Machine Learning Using Quantum Computing

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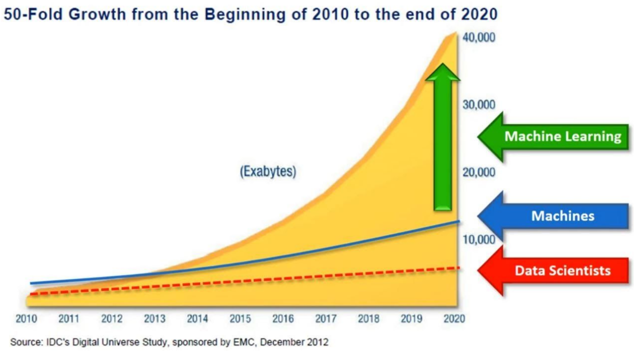
Abstract*—Quantum computing is one of the most trending topics in the field of research .Also we have a plentiful amount of achievement in machine learning, yet more to be explored. The whole paper consists of how we can relate quantum computing to machine learning in one way or another. With an ever-growing amount of data, current machine learning systems are rapidly approaching the limits of classical computational models and quantum computers can solve the problem exponentially faster than the classical computers. Increasing computing power and machine learning techniques will fuel the problem solving capability and can become the powerful tool for finding patterns in data. So it is logical to postulate that quantum computers may surpass classical computers on machine learning tasks. This paper presents the impact of quantum computing when it is applied to machine learning .It shows the comparative study between classical and quantum machine learning in solving problems.Also we provide the history and the current status of quantum machine learning.

Keywords*—Quantum Computation, Quantum theory, learning, applications, Quantum-machine learning, Neural network.

I. INTRODUCTION

From strength is power to knowledge is power to today data is power ,indeed we have come a long way ahead.We live in the 21st century., and wherever you go this data and in fact there's even a term for it ‘data exhaust’. So as you go by your day you are constantly leaving this data exhaust, whether it's through your text messages that you're sending or you're going on facebook or just simply walking through the city and different antennas are picking you up as you're leaving GPS data. So you're constantly leaving this data whether you are aware of it or not and probably the only way to not leave dead exhaust is to go live in the forest for a couple days. So that's the reality we live in and this data is just growing exponentially it's accumulating all the time. Now let's see how this has been happening throughout the history of the human race.Since the dawn of time up until 2019 humans had created 18 zettabytes of data. Let's try to understand how much data is one exabytes. So let's go and drill into this to understand what this actually represents. So here have got a letter a right so letter as a single letter and a letter on a computer takes up one byte of data. Now if we zoom out a thousand times we have a thousand letters and 1000 letters represents about a page on a small book and that fits into one kilobyte. Now if we zoom out another thousand times and we have a thousand kilobytes which is a megabyte and that is about a book with 500 pages double sided. Now if we zoom out another thousand times we get a gigabyte and it is unbelievable to notice that you can fit the human genome onto one gigabyte So it actually takes about seven hundred twenty five megabytes of space and you can encode if you think about it, you can encode a whole human being on a one gigabyte. You'll probably say that's you know a human is not just his genome it's just his DNA it's also the life experiences that he has. You know all the things that he does in his life you can put that on to the goodbye. A gigabyte can shoot the video of his whole life. So for about 80 years every minute every second of your life and you feel everything you do and put all of that in HD video that will fit into one terabyte.Let's zoom out another thousand times .Here we got the Amazon rainforest. It has about 1.4 billion acres of trees every acre has about

500 trees in it. So that makes it about 700 billion trees in the Amazon rainforest. So if you take all of those trees and hypothetically if you take all those trees and you were to chop them down put them into paper and fill every single page of their paper with letters with text then you will get about one to two terabytes of data. So that should give you an idea of how huge a terabyte is. Now if you zoom out another thousand times that's where you got an exabytes.A zettabyte is 1,000 exabytes. As you can imagine these numbers are astonishing, but what's even more astonishing is the exponential growth of data that we're seeing and if you visualize it looks something like this.



This is the reality that we live in and how quickly the data is growing every single year. Now the scenario is perpetuated when machine learning comes into play and it has potential to use this data thereby leading to produce more efficient models.

II. QUANTUM COMPUTING

Quantum supremacy sounds like something out of a Marvel movie. But for scientists working at the forefront of quantum computing, the hope—and hype—of this fundamentally different method of processing information is very real. Thanks to the quirky properties of quantum mechanics (here's a nifty primer), quantum computers have the potential to massively speed up certain types of problems, particularly those that simulate nature.

Quantum Concepts That Influence Machine Learning –

Quantum machine learning is an interdisciplinary approach that combines machine learning and the principles of quantum Physics. To understand this, let's take a look at some of the basic concepts in quantum physics that are at play here –

<u>Quantum:</u>

Physicist Max Planck in 1900 proposed that at the subatomic level, energy is contained in tiny discrete packets called quanta, which behave as both waves and particles, depending on their environment at the time. The basis of quantum theory relies on the observation that at any point in time, these particles could be in any state and may change their state.

<u>Qubits:</u>

The classical computing methods we use today work on chips that process all data using 2 bits – 0 and 1. Even the most complex data or algorithm you input gets broken down into these two bits. Quantum machine learning on the other hand uses the unit 'qubits', short for quantum bits. In quantum physics, these qubits could be electrons or protons orbiting a nucleus in an atom.

<u>Superposition:</u>

These quantum particles or Qubits may exist as both 0 and 1 at the same time. This is a phenomenon known as *Superposition*. Essentially, this means that a particle can exist in multiple quantum states and when placed under supervision, i.e. when we try to measure its position, it undergoes change and its superposition is lost.

<u>Entanglement:</u>

Different qubits interact with each other on an atom in a way that the state of one particle cannot be described independently of the other particles. So even when the particles are separated by a large distance, they communicate with each other in a correlated manner

So How Does All This Figure in Machine Learning?

Understanding the quantum physics of matter can help develop new special purpose hardware or quantum computers that are superior to the ones we have right now in terms of how much data they can process per second and the kind of computing they can accomplish. Quantum computers offer the immense computational advantage of being able to classify objects in their nth dimension, a feat impossible to achieve on normal classical computers. Using the above described principles of superposition and entanglement, these devices pack in an incredible amount of computational power.

If you are already in awe of hardware such as ASICs (application-specific integrated circuits) and FPGAs (field-programmable gate arrays) to facilitate machine learning, prepare to experience a performance of a much higher order with quantum machine learning. Quantum chips can be used to map out phenomenal computer algorithms to solve complex problems. While quantum computing proponents make promising advances into arenas of creating new chemicals and drugs with this technology, machine learning aficionados are looking into a future where complex algorithms can map out the brain circuitry, decode the genetic makeup, build a specialized infrastructure that combines biometrics and IOT devices to enable high level security devices and even unlock some phenomenal new discoveries about the vast mysterious universe. Yes, quantum machine learning could facilitate mapping out trillions of neurons firing in our brain at the same time.

Some of the current machine learning processes that can be accelerated by quantum machine learning are –

Linear Algebra:

When it comes to executing linear algebra computations, quantum computers can exponentially speed up the prospects. A quantum gate can execute an exponentially large matrix with an equally large vector at advanced speed in a single operation, helping build machine learning models out of quantum algorithms. This significantly brings down the costs as well as times associated with linear algebra computations.

Optimization:

Be it physicists, chemists or data scientists, everyone is trying to find a way to the point of lowest energy in a high-dimensional energy landscape. In the world of adiabatic quantum computing and quantum annealing, optimization is everyone's priority. Quantum machine learning can have a strong footprint in optimization, which also happens to be one of the first tasks physicists attempted in the context of quantum machine learning.

Kernel Evaluation:

Quantum machine learning can be used to perform kernel evaluation by feeding estimates from a quantum computer can be fed into the standard kernel method. While the training and inferencing of the model will have to be done in the standard support vector machine, using special-purpose quantum support vector machines could help accelerate the process. As the feature space expands, kernel functions in classical computing become computationally expensive to estimate. This is where quantum algorithms step in. Quantum properties like entanglement and interference help create a massive quantum state space that can hugely improve kernel evaluation.

Deep Learning:

Deep learning is one of the most impactful applications of machine learning and artificial intelligence in recent times. Quantum computers could make deep learning a whole lot more profound by solving complex problems that are intractable on classical computers. In an experiment to train a deep Boltzmann machine, researchers from Microsoft used quantum models and found that they could not only train the Boltzmann machine faster but also achieve a much more comprehensive deep learning framework than a classical computer could ever yield.

Today quantum technologies have three main specializations: quantum computing, quantum information and quantum cryptography. The power of quantum computation comes from the expansive permutations which make quantum computers twice as memory-full with the addition of each qubit. To specify N bits classical bits system we need to have N bits of binary numbers. Now, we know in quantum systems the two possible definite states are |0i and |1i. A general state of a bipartite quantum system can be represented as Φ = α |00i+β |01i+γ |10i+δ |11i, we can easily see that from a two-qubit quantum system we get four classical bits of information (α, β, γ, δ). Similarly, from the N-qubit quantum system we can get 2 N bits of classical information. A mathematical model of computation that conceptually defines the aspect of a machine and is in turn capable of manipulating symbols on a strip of tape with a given set of rules can be defined as a Turing machine. Quantum computers are universal Turing machines. Quantum mechanics allows superposition of quantum states resulting in quantum parallelism which can be exploited to perform probabilistic tasks much faster than any classical means.

Quantum computers have been making rapid progress over the last two or three years, and they are becoming useful for a couple of tasks and one of the tasks that we are looking at solving with quantum computers is a couple of challenges in machine learning. So machine learning has also been making rapid advances. For instance ,in deep learning we have large neural networks which can solve classification problems very effectively. In fact these deep learning networks are relatively simple to do them on using parallel resources. Quantum machine learning is mainly about finding difficult models. For instance probabilistic models over graph structure that resists calculation of classical computers. That's the main pitch for quantum machine learning.

III. MACHINE LEARNING

Machine learning is an application of artificial intelligence (AI) that provides systems the ability to automatically learn and improve from experience without being explicitly programmed. Machine learning focuses on the development of computer programs that can access data and use it to learn for themselves. The process of learning begins with observations or data, such as examples, direct experience, or instruction, in order to look for patterns in data and make better decisions in the future based on the examples that we provide. The primary aim is to allow the computers to learn automatically without human intervention or assistance and adjust actions accordingly. Some machine learning methods Machine learning algorithms are often categorized as supervised or unsupervised.

- Supervised machine learning algorithms can apply what has been learned in the past to new data using labeled examples to predict future events. Starting from the analysis of a known training dataset, the learning algorithm produces an inferred function to make predictions about the output values. The system is able to provide targets for any new input after sufficient training. The learning algorithm can also compare its output with the correct, intended output and find errors in order to modify the model accordingly.

- In contrast, unsupervised machine learning algorithms are used when the information used to train is neither classified nor labeled. Unsupervised learning studies how systems can infer a function to describe a hidden structure from unlabeled data. The system doesn’t figure out the right output, but it explores the data and can draw inferences from datasets to describe hidden structures from unlabeled data.

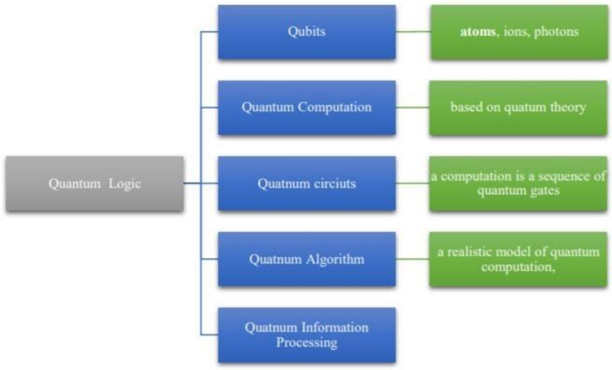
- Semi-supervised machine learning algorithms fall somewhere in between supervised and unsupervised learning, since they use both labeled and unlabeled data for training – typically a small amount of labeled data and a large amount of unlabeled data. The systems that use this method are able to considerably improve learning accuracy. Usually, semi-supervised learning is chosen when the acquired labeled data requires skilled and relevant resources in order to train it / learn from it. Otherwise, acquiring unlabeled data generally doesn’t require additional resources.

- Reinforcement machine learning algorithms is a learning method that interacts with its environment by producing actions and discovers errors or rewards. Trial and error search and delayed reward are the most relevant characteristics of reinforcement learning. This method allows machines and software agents to automatically determine the ideal behavior within a specific context in order to maximize its performance. Simple reward feedback is required for the agent to learn which action is best; this is known as the reinforcement signal.

Machine learning enables analysis of massive quantities of data. While it generally delivers faster, more accurate results in order to identify profitable opportunities or dangerous risks, it may also require additional time and resources to train it properly. Combining machine learning with AI and cognitive technologies can make it even more effective in processing large volumes of information.Quantum Machine Learning

Quantum-improved Machine learning [20] expresses the proposed solutions for quantum tasks based on machine learning. Such algorithms typically require the encoding and conversion of the given classical dataset into a quantum computer, to make it accessible for quantum information processing.

Quantum processing of data often can be utilized on the quantum computation results. The result is educed by a quantum system evaluation. For example, the result of the measurement of a qubit could disclose the result of a binary classification task. Many researches of the proposed algorithms for quantum machine learning focus on the theoretical only because they should apply the testing data on the quantum computers. However, some QML algorithms have been implemented on special purpose quantum devices or on small-scale. The major commitment of quantum computing refers to the use of multiple computers machines based on the power of computing working continuously. Rigetti Computing might be on the brink of accomplishing just that.



IV. QUANTUM ENHANCED MACHINE LEARNING

The combination of using AI and ML improves solutions exponentially and processes the dataset faster when using quantum computing. Quantum computers became a hot area of research especially with the development of machine learning algorithms. This area of research is implementing at glowing the speeds entitled “Quantum Machine Learning.” There are several recent research in quantum algorithms with constructing blocks and machine learning techniques although the challenges illustrate the combination of the challenges of hardware and software. There are four approaches to machine learning, categorized by whether the system under study is classic or quantum, and whether the information-processing device is classical or quantum.

1) Quantum computer performing machine learning algorithms for problems beyond the reach of classical computers: Big data quantum techniques, Adiabatic optimization , and Gibbs sampling .

2) Techniques implemented for quantum theory can enhance learning algorithms such as Tensor and Bayesian networks.

QML is considered one of the future areas of research in using machine learning and deep learning algorithms. How can ease the machine learning algorithm though the quantum computation. Deep learning becomes a familiar technique in ML that can depend on the artificial networks. Quantum machine learning is the optimization of classical AI systems like neural nets with the help of quantum computers.

The Usage of Quantum machine learning

Quantum learning theory targets using a mathematical analysis of the quantum generalizations to improve the classical learning models and of the potential speed enhancements. Any proposed framework targets enhancing a classical computational learning theory that must include a quantum information device and quantum information processing. Whether used the classical data or quantum data. It can also be used in simulations and search such as:

1. Quantum simulation: the simulation is a new trend to support various research areas such as nanotechnology. The simulation in the chemistry field depends on the meaningful 10 quantum systems. Quantum simulation that is utilized efficiently in simulation of the atoms and particles behaviors at exceptional events .

2. Quantum search: the search process with quantum systems can provide discrete logarithms and quantum algorithms. That will propose a higher polynomial speed rate than the top algorithms of classical methods for various challenges and situations, containing the physical chemistry processes with quantum and solid state physics, the parataxis of Jones polynomials, and making a solution of Pell's equation .

V. THE PROS AND CONS

The advantages of using Quantum ML: simple to use, high calculation, fast applying algorithms, query complexity, facilities to several and new algorithms. Expected exponential speed-up of quantum algorithms.

The disadvantages of using Quantum ML: this technology requires constructing a quantum computer with high cost. The technology required to build a quantum computer is currently beyond our reach. This is because the main coherent status for operation on the quantum computer, is broken as its evaluated impacts on the environment. Efforts research in this challenge can't reach a suitable contribution with the correct solution. The work on searching practical solutions to make continuously through several encryption challenges that relies on quantum encryption algorithms by using Prime Factors and utilizing a Quantum Computer. The biggest disadvantage is the fact that it has not been invented yet, and people are still making parts and projections about what this computer shall resemble.

The coherent status of this new scientific technology impacted by the quantum computing environment based on the encryption-decryption Algorithms. Machine learning Challenges can provide a new solution based on quantum computing: QC plays a vital role in artificial intelligence. These solutions based on Quantum computers often rely on the factoring big numbers, making a solution for a complex challenge of optimization, and executing ML algorithms. And there will be applications nobody has yet envisioned." Clearly, quantum machine learning (QML) is going to be the next big thing, disrupting the already mind-boggling field of artificial intelligence.

VI. CONCLUSION

Quantum computing has a wide range of research and infers in several fields. It relies on using quantum computers which can be affected by coherence and entanglement. Most usage of quantum computing deals with quantum data and target speed-up the processes. The previous research proves the results of high performance, powerful, and speed. There are groups of quantum algorithms that are mentioned in this chapter, to introduce solutions for searching, simulation and others. Quantum computing becomes highly related with machine learning algorithms and methodologies that conclude this relation many times as marriage. Because quantum can't achieve the highest results in performance, fast and entanglement without machines learning algorithms. So the "quantum machine learning" keyword is concluded from this relationship. Quantum machine learning also requires quantum physics to be better. This research introduces a comparative study between twelve pervious researches in quantum computing. The results of this comparison declares the importance of machine learning and how to be a hot area of research. It also presents a comparative study of thirteen toolkits in quantum computing in their usage, advantages and challenges. Finally, we provide this research by seven research problems and trends that can support other researchers to work on quantum machine learning.

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