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Define, refined and re-defined concepts of quantum machine learning : A review

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Abstract

Quantum Machine Learning (QML) is a new phraseology in the world today. With various upcoming Artificial Intelligence (AI) technologies, everyday data scientists and corporate around the world are trying to harness its power. QML borrows concepts of Quantum Computing and QML algorithms enhance the existing Machine Learning (ML) algorithms by processing datasets more efficiently. Quantum Computers are a powering force driving QML algorithms that boosts computational power and helps analyse data. QML algorithms can be applied in sectors involving number crunching, pattern identification and so on. In the existing world, QML can be a game-changer for organizations that work on identifying product correlations and customer behaviour in a brief time. This paper discusses studies related to principles of Quantum Mechanics, Quantum Computing and QML algorithm. Additionally, it explores opportunities and challenges faced in the field of QML. Lastly, the paper talks about QML applications and compares various available QML toolkits from the market. Future direction and exhaustive survey of papers from various spectrums related to Quantum Computing is presented in this paper.

Subject Classification: *81T25.*

Keywords: *Quantum machine learning, Quantum computing, Machine learning, Quantum algorithms, Quantum clustering.*

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1. Introduction

QML [1] is a new field of research that takes a significant step towards speed and performance. Intelligent learning applications and technologies of quantum information [3] are exciting topics for informatics evolution. Now quantum information can be deployed in Artificial Intelligence (AI) [4] and ML [3]. Quantum information is dependent on quantum Information theory and reflects the effects of the aforementioned theory on various techniques called Quantum Information Processing. ML [2] is an essential wing of AI that relies on learning from data. Quantum Computing [5] is quite an intriguing topic of the 21st century. Quantum Computer is based on the principles of quantum mechanics that are difficult to harness but are good at solving complex problems, problems that are considered rather unsolvable using traditional computation techniques. A Quantum Computer [6] is not a silver bullet. Quantum Computers are not only about building faster computers but also about creating a unique technology different than a traditional classical computer [6]. The study incorporates the crossway field of Quantum Computing and ML that is termed as Quantum Machine Learning (QML). QML expresses the frontlines of research like the design of a new classical ML algorithm which depends on quantum structure and ML techniques to investigate the quantum processes' output. This paper describes QML and is divided into various sections that encompass aspects related to QML and its touch points with physics, Mechanics, computer etc. An initial section consists of ML and its types. It also discusses similarities between ML and Quantum Physics. Before diving deep into QML a couple of sections explain the nuances of the concept. Next section after ML is about Quantum Computing and its features. Following this section, we have a section with a brief idea about Quantum Computers and theories related to Quantum Computers and comparison with a classical computer. After this comes section highlighting the need for QML. From this section, we dig deep by understanding its need and in consecutive section; we talk about methods like Quantum Enhanced Learning and circuit properties. Next section consists of quantum algorithm wherein its processes are discussed along with its related work. QML application areas are shared in the next section and available QML algorithms Toolkits are explained. In the second last section, dataset overview is provided with some examples and lastly, we try to discuss and conclude findings from the aforementioned issues/problems.

1.1 *Machine Learning:*

As we are aware, a lot of data is generated not only by people but also by computers, phones, and other devices. This will only continue to grow in the years to come. Traditionally, humans have analyzed data and adjusted systems to incorporate changes in the data patterns. ML promises to derive insights from available data and can be utilized to answer various questions using data-driven methods. However, the volume of data surpasses the ability of humans to process it and find its meaning due to which there is a need to automate systems that can learn from the data and make an important change in the process to adapt to a shifting landscape. We are surrounded by ML by the different products that we use every day. Evident examples of ML [7] can be cited on social media that use features like object tagging and face recognition. ML's immediate applications are image recognition, fraud detection, data classification [8] and recommendation systems. It can also be applied on various platforms such as audio, video, text and numerical data. Consider the Figure 1 below, it describes the life cycle of the ML process. As more data is gathered, the model can be improved over time and new predictive models can be deployed.

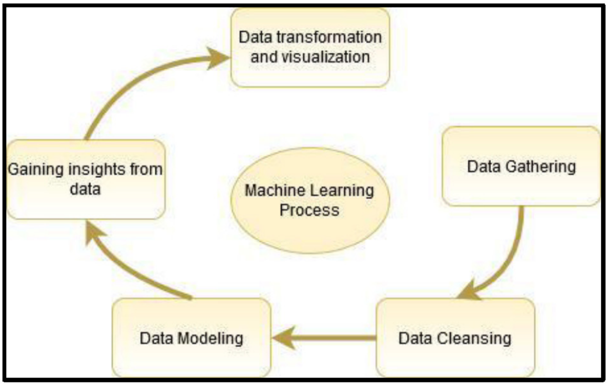


Figure 1

Process of ML fetched from [7]

2. The field of Quantum Computing

Quantum Computing [13][14] is now used to speed up existing ML algorithms creating entirely new classes of ML algorithms that were not possible before. Quantum Computing and quantum algorithm exploit three features from quantum mechanics. These features are represented in the Figure 2:

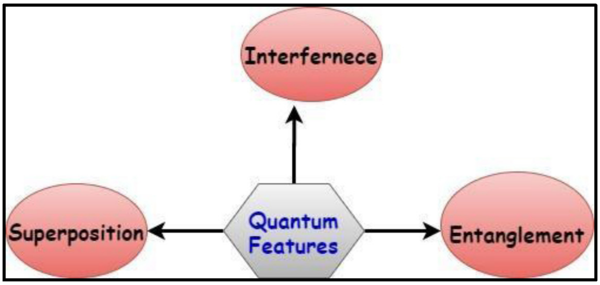


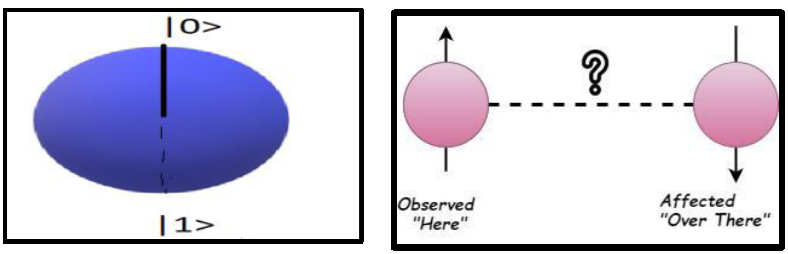
Figure 2

Three features from quantum mechanics fetched from [15]

When a set of instructions are executed together it is called Quantum Parallelism. It is one of the states of quantum memory register and superposition is at the heart of Quantum Parallelism [15]. This enables a quick execution/solving of certain scenarios. Remember flipping of the coin? Scenarios such as, coin being in mid-air or both being heads or tails is called superposition.

$$A|0\rangle + B|1\rangle \qquad ...(1)$$

Equation (1)[15] is the superposition of the 0 and 1, Ket with different co-efficient A and B, this is called Probability Amplitudes. Qubits can be represented by using a three-dimensional object.



(a) (b)

Figure 3

(a) Block Sphere created for better understanding of Qubits. (b) Example of Entanglement fetched from google database

The block sphere helps to represent Qubits (refer to Figure 3 (a)); it is the three-dimensional sphere but possesses a slightly different geometry than that of a normal sphere. The North Pole is identified with |0> and the South Pole is identified with |1>. A Qubit can represent n number of states within the provided range. Qubit is compared with classical probability distribution where every single probability lies on this straight line as opposed to its large two-dimensional surfaces of the block sphere [42]. Interference is a phenomenon where different basis vectors and coefficient interact in a calculation. The pattern formed by a wave collision is known as Interference. Waves overlap and cancel each other. The probability amplitude of |0> destructively interferes and vanishes from the superposition to get the deterministic |1> outcome. Measurements introduce Quantum State as a generalization of classical probabilities that always select the best possible output from various superposition outputs. The measurements selection method is rather unknown and can be described as one that selects based on intuition. Measurement always gives random outputs similar to random variables. Measurement outcome is a projection, for instance, if a model gets 0 as its outcome then we take the corresponding projection and apply it on the Qubit [10]. Entanglement [16] is a very powerful and a different way of thinking about correlation. Entanglement learning can be derived using Qubits as Hamiltonian [17] and measurements. Two particles if entangled affect each other, observe Figure 3(b) below. A particle "Here" is going to affect the "Over There" irrespective of the distances between them; they can be a meter wide or universe apart. Due to this, the states of entangled Qubits cannot be described as independent of each other [11].There are four ways to use Quantum Computing in ML [12, 18-20].

1. Optimization
2. Sampling
3. Kernel Evaluation
4. Linear Algebra

2.1 *The concept of Quantum Computer*

A bit in classical computing can either be 0 or 1 [26]. In Quantum Computing [27] a bit can be both 0 and 1 at the same time as discussed previously. Quantum bits are known as Qubits. Quantum Computer [21] is using Qubits to supply information and communicate through the system. Let's take an example where a user or a person has saved word file on the server that is hosted on the cloud along with many servers. Classical computer sorts through all servers available on the cloud but a Qubit from a Quantum Computer that uses the concept of superposition [22] can scan multiple servers simultaneously and provide lightning-fast outputs compared to a classical computer. Companies providing Quantum Computers are D-wave, Google, IBM, Microsoft, Intel.

2.1.1 The speed of Quantum Computers vs classical computers

For some problems, Quantum Computers [23-24] are faster than classical computers. It is not like a Quantum Computer will completely replace a traditional classical computer. Quantum Computers [25] are great at solving problems that involve quantum data or anything involving a simulation just like the universe. Universe operates using both classical and quantum mechanics and that is in fact why Richard Feynman wrote in his paper combining both theories [25]. A couple of decades ago Feynman envisioned a computer that simulates reality perfectly, the only way to do that is via Quantum Computers. A Quantum Computer can solve ML algorithms quickly and efficiently. QML [28] is part of the quantum world and objectives defined in QML have a major impact in defining problems. In the quantum world, ML is used for defining an objective function. The objective function is going to learn from a function with the proper coefficients using some optimization scheme like gradient descent to solve defined objectives. Neural networks are the brain behind deep learning, a lot of experts suggest that neural networks and QML work on similar lines. What does the Neural Network use you ask? It uses matrix operation and graphics processing units (GPUs) to speed up the matrix operation. GPU operations are executed in parallel. Marrying QML to Neural Networks will no doubt enhance its processing speed and capabilities [30].

2.2 *Quantum Machine Learning arena*

QML is one of the interesting areas for researchers and data modellers' (Refer to which Table 1). Quantum tools are handy for classical ML and these have to do with linear algebra. Linear algebra is one of the important aspects and a quantum machine using these features provides a basis for exploration [35-42].

Table 1

Salient Features of QML

Features	Comments
Powerful quantum tools for linear algebra [28][36]	Matrix multiplication SVD, linear systems (training NN, linear regression, SVM)
Distance estimation [31]	Simple quantum circuits for estimation distances between Quantum states
Noise resilient algorithm [32]	There is a lot of noise in ML date but the algorithm can deal with it
Multiple goals [28,15]	Efficiency, Accuracy, Explain-ability, Energy
Loading classical data as Qubits [29]	Taking full advantage of QML algorithm needs an efficient quantum loader
Getting classification information out of quantum algorithm [33]	Quantum outputs encode a classical solution that needs to be extracted

Swap test helps the researcher determine the distance between two Qubits. This accords useful information relevant to both ML [14] and QML and is termed as estimated distances between Qubits. Another reason why quantum [28] is an interesting field for ML is that ML already has to deal with a lot of noise as the data is very noisy even after training using Neural Networks. Due to the drawback mentioned above, researchers need to come up with an algorithm that can deal with noise. Quantum Computers are well equipped to deal with noisy data and hence are better suited to handle ML. Additionally; Quantum Computers have a high processing speed. Algorithms executed via Quantum Computers provide various results [38], [41]. These results need not be accurate but can be explained, by saying so it gets its property of explainability by considering various scenarios. This is crucial especially for people in healthcare where they wish to use ML to understand the pattern that can help them make informed decisions. There are still issues around how to upload classical data as a Qubit. As of now linear algebra tools will serve this purpose and might help us with future methods.

2.3 *Methods of QML*

In this section, various methods related to QML are discussed including Quantum Enhanced Learning and Exponential Speedup within it. Author [34] claims exponential speedup for Support Vector Machine (SVM), Principle Component Analysis (PCA) and Quantum Principle Component Analysis (QPCA) uses the state same as that of Hamiltonian. Whenever different states are manipulated the performance outcome reviews the Eigen structure of the state.Collection of Eigen structure of the state simplifies the calculation of PCA, linear regression is exponentially faster and can be applied on the least square formulation of support vector machine method of SVM. Let's assume that the given data is from Quantum Random Access Memory (QRAM) [35], QRAM is used to generate a scheme and to show how data is retrieved from superposition. Considering from ML perspective, it is restricted to the linear kernel and least square formulation to which we use sparsity of the Support Vector Machine (SVM).

2.3.1 Quantum Deep Learning

Quantum Deep Learning [38] takes the Boltzman machine as a starting point similar to the Hopfield Network. The roots of the Boltzman concept are from physics. In the case of Boltzman machine most likely state that describes observation are by hidden variables and described by Boltzman distribution. A familiar problem in Quantum physics is that it can pre-train appropriate state and start sampling to completely bypass the gradient descent.

2.3.2 Quantum Simulation

Quantum simulation [39] is the first natural application of Quantum Computing. Universal Quantum Computer is a device that's capable of performing any unitary transformation on a set of Qubits. Quantum physics describes the dynamics of Qubits as a unitary evolution on a Qubits. The lattice Hamiltonian problem, where the qubits are arranged in a lattice and the Hamiltonian only incorporates geometrically local interactions, was examined by the author. The described approach [40] is based on a Lieb-Robinson bounds-based decomposition of the time-evolution unitary into a product of tiny unitaries. Quantum simulation [39] [44] is an entire toolbox in itself. There are a host of different techniques that solve not just the standard ones but all the problems. These techniques have been used in other places such as QML algorithm.

2.3.3 Properties of Quantum Circuits:

Variation Quantum circuit [41] is a smaller circuit; one can view it as a program that can be trained and can be run on Quantum Computer. Being a small Quantum circuit, it [42] uses some of the Quantum computing power. A hybrid training scheme makes use of a traditional computing surrounding. This does all the bookkeeping, takes care of the pre-processing of the data and post-processing of the results. Quantum circuits do an effective job of training moderate size ML solutions. Recently Quantum community put in lots of efforts and hours in creating various open-source proposal and offerings where ML solutions based on Quantum variation circuits are reduced to practice.

2.3.4 Quantum Algorithm:

In the future, Quantum Computers [25] have the potential to solve certain problems exponentially faster than classical computers. Quantum Computer has the potential to solve existing problems solved by classical computers and complex problems which classical computers cannot solve rapidly. The relationship between algorithm and computer hardware is more than that of a computer being only a programmable machine that obeys the laws of physics. An algorithm [34, 43] is a recipe for solving problem, so an algorithm is a sequence of steps that leads to a solution. The design of an algorithm focuses on a machine that plans to run and execute each of the steps (refer to Figure 4). Quantum computers [27] use a fundamentally different instruction set than classical computers. As a result, Quantum computers can run multiple algorithms. The algorithm which cannot run on classical computers makes use of Quantum effects like entanglement, superposition and interference. An algorithm might work on classical inputs for a problem processing and converting it to Qubits which are a superposition of an exponential number of classical states. The aim is to transform Qubits which encode the solution. Later these Qubits can be measured to fetch a solution. Now, of course, making this work is a bit of an art. In the simulation of Quantum systems number of theoretic problems arise like integer factorization and certain types of search problems. One of the caveats is that most of these algorithms are designed for future Quantum computers [44] which have many Qubits and at the moment researchers are building small and modest size Quantum Computers, so it is an exciting research area to understand what researchers can do with Quantum devices [45].

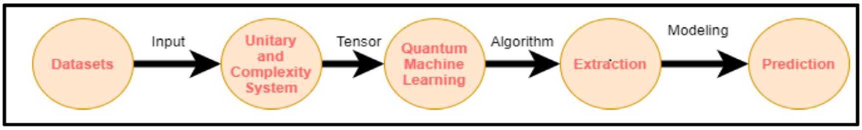


Figure 4

Quantum algorithm Process created from extensive research

2.3.5 Quantum Fourier Transform and Amplitude Amplification

Quantum Fourier Transform (QFT) is a unitary operator on Hilbert space. Consider QFT as a basis transforming operator. Every transformation converts the Z basis to an orthonormal basis. For the Hadamard, the operator has another basis called the X basis. QFT is also known as Fourier or frequency basis as it is just a gate and uses frequency basis. For Discrete Fourier Transform (DFT), a linear transformation that has mapped N-dimensional vectors to other N-dimensional vectors. The most instructive way to picture the new QFT is to lean on a definition as follows: Every H^n has 2^n coordinates. So, apply 2^{nth} order DFT to those coordinates and get a new vector also with 2^n coordinates. Those new coordinates define the output of QFT and forms the Hilbert space vector uses them as the 2^n amplitudes. Table 2 and Figure 5 explain the different Fourier Quantum Computing Algorithms. In order to achieve supremacy in quantum computing, QuantQueryEXP implements the Deutsch-Jozsa

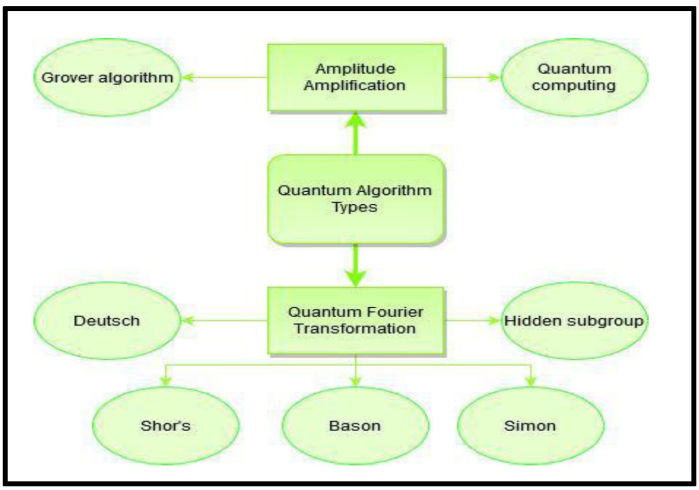


Figure 5

Fourier Quantum algorithms information fetched from several research papers

algorithm in a different way, providing a replacement for query expansion and suggestion using quantum techniques that provides much higher accuracy (90.43%) and complexity optimization than any traditional algorithm [47]. The Grover's search [50] finds an entanglement in an unordered set in a quadratic time using n number of elements, whereas classically it needs at least n steps. In the Grover search [50], input and output are both in classical form. There are problems with this: one has to make sure that the objective function is not generated and it has only one single optimal point. This function is not true if it doesn't know when to stop amplifying the amplitude. If it doesn't stop at the right time, then the probability decreases again and the optimal state is not achievable with the high probability.

Table 2

Types of Fourier Quantum Algorithms

Fourier Quantum Algorithms	**The explanation found in these research papers**
Simon's [9]	• It is relatively elementary & not very applicable to any practical problem. • A probabilistic technique designed directly. • It is exponentially faster than a classical algorithm. • It is emblematic of a class of problems that seek to find an unknown period of the periodic function • It solves a particular periodic problem
Shor's [46]	• Selec at a number which needs to be factored and using number 3 turn the problem into a problem of finding the period of your long sequence. • With help of this algorithm, a quantum computer used as a computational interferometer • An elite algorithm is a polynomial-time
Deutsch [46]	• Used to determine whether an unknown function f(x) is constant or balanced • It gives a solution for a constant number problem of queries with the help of small probability error
Hidden subgroup problem [48]	• It is used to solve finite abelian groups • Commonly used to make a solution for quantum computers
Boson sampling problem [49]	• It can implement a classic hard algorithm based on summation probabilities • A simplified model for optical quantum computing

3. Related work

Essential to understand the basic concepts of amalgamation of two technologies including Clustering and Quantum Computing together. To begin with the first literature which was reviewed includes one chapter from the book by Wittek P. [53] in which the authors narrated about Quantum Random Access Memory (QRAM), Quantum Pricipal Component Analysis (QPCA), Quantum k-medians, Quantum Hierarchical Clustering – a divisive form, Quantum k-means and Quantum Manifold Learning etc. The authors also emphasized on "bucket-brigade" architecture of QRAM. Author further discusses the importance of Grover's search technique used for extending the capabilities of k-means and k-medians algorithms. David [52] did work on a new Support Vector Clustering (SVC) algorithm which is based on based on physical intuition derived from quantum mechanics.Authors worked on cluster cores, using minima concepts and scale-space probability funcion. In their another paper David [52] worked on scale-space clustering and support-vector clustering. By limiting the evaluation using Schrödinger equations at the locaiton of data points and with the help of state-space probability function and with Hilbert space concept, increasing dimentionality was easily achieved in their paper. Gradient Discent Algorithm was developed and deployed to allocate data points to clusters. Author [61] have discussed about method of reconstructing the joing trajectories using transmon qubit measurement setup. A new approach about concurrence-readout relation is derived, and concurrence distribution is calculated. The process described and experiemented in this paper and their work is used as a control mechanism to entangle remote systems for Quantum-information-processing purposes. Author [60] in their very effective short but highly technical paper discussed about the Quantum Computing concepts to begin with and thereafter narrated about IBM Experience platform, which is a 5-digit Quantum Computer, was crafted in 2016 by IBM especially for Quantum Computing. To address the challege of how to solve progamming problems, IBM in 2017 came up with 16 qubit platform which eventuall became 50 bit after few years. In late 2017, Microsoft released Q#, progamming platform for across Operating System and which synchronized with Python code too. Author [59], A comparative study using biology experiement data is carried out in this paper using SVM trained on D-Wave 2000Q Quantum Annealer vs SVM trained on conventional computers. QA-SVM is practical alternative to C-SVM. In [58] ML, Deep Learning (DL), Reinforcement Learning, Supervised learning etc. are discussed at length at the beginning of this chapter.

Table 3

Quantum Machine Learning Algorithms

Author Names	Quantum Clustering	Quantum Classification	Quantum Pattern Recognition	Adiabatic Quantum Computing	CC	CQ	QC	QQ
David et.al. 2001 [52]	✓	✓						
David et.al 2002 [51]	✓	✓			✓			
Areeya et.al. 2016 [61]		✓				✓		
Ding et.al. 2018 [60]			✓	✓			✓	✓
Willsch et.al. 2019 [59]			✓	✓			✓	
Doaa 2019 [58]		✓		✓				
Patrick et.al. 2014 [57]		✓					✓	
Seth et. al. 2013 [56]	✓						✓	
Jacob et.al. 2018 [55]				✓				
Scott 2015 [54]	✓						✓	
Frank 2020 [37]		✓					✓	✓
Mark et.al. 2019 [64]	✓	✓						
Sergio et.al 2019 [63]	✓	✓	✓					
Fastovats et.al. 2019 [62]		✓					✓	
Sabyasachiet.al 2019 [69]	✓							
Sam 2019 [68]			✓					
Heidi et.al. 2016 [67]	✓		✓					
Roman et.al. 2019 [66]	✓	✓					✓	
Belal 2010 [65]		✓	✓					

Contd...

Preskil et. al. 2018 [70]	✓			✓				
Nathan w. 2012 [71]		✓				✓		
Seth Loyd et. al. 2013 [34]	✓					✓		
P.Rebentrostet. al 2014 [72]		✓				✓		
Xin et al 2020 [73]				✓			✓	
Adhikary S. et. al.2020 [74]			✓				✓	
Liang J. et. al. 2020 [75]		✓					✓	
Gyongyosi et. al. 2020 [76]	✓						✓	

Quantum Computing, QML, Quantum Enhancement Learning and other related terminologies are described thereafter. Author [57], It is observed after reading many articles on Quantum Computing that SVM is widely used. In this paper too, the authors worked on SVM and successfully implemented optimized binary classifier on Quantum Computing. The authors said "At the core of this quantum big data algorithm is a non-sparse matrix exponentiation technique for efficientlyperforming a matrix inversion of the training data inner-product (kernel) matrix.". Authors have observed that "speed of the quantum algorithm is maximized when the training data kernel matrix is dominated by a relatively small number of principal components." Below Table 3. Consist of author names, their related work in regards to Quantum algorithms and types of QML. Following abbreviations are shown in Table 3.

CC: Classical machine with classical environment

CQ: Classical machine with quantum environment

QC: Quantum (hybrid) machine with classical environment

QQ: Quantum machine with quantum environment

Described [64] the experience of bringing full functionalities of ML in healthcare. The authors narrated that the journey from the ML equations on blackboard to bedside is extremely challenging and is practiced since past 3 years at Duke Health. To enhance the powers of clinical care operations, ML is applied and practiced especially at retinopathy images classification and breast cancer metastases at a level where experts cannot reach and this was feasible due to use of deep learning principals.In [63], also discusses about clinical decision making systems in their study. Intrinsic processes used by clinicians with every case need to be studied in depth to develop revolutionize clinical decision making systems, is suggested by the authors. To introduce [67, 69] revolutionary changes in personalized medicine and medical therapies it is essential to carefully and effectually work on hospital data, patient data, tests data, biomedical data, data generated from various devices etc. ANN [68] for diagnostic imaging, deep learning in radiology, various commercial software industry involvement in these aspects and in improvement of algorithms / technologies to produce an effective ecosystem in healthcare domain. Author [67] have provided the detailed pilot case study focusing on communication in acute healthcare setup based on quantum physics principles. Various participants took active part in this pilot study and accepted that quantum physics provided a language and framework which are utmost important in improvising the communication in healthcare environment. Explains the use of ML techniques in Quantum Computing [62] and demonstrated the multiclass tree tensor network (TTN) algorithmbased on softmax function idea using IBM quantum processor, in addition to introducing classical ML and Quantum Computing concepts.

Drug design can do with pattern recognition that can help them identify chemical composition and the likelihood of forming compounds etc. can also be established with drug classification and clustering. Algorithms such as QPCA, Feature selection, quantum classification,

Table 4

QML Application areas

Application Areas	QML Algorithms	Total Number Papers
Finance	QPCA, QSVM,QNN, Quantum Pattern Recognition [77-88] [65-67]	13
Healthcare	QNN, Quantum Clustering, Quantum Markov, Quantum Tomography [37] [63-64] [89-92][68]	9
Weather	Tripartite Model, Regression, Quantum Bayesian System [93-97]	5
Drug Design	QPCA, Feature Selection, Quantum Classification, Quantum clustering [98-103]	6
Cryptography	Quantum Search with Grover [104-107]	4

Quantum Clustering (QC) come in handy.Upcoming trend of cryptography can also leverage the use of QML.

We have identified 4 papers for the same where Quantum search with Grover's algorithm can be utilized. QML can also be utilized to focus on security and communication aspects. Table 4 above describes niche areas, QML algorithms and a total number of papers. From this table, it is evident that a lot of work has been done in the area of finance sector compared to other fields but we will be focusing on 13 papers. These papers consist of algorithms such as QPCA, QVSM, QNN and Quantum paper recognition. QML can be used for number crunching and defining important ratios. Following the finance sector is the healthcare sector with 9 papers. The healthcare sector shows a lot of promise for a QML application. QML application can be a powerful tool providing meaningful insights and signals enabling healthcare professionals to take calculated decisions. As per paper QNN, QC, quantum Markov, quantum Tomography is applicable QML algorithms. For weather application are we will focus on 5 papers. These papers discuss algorithms such as the tripartite model, Regression, Quantum Bayesian Systems. Weather area mostly operates on a predictive model and QML's linear algebra-based algorithms can derive indicative numbers and can be exploited.

4. The study of research: QML Algorithm Toolkits

Lot of companies nowadays have their own research lab. These labs primary focus to work on upcoming technologies, try to find something new or breakthrough so that it can be leveraged for business and researchers. Below Table 5. Discusses above companies, toolkits offered by them and features available in these toolkits.

5. Datasets Overview

QML needs a huge amount of data which without data training cannot be possible. A multi-dimensional array can be loaded to hold quantum data. QML can be used to categorise various diseases predictions such as cancer kinds, infectious diseases and it will aid in the comprehension of its associated molecular subtypes[14,139]. With comparatively large training data, it can deliver significantly better accuracy and performance. Without a doubt, this improves ability to show how effective the strategy is. With comparatively large training data, it can deliver significantly better accuracy and performance. Without a doubt, this improves ability

Table 5

Observation explanation between QML Applications and Toolkits

	IBM Quantum Experience [108-115[131]	Microsoft Quantum Development Kit [116-119]	Rigetti Forest [117] [120-124]	D-wave's Qbsolv [125-126]	ProjectQ [117] [127-130]	Quantum Computing Playground [117] [132-134]
Explanation	Offers to access quantum computers to work on cloud platform Quantum gate technology can be used	Use to develop simulate and debug quantum computing solution	First full stack environment for quantum programming	Open source platform	Open source platform Implement quantum program using intuitive syntax	Quantum computer with simple IDE interface Execute Shor's and Grover's algorithm Variety of quantum gates can be built
How to use	Access available on IBMQ network User access is free	Install Q# for Jupyter program on azure cloud platform Different charges may apply	Run on Rigetti's quantum virtual machine	It has tool which takes large quadratic unconstrained binary optimization(QUBO) problem	Simulation on classical and quantum chips	It is browser based webGL chrome experiment
Pros	Easy to use	New language Q# for quantum	Design 3D integrated quantum circuits in 2 weeks	High performance Can access via cloud service	C++ used High performance	Up to 22 qubits quantum register can be efficiently simulate
Cons/ Challenge	Need to learn procedure documentation	Difficult to learn Q#	No access to quantum algorithm library	Optimization is difficult Difficult to understand	Moderate learning skill required	Difficult to understand
Code base language	Python	Q#	Python	Python	C++	Javascript

to show how effective the strategy is. The most of the author's [139] discussion of privacy in QML applications. For testing purposes, it is applied to a dataset of Wisconsin breast cancer cases.

This is used to evaluate the effectiveness and operation of the suggested mechanism. The author [74] presents a theoretical analysis of quantum correlations. It discusses the significance of quantum correlations on a dataset. Understanding the nature of quantum correlations and how it affects the training outcomes for the cancer dataset will always be helpful. In order to distinguish between carcinogenic and non-cancerous pigmented skin lesions in the HAM10000 dataset, the another author [140] implements a hybrid quantum mechanical system with two qubits. The aforementioned publication includes a discussion of wine datasets[136]. A hybrid clustering approach using both conventional and quantum SVM is discussed by the author. Additionally, it contrasts classical and quantum SVM, demonstrating the effectiveness of both. From a design and implementation standpoint, this is a quantum algorithm breakthrough. In paper [135], a wine sample from northern Portugal is discussed. Red and white Vinho Verde wine samples make up the dataset. 13 dimensions, 3 classes, and 178 numbers of instances make up the aforementioned dataset. 80 instances of one label and 98 instances of another. For this investigation, the QPCA method is employed. On the iris and circle dataset, author [137] studies classifier testing. The conducted study is extremely potent and highlights QML's potential. The key learning would be how to expand quantum binary classifiers to multiclass classifiers. The primary bottleneck for running QML algorithm is this [138] article. The training and test datasets for this iris study were divided at random into 80% training data and 20% test data. Number solution was supplied for

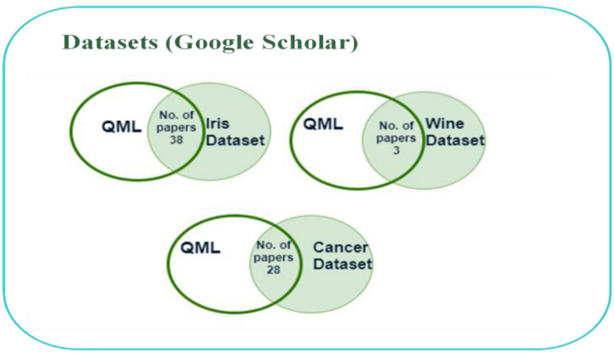


Figure 6

Pictorial representation of datasets available in papers on Google Schola

thorough classifier examination. It offered important information about how the model might be used with actual quantum processors. You can use this model to identify patterns. Figure 6 represents the Venn diagram of available number of papers in a particular dataset on Google Scholar.

4. Discussion and Conclusion

The era of QML explores how to devise and implement concrete quantum software that offers advantages. Recent work makes it clear that there are considerable hardware and software challenges but paths towards solutions have also opened up. A few years ago a considerable amount of research work in this field was mostly theoretical. What is truly astounding is we now have demonstrable QML algorithms. As expected, these algorithms are more effective and significantly faster than their classical counterparts. This union of quantum computers and ML has enabled us to run classical algorithms significantly faster in a large number of cases. After the extensive literature review carried out using many research databases and learning from various white papers, industry research work and professional platforms supporting QML all over the world, it is observed that a) Quantum computation technologies have scope using quadratic unconstrained binary optimization which has ability to utilize quantum parallelism, b) healthcare has enormous opportunities in real world to handle real time dynamic data, Markov model will be useful to observe the patients' health state, c) Quantum anomaly detection algorithms has yet to be unexplored while anomaly detection algorithms on ML has various applications, d) QML is applicable in drug design domain extensively due to its inherent nature and requirement, dynamic environment, e) QML is more effective in clustering compared to Classical ML with a scope to further study on how to overcome the lack of the quantum hierarchical clustering and quantum incremental learning algorithms, f) it is necessary to explore the opportunities related to local tuning of local variances over the data points and allocate points for detection of outliers, g) Quantum can offer some interpreter algorithms like SVM and feature selections that transact data rapidly and with great accuracy, h) QC using fixed distance has limitations in terms of learning iterations, distance matrix and execution time, i) Incremental clustering algorithm executes data by processing it one at a time and by typically storing small numbers and difficult to handle influx of data dynamically,

Table 6

Future direction steps related to QIC algorithm

Step 1	Store V € R^{N*d} (rows of v) in quantum random access memory. Select M initial centroids. Insert time of V_{ij} O ($\log^2$(N))
Step 2	Perform superposition on $\sum_i^N \lvert i\rangle \oplus \lvert j\rangle \lvert 0\rangle$
Step 3	Measure label qubits $\sum_i^N \lvert i\rangle \oplus \lvert j\rangle d^2(V_j, C_j)$
Step4	Calculate min distance (d^2(Vj, Cj) where j € M and perform $\sum_i^N \lvert i\rangle \oplus \ell(V_j)$ Where i € {V_{ij}}
Step 5	Using quantum matix multiplication calculate: V^T and $\frac{\lvert C_j^t\rvert}{N}$
Step6	Perform U|0> = |i> (tomography) for C_j^{t+1} and update centroid
Step 7	Redo the last step until all clusters are found and update QRAM
Step 8	When new data V_1 € R^{N*d} arrived, repeat steps from Step 1 to Step 7
Step 9	Compare C_j^t and C_j^{t+1}, if a match is found then update the existing cluster, else create new cluster

Our present, as well as future social needs, dictate us to conjure a new plan of action to organize a huge quantity of data in order to derive relevant data. A huge quantity of medical data gathered across diverse platforms has challenged data scientists to integrate and implement them carefully. Moreover, the development of new strategies and technologies should take place so as to understand the structured, semi-structured, unstructured nature, the complexity of dimensions and attributes and the volume of the data to extract meaningful information. To overcome the obvious flaws and shortcomings of the QC algorithms, the Quantum Incremental Clustering (QIC) method and more such methods have been introduced. The QIC method preserves traditional QCs ability to find clusters of any shape and consecutive determination of the cluster centre using basic information from the data without any previous understanding regarding the number of clusters, this happens to be its obvious benefit. Also, the introduced algorithm applies to high-dimensional data sets, particularly to complex datasets. The prime focus of this research is to improve the QC algorithm without disturbing or considering the importance (weight) of each property. QC method conserves the benefits and advantages of the traditional clustering algorithm, for example, it detects the clustering centre for arbitrary shapes according to the basic information of the data itself and the samples don't require any sort of pre-processing. The transition from QC to QIC is the potential path to manage the large generation volume of unstructured data. The incremental clustering problem is presented as follows, an update sequence of n points in M, maintains a collection of k clusters such that as each input point is presented, either it is assigned to one of the current k clusters or it starts off a new cluster while two existing clusters are merged into one. This shall enable the QIC algorithm to propel a virtuous cycle of innovation similar to the one that occurred in classical computing. In the steps (See Table 6), QIC theoretically explained for future researcher or reader. This paper presents a review of prior studies in QML. The findings of this study highlight the significance of QML and QC as hot research areas. Additionally, a comparison of various quantum computing toolkits' benefits, drawbacks, and applications is presented. In order to encourage other researchers working on QML, we conclude this research by presenting an alternative approach to QC research concerns.

Appendix

The pictorial representation shows the overview of Quantum computing with the types of QML algorithms along with datasets and application.

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