QUANTUM TECHNOLOGY

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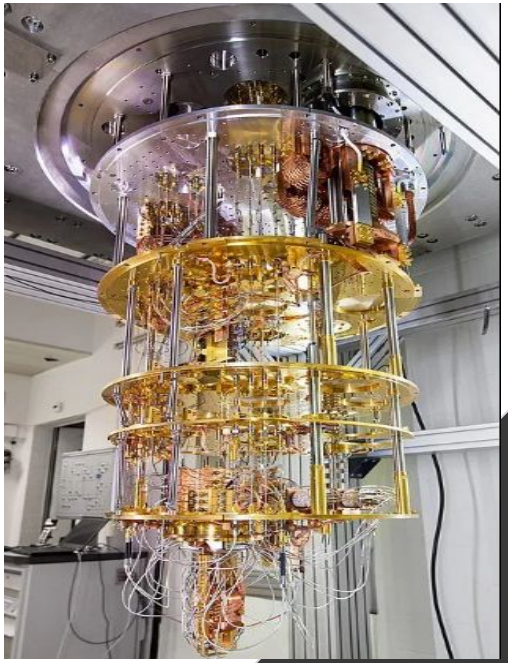
WHAT IS QUANTUM COMPUTING

1. Quantum computing is a multidisciplinary field comprising aspects of **computer science, physics, and mathematics** that utilizes quantum mechanics to solve complex problems faster than on classical computers.
2. Quantum computers work on the principles of quantum mechanical effects, such **as superposition , quantum interference and entanglement.**
3. By tapping into these quantum properties, quantum computers handle information in a fundamentally different way than “classical” computers.
4. According to a report - In 2019, Google’s quantum computer did a calculation in less than four minutes that would take the world’s most powerful computer around 10,000 years to do the same task.



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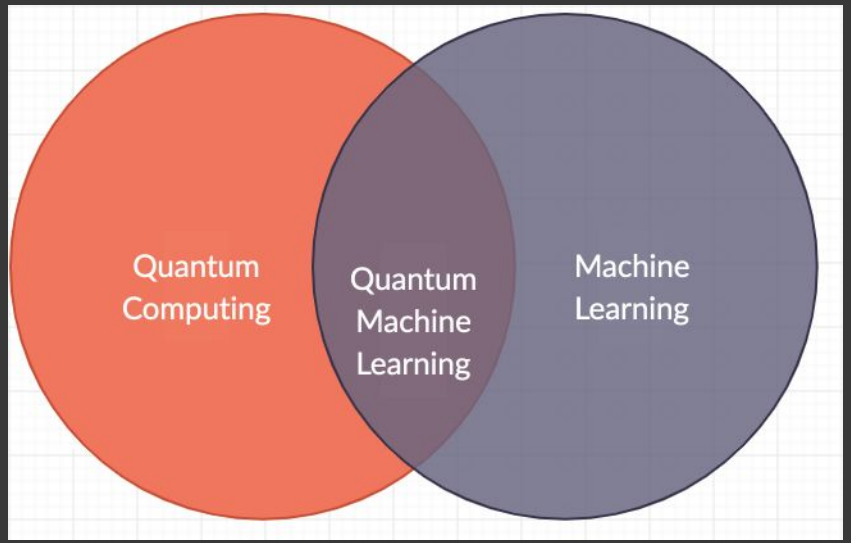


- In simple words quantum machine learning is the combination of the concepts of machine learning and the concepts of quantum mechanics.
- Quantum machine learning leverages the information processing power of quantum technologies to enhance and speed up the work performed by a machine learning model.

QUANTUM IMAGE PROCESSING

It is branch of study which takes the concepts of quantum properties to represent images in a quantum computer and then implement various image operations and train models and predict the data.

DIFFERENT MODELS FOR IMAGE RECOGNITION

ANN

Artificial Neural Network

QNN

Quantum Neural Network
Analogous to ANN

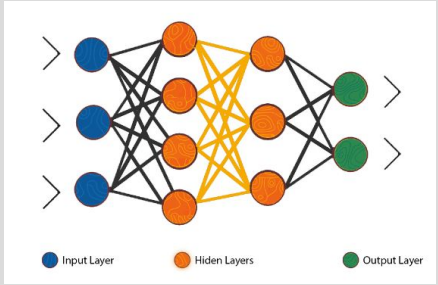
CNN

Convolutional Neural Network

QCNN

Quantum Convolutional Neural Network
Analogous to CNN

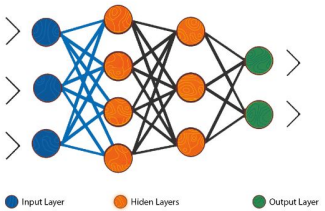
Reference - Analytics Vidya



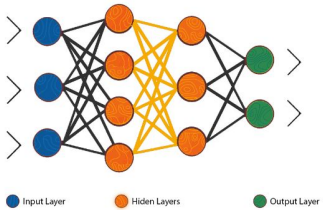
What is ANN ?

Artificial neural networks (ANNs) are a type of machine learning algorithm inspired by the structure and function of the human brain(basically the neurons). ANNs consist of interconnected nodes, or neurons, which can process and transmit information. By adjusting the strength of the connections between neurons, ANNs can learn to recognize patterns and make predictions.

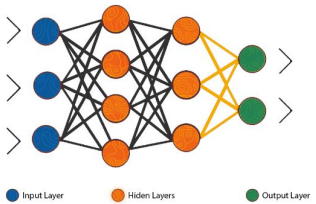
WORKING OF ANN →



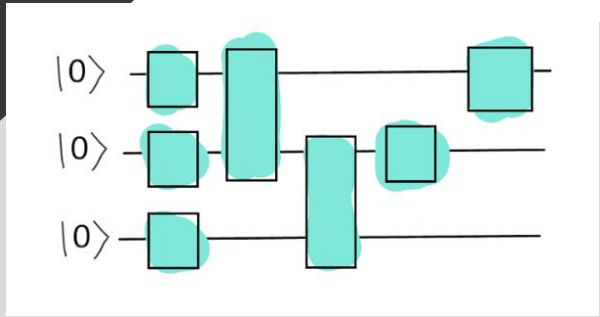
STEP 1 -: The input data is fed into the input layer of the network.



STEP 2 -: The input data is multiplied by the weights of the connections between neurons in the hidden layers. The result is passed through an activation function that determines whether the neuron should be activated or not. This process is repeated through multiple hidden layers until the final output layer is reached.



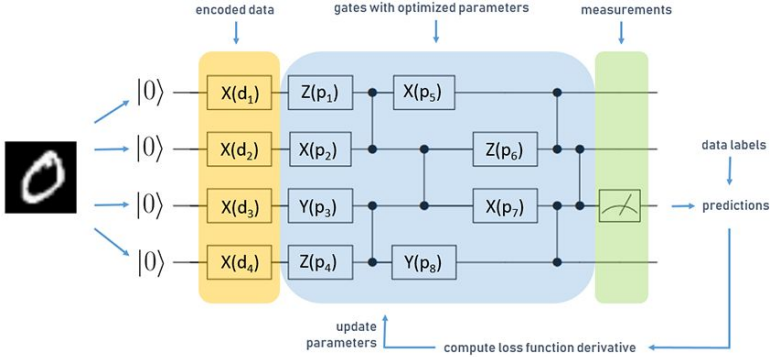
STEP 3 -: The final output layer produces a prediction or classification based on the activation levels of the neurons in the previous layers.The network's performance is evaluated by comparing the predicted output to the actual output, and the weights are adjusted using an optimization algorithm such as backpropagation to improve accuracy. The training process is repeated until the model reaches a satisfactory level of accuracy.



What is QNN ?

Quantum Neural Network (QNN) can be defined as a neural network that utilizes quantum computing principles to perform machine learning tasks. Similar to classical neural networks, QNNs consist of interconnected nodes or neurons that process data to make predictions or classifications. However, unlike classical neural networks, QNNs use quantum bits or qubits instead of classical bits for computation, which allows them to perform certain tasks faster than classical counterparts

WORKING OF QNN →



Reference - argmax.ai

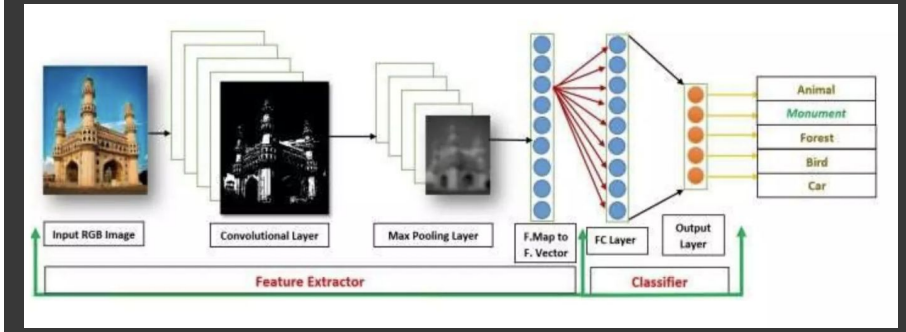
STEP 1 : - The qubits are initialized to a known state that encodes the input data.. After the first step of encoding the classical bits into qubits we then have the data which will be passed from our neural network. (mainly the quantum data points have been generated)

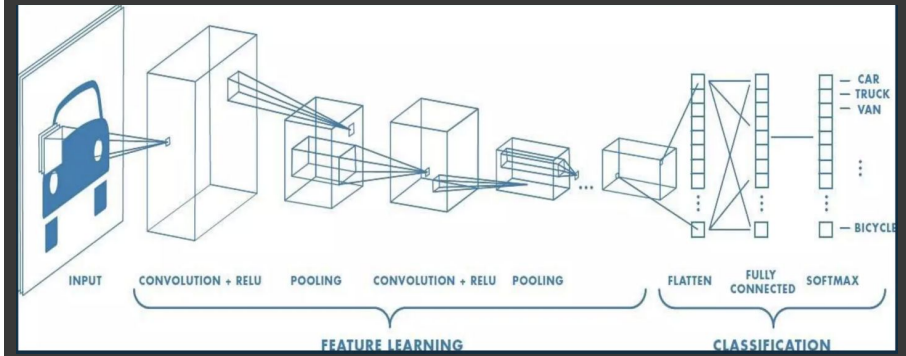
STEP 2 : - In the second step the quantum bits are passed through quantum circuits Quantum gates are applied to the qubits to perform operations on the input data, which are typically represented as unitary matrices.

STEP 3 : - After applying the quantum gates, the qubits are measured to obtain a classical output. The measurement results are probabilistic and depend on the quantum state of the qubits.The measurement results are post-processed using classical algorithms to produce the final output, which is typically a prediction or classification. During the training process, the quantum gates and parameters are adjusted to optimize the network's.The performance of the QNN is evaluated by comparing the predicted output to the actual output on a test dataset.The training process is repeated until the model reaches a satisfactory level of accuracy.

CNN INTRO

CNNs learn multi-level features and classifiers in a joint fashion and perform much better than traditional approaches for various image classification and segmentation problems.

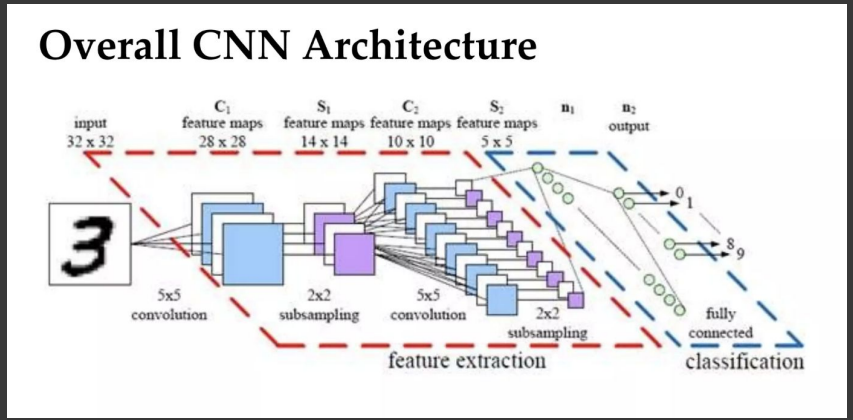




CNN WORKING...

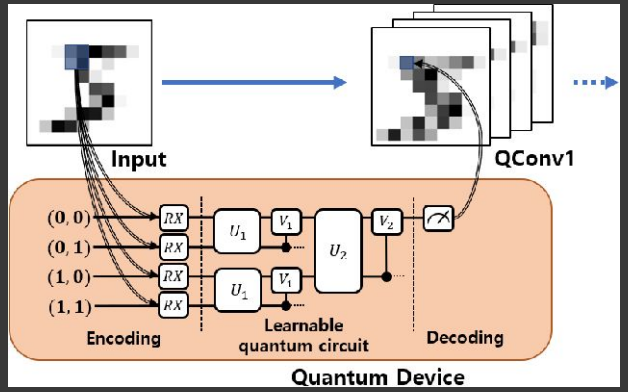
- Data passes through a set of filters.
- Feature Extraction takes place.
- ReLU activation for non-linearity.
- Pooling Layers.
- Repetition of the steps above and the combining them into a fully connected layer.
- Output

The CNN learns the optimal set of filter weights through a process called backpropagation, where the error between the predicted and actual class labels is propagated backwards through the network, adjusting the weights to minimize the error



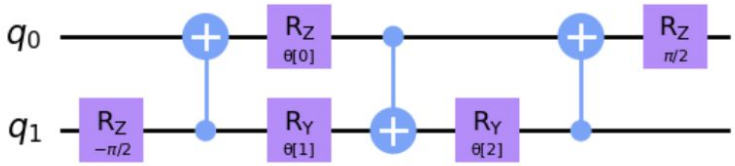
QCNN INTRO

A quantum convolutional neural network (QCNN) is a type of neural network that leverages the principles of quantum computing, such as superposition and entanglement, to perform convolutional and pooling operations in a quantum fashion. QCNNs are designed to potentially outperform classical convolutional neural networks (CNNs) due to the exponential speedup of quantum computers for certain types of calculations. However, developing and optimizing QCNNs is still a challenging task due to the limitations of current quantum hardware and the need for specialized quantum algorithms and architectures.



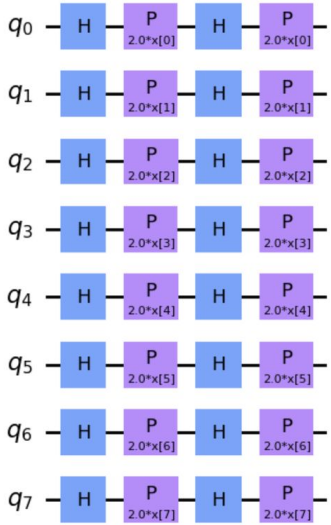
SOURCE - https://d3i71xaburhd42.cloudfront.net/4296f661e1be182292f13f76ccd7b77926b845e2/2-Figure2-1.png

QCNN Working ..



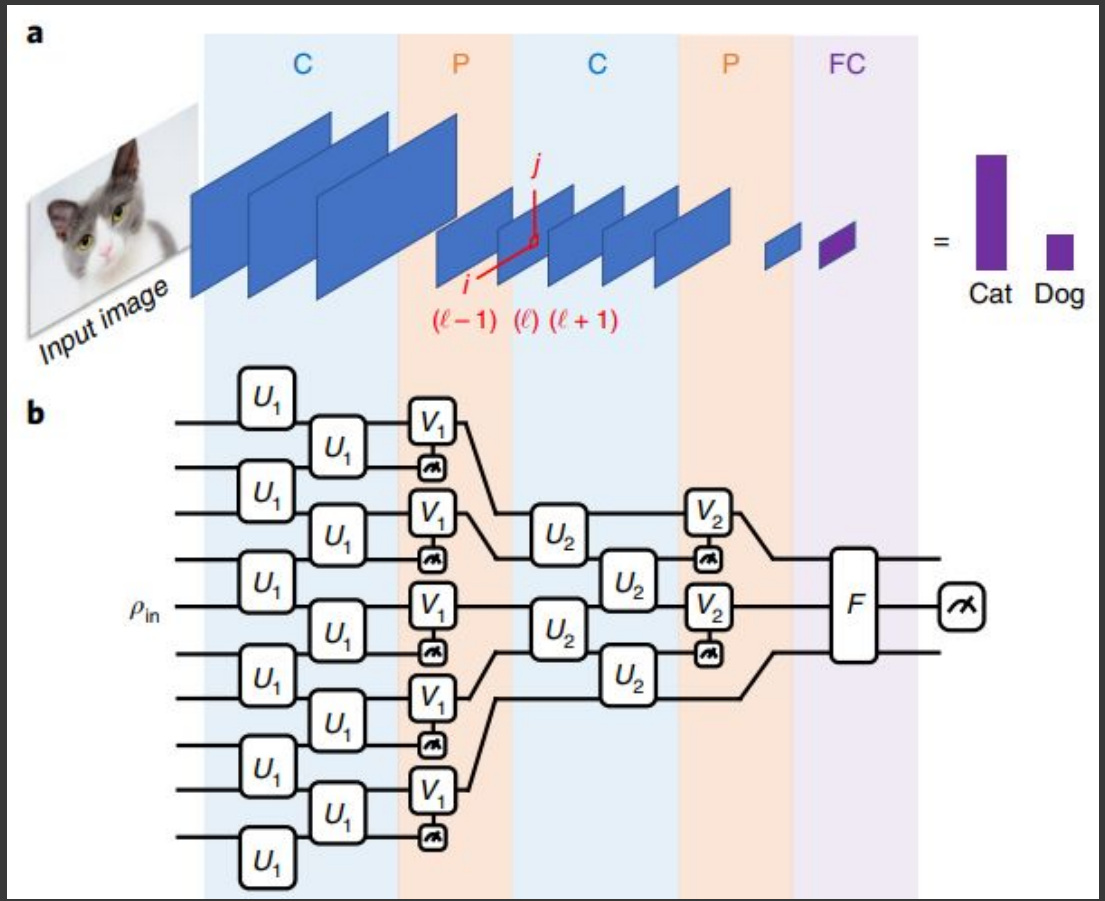
PART 1 : - For convolution, a parameterized unitary gate is created that would be later used for convolution and pooling.

PART 2 : - For applying a convolution layer wedo so by applying two qubit unitary to neighboring qubit.



PART 3 : - Now that we have defined both the convolutional layers it is now time to build our QCNN, which will consist of alternating pooling and convolutional layers.As the images in our dataset contains 8 pixels, we will use 8 qubits in our QCNN. We encode our dataset into our QCNN by applying a feature map. One can create a feature map using one of Qiskit's built in feature maps, such as Z Feature Map or ZZ Feature Map.

The Architecture Of **CNN** and **QCNN**



Reference: https://arxiv.org/pdf/1810.03787.pdf

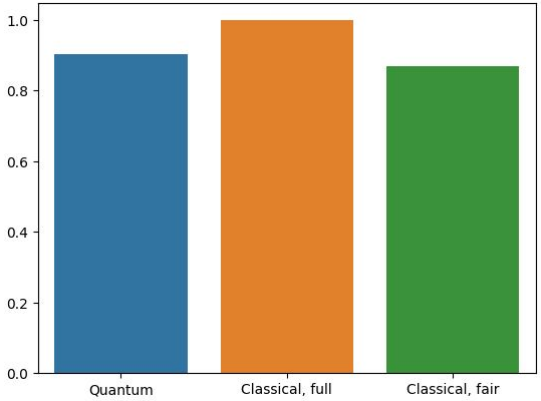
CNN

In the field of deep learning, convolutional neural network (CNN) is among the class of deep neural networks, which was being mostly deployed in the field of analyzing/image recognition.

QCNN

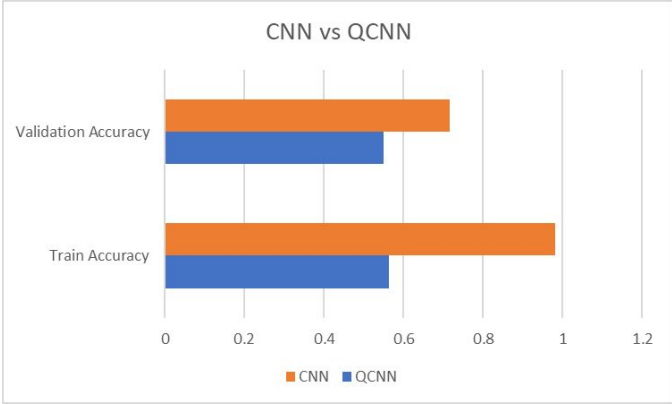
Quantum Convolutional Neural Networks works similar to CNN just uses random Quantum Circuits instead of Kernel Matrix to perform convolution. This Quantum Machine Learning Algorithm is also used for Image Processing.

RESULTS OF THE MODELS



Here Quantum , Classical - full and Classical - fair refers to QNN , CNN and ANN respectively. This is the result for binary classification.

We can clearly see that the quantum algorithms did not perform better than the classical networks. The accuracies of quantum models are less than compare to the classical models in each of the case.



The best model among all of the models is CNN with an accuracy of 99.85 %

Some of the reasons behind these results :-

- Quantum models rely on encoding classical data into quantum states, which can result in a loss of information or accuracy during the encoding process. Classical models, on the other hand, can work directly with raw image or signal data, without the need for encoding.
- Quantum models require specialized hardware, such as quantum computers or simulators, which can introduce additional noise and errors that can degrade the accuracy of the model. In contrast, Classical models,can be implemented on standard CPUs or GPUs, which are well-established and well-understood technologies.
- CNNs have been extensively studied and developed over the years, and there is a large body of research and expertise in training and optimizing them. On the other hand, QNNs are a relatively new field, and researchers are still exploring different approaches to train and optimize them effectively.

LIMITATIONS

1. Hardware limitations: Currently, there are only a few companies that offer quantum computing hardware. This means that access to quantum hardware is limited, and researchers may have to rely on simulations to test their QCNN models.

2. Limited qubit resources: Quantum computers are still in the early stages of development and have limited qubit resources. This makes it difficult to train and run large QCNN models that require a large number of qubits.

3. Lack of training data: QCNN models require large amounts of training data to learn complex patterns and features in images. However, the availability of quantum image datasets is currently limited, making it challenging to train and test QCNN models.

ACKNOWLEDGEMENT

We would like to show our sincere gratitude towards Dr. V Narayanan for guiding us with the project throughout the semester and helping us to learn and explore what quantum computing and quantum machine learning has to offer.
We would also like to thank Ravikant Sir who constantly supported us and motivated us throughout the project.

THANK YOU

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HOW ARE QUANTUM COMPUTERS DIFFERENT FROM CLASSICAL COMPUTERS

QUANTUM COMPUTING VS CLASSICAL COMPUTING

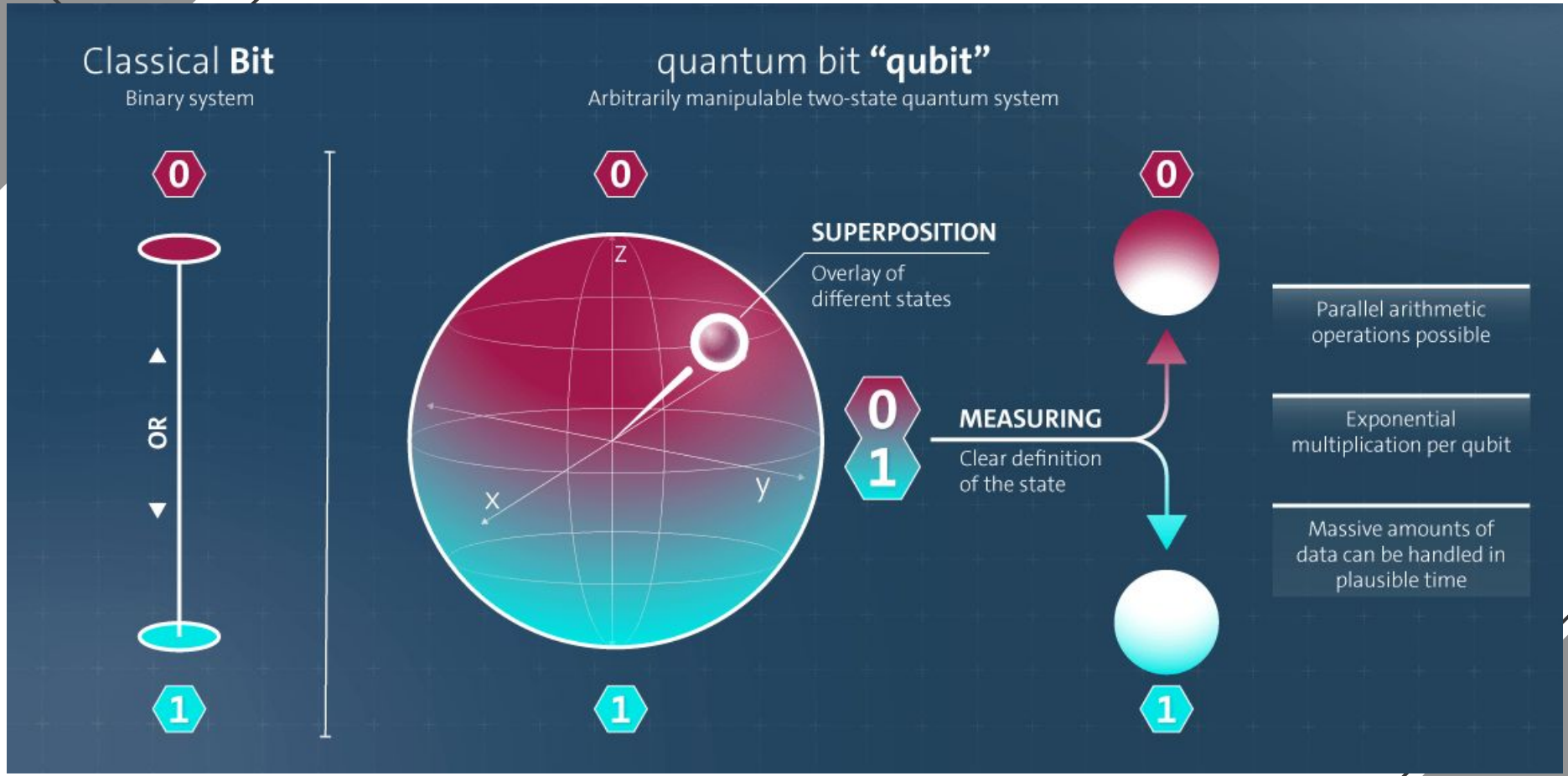
1. The most basic difference between Quantum and classical computing is that Quantum computers process information in a fundamentally different way to classical computers.
2. Instead of relying on transistors which can only represent either the “1” or the “0” of binary information at a single time quantum computers use qubits, which can represent both 0 and 1 simultaneously.

Now the question is what are Qubits ?

3. A qubit can be considered analogous to classical bits where bit is the most basic unit of information and the information is encoded in bits, where each bit can have the value **zero or one.** Similarly in quantum computing the information is encoded in qubits and the qubits are the unit of information,
4. A qubit is a two-level quantum system where the two basis qubit states are usually written as $|0\rangle$ and $|1\rangle$. A qubit can be in state **$|0\rangle$, $|1\rangle$ or (unlike a classical bit) in a linear combination of both states.**

WHAT IS SUPERPOSITION AND ENTANGLEMENT

Source - https://devopedia.org/qubit



ENTANGLEMENT

Quantum entanglement is the state where two systems are so strongly correlated that gaining information about one system will give immediate information about the other no matter how far apart these systems are.In quantum computers, changing the state of an entangled qubit will change the state of the paired qubit immediately. Therefore, entanglement improves the processing speed of quantum computers