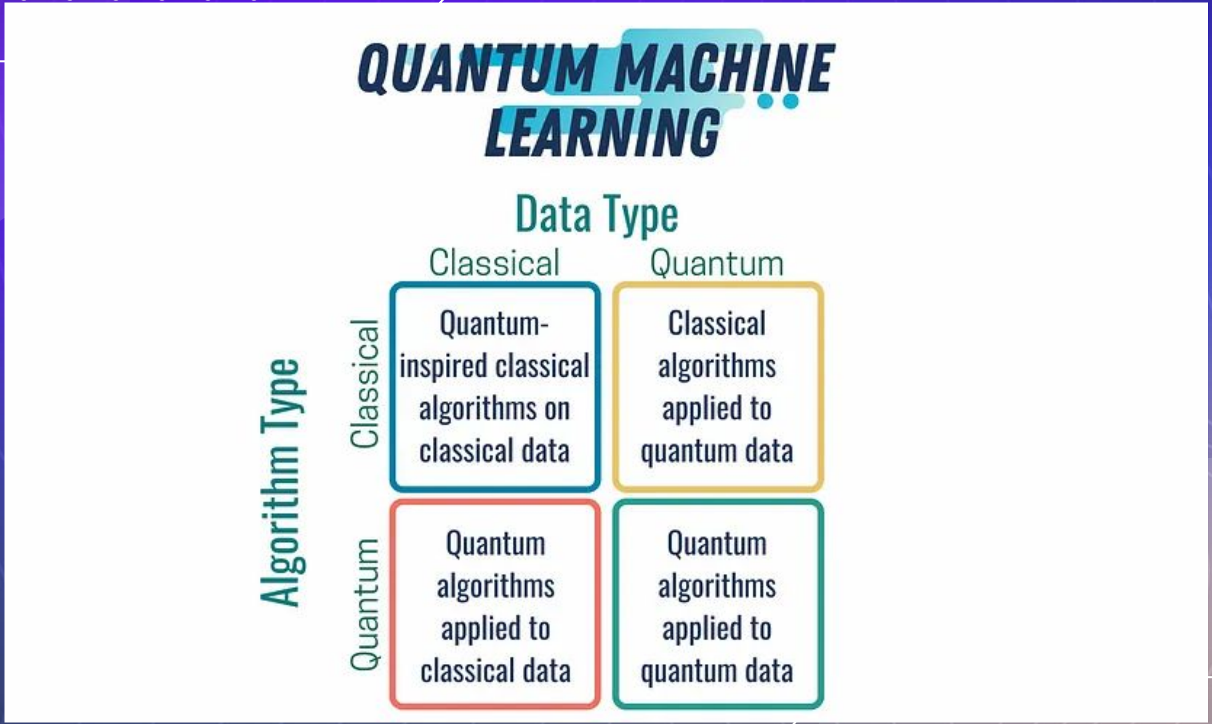


Thermal jump
Quantum
tunneling
Cost
Configuration
Local minimum
Local minimum (better)
Global minimum (best)

Quantum ML

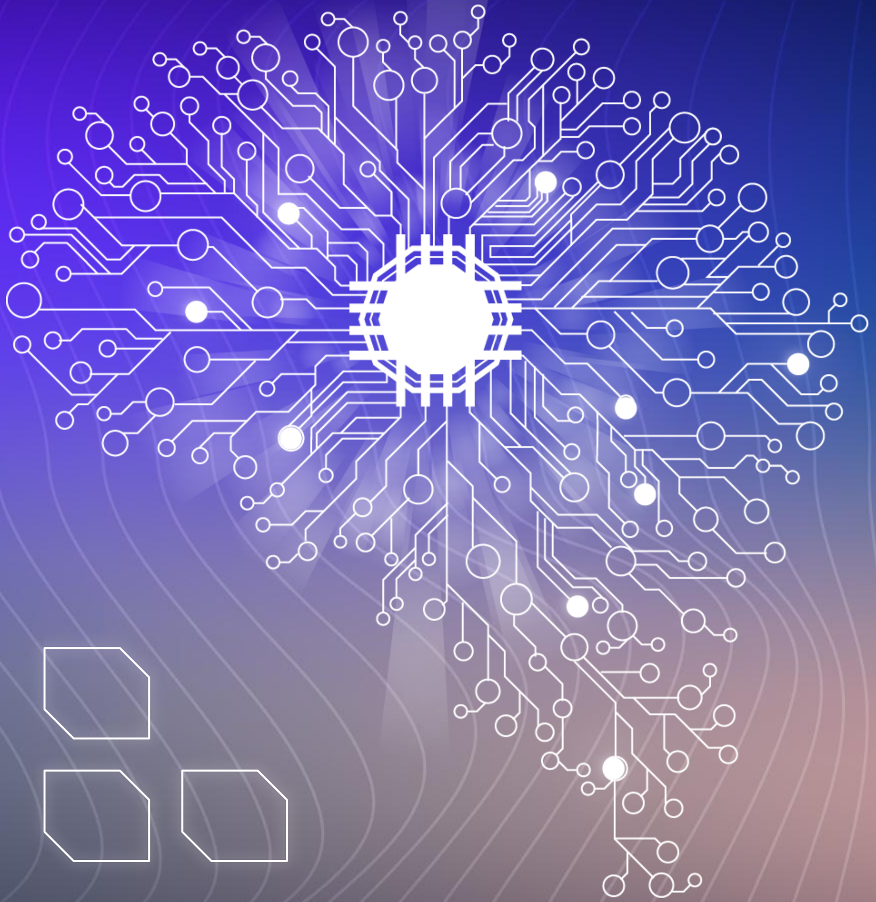
It seeks to leverage the unique properties of quantum computing, such as superposition and entanglement, to develop new algorithms and methods for data analysis and prediction.




QUANTUM MACHINE LEARNING
Data Type
Classical
Quantum
Algorithm Type
Classical
Quantum
Quantum-inspired classical algorithms on classical data
Classical algorithms applied to quantum data
Quantum algorithms applied to classical data
Quantum algorithms applied to quantum data

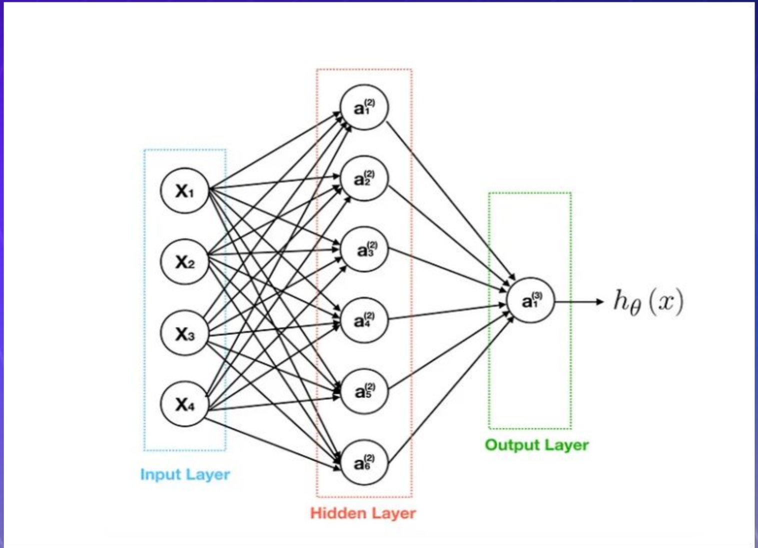
Quantum Encryption

It is a technique for secure communication that uses the principles of quantum mechanics to ensure the confidentiality and integrity of messages.



Classical Neural Networks

- Consist of multiple layers of interconnected neurons
- Each connection has a weight associated with it
- Universal approximation theorem
- Application:
    - Classification
    - Recognition



$$\hat{y} = f(x, \theta)$$

Linear model $\hat{y} = \theta x + b$

Perceptron model $\hat{y} = \sigma(\theta x + b)$

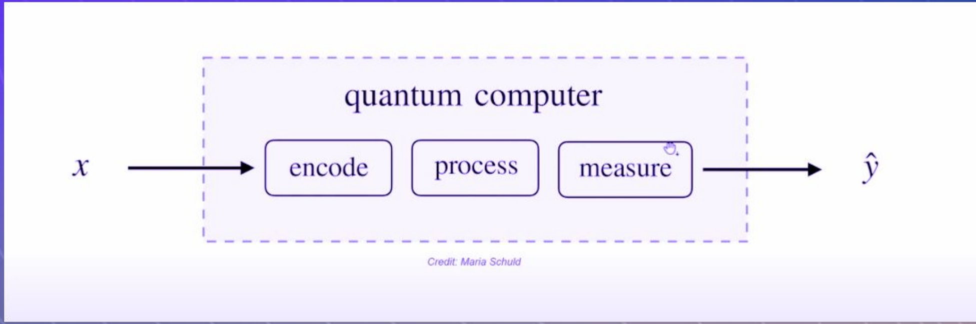
Feedforward neural network with one hidden layer $\hat{y} = \sigma_2(\theta_2 \sigma_1(\theta_1 x + b_1) + b_2)$

Quantum Neural Networks

- Quantum computing with classical neural networks

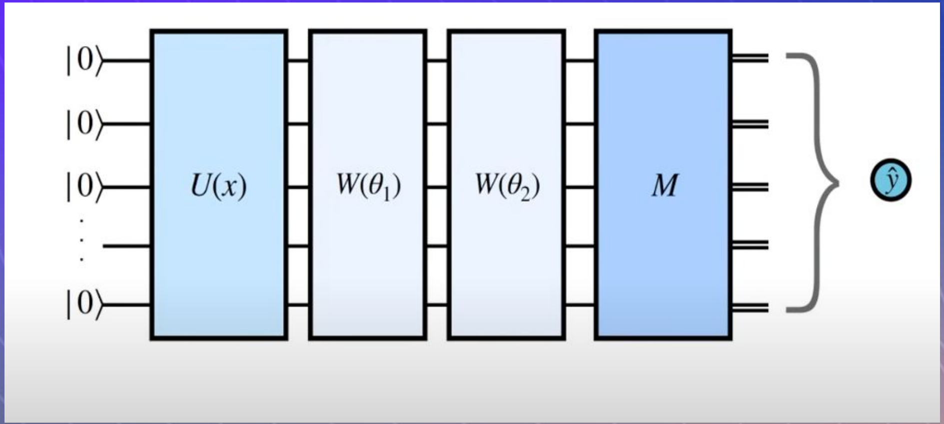
- Quantum computing principles

- Consist of a quantum circuit followed by a classical neural network



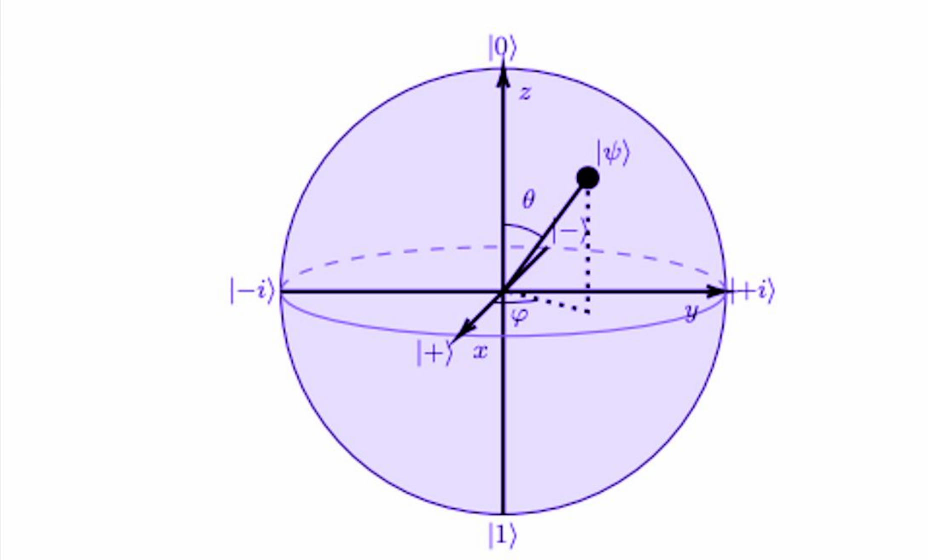
Working Of Quantum Neural Networks

- Encoding:
  - Angle encoding
  - Amplitude encoding
- Processing:
- Training:
  - optimization process
  - gradient descent
  & Bayesian optimization.
  - minimizing a loss function



Angle Encoding

- Applying rotation gates to a set of qubits in the quantum circuit,
- Each gate corresponding to an input feature.
- To represent classical data as quantum states.
- Particularly useful for problems where the input data is continuous and high-dimensional
- Example:



Angle Encoding

Example:
X => real number

Formulas:
$\theta = \cos^{-1}(\mathrm{sqrt}(x))$
$\phi = 2\pi x$

Quantum State:
$|\Psi\rangle = \cos(\theta/2)\,|0\rangle + e\^{}(i\phi)\,\sin(\theta/2)\,|1\rangle$

Here, $|0\rangle$ and $|1\rangle$ are the two computational basis states of a single qubit

Working Of Quantum Neural Networks

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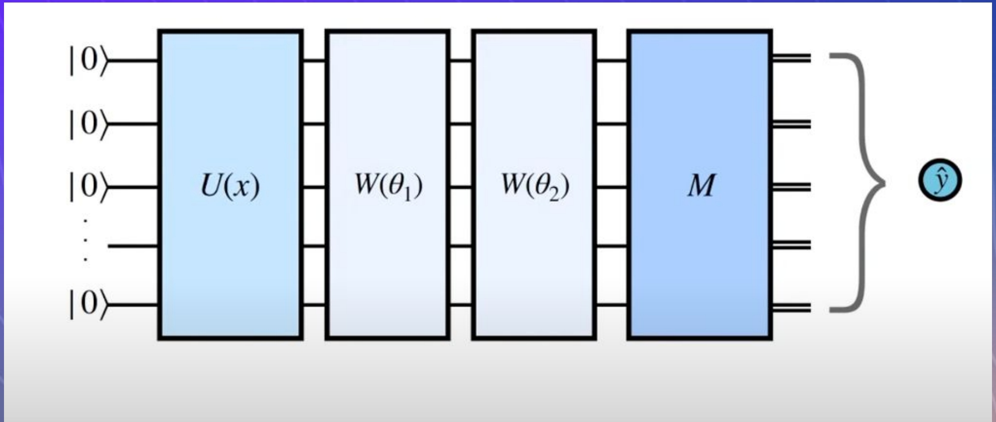
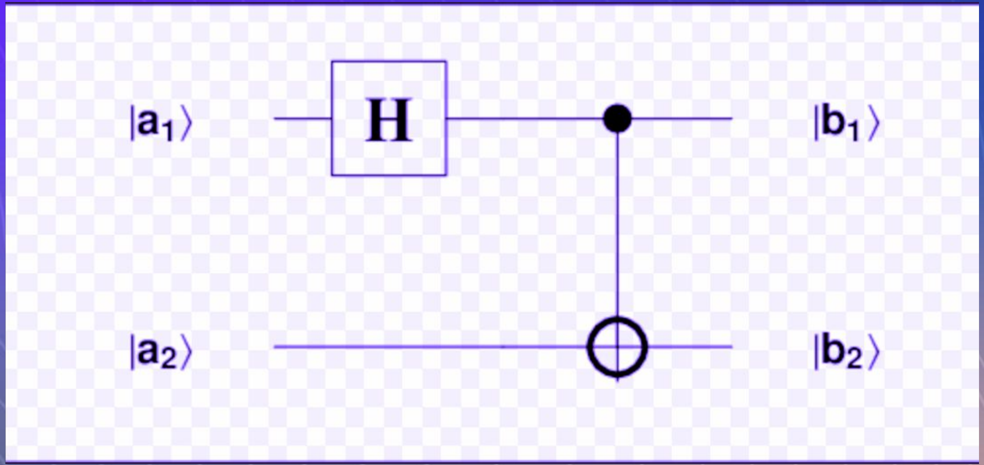


Quantum Circuit

- Sequence of quantum gates
- Building blocks of quantum algorithms
- Working:
  - Unitary transformations
- Gates:
  - single-qubit gates
    - Hadamard gate
    - phase gate
  - two-qubit gates
    - CNOT gate



CNOT gate

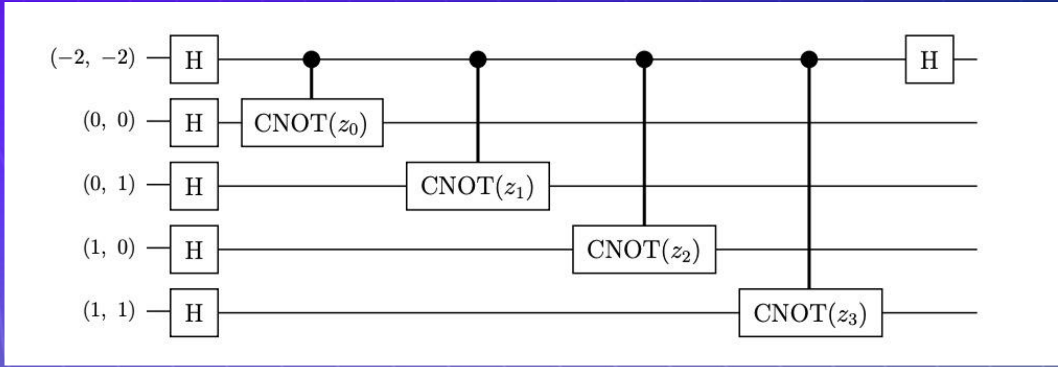
- Controlled –Not gate
- Operates on two qubits.
- Used to implement quantum algorithms

$$\text{CNOT} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

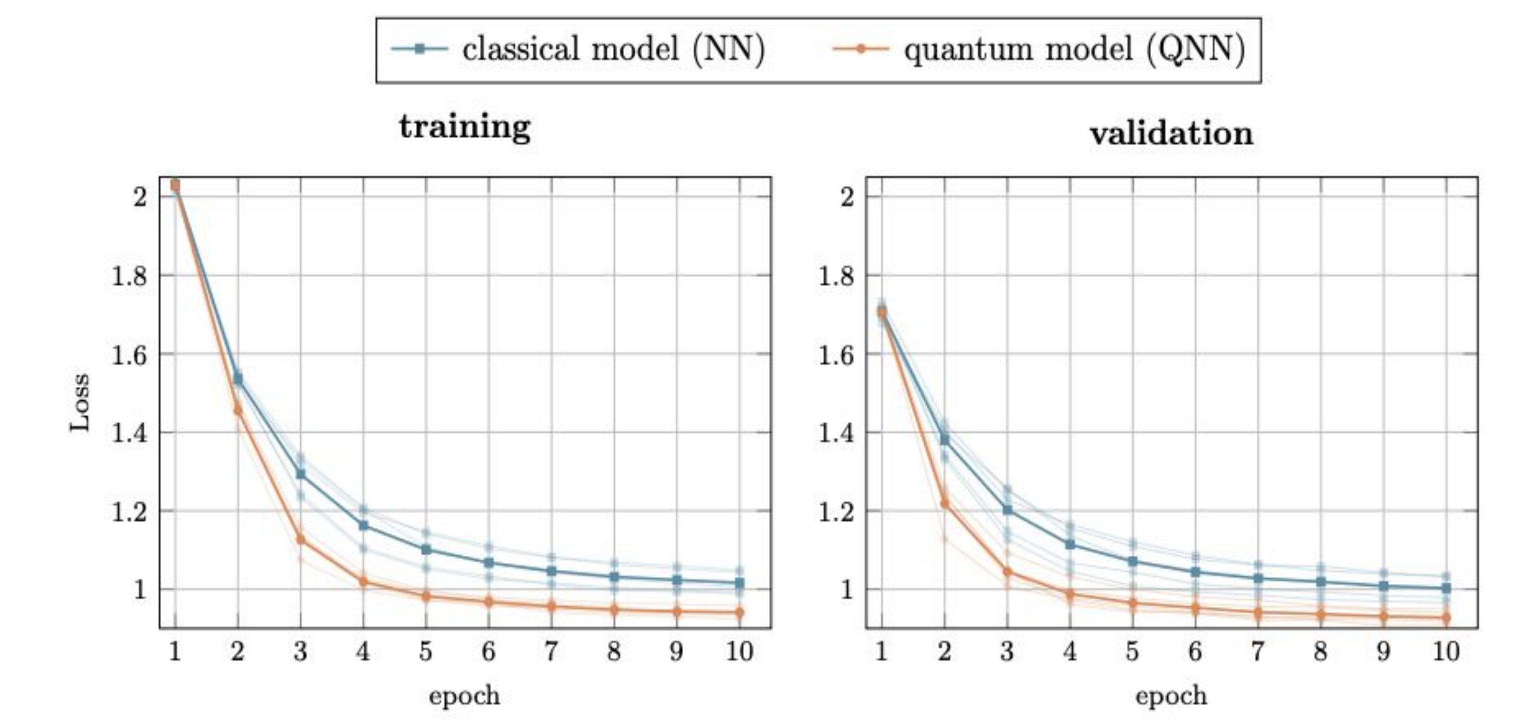
$$|00\rangle \rightarrow |00\rangle$$
$$|01\rangle \rightarrow |01\rangle$$
$$|10\rangle \rightarrow |11\rangle$$
$$|11\rangle \rightarrow |10\rangle$$

Working Of Quantum Neural Networks

- Encoding:
  - Angle encoding
  - Amplitude encoding
- Processing:
- Training:
  - Architecture
  - loss function
  - Executing the QNN circuit
  - Updating the parameters



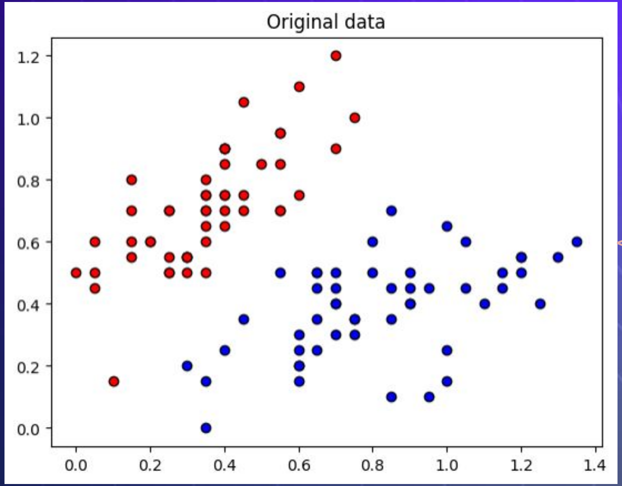
Comparison

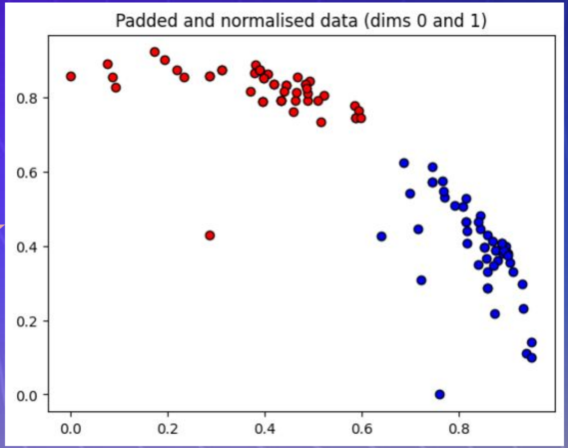


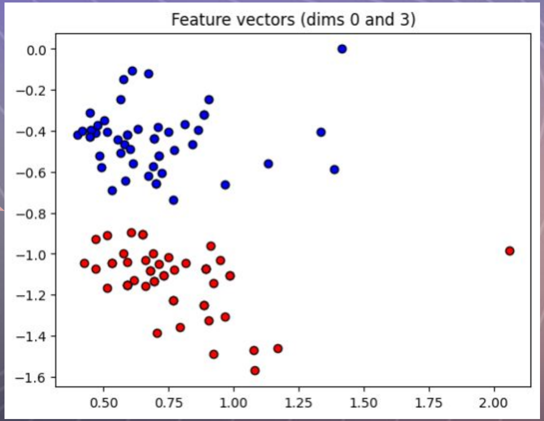
classical model (NN)
quantum model (QNN)
training
validation
Loss
2
1.8
1.6
1.4
1.2
1
1 2 3 4 5 6 7 8 9 10
epoch

DEMO

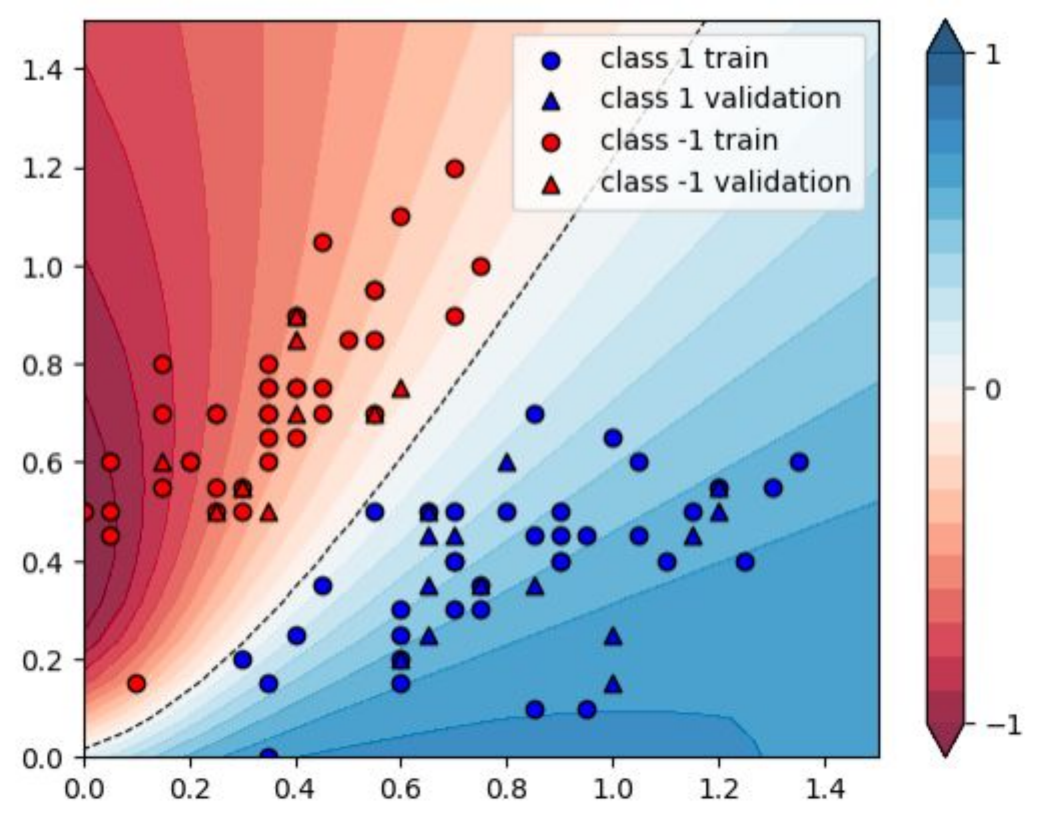
QML Variational Classifier: IRISH DATA SET







Final QML Classification Model



CONCLUSION

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