A REVIEW OF QUANTUM MACHINE LEARNING AND DISCUSSION OF ITS CURRENT STATUS

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ABSTRACT
The Quantum Machine Learning is at the combination of the two of the most sought study topics today, i.e., quantum computing and conventional machine learning. Quantum machine learning is the hybrid of two fields. When it comes to quantum machine learning, the goal is to understand how findings from the quantum realm may be applied to challenges in machine learning. Quantity of data is required to properly train a traditional computation model is increasing all the time and is approaching the boundaries of what can be handled by conventional computing machines. The use of quantum computing may help in the continuation of training with large amounts of data in such a circumstance. Quantum machine learning aims to create learning algorithms at a quicker rate than their conventional equivalents, according to the researchers. Classical machine learning is concerned with the search for data patterns and the use of data patterns to predict future occurrences in the data. However, quantum systems exhibit abnormal patterns that are not reproducible by classical systems, leading some to speculate that quantum computers may be able to outperform conventional computers on machine learning tasks in the future. The prior literature on quantum machine learning is reviewed in this paper, as well as the present state of the field.
Keywords: Quantum machine learning, Quantum computing, Quantum algorithm, Quantum support vector machine.

Introduction

Our classical knowledge is based on the experiences that we have throughout our lives; nevertheless, these experiences do not represent the ultimate underlying mechanism of nature. The underlying and more fundamental mechanics, which are referred to as quantum mechanics, are responsible for everything we see around us. The phenomena of quantum mechanics do not align with the common sense we have. In point of fact, these fundamental mechanistic underpinnings were obscured from our view for a significant portion of the history of both science and human comprehension. It wasn't until the past century that people started paying attention to this facet of natural phenomena. As the investigation went on, our world-class researchers came up with hypotheses and mathematical models to explain their findings. Due to the probabilistic nature of quantum theory, it naturally draws in a large number of philosophical discussions. There are many quantum phenomena that continue to captivate our interest, like quantum superposition, the collapse of the wave function, and quantum tunnelling, and others. Our current knowledge does not fully include the fundamental quantum aspect of existence, which remains a mystery. The goal of quantum technologies is to take use of these fundamental principles in order to advance technology. The applications that are based on the rules of quantum mechanics have progressed by leaps and bounds over the last ten to twenty years, with the goal of either replacing or going it is parallel to traditional (classical) machines.

The quantum technology can be broken down into three primary subfields: quantum computing, quantum information, and quantum cryptography.

Review of Literature

Introduction to Review of Literature

Quantum computing involves utilizing the principles of quantum mechanics to carry out computational operations; quantum information refers to the application of quantum phenomena to the assistance of information transfer, storage, and reception (employing quantum phenomena to devise more advanced cryptographic methods). Expansive permutations that come with quantum processing provide the Quantum computers double the memory space with addition of each of the qubit, which is where the strength of quantum computing comes from. If we want to define a classical bit system with N bits, we would need N bits to represent binary numbers. Now, we are aware that there are two potential definite states in quantum systems, and those states are 0 and 1. It is easy to understand that a 2 qubit quantum system, can provide us 4 traditional bits of information (, and). A generic state of a bipartite quantum system may written like = |00 + |01 + |10 + |11.

In a similar manner, we are able to get 2N bits of information from a quantum system that has N qubits. A Turing machine is mathematical model that defines the essential features of a machine used for computation. The components of Turing machine include a strip containing symbols, an automation, a write-read head, and a set of rules represented by a transition function, which can frame-up symbols which is there in the strip. This model of computation can be thought of as conceptually defining the aspect of a machine. Turing machines are equivalent to quantum computers in every way. The superposition of quantum states is made possible by quantum physics, which leads to quantum parallelism. This phenomenon, which may be used to accomplish probabilistic jobs considerably more quickly than using conventional methods, can be utilised.

Srivastava, Katiyar & Goel, (2021) Quantum computing is a new and exciting field that combines quantum mechanics and computer science to create a faster computing system. While the potential for quantum computing is significant, it is still in the early stages of development, with critical quantum computers still a long way off. However, governments and companies are investing heavily in research and development, and it is expected to change how computers operate in the future. Quantum computers have the potential to solve computing tasks that are beyond the capabilities of even the best computers we have today.

Shor, (1994) Quantum computers are known to be capable of solving problems that classical computers cannot, such as factorizing large numbers using Shor's algorithm. Furthermore, in some cases, combining classical and quantum computing can lead to more efficient problem-solving, with quantum algorithms proving to be more effective than classical ones.

Bhatt & Gautam, (2019).The research paper explores the exciting field of quantum computing, which utilizes the laws of quantum physics for high processing capabilities and accuracy. The paper provides an overview of quantum computers, their introduction, how they work, features, benefits, and future uses. It highlights the potential benefits of quantum computing in solving complex problems in fields such as chemistry.

Bermejo & Zatloukal, (2015) A new development in quantum algorithms related to the hidden normal subgroup problem (HNSP), which has been connected for the first time with abelian hypergroups. Abelian hypergroups are mathematical structures used to model physical particle collisions. The researchers develop a stabilizer formalism using abelian hypergroups, and using these tools, they create the first quantum algorithm for finding hidden subhypergroups of nilpotent abelian hypergroups. They also develop a hypergroup-based algorithm for the HNSP on nilpotent groups. The researchers also describe efficient methods for manipulating non-unitary, non-monomial stabilizers and an adaptive Fourier sampling technique.

Somma,(2016). Quantum computers have made significant advancements in the areas of optimization and simulation, including the computation of partition function properties, simulation of various quantum systems, and performing approximate optimization. Quantum simulations also have practical applications in fields such as quantum optics and condensed matter physics.

Gotarane & Gandhi (2016). Quantum computing uses quantum phenomena to perform operations on data with the goal of finding algorithms that are faster than classical algorithms. Although actual quantum computers are yet to be developed, research is being funded to develop them. Quantum computers use qubits instead of binary digits, and a quantum Turing machine is a theoretical model of such computers.

Russell & Norvig, (2016). Machine learning refers to a type of artificial intelligence that allows machines to learn from data and improve their performance on specific tasks. There are three main types of machine learning methods: supervised learning, unsupervised learning, and reinforcement learning. Supervised learning involves training a machine using labelled data to identify patterns and characteristics. Unsupervised learning involves clustering and grouping similar data without prior labelling. Reinforcement learning involves machines learning through feedback and rewards based on their actions. Machine learning has applications in various fields, such as image and speech recognition, natural language processing, predictive analytics, and robotics.

Saini, (2020) Quantum machine learning (QML) explores the interaction between quantum computing and machine learning, with the goal of developing quantum software that enables faster machine learning. QML includes quantum neural networks as a promising area of research, leveraging the unique properties of quantum computing to enhance machine learning algorithms.

Rebentrost, Mohseni & Lloyd, (2014). Quantum Support Vector Machine is the most common supervised machine learning algorithm used in quantum machine learning. The algorithm utilizes optimization boundaries in a higher-dimensional vector space to classify the labelled data's classes.

Abdi & Williams, (2010) Principal Components Analysis is a commonly used algorithm in quantum machine learning, serving as the quantum equivalent of unsupervised machine learning, in that it takes a large amount of unlabelled data and creates a pattern out of it before significantly reducing the amount of data to make it simpler for subsequent analysis.

A.

B. Objectives

The objective of the paper is to provide an overview of quantum machine learning and its algorithms. It helps to develop algorithms and techniques to leverage the unique properties of the quantum computing to enhance machine learning tasks.

Research Methodology

The methodology used in this paper is secondary data which involved in conducting a systematic review of relevant literature from various databases, such as IEEE, Springer, and Google Scholar, to identify existing studies, theories, and applications of quantum machine learning. The search was performed using specific keywords and criteria, and the selected studies were critically analysed, synthesized, and evaluated based on their relevance, quality, and contributions to the research topic. The analysis was based on a qualitative approach, and the findings were presented using narrative descriptions.

Machine learning models

C. Artificial Neural Networks

The biological neural network served as the inspiration for a particular class of computing models known as artificial neural networks. In a general sense, they are designed to simulate the functioning of the natural neural network. The system adheres to the same rules on a more general level when it comes to artificial neural networks, Similar to how a natural neuron requires a specific excitation to fire and the firing of a series of neurons determines the subsequent action, so too does the system adhere to the same rules when it comes to firing when it comes to artificial neural networks. Different sorts of neural network models are used, each of which is determined by the nature of the challenge that we are now confronting. One way to think about the structure of a neural network is as a series of layers of neurons, each of which generates a firing pattern that is determined by the behaviour of the neuron.

Image classification is the primary application for the Convolution Neural Network. In this case, the value of the output is determined by vector consisting of biases and weights, which is applied to inputs. Between layers that are being input and the layers that are being produced, there are several hidden levels. In addition, there is an activation function (which is often referred to as the RELU Layer), which is then followed by succeeding pooling layers. The fact that the convolution procedure is carried out by using a kernel is where the nomenclature originates from. Back propagation is another method that might be used to optimize the distribution of weights in a neural network.

A recurrent neural network is a type of neural network where the output from the previous time step serves as the input to the phase that comes after it. One of the uses of this that is the most well-known to users is predictive text. In order for the algorithm to correctly anticipate the next word, it must first store the word that came before it. By standardising the weights and biases across all of the RNN's layers, recurrent neural networks transform the independent activation into the dependent activation.

The A.N.N. (artificial neural network) was implemented, consisting of the input layer, output layer, and one or more hidden layers. The input dataset is pre-processed and transformed into an input array that is fed into the network. Each input set is associated with a label value, which is used to evaluate the performance of the network. The network is trained to identify the output label function of the fed dataset after it has been fed to the network and given the opportunity to do so. The error is calculated based on how much the predicted label value deviates from the actual label value; the training parameter is what ultimately decides which value corresponds to the least amount of error.

D. Support Vector Machines for Supervised Learning

In the year 1992, at the COLT-92 conference, Boser, Guyon, and Vapnik came up with the idea that would later become known as the Support Vector Machine (SVM). Support Vector Machines are a kind of model that belongs to the generalised linear classifiers that are based on supervised learning. These SVM models would be used for solving problems of regression as well as classification. The systems that use support vector machines (SVMs) are built on the assumption that a linear function in high dimensional feature space can be used as hypothesis space. Handwriting recognition is one of the powerful illustrations of Support Vector Machine in action. These classifiers use pixel maps as their inputs, and their performance is equivalent to that of complex neural networks equipped with characteristics tailored specifically for the detection of handwriting. Numerous applications have been developed, particularly for pattern classification and regression-based applications as a result of promising aspects such as improved empirical performance of SVMs. This has led to the emergence of many new applications. Analyzing handwriting, faces, and other physical characteristics are only a few examples.

SVMs outperform conventional neural networks in some cases because they use the Structural Risk Minimization (SRM) principle, which is considered more effective than the traditional Empirical Risk Minimization (ERM) principle used in neural networks. SVMs are able to generalise better than traditional neural networks thanks to the fundamental difference between the two, which is that SRM seeks to minimise the upper bound on the expected risk while ERM seeks to minimise an error on training data. As a result, SVMs are better suited to statistical learning than conventional neural networks. Because of this, SVMs are more recently been used, in addition to their more typical use for classification difficulties, to the analysis of regression problems.

Quantum Machine Learning (QML)

The essence of the machine learning is in the process of teaching a computer system to learn from the underlying algorithms that are used to process data. This branch of computer science and statistics makes use of computational statistics and artificial intelligence. The traditional approach to machine learning may, via its supervised and unsupervised subsets of deep learning, assist with the classification of pictures, the recognition of patterns and voice, the management of large amounts of data, and many other tasks. On the other hand, as of right now, a tremendous quantity of data is being produced. Therefore, new ways are necessary in order to handle, organise, and categorise such large amounts of data. The traditional approach to machine learning is able to identify patterns in data in most cases, but classical algorithms are unable to address effectively the issues that need very large data sets. Companies who deal with the administration of large databases are aware of these limits, and as a result, they are actively exploring for alternatives. One of these solutions is quantum machine learning.

The development of classical machine learning into quantum machine learning is facilitated by the use of quantum phenomena, such as superposition and entanglement, to the solution of issues. In quantum systems and by means of quantum computers, algorithms make use of the many superposition states |0 and |1 to make it possible to perform any computing method simultaneously. This gives them an advantage over traditional machine learning. To implement classical algorithms on a quantum computer, as part of the quantum machine learning approaches, we create quantum algorithms. These quantum algorithms are then run on the quantum computer. As a result, the data may be categorised, sorted, and examined.

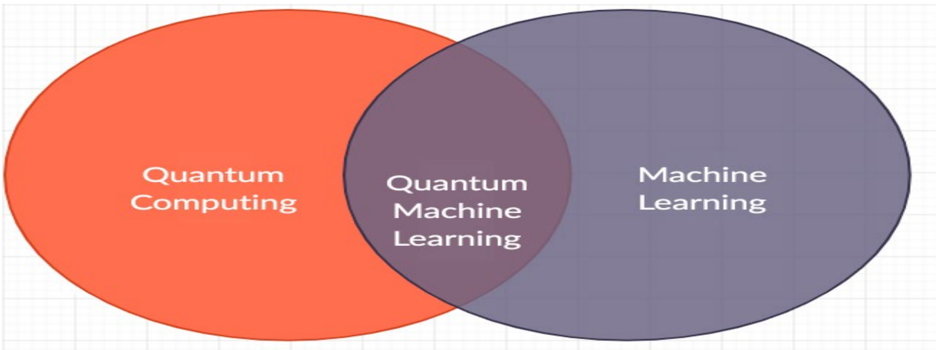

Figure 1: Quantum Computing and Machine Learning used for QML (Source: https://blog.paperspace.com/)

1. Quantum Artificial Intelligence

The more important issue to ask at this point is "Can the world of quantum offer anything to the field of AI?" Using simulations of various kinds, we will now attempt to establish a connection between quantum information processing and artificial intelligence. Quantum computing (QC) has the ability to simulate massive amounts of quantum data and may make it possible to explore and optimise more quickly. Particularly beneficial for AI is this specific point. Additionally, new advancements in QML system have generated exponent increases in machine learning problem solving. We are currently trying to understand Projective Simulation (PS), where an agent is situated in an environment that is specifically created to enable the agent to interact with it, while also providing the agent with specific physical inputs. As a result, the agent acquires knowledge via experience. The Episodic Computational Memory is the most important component of the PS model (ECM). ECM assists the agent in projecting themselves, and as a result, it produces a random wander over the realm of episodic memory.

Quantization of the PS model is straightforward. Any autonomous agent that interacts with classical settings while also possessing a memory with quantum degrees of freedom is considered to be a quantum-enhanced autonomous agent.

The agent is going to go on a quantum stroll around its memory space right now. The transitions that have been created are now quantum superposition's, which means they are susceptible to interference. Additionally, quantum leaps are produced between the various states of the clip. Due to the fact that the PS model is capable of being quantized, the model has the potential to achieve significant speedups while traversing memory. As a result, the concept of embodied quantum agents has been defined for the very first time thanks to the expansion of the PS model to the quantum realm.

2. Recent Developments

The University of Pavia researchers were among the first to study artificial neural networks using IBM's 5-qubit quantum hardware for their experiments In addition, IBM and Raytheon BBM have been working together, to improve the efficiency of specific black-box machine learning tasks. At the moment, superconducting electronics are getting a lot of interest as a possible option for development of the quantum hardware. The cooperation between Quantum AI Lab of Google and UC Santa Barbara was the most recent endeavour in this direction. A recently published research paper suggests that quantum computing may not be relevant to current AI alignment research due to safety concerns, until certain protocols are made more efficient.

Quantum-inspired classical machine learning algorithms that leverage quantum-inspired techniques, such as tensor networks and quantum-inspired neural networks, to improve classical machine learning performance. Quantum neural networks that use quantum computing to implement neural network architectures and computations, such as quantum convolutional neural networks (QCNNs) and quantum recurrent neural networks (QRNNs).This is the case even though the paper was written on the topic of quantum computing for artificial intelligence alignment.

The other development in quantum machine learning is the concept of variational quantum algorithms, which combine classical optimization techniques with quantum computing to solve machine learning problems more efficiently. These algorithms make use of quantum circuits that can be modified and tuned based on classical feedback, allowing for iterative optimization of the quantum circuit to improve performance.

Indeed, the combination of machine learning and quantum physics has the potential to bring about ground-breaking advances in various fields. However, as with any new technology, it is difficult to predict the exact impact and potential applications of quantum machine learning. Nonetheless, researchers and experts are optimistic about the possibilities and are actively exploring ways to leverage the strengths of both fields to push the boundaries of what is currently possible.

E. Conclusion

This purpose of this study was to explore and understand the current and potential future impacts of quantum computers on machine learning. The QML field was still in its infancy. This progress has been made possible by advances in quantum hardware and the development of new quantum algorithms that are tailored to the unique capabilities of quantum computers. The majority of the research activities in these disciplines were mostly theoretical. And as was to be anticipated, these more modern algorithms are both noticeably quicker and more effective than their more traditional equivalents. The combination of machine learning with quantum computing has given us the ability to execute traditional algorithms substantially more quickly in a number of contexts. Quantum computers have the potential to have a very significant impact on machine learning. This impact might be exceedingly extensive. The assessment of the impact of quantum computers on machine learning will become more accurate as more quantum algorithms become testable with larger qubit quantum computers. Due to huge number of qubits that are required, many of these were only able to be implemented on an actual quantum computer. However, as research in this area continues to advance, we will eventually have better quantum computers as well as better algorithms to overcome the issues we have with machine learning. The recent developments in quantum machine learning have the potential to revolutionize several industries, including healthcare, finance, and cyber security. However, there are still significant challenges that need to be addressed, such as hardware limitations and the need for more quantum data.

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