

## CHAPTER 12

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# Application of Quantum Computing in the Field of Machine Learning

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### ABSTRACT

A promising answer to challenging computational problems is provided by combining quantum computing with machine learning (ML). Superposition and entanglement, two distinctive features of quantum computing, allow for the creation of revolutionary algorithms and models that completely alter pattern detection, data analysis, and optimization. The study examines the theoretical foundations, applications, and suitability of quantum ML algorithms for ML tasks. However, it also has drawbacks including restricted qubit coherence, noise reduction, and error correction. The solutions to these problems are described, and practical implementations demonstrate how quantum computing outperforms traditional techniques by improving feature selection and resolving combinatorial optimization issues. Overall, the domains of ML and data-driven decision-making could be completely transformed by quantum computing.

### 12.1 INTRODUCTION

Considering the potential to resolve complicated issues that are currently beyond the capabilities of conventional computers, quantum computing

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is poised to completely alter the machine learning (ML) environment. Quantum bits, also known as qubits, may exist in a superposition of states, allowing them to simultaneously represent numerous possibilities, in contrast to classical bits, which only represent information as a 0 or 1. Quantum computers can do some operations tenfold quicker than their conventional counterparts due to their inherent parallelism. This could result in significant improvements in optimization, simulation, and data analysis in the context of ML. Solving optimization issues is one of the most intriguing uses of quantum computing in ML [3, 4]. Finding the best parameters or training deep neural networks are two common ML problems that involve intricate optimization procedures. By utilizing their unique capacity to consider numerous options concurrently, quantum computers offer the potential to significantly accelerate these operations. This might result in more rapid convergence and effective model training. Quantum computing also has the potential to transform simulations, allowing scientists to precisely simulate and examine complex molecular, chemical, and physical processes. This might have significant effects on medicine development, materials research, and other areas of science, which would ultimately speed up innovation [1]. The science is still in its infancy, even though quantum computing has a lot of potential. It is extremely difficult to create and maintain stable qubits, and error rates are still rather high. Researchers are developing approaches for error correction and better qubit designs as the area develops. In this chapter, we discuss the application of quantum computing in the field of ML [2].

## 12.2 APPLICATIONS

### 12.2.1 QUANTUM NEURAL NETWORKS (QNNs)

By utilizing the special characteristics of quantum physics, QNNs provide a fresh method of ML. QNNs use quantum bits, or qubits, which may be in a superposition of states and enable parallel computing, as opposed to conventional neural networks, which work with binary bits. Qubits are manipulated by quantum gates, and the entanglement phenomenon enables qubits to instantly correlate with one another. Similar to classical network training, QNNs frequently employ quantum variational circuits that modify quantum gates in order to minimize a particular cost function. Data classification, feature mapping, generative modeling, optimization,

and support vector models are some of the applications of QNNs. However, qubit stability and correction of error present difficulties for actual application. QNNs show promise for more effectively handling challenging ML tasks as quantum technology develops [5].

### **12.2.2 QUANTUM SUPPORT VECTOR MACHINES (QSVM)**

The use of quantum computing in “QSVM.” QSVMs accelerate traditional support vector machine (SVM) calculations by taking advantage of the built-in parallelism of quantum systems. SVMs are frequently employed in ML for applications involving regression and classification. QSVMs can provide quicker methods for locating the ideal hyperplanes in feature spaces with high dimensions by utilizing the processing power of quantum bits (qubits). This acceleration results from qubits’ capacity to do intricate mathematical operations concurrently while existing in various states. In order to improve the effectiveness of tasks like data categorization and regression, QSVM algorithms employ quantum entanglement and superposition, which could potentially offer a considerable speedup over conventional methods [6].

### **12.2.3 QUANTUM DATA PROCESSING**

Fundamental data processing operations like reduction of dimensionality and feature selection may be streamlined with quantum computing. The effectiveness of pipelines for ML can be greatly increased by doing these tasks. Quantum techniques, such as quantum singular value decomposition (QSVD) and quantum principal component analysis (QPCA), may effectively evaluate and extract crucial data from enormous datasets. For example, QPCA can reduce the dimensionality of the data in question while identifying the most crucial characteristics, greatly accelerating future learning tasks. Quantum data processing uses the entanglement and parallelism that exist in nature to investigate several possibilities at once, possibly outperforming traditional approaches in terms of efficiency and resource use. However, addressing difficulties related to qubit error rates, decoherence, and additional fundamental hardware restrictions is essential for practical realization [7].

### **12.2.4 QUANTUM CLUSTERING AND CLASSIFICATION**

Fundamental activities in data analysis like clustering and classification can potentially be accelerated by quantum algorithms. Utilizing superposition and quantum parallelism, quantum k-means clustering explores various cluster assignments at once, possibly resulting in faster convergence and more effective solutions. Similar to classical SVMs, QSVM use quantum states to speed up optimization and locate the best hyperplanes for classification problems. For some datasets, these quantum-enhanced techniques may outperform conventional ones in terms of computational effectiveness. However, solving difficulties related to error correction, qubit stability, and noise in quantum hardware is a prerequisite for the practical application of quantum clustering and classification methods. These quantum-enhanced algorithms hold promise for raising the effectiveness and precision of clustering and classification as quantum technologies develop [8].

### **12.2.5 QUANTUM BOLTZMANN MACHINES (QBMS)**

ML's use of "QBMs". For generative modeling and autonomous learning, QBMs are a quantum equivalent of conventional Boltzmann machines. To better represent complicated data distributions, these quantum models make use of quantum mechanical concepts like superposition and entanglement. A qubit is represented by each of the interconnected quantum nodes that make up QBMs. QBMs can sample from complex distributions of probabilities thanks to quantum fluctuations and correlations among these qubits, which is essential for activities like data production and feature learning. QBMs have the ability to overcome the drawbacks of conventional generative models and provide enhanced capabilities for pattern recognition, data synthesis, and additional unsupervised learning tasks by taking advantage of the quantum nature of their constituent parts. However, to reduce the effects of quantum noise and decoherence, practical QBM implementation calls for reliable quantum hardware and efficient error-correction methods. QBMs provide the potential for enhancing generative modeling and autonomous learning in the field of ML as quantum computing technology develops [9].

### **12.2.6 QUANTUM-ENHANCED OPTIMIZATION**

Finding the best model parameters or reducing cost functions are two examples of optimization challenges that frequently arise in ML projects. Employing quantum annealing and quantum optimization methods, quantum computing has the potential to speed up various optimization procedures. One such method that effectively incorporates both classical and quantum elements is the Quantum Approximation Optimization Algorithm (QAOA). With the help of quantum gates, QAOA explores several parameter configurations at once, taking advantage of quantum parallelism to perhaps identify more effective solutions faster. On the other hand, quantum annealing makes use of tunneling quantum mechanics and temperature swings to avoid local minima and enhance the results of optimization. The issues associated with feature decision-making, hyperparameter tuning, and model training problems can all be solved using these quantum-enhanced optimization methods. However, for quantum-enhanced optimization to be used in practice, it needs reliable quantum hardware, error-correcting systems, and algorithmic advancements. Quantum-enhanced optimization has the potential to greatly improve ML optimization methods' efficiency as quantum technologies develop [10].

### **12.2.7 QUANTUM DATA ANALYSIS**

Fundamental data processing activities that support different algorithms for ML could be accelerated by quantum computing. For instance, many data processing and modeling processes depend on operations like matrices inversion, eigenvalue and eigenvector calculations, and singular value decomposition. Compared to their classical counterparts, quantum algorithms can perform these tasks more quickly by taking advantage of superposition and quantum parallelism. The quantum singular value transformation method and other quantum algorithms for linear algebra use quantum gates that are used to approximate solutions to matrix factorizations and eigen decompositions. These quantum methods have the capacity to speed up data pretreatment and analysis, producing machine-learning results that are both quicker and more accurate. However, similar to other quantum applications, hardware stability, noise, and qubit error rates pose difficulties for practical implementation. Quantum data

analysis shows potential for accelerating the speed and effectiveness of crucial data processing activities in ML pipelines as quantum technologies advance [11].

### **12.2.8 QUANTUM REINFORCEMENT LEARNING (QRL)**

Reinforcement learning problems' training and decision-making procedures can be improved by quantum computing. In order to optimize cumulative rewards, reinforcement learning entails teaching agents to make decisions sequentially. The intrinsic parallelism of quantum computing and its capacity to simultaneously explore various states present potential advantages in terms of optimizing policies and value functions. Reinforcement learning issues can benefit from the use of quantum-enhanced optimization techniques, such as the QAOA, which can speed up policy search and boost convergence rates. In situations where classical approaches encounter difficulties because of vast state spaces or high-dimensional action spaces, QRL has the potential to accomplish complex control tasks more effectively by taking advantage of the quantum advantage. This may result in better-performing agents and quicker learning. However, reliable quantum hardware, methods for preventing errors, and improvements in quantum optimization algorithms are necessary for the effective implementation of QRL. QRL provides the potential for improving the capacity of reinforcement learning algorithms and solving difficulties in making choices and maintaining control in complex contexts as quantum technologies improve [12].

### **12.2.9 QUANTUM NATURAL LANGUAGE PROCESSING (QNLP)**

Linguistic analysis, sentiment analysis, language synthesis, and machine translation are just a few of the jobs that can be improved by quantum computing. The complicated links between words and sentences can be processed and analyzed concurrently by quantum algorithms, enabling more effective semantic interpretation and sentiment extraction from textual information. Better language generation systems that capture intricate linguistic patterns might be produced using quantum-enhanced optimization techniques. Additionally, by using quantum parallelism to simultaneously test several translation hypotheses, quantum models may

enhance the effectiveness of machine translation systems. However, overcoming the difficulties of quantum error correction, qubit stability, and the creation of appropriate quantum language models are necessary for the effective application of QNLP. QNLP has the promise of improving language interpretation and production tasks in ML as quantum technologies develop, paving the path for more advanced and effective language-related applications [13].

### **12.2.10 QUANTUM RECOMMENDATION SYSTEMS**

By utilizing the capabilities of quantum computing, quantum recommendation systems provide a cutting-edge method for providing individualized content recommendations. These systems are designed to improve recommendation algorithms' effectiveness and precision, especially in circumstances requiring massive volumes of user data and intricate interactions. Large user-item interaction matrices could be processed more quickly by using quantum algorithms like QPCA or quantum singular value breakdown (QSVD), which can simultaneously capture subtle preferences and correlations. Quantum recommendation systems could fundamentally alter sectors like e-commerce and entertainment, where user engagement depends on personalized recommendations. These systems may offer more accurate and timely recommendations by making use of quantum parallelism and entanglement. This might increase user happiness and possibly increase business profits. However, strong quantum hardware, error-correction methods, and the conversion of conventional recommendation algorithms into quantum equivalents are required for practical implementation. Quantum recommendation systems have the potential to revolutionize how tailored content is presented as quantum computing technology develops, influencing the future of engines for suggestions in a variety of disciplines [14].

### **12.2.11 QUANTUM ANOMALY DETECTION**

Utilizing the inherent benefits of quantum computing, quantum anomaly detection offers a viable method for finding uncommon and anomalous occurrences inside large, complicated datasets. This application uses the special qualities of quantum bits to improve anomaly detection methods.

Quantum algorithms, such as QSVM or QPCA, can handle high-dimensional data effectively to find minute variations from predicted patterns, which are frequently difficult to find using conventional techniques. Practically speaking, quantum anomaly detection may have uses in a number of fields, including the identification of fraud in financial transactions and the detection of anomalies in manufacturing processes. These systems may excel at spotting anomalies more quickly and correctly while lowering false positives and negatives by utilizing quantum parallelism and entanglement. However, overcoming obstacles like qubit stability, noise, and correction for errors is necessary for a successful implementation. Quantum anomaly detection has the potential to provide better insights into complicated datasets as quantum technologies advance, enabling speedier reactions to anomalous events and improving overall data integrity and security [15].

### **12.2.12 QUANTUM GRAPH ANALYTICS**

By utilizing the capabilities of quantum computers, quantum graph analytics represents a revolutionary method for studying complex network structures like social networks, chemical interactions, and transportation systems. With regard to large-scale graphs, this application seeks to elucidate hidden patterns and insights, a task that conventional approaches frequently find computationally challenging. Quantum algorithms, like Quantum Walks or Quantum PageRank, may be able to simultaneously explore a number of paths and links, giving them a quantum advantage while navigating intricate network topologies. Quantum graph analytics has the potential to have an impact on a variety of disciplines, including social science, biology, and urban planning. By harnessing quantum parallelism and entanglement, these systems may identify influential nodes, detect communities, or optimize routing in networks more efficiently. However, the successful realization of quantum graph analytics requires addressing challenges like error correction, decoherence, and mapping classical graph algorithms to quantum equivalents. As quantum technologies advance, quantum graph analytics holds promise for enhancing our understanding of intricate network structures, enabling more accurate predictions, and contributing to improved decision-making across various domains [16].

### **12.2.13 QUANTUM CHEMISTRY SIMULATION**

At the nexus of quantum computing and computational chemistry, quantum chemistry simulation is a game-changing application. It has the potential to revolutionize precise molecular and chemical relationship modeling, which is essential for understanding chemical reactions, developing new drugs, and researching new materials. Quantum algorithms can simulate quantum systems with an accuracy that frequently exceeds that of conventional techniques, such as the variational quantum eigensolver or quantum phase estimation. These algorithms effectively calculate molecule energies, bond disintegration energies, and reaction routes by taking advantage of quantum superposition and entanglement, offering insights into intricate chemical phenomena. By more accurately simulating chemical interactions, quantum chemistry simulation could speed up the discovery of new medications and produce more potent pharmaceutical formulations. Similar to that, it might hasten the creation of new materials by enabling a better understanding of their quantum-level characteristics. However, overcoming difficulties like error correction, noise reduction, and the requirement of powerful, fault-tolerant quantum computers is essential for the effectiveness of quantum chemistry simulation. Quantum chemistry simulation has enormous potential to alter computational chemistry, enable molecular design breakthroughs, and catalyze developments in a variety of scientific and industrial domains as quantum computer technology develops [17].

### **12.2.14 QUANTUM IMAGE AND VIDEO ANALYSIS**

The area of quantum computing and visual data processing known as quantum image and video analysis is an attractive one. With the help of this program, image and video analysis tasks including object recognition, image segmentation, and video comprehension should be performed more quickly and accurately. By utilizing quantum parallelism and entanglement, quantum algorithms, especially QSVD or QPCA, can analyze visual data more quickly and enable the extraction of complex patterns and features. Quantum image and video analysis has the potential to change industries including surveillance, driverless vehicles, and medical imaging in real-world applications. These systems could offer more rapid

and precise detection of objects, anomalies, or patterns in visual data by utilizing the capabilities of quantum computation. However, overcoming obstacles including qubit error rates, noise, and the conversion of conventional computer vision algorithms into quantum counterparts is necessary for successful implementation. Quantum image and video analysis has the potential to provide sophisticated visual data processing, boosting the functionality of numerous applications and developing the field of computer vision as quantum technologies advance [18].

### **12.2.15 QUANTUM TIME SERIES ANALYSIS**

An intriguing use case that uses quantum computing to handle complex temporal data patterns is called quantum time series analysis. The goal of this subject is to improve the analysis and forecasting of time-dependent phenomena, including physiologic signals, weather patterns, and financial market movements. By utilizing quantum parallelism and entanglement, quantum algorithms, such as QSVD or Quantum Fourier Transform, have the ability to handle time series data more effectively, facilitating the quicker extraction of underlying periodicities and trends. Quantum time series analysis has the potential to change fields including economics, climatology, and medicine. These systems could offer quicker and more precise forecasts of market trends, climatic shifts, or disease outbreaks by utilizing quantum capabilities. However, overcoming difficulties like qubit stability, error correction, and quantizing conventional time series analytic methods is essential for a successful deployment. Quantum time series analysis shows potential for deciphering complicated temporal correlations and assisting in better forecasts and making decisions across a range of time-dependent phenomena as quantum technologies advance [19].

### **12.2.16 QUANTUM GENERATIVE ADVERSARIAL NETWORKS (QGANS)**

With a chance to revolutionize data synthesis and the production of creative material, QGANs represent an intriguing nexus of generative modeling and quantum computing. Quantum parallelism and entanglement are

used by QGANs, an extension of conventional generative adversarial networks (GANs), to provide more varied and accurate data samples. Quantum generators and discriminators work together in QGANs to create data distributions that mirror real-world data. Quantum generators alter quantum states, and discriminators evaluate the validity of the created samples. QGANs aspire to outperform classical GANs in the generation of detailed and complicated data patterns, from visuals and music to scientific simulations, by utilizing quantum characteristics. By creating innovative and distinctive content with an unparalleled level of complexity and depth, quantum GANs have the potential to completely transform the creative sectors such as art, entertainment, and design. They could also speed up the creation of high-quality synthetic data for ML model training in cases where real data is limited or privacy-sensitive. However, in order to fully utilize QGANs, issues with qubit stability, error correction, and training strong QNNs must be resolved. QGANs possess the potential to usher in an entirely novel age of creative content generation and data augmentation, with far-reaching ramifications across multiple areas, as quantum computing develops [20].

### **12.3 CONCLUSION**

A new era of computational potential is ushering in with the convergence of quantum computing and ML. The mutually beneficial interaction between these two disciplines offers exciting possibilities for resolving complicated issues that were previously thought to be beyond the scope of conventional approaches. The ability of quantum computing to refine algorithms and reveal complex data patterns opens up a promising new path for ML research. Researchers and practitioners are on the verge of a revolutionary age as the quantum computing landscape develops and technologies advance. Unlocking the full potential of this synergy will depend on continued innovation and collaboration between experts in ML and quantum physics. The development of quantum-enhanced ML will expand our capacity to decipher the intricacies of the world around us as well as change the limits of computation. In essence, the potential and intrigue of ML combined with quantum computing are exciting. It requires an ongoing investigation of potential, a dedication to overcoming obstacles, and a shared vision of utilizing quantum capabilities to open the door

for a new generation of intelligent systems that are capable of taking on the most difficult problems. Quantum computing holds the possibility of altering decision-making paradigms and transforming industries through its potential applications in ML, which range from enhancing feature spaces to expediting optimization procedures. However, there are many obstacles in the way of fully realizing this promise, including the requirement for more durable quantum hardware and error-correcting systems.

## KEYWORDS

- **machine learning**
- **quantum image**
- **quantum neural network**
- **quantum singular value decomposition**
- **quantum time series analysis**
- **reinforcement learning**
- **video analysis**

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