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Quantum Machine Learning- Using Quantum Computation in Artificial Intelligence

Quantum Computation and Machine Learning in Artificial Intelligence

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Abstract: Artificial Intelligence mostly deals with tasks of modifying and supervising problems taken as vectors in multi-dimensional space. The Primitive algorithms which are used take Polynomial Time for computing such vector problems which are not fruitful for us, on the other hand, Quantum algorithms have the capability to solve such vector problems in a considerable amount of time by using Quantum-Mechanical operations. For example, we can perform a Database Search in a time which is Quadratic-ally faster than the primitive search algorithm. Quantum Algorithms rely on Quantum physics and therefore the algorithms are Incoherent in nature and this property makes them more interesting to study. In this paper, we provide the insights of Quantum Machine Learning and we formally prove that the Execution Time of the algorithm is greatly optimized with the help of Adiabatic Quantum Learning. Data mining concept is very similar to Machine Learning and thus we will also show how Quantum Machine Learning will be advantageous in similar cases.

Keywords: Quantum Machine Learning; Quantum Computation; Artificial Intelligence; Deep Learning; Quantum Annealing; Artificial Neural Network; Data Mining; Quantum Entanglement; Computational Modeling; Quantum Walks

I. INTRODUCTION

Machine Learning refers to a field where several components or parts are identified by a particular machine from the data.

There is a special type of Quantum Learning algorithm known as Quantum Reinforcement Learning Algorithm. In this type of algorithm the machine is rewarded for every prediction, it makes in the Quantum Environment. [11] [10] [1] These Rewards tells the machine how efficiently it has performed the prediction. The primary aim for this type of learning is to find the optimal reward which can be provided for every prediction. [3] [7] [12] [15] The advantage of Quantum Reinforcement Learning is that a particular part of the algorithm interacts with a classical environment and produces the result in the Quantum environment, which is reversible in nature. So, the drawbacks of the Time Complexity in Brute Force Method or Classical Probabilistic Method are solved. The algorithm behaves in such a way to predict the output in much optimum manner, so the machine has to learn certain part or concept of the problem. The Learning and the Processing of the machine have to be done in parallel so that the algorithm can perform efficiently.

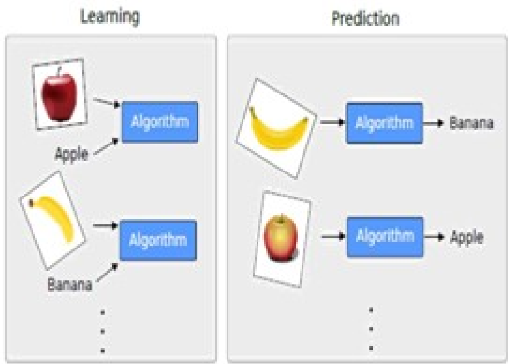

Fig 1. Machine Learning Prediction Example

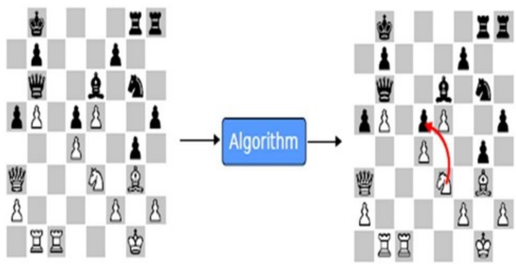

Fig 2. Quantum Reinforcement Machine Learning

Quantum Computation works in Qubits. The classical bit 0 or 1 is replaced by the Qubits which is the backbone in Quantum Information Processing and Quantum Data. Different operations are performed in these Qubits like “Entanglement”, “Superposition” etc. Data Mining is a field in computer science which is often correlated with Machine Learning, but they differ from each other. Data Mining basically deals with the analysis of data. Data is available to us from various sources and in various forms.

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II. GENERALIZED QUANTUM MACHINE LEARNING

A. Proposed Model in Quantum Learning

Let us consider an Algorithm which can reproduce a result with an accuracy of 100%, but is not able to predict the result in the case of unseen inputs. So, our algorithm is much efficient in the first case, but in the long run, we have to look for a better algorithm.

Let us consider a Model which generates an output as:

$$0(x) = y \qquad (1)$$

This is based on the input data set as:

$$\{(x_1,,y_2),(x_2,y_2),(x_3,y_3)\ldots.,(x_i,y_i)\}$$

f(xi): be the function responsible for the generation of the output.

Here the Input has some Disruptions and Noise in it and let it mean be zero and Variance.

We define a function L which indicates the loss in the machine predicted the output.

$$L[y(i),f(x_i)] = \{|y_i - f(x_i)|\}x_i^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

And the Absolute Error is:

$$L[y(i),f(x_i)] = [y_i - f(x_i)] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..\ldots(3)$$

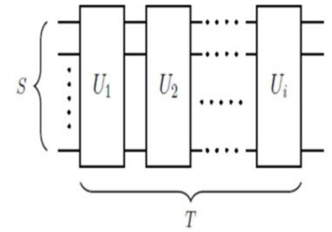

Fig 3. Proposed Quantum Machine Learning Model

Given the function 'L', the Machine Training Error Rate will be:

$$E = \frac{1}{n}\left(\sum L(y_i\ , f(x_i)\right) \qquad (4)$$

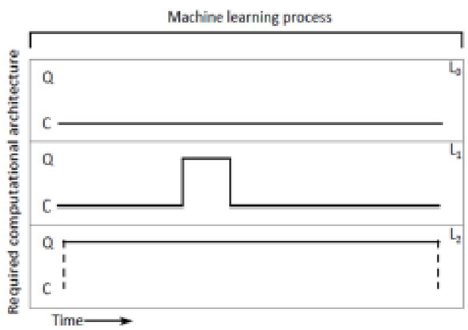

Fig 4. Graphical Representation of the Quantum Model

Here let us calculate the Complexity of the proposed model.In this Model 'S' denotes the amount of space or Qubits required for computation of the model [1] [4] [18]. Now if the total number of Qubits be 'S' then the equivalent referred Hilbert Space will be 2S. Here 'T' represents the Time required to make the machine learn and apply the respective Logic Gates in the circuit. The above figure (Fig. 4) represents the comparison of Quantum Model 'Q' of the Classical Computational Model 'C' required to solve a linear problem L0,L1,L2. The Dotted line represents the phenomenon of Quantum Annealing which tries to find the global optimum complexity in both the cases. While the classical algorithm has an exponential complexity, on the other hand, we see a linear complexity in the case of the Quantum Model. However, the Complexity of the Quantum Model is not always Linear due to the phenomenon was known as Quantum Fluctuation which changes the energy present in a Qubit at a particular point in time.

III. QUANTUM NEURON ARCHITECTURE

Quantum Neural Network is defined to be a system of blocks with some specific input and output. This type of Neural Structure is derived from the Biological Neuron which is present inside our brain. Our Brain is responsible for the functioning of the entire system of our body. Similarly, neural networks are the building blocks of any Machine Learning Systems, Quantum or Classical both.[23] [26] [21] [24] The QANN are very flexible in handling a large amount of input data and complex functions to analyze and predict the output. In the case of any neural network, we have a weight assigned to each path or node which indicates the optimum value which a machine will get using such path. A Quantum Network has different layers associated with it, for example, Input Layer or Output Layer, Decision Layer etc. Every layer has a specific representation in the network and varies accordingly. A Quantum Artificial Neural Network has many parameters depending upon which a decision is made by a machine.

The first is the pattern of the connected layers in the ANN. The second is the value associated with each node present.

The third is the activation threshold function value which converts the ANN input weight to its corresponding output.

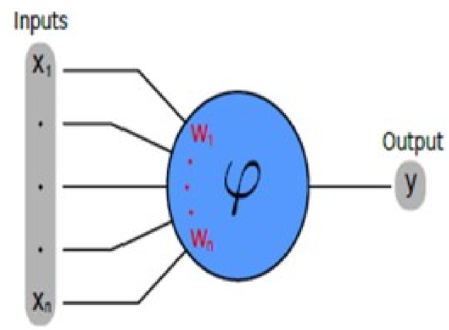

Fig 5. Quantum Artificial Neuron Architecture

In the above Quantum Neuron (Fig. 5) x_1 to x_n represents the input to the structure. While w_1 to w_n

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represents a particular function which is responsible for converting the input to its corresponding output.

$$y = \varphi\left(\sum_{k=0}^{n} w_i\, x_i\right) \qquad (5)$$

The Quantum Neuron is a single basic building block in the entire architecture. Combining several of these neuron cells we can design various QANN models for our purpose.

Now these Quantum Neurons make estimation to a Quantum State ψ which is defined as

$$\psi(p,t) = \sum_{k=0}^{n} G(p,t) \qquad (6)$$

Where 'p' is the estimated position and 't' is the time factor in . Here G is a prediction operation w.r.t position 'p' and time 't'.

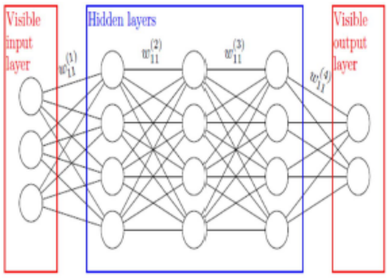

Fig 6. Proposed Quantum Neuron Layer

Using the different layers in our model a Machine can describe an intelligent algorithm that can signify various features of learning from complex situations. Like for example: If we have a picture of a man, using various layers the machine can detect whether the man is 'standing' or 'sitting', 'walking' or 'running' etc. So, these layers play an important role in training the machine accordingly. (Fig. 6)

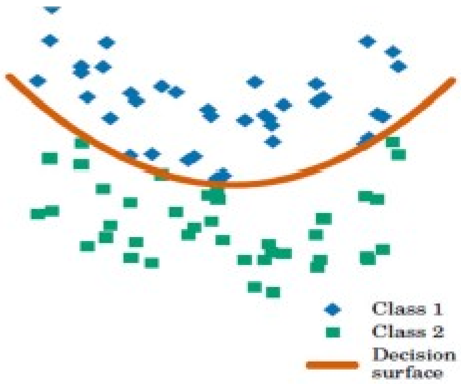

Fig 7. Cluster Decision Layer for Class 1 and Class 2 Quantum Neuron Decision

Quantization in quantum Environment means converting a given Primitive code into blocks of Quantum Code which can be stimulated in any virtual environment. Clustering in QANN is defined as breaking a set of a problem as "Clusters" in a particular code and then implementing the set of subparts one by one implementing the results. The concept of Cluster Computing in modern generation computing is very much similar to Unsupervised Machine Learning. The concept of Quantum Cluster Computing [12] was implemented to work with large inputs set or basically clusters effectively. The time complexity of the Quantum algorithms is much less and efficient than the primitive algorithms which could take even polynomial or logarithmic time. The working of the algorithm in Quantum Clustering is dependent on it nodes, as they are serially connected the speed up of the algorithm is biased. If the performance of the previous cluster is not up to the mark, the rest of the family will suffer. (Fig. 7)

A. *Representation of ANN in the Quantum Environment*

Quantum Neural Networks are simulated by software. Meaning we can use a Quantum computer to run various small 'mini' size programs to stimulate the functioning of the brain.

These small programmed neurons are connected and they form powerful Quantum Intelligent machine capable enough to do the complex task and can take decisions on behalf of humans. Now a Quantum Sigmoid Neuron is the basic and smallest unit of a QANN. A QSN takes many inputs and produces a single output on superposition. The inputs have specific weights assigned to it and the output is determined by

$$\begin{cases} |0\rangle & if \sum_i x_i w_i < Activation\ Value \\ |1\rangle & if \sum_i x_i w_i > Activation\ Value \end{cases} \qquad (7)$$

Here xi is the input set and can take any value between |0> and |1>, w_i signifies the weight or value considered in the QSN. Unlike classical perception concept, the output generated by the QSM is not one or zero, it is the superposition of |0> or |1>. For Example

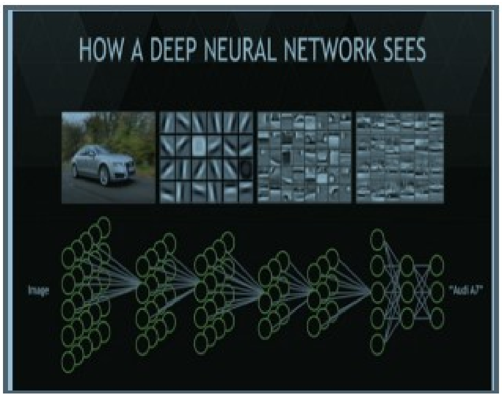

Fig 8. Quantum Sigmoid Representation of a Car

Here (Fig. 8) as we see the neural network is parted in several stages and each stage has independent

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functionality. The formation of these layers is dependent on the input used, in this case, the car picture. Another clever method is to incorporate both primitive and quantum subparts in the algorithm so that upon measuring the quantum state the wave function collapses nonlinearly. Several

Researchers argue that a full quantum neural network performs less efficiently than the hybrid one, consisting of both primitive and quantum subroutines. As we know the wave function collapses as soon as we try to measure a particular quantum bit, so the neural network has to be put in 'start' condition again and again to perform another operation. Many algorithms put the neural network in the start position every time we measure the value.

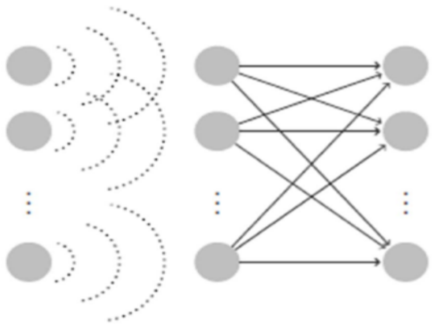

Fig 9. Quantum Representation of Interference in QSM

The main hard part of the algorithm has classical architecture while there are several quantum subroutines placed as layers in the algorithm. The algorithm is made to interact with the quantum environment and the observation is recorded. The layers in the neural network are made indifferently and theyare very likely to be same because of the no-cloning theorem.

(Fig. 9) The Quantum neuron network is made to learn a particular set of data in a quantum environment by repeating a particular portion of the algorithm over various data to gain improvement. Now the algorithm checks for different values attached to each connected nodes and adjusts its position accordingly. The most important concept in QANN is the value of the node, using which the algorithm will take any decision. The Quantum Network reads the given input data set and memorizes the steps and features and reorganizes the output function accordingly so as to efficiently interact with the algorithm to reach an optimal level. As many such training input data sets are passed into the machine, the error rates are expected to decrease and we see an improvement in the level of accuracy. However if the Quantum Networks are forced to be trained over a long period of time, the algorithm may be packed and may not be able to predict accurately.

The Hopfield system can be defined as:

A={Y,m}

Where, Y is a set of Artificial Neurons and 'm' is an output function which basically acts as a dependent variable for a particular node in the Hopfield System. (Fig. 10)

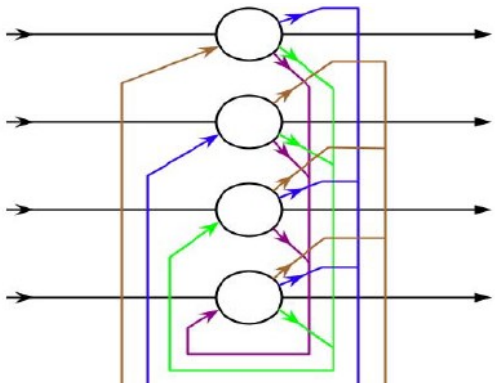

Fig 10. Representation of a Connected Hopfield Network

When a particular algorithm tries to find the optimum value of the next node, there is a need to replace or update the weight of the particular node in the code.

Such replacement is done:

$$u_i = \begin{cases} -1, & if \sum_j w_{ij} u_j < \theta \\ 1, & if \sum_j w_{ij} u_j \geq \theta \end{cases} \tag{9}$$

Where, w_{ij} is the approx value of the connected node i and j; θ is the Activation Function; u_j: is the present state of node j.

The replacement in the Hopfield Systems can be done in two ways: Synchronous and Asynchronous, each being stimulated by a common clock.

Now the values of the current nodes acting play an important role in the replacement policies. Let the value be wij for node i and j.

$u_j = 1$: meaning the value of $j>i$
$u_j = -1$: meaning the value of $j<i$.

B. *Quantized Energy in the Hopfield System*

Whenever a Quantum Particle entangles a new state some Energy is quantized in form of entangled neurons and is described as:

$$E = -\frac{1}{2}\sum_{i,j} w_{i,j} u_i u_j + \sum_i \theta_i s_i \tag{10}$$

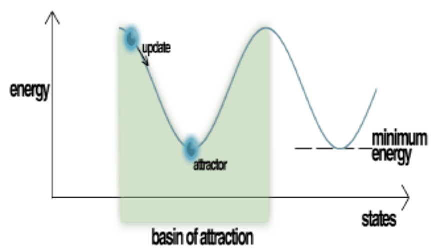

Fig 11. Representation of Energy in Quantum Hopfield Network

This equation ensures that the network is in a stable environment and when the system is passed through multiple training operations then the energy states become more quantized and finally it converges and the pattern is recorded.(Fig. 11)

IV. CONCLUSION

The Paper represented the concept of Quantum Machine Learning in an application with Big Data and Artificial Networks. The main advantage of the Quantum Learning Algorithm is that the ability to react and adapt independently in Classical as well as in the Quantum environment. While the improvement in the Time Complexity is of significant use when we figure out newer algorithms in the Quantum domain The recent advancement in Open Quantum Systems will be beneficial for QML as they a dynamic nature which adds to their decision making. Also, Quantum Access Memories were introduced much later to cope up with the increasing demand of such Quantum Algorithms.

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