Quantum Computing – A Tech Story

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Abstract

The growth in technology is endless and touched the base of Quantum computing and justifies overcoming the limitations encountered in the field of simulation, optimization, and machine learning problems and several domains of modern technologies. This article will review the growth of computing, Machine Learning, the basic building blocks of quantum computing and its related concepts, Quantum Machine Learning, and focused applications. The real-time applications of Quantum computing in various fields are summarized to get an insight into its benefits. Despite the tremendous growth, scientific and engineering challenges are seen in the development of quantum computers and computing by considering the application of technology to applications in real-time. Quantum Computing provides supervised and unsupervised machine learning algorithms with the speed of training and computational power at less price, and it is a great gift to the Artificial Intelligence (AI) and Machine Learning Community.

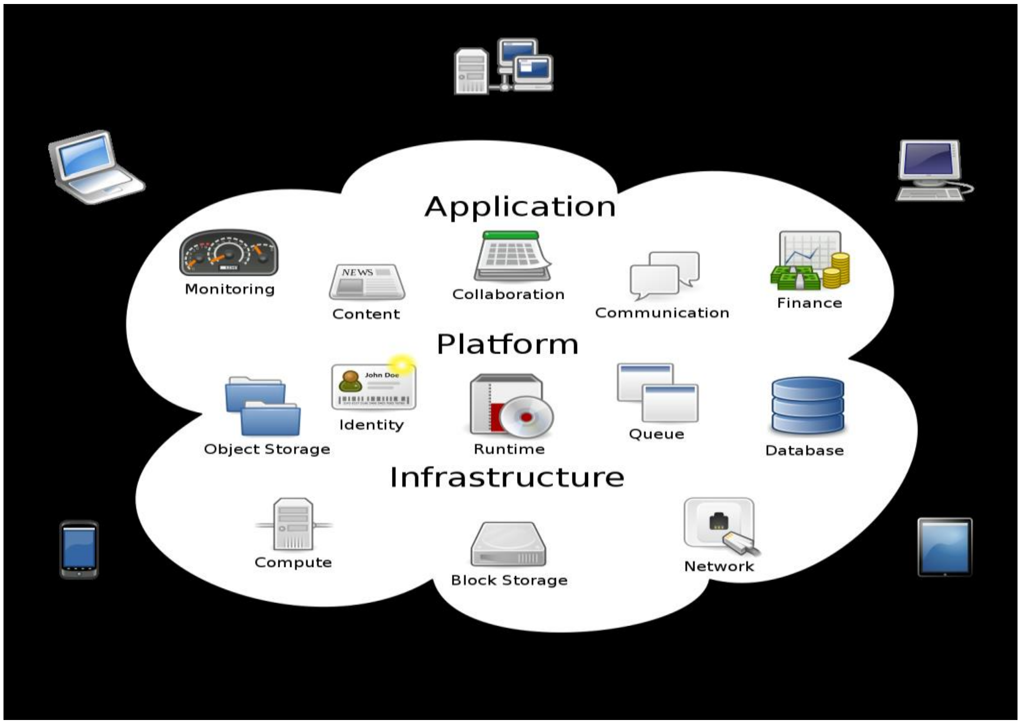
Keywords: Machine Learning, Quantum Computing, Computations, Supervised and unsupervised algorithms

1. Introduction

Computing is using computer technology to do or finish a given task. Computing has less power than Quantum computing. Quantum computing solves complex problems that normal computing cannot do. Quantum computing works under a set of conditions because of its quantum mechanics. Computing is a purposeful activity requiring and benefiting from computing machinery. Computing includes the study and experiment of algorithmic processes and the development of both hardware and software. Computing has distinct aspects:scientific, engineering, mathematical, technological, and social. Computing is used for designing virtual products, video conferences, and interior design.

1.1 Growth of Computing

The Co-founder of Intel, Gordon E. Moore states the Moore's Law in 1965 as the number of transistors on computer chips doubles every two years. In 1975, it was proved to be accurate and added as, "in addition to computing power doubling every two years, the cost of that computing power would be cut in half every two years". This is a justification for how technology is changing with an observation of the long-term trend. The exponential growth is witnessed due to the rapid increase in computing capabilities, the computational capacity of computers has increased exponentially doubling every 1.5 years from 1975 to 2009. Later, an increase and exponential growth is seen in supercomputer power. It is approximately 50-60 times faster than Moore's law discussed above. With the growth in technology and computing devices, the world is ruled by Artificial intelligence, and it has given an increase of 300,000 folds between 2012 and 2018. Since then, technology has its growth towards AI and the same way is Computing. Automated coding accessibility and cloud-based applications are becoming popular.



1.2 History of Quantum Computing

It is true behind the fact that Quantum Computers and computing were proposed by Richard Feynman and Yuri Manin in the 1980s. The intuition behind Quantum computing stemmed from remarkable scientific progress faced with the inability to model even systems in Physics [2].

1.2.1 Hybrid Quantum Computing:

It is the processes and architecture of a classical computer and a quantum computer working together to solve a problem. The main idea behind this is that classical computers are used in Quantum Computing to define quantum gates, control the configuration of the quantum computer, handle jobs, and process results from the quantum computer [1]. Due to the advancement in quantum technology, the integration of classical and quantum computers is increasing. Here comes, Microsoft developed a precise taxonomy like Batch Quantum Computing, Interactive quantum computing, integrated quantum computing, and Distributed quantum computing.

2. Machine Learning

Machine learning is a branch of artificial intelligence and computer science that is mostly focused on the use of algorithms and data to resemble the way that humans learn, which slowly improves its accuracy. Machine Learning is a subset of AI, and the study of making machines to be more human-like in their behavior and decisions by giving them the ability to learn and develop their programs, which is done with minimum human intervention as in no explicit programming.

Machine Learning has its place in computing because it is used widely in many industries such as finance, e-commerce, and healthcare, and you are open to a wide range of career opportunities. They also can be used to build intelligent systems to make predictions and decisions based on the data given. They are an essential tool for data analysis and visualization. Machine Learning allows us to get insights and patterns from large datasets used to understand complex systems [3]. It is a rapidly growing field with many research opportunities and developments.

There are 7 steps in Machine Learning which are gathering data, preparing the gathered data, choosing a model, Training, Getting evaluated, hyperparameter tuning, and Prediction. Machine Learning is important because it gives a view of trends in customer behavior and business patterns. Machine learning is a central part of Facebook, Google, and Uber's operations.

There are 4 distinct types of Machine Learning which are,

- Supervised learning
- Unsupervised learning
- Semi-supervised learning
- Reinforcement learning.

There are 4 main benefits of machine learning which are natural language processing which allows machine learning to process language-based inputs from humans, recognizing images which recognizes images and separates them into different categories, Data mining which accesses data, finds patterns, and identifies spam emails, assesses credit risks, and detect fraud attempts.

The advantages of Machine Learning are it easily identifies trends and patterns, doesn't need a single bit of human intervention, and has wide applications, on the other side there are some disadvantages, which are time and resources, it needs a lot of time to process and a massive number of resources to process. The second disadvantage is Data, it requires a large amount of data that needs to be inclusive, unbiased, and of good quality. The last disadvantage is the High error susceptibility, which means Mistakes can have a chain of errors that can go unsolved for a long time. When they are going to get solved, it takes a long time to recognize the issue, and a longer time to correct it.

3. Quantum Computing

Quantum computing, a rapidly emerging technology that harnesses the law of quantum mechanics to solve complex problems that normal computers can't solve. Normal computers do everyday things like representing data, processing it, and controlling mechanisms. But, Quantum Computing is a multidisciplinary field that includes computer science, physics, and mathematics and brings the services of quantum mechanics to solve complex problems much faster compared to classical computers. Both research in hardware and application development paves the road for quantum computing.

3.1.1 Concepts in Quantum Computing

It is a fact that classical computers operate on bits, the same with quantum computers also. The main difference is with the representation of quantum bits by 0 or 1 or a combination of both. A few concepts in Quantum computing are [4]:

- ***Qubit:*** It is a bit which represents the value of 0 or 1 or combination of both. It is also called quantum bit.
- ***Superposition:*** the linear combination of quantum bits 0 or 1 is called Superposition. Group of qubits in superposition creates complex and multidimensional computational spaces which provides the opportunity to represent complex problems in different new ways.
- ***Entanglement:*** It is an effect that correlates the behavior of two separate things. As per the research, when two qubits are entangled, changes to one qubit directly impact the other.
- ***Interference:*** The environment of entangled qubits placed into a state of superposition creates waves of probabilities, which are the outcomes of a measurement of the system. So, it brings in two forms of interference, these waves can build on each other when many of them peak at a particular outcome or cancel each other out when peaks and troughs interact.

3.1.2 Benefits of Quantum Computing

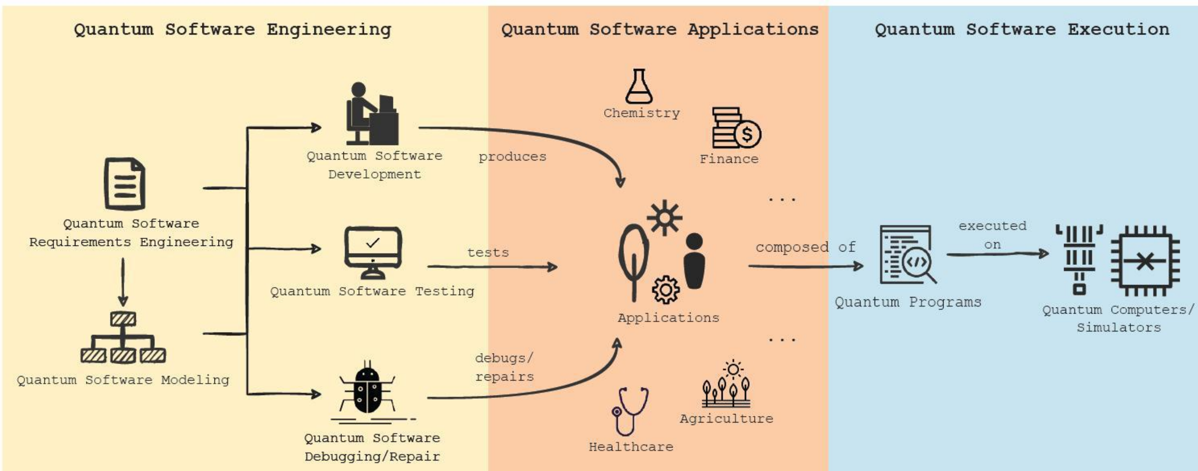
The pros of Quantum computing are:

- It excels at complex problem solving so problems can get their solutions faster, and the properties of qubits let them solve problems quicker and more efficiently than traditional computers.
- Quantum technology is advantageous for science, pharmaceutical research, subatomic physics, and logistics.

- Quantum error correction and post-quantum cryptography, and Unintended consequences by Quantum-powered AI.

Quantum Computing has a wide option of uses. The **seven main uses** of Quantum Computing are.

- AI and Machine Learning can be used to discover ways to automate and optimize tasks.
- Financial modeling can be used to better model the investments and securities at scale.
- Cybersecurity in which quantum computing has data encrypted while it is in use, then also provides both in-transit and at-rest protections.



3.1.3 Application Areas:

Because of the high cost, most of the businesses have not used their application in quantum computing. Few businesses have started or started to think of quantum computing in their business:

- JP Morgan chase
- IBM - ???/
- Microsoft – Microsoft Axure Quantum Platform
- D-Wave
- Rigetti Computing

3.1.4 Limitations

- But there is a big problem with quantum computing, which is qubit decoherence. This is a big problem because qubits are sensitive to the environment so small disturbances can make them lose their quantum properties which are called decoherence.
- Route and traffic development processes the data in real-time and adjusts routes for an entire group of vehicles.
- Manufacturing that runs more accurate and realistic prototyping also reduces the cost of prototyping, and outputs better designs that don't necessarily need testing.
- Drug and Chemical research, in which the development of chemical compound and drugs, also research on its interactions with other elements.
- Batteries help manufacturers incorporate new materials into batteries and semiconductors and help understand lithium compounds and batteries.
- Spotting patterns in Large Datasets
- Facilitating Integration of Diverse Data Sets
- Optimizing Solutions

There are so many pros and cons but there is a significant controversy in quantum computing. As said before, Quantum computing finds solutions to complex problems, but the machine's ability to make solutions with flaws in its code can result in unintended and unanticipated outcomes. This relates to the qubit decoherence as the errors in code can decrease the quality of computation.

3.1.5 Challenges

The wider growth in technology introduces Quantum Computing with benefits, but still,
It experiences a few challenges such as,

- Error Correction
- Scalability
- Hardware and Software Development
- Classical Computers Interfaces
- Standards and Protocols
- Trained Talent
- Overall higher expenses.

4. Quantum Machine Learning

Quantum Machine Learning details the research that combines the integration of quantum algorithms with machine learning concepts and applications. It also extends the pool of hardware for machine learning concepts and algorithms by a computing device, known as a quantum computer. It resides with the law of physics, and quantum theory to handle the information processing. Quantum Machine Learning is mainly built on two concepts, quantum data and quantum classical models. Quantum Data are natural data that occur in a quantum system. Some examples of Quantum Data are, Quantum metrology, Quantum communication networks, and chemical simulation. There is a possibility that quantum data generated are noisy and so it is entangled before handling any measurement [5]. Then, Machine learning algorithms are used to create models to handle the objective of the problems, like Classification, segmentation, etc. The Quantum Computing with Machine Learning combinations are discussed in four options [5] as,

- ***Classical-Classical approach:*** The quantum-inspired algorithms are applied on classical data which could run on classical computers.
- ***Classical-Quantum approach:*** The quantum machine learning algorithms are applied on classical data to increase the efficiency of machine learning tasks.
- ***Quantum-Classical approach:*** Classical Machine Learning algorithms are applied to facilitate quantum computers to get valuable insights of quantum data.
- ***Quantum-Quantum approach:*** Both quantum data and algorithm are great combinations to manipulate the quantum states.

The translation of the Support Vector Machine and Classical K-means algorithm as quantum support vector machine and quantum k-means algorithm are considered as suitable examples of quantum machine learning.

4.1 Impact of Quantum Machine Learning on real-world problems

Quantum Machine Learning (QML) has more advantages or benefits over machine learning algorithms. The research of QML from different authors helps to solve NP & P problems and is shown in the table below.

Problem identified	Proposed	Limitations
Image Processing	Quantum realization of the nearest neighbor value interpolation method for INEQR [9].	The Quantum circuit used can be optimized in terms of complexity and the model can be generalized for all-scale rations.

Pattern Classification	• Quantum Computing for Pattern Classification [7]. • Quantum decision tree classifier [8].	• The algorithm has limitations for continuous inputs. • Doesn't suit for missing attribute values and training data with quantum noise.
Pattern recognition	Quantum Pattern Recognition – Quantum Associative memory based on pattern recognition is proposed [6].	Identification efficiency could not be tuned.
Natural Language Processing	QNLP in Practice: Running Compositional Models of Meaning on a Quantum Computer [10].	Scalability issues as the size of vocabulary increases.

Also, it justifies that QML is applied to different domains like communication networks, privacy preservation, bioinformatics, image processing, video processing, NLP and so many. The growth in technology and the tremendous amount of data and its processing make it very hard to find solutions for real-world problems.

In relation to its impact on Artificial Intelligence (AI), Quantum Computing boosts the potential of AI by amplifying its velocity, efficacy, and precision. This remarkable advancement empowers quantum computing to find its applications across diverse AI use cases like Medical Care, Financial applications, maritime logistics, semiconductors, electric vehicles, etc. Quantum computing enables faster learning and robust simulations for real-world problems by ensuring lifelong learning without losing previous knowledge.

Conclusion

Computing is the basic version of Quantum Computing. Quantum computing can use qubits, which can be 1 or 0 at the same time but computing uses bits, which can only be 1 or 0. Quantum Computing's power grows faster in relation to the number of qubits linked together, and it is 158 million times faster than a normal computer. Quantum Computing is filled with complex conditions that help to solve complex problems and find a solution faster and more effectively. Quantum computing is going to change the world with new materials and innovative solutions to old problems and improvised solutions to old problems with answers that might be devised to fit the present world.

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