
QUANTUM COMPUTING APPLICATIONS IN MODERN COMPUTER SYSTEMS

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ABSTRACT

Quantum computing is a new and quickly changing area of computer science that uses the basic ideas of quantum mechanics to process and change information in ways that classical computers can't do well. Whereas classical computers use binary bits (0 and 1), quantum computers use quantum bits, or qubits. Qubits can be in superposition, meaning they can exist in multiple states at once. Also, quantum systems are capable of conducting massive parallel computation through phenomena like entanglement and quantum interference, which can significantly boost computational power for specific problem domains. In this review paper, basic concepts of quantum computing are reviewed including qubit representation, quantum gates and quantum circuits. The report also discusses how quantum computing can revolutionize existing computer systems with applications in secure communication using advanced cryptographic techniques, speed up machine learning algorithms and optimize complex systems, and advance drug discovery and material science through molecular simulation. Quantum computing is a promising technology. But there are many technical and practical challenges to overcome. These include issues like qubit decoherence and error correction, scalability, and specialized hardware environments. The paper also discusses ongoing research efforts and recent developments to overcome these limitations. In conclusion, this research discusses the future scope of quantum computing and its power to revolutionize industries and redefine the bounds of computational power in the next few decades.

KEYWORDS: Quantum computing, Parallel computation, Cryptography, Machine Learning.

1. INTRODUCTION

Modern computer systems are based on classical computing. In classical computing, information is represented by binary digits (bits) which can be either 0 or 1. In the last few decades, classical computers have made tremendous strides in speed, storage, and processing power. But as the computational problems become more and more complex: big data analysis, cryptography, molecular simulation, and optimization, classical systems start to encounter problems with efficiency and scalability.

Quantum computing has become a new paradigm that can solve these shortcomings based on the laws of quantum mechanics, which is a subdivision of physics that studies the behavior of matter and energy at atomic and subatomic scales. In contrast to classical systems, quantum computers work with quantum bits, or qubits, which can be in many states at the same time, as a result of the phenomenon of superposition. Moreover, this entanglement phenomenon enables qubits to be connected in a manner that enables the state of one qubit to have an immediate effect on another qubit, irrespective of distance. Such distinctive properties allow quantum computers to run a large number of possibilities simultaneously, providing exponential speed increase on some kinds of computations.

Theoretical principles of quantum computing were initially put forward by the likes of Richard Feynman and David Deutsch who proposed that quantum systems could be efficiently simulated using quantum machines. Since, notable progress has been achieved since then by leading technology companies like IBM and Google among other research institutions across the world in creating practical quantum hardware and algorithms. Nowadays, quantum computing is regarded as one of the most promising technologies of the future, and it has to revolutionize many areas such as cryptography, artificial intelligence, healthcare, finance, and materials science. The purpose of this paper is to investigate the principles of quantum computing and examine how it is applied in the current computer systems, its challenges, and future perspectives.

2. Literature Review

Quantum computing has been a subject of thorough research among physicists, computer scientists, and engineers. Initial theoretical work was done by people like Richard Feynman (1982) who suggested that quantum computers would be more efficient at simulating quantum systems than classical machines. Subsequently David Deutsch (1985) proposed the idea of a universal quantum computer, which gave a formalization of quantum computation.

Major advances in quantum algorithms came with Peter Shor (1994) who created an efficient integer factorization algorithm, showing that quantum computers could solve popular cryptography. Likewise, Lov Grover (1996) proposed a quantum search algorithm which offers a quadratic speed increase compared to classical search algorithms. These discoveries laid the groundwork to the computational benefits of quantum systems.

The works of Michael Nielsen and Isaac Chuang (2010) were a groundbreaking source of knowledge on the subject of quantum computation, as their contribution gave a detailed theoretical and practical insight into this area. Moreover, John Preskill (2018) introduced the latest age of quantum technology as the NISQ (Noisy Intermediate-Scale Quantum) era that is characterized by the potential and constraints of the currently existing quantum devices.

The recent studies have been dedicated to the practical implementations and real-life applications. Major companies like IBM, Google, and Microsoft have achieved a lot in the construction of quantum hardware and quantum computing platforms in the clouds. An example is the case of Google, which exhibited quantum supremacy, which implied that a quantum computer could resolve the problem that classical systems were not able to.

Moreover, the papers published by some organizations, such as the IEEE and Association of computing machines, have examined how quantum computing can be utilized in fields such as cryptography, machine learning, and optimization. The National Institute of Standards and Technology (NIST) has carried out research aimed at developing post-quantum cryptographic methods to make sure that data security is maintained in the quantum world.

On the whole, the literature suggests that quantum computing is in its early days, but it has already shown that it has a great theoretical and practical potential. Continued research is expected to address the current limitations (scalability, error correction, and hardware limits) to achieve more widespread implementation in modern computer systems.

3. Basics of Quantum Computing

Quantum computing is founded on quantum mechanics, which applies to the behavior of particles at an atomic and subatomic scale. Contrary to classical computing where deterministic logic is used, quantum computing provides probabilistic and parallel computation based on special quantum properties. The basic ideas of quantum computing are as follows:

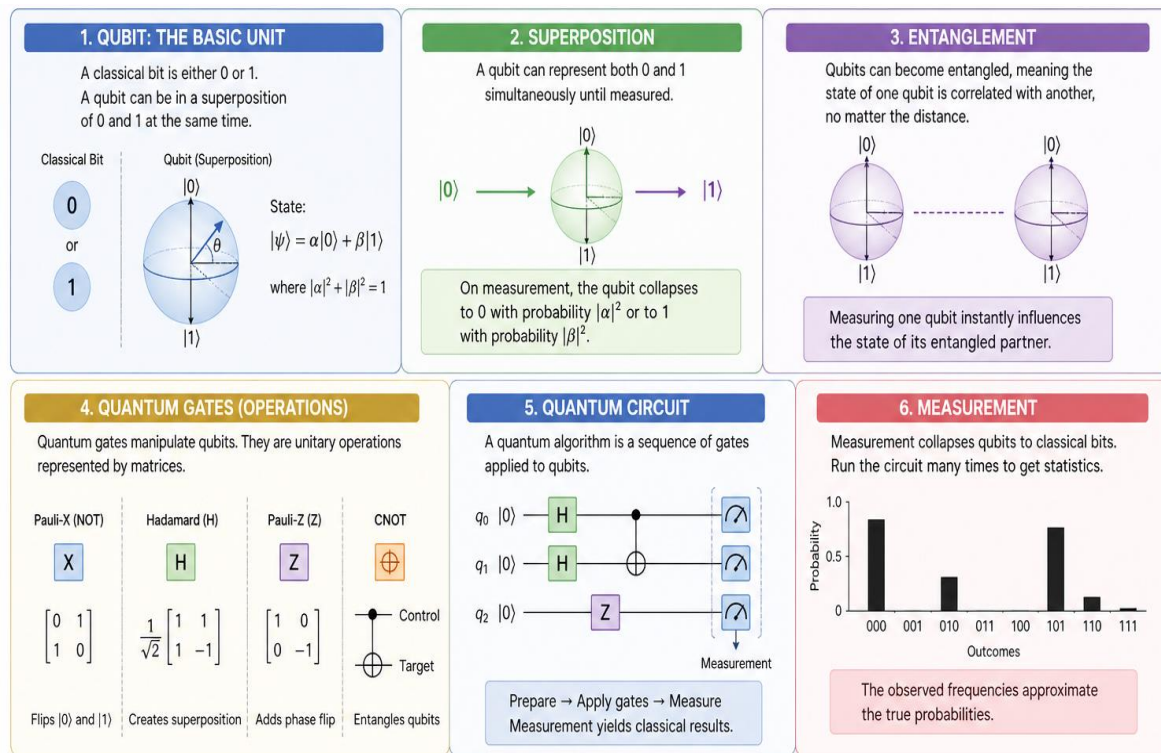


Fig:1 Basics of Quantum Computing.

3.1 Qubits

The unit of quantum information is called a quantum bit or qubit. A qubit can be in either a superposition of the two states (0 or 1) as opposed to classical bits which can only be in one state at any time (0 or 1). This can be mathematically modeled as a linear combination of basis states so that a qubit can encode more information than a classical bit.

Qubits may be physically modeled with a wide range of technologies, including photons, trapped ions, or superconducting circuits. The fact that qubits can be in many states underpins the enhanced computation capability of quantum systems.

3.2 Superposition

Superposition is a basic concept of quantum mechanics which enables a quantum system to be simultaneously in more than one state. When applied to quantum computing, this implies that a qubit can be both in 0 and 1 states until it is measured. This property allows quantum computers to do numerous computations simultaneously, which greatly enhances processing efficiency. The computational capacity of quantum systems is exponentially dependent on the number of qubits, so they are especially useful in solving complex problems.

3.3 Entanglement

Entanglement is a special quantum effect whereby two or more qubits are coupled in a manner that the state of one qubit is directly correlated to another qubit state, no matter the

distance between them. This correlation enables quantum computers to process information in a very coordinated fashion. Entanglement is an important part of quantum algorithms, quantum communication and quantum cryptography because it helps to transmit information faster and more securely.

3.4 Quantum Gates

Quantum circuits are made up of quantum gates and they are employed to control the state of qubits. Just like classical logic gates (AND, OR, NOT), quantum gates operate on qubits; the difference is that they are governed by the laws of quantum mechanics. Quantum gates are reversible and are modeled by unitary matrices. The popular ones are the Hadamard gate, Pauli-X gate, and CNOT gate. With these gates, superposition and entanglement can be generated and complex quantum computations are possible.

3.5 Quantum Measurement

The action of measuring the state of a qubit is termed as measurement. A measurement of a qubit causes its superposition to collapse to one of the classical states (0 or 1). The result is probabilistic and will be determined by the pre-measurement state of the qubit. Measurement is an important part of quantum algorithms, because it defines the result of a quantum calculation.

4. Applications of Quantum Computing in Modern Systems

Quantum computing can transform several fields by addressing the issues that can be solved currently by classical computers. Its capacity to handle large volumes of information at a time and calculate intricate calculations effectively, makes it of great importance in contemporary computer systems. Its main areas of application are as follows:



Fig:2 Applications of Quantum Computing in Modern Systems.

4.1 Cryptography

The impact of quantum computing in the area of cryptography is one of the most important ones. Classical encryption, like in RSA, is based on the complexity of the factorization of large numbers. But such encryption systems can be effectively broken by quantum algorithms such as the Shor algorithm. Simultaneously, quantum computing also presents new secure communication protocols, including Quantum Key Distribution (QKD), that apply the principles of quantum mechanics to provide secure data communication. Such systems are in theory resistant to eavesdropping, because intentional eavesdropping will change the quantum state of the system, and will be detected.

4.2 Artificial Intelligence and Machine Learning

The field of quantum computing can be used to improve the Artificial Intelligence (AI) and Machine Learning (ML) systems in a significant way. Compared to classical algorithms, quantum algorithms are able to process and analyze large datasets much faster, resulting in better machine learning model training.

Pattern recognition, natural language processing and decision-making systems can be enhanced with techniques like quantum neural networks and quantum-enhanced

optimization. This can result in more effective AI uses in image recognition, robotics, and predictive analytics.

4.3 Optimization Problems

Optimization problems are prevalent across different industries, such as logistics, transportation, finance, and manufacturing. Scaling up classical computers can be difficult because the number of potential solutions can exponentially grow.

The algorithms such as Quantum Approximate Optimization Algorithm (QAOA) can be applied to quantum computing to tackle these problems. These algorithms are effective in identifying optimal/near the optimal solutions, which enhance route planning, supply chain management and resource allocation.

4.4 Drug Discovery and Healthcare

Quantum computing is of great relevance in healthcare, especially in drug discovery and molecular simulation. Computational limits in classical computers make it challenging to precisely simulate complex molecular interactions.

Quantum computers have the potential to model molecular structures in the quantum regime, providing scientists with a clearer insight into chemical reactions. This enhances rapid development of new drugs, lowers the cost of developing new drugs and enhances personalized medicine. It also has the potential to aid in disease modeling and early diagnosis.

4.5 Financial Modeling

Quantum computing is applicable in the financial industry to risk analysis, portfolio optimization, and predicting the market. Financial systems are associated with complicated computations and massive amounts of data that cannot be effectively processed by classical systems. Quantum algorithms are able to compute various market variables at the same time to assist financial institutions in making superior investment choices. This results into better predictability, less risk and better trading strategies.

5. Role of Quantum Computing in Modern Computer Systems

Quantum computing has a revolutionary role in contemporary computer systems as it has the ability to improve the computational power beyond the classical computing limits. Its peculiarities, including superposition, entanglement, and quantum parallelism make it more efficient and accurate in solving a complex problem. The key roles are discussed below:

5.1 Enhancing Computational Power

Quantum computing increases processing power by enabling many calculations to be performed at once. Classical systems compute data sequentially, while quantum systems

perform computations in parallel. Hence, quantum systems are very efficient for solving complex problems.

5.2 Revolutionizing Data Security and Cryptography

Quantum computing can both help and hurt cybersecurity. On the one hand, it can break traditional encryption techniques such as algorithms like the Shor's algorithm. On the other hand, it brings highly secured communication methods like quantum key distribution (QKD), which ensures data protection in the modern systems.

5.3 Accelerating Artificial Intelligence and Machine Learning

Quantum computing lets AI and machine learning to quickly process large data sets and helps to make algorithms more efficient. It helps to improve pattern recognition, predictive analysis and decision-making systems and hence AI applications become more powerful and accurate.

5.4 Solving Complex Optimization Problems

Today's systems in logistics, supply chains and financial planning make extensive use of optimization. Quantum computing can process many possibilities at the same time, so it can arrive at optimal solutions more quickly than classical approaches.

5.5 Advancing Scientific Research and Healthcare

Quantum computers can accurately simulate molecules and chemical reactions, which classical computers cannot do. This is relevant for drug discovery, disease modeling and personalized medicines.

5.6 Improving Financial Systems and Risk Analysis

In finance, quantum computing is used to analyze large data sets, predict market trends and optimize investment strategies. It helps in decision making and reduces financial risk.

5.7 Supporting Big Data and Complex Simulations

Quantum computing has the ability to handle large datasets and perform simulations in fields such as material science, climate modelling and space research, leading to scientific and technological progress.

5.8 Enabling Next-Generation Technologies

Quantum computing allows for faster and more efficient data processing, speeding up the development of emerging technologies like smart cities, Internet of Things (IoT) and advanced robotics.

5.9 Driving Innovation in Hybrid Computing Systems

Quantum computing is not a replacement for classical computers but a complement. We expect hybrid systems of classical and quantum technologies to tackle more real-world problems.

6. Advantages of Quantum Computing

Quantum computing offers a number of advantages over conventional systems, especially for large-scale systems:

High Computational Speed:Quantum computers can simultaneously explore many possibilities (superposition and parallelism) which can result in exponential speedup for some algorithms.

Ability to Solve Complex Problems:Quantum computers can more efficiently solve problems intractable for classical computers, such as large factorization, molecular simulations and optimization.

Improved Data Security Methods:Although quantum computers can decipher conventional encryption schemes, they can also provide new cryptographic methods, such as quantum cryptography, which offer extremely secure communication.

Efficient Handling of Large Datasets:Quantum systems can process large amounts of data more efficiently, making them valuable for big data analytics, artificial intelligence and scientific explorations.

Intrinsic Parallelism (Additional Point):Quantum computers can perform parallel processing, enabling them to explore multiple options simultaneously, which enhances efficiency in search and optimization tasks.

7. CHALLENGES AND LIMITATIONS

But there are some serious issues with quantum computing:

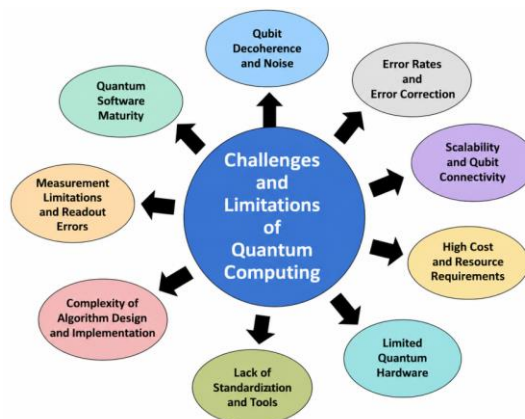


Fig:3 Challenges and Limitations.

High Cost of Development:Quantum computers are expensive to build and operate due to the high-tech equipment and facilities needed.

Qubit Errors and Noise:Qubits are easily influenced by environmental factors, causing errors and instability.This is referred to as quantum decoherence.

Limited Practical Implementation:Quantum computers are still largely in the research phase and are not yet readily accessible for practical applications.

Requirement of Extreme Conditions:Quantum technologies may need to operate at very low temperatures (near absolute zero) and in very controlled environments.
Scalability Issues (Additional Point):Scaling up the number of qubits without compromising stability and accuracy is difficult.

8. Future Scope

Quantum computing is set to have a profound impact on technology and innovation.With ongoing research and development, we will see the development of more stable, scalable and efficient quantum systems.In cybersecurity, quantum computing will result in quantum-safe encryption.It will accelerate drug design and tailor treatment approaches.



Fig:4 Future Scope.

It will improve the capabilities of artificial intelligence, making it more powerful and efficient. Large tech players like IBM, Google and Microsoft are heavily involved in quantum research, suggesting good growth prospects for the sector. In the next few years, quantum computing will likely coexist with classical computing to create hybrid systems that can solve complex problems.

9. CONCLUSION

Quantum computing is a remarkable breakthrough in computer technology that introduces a novel computing model, leveraging quantum mechanics. The potential to carry out complex calculations at a faster rate than traditional computers make it a promising technology for applications that are impossible with current computer systems. While it is still in its infancy and the technology is expensive, error-prone and difficult to scale, ongoing research and development is helping to address these challenges. Its potential applications in cryptography, AI, medicine, and finance show its promise. Overall, quantum computing will have a transformative impact on technology and society. As research and development continues, it is set to open new doors and greatly improve computing power in the near future.

10. REFERENCES

1. Nielsen, M. A., & Chuang, I. L. (2010). Quantum computation and quantum information. Cambridge University Press.
2. Preskill, J. (2018). Quantum computing in the NISQ era and beyond. *Quantum*, 2, 79.
3. Aaronson, S. (2013). Quantum computing since Democritus. Cambridge University Press.
4. Feynman, R. P. (1982). Simulating physics with computers. *International Journal of Theoretical Physics*, 21(6–7), 467–488.
5. Deutsch, D. (1985). Quantum theory, the Church–Turing principle and the universal quantum computer. *Proceedings of the Royal Society A*, 400(1818), 97–117.
6. Shor, P. W. (1994). Algorithms for quantum computation: Discrete logarithms and factoring. In *Proceedings of IEEE Symposium on Foundations of Computer Science* (pp. 124–134).
7. Grover, L. K. (1996). A fast quantum mechanical algorithm for database search. In *Proceedings of the Annual ACM Symposium on Theory of Computing* (pp. 212–219).
8. Bernhardt, C. (2019). Quantum computing for everyone. MIT Press.
9. Lloyd, S. (2006). Programming the universe. Knopf.

10. IBM. (n.d.). Quantum computing research. Retrieved from <https://www.ibm.com/quantum>
11. Google. (n.d.). Quantum AI. Retrieved from <https://quantumai.google>
12. Microsoft. (n.d.). Quantum development kit. Retrieved from <https://azure.microsoft.com>
13. National Institute of Standards and Technology. (n.d.). Post-quantum cryptography.
14. IEEE. (n.d.). IEEE Xplore digital library.
15. Association for Computing Machinery. (n.d.). ACM digital library.
16. Nature Publishing Group. (n.d.). Nature quantum information.
17. ScienceDirect. (n.d.). Quantum computing research articles.
18. arXiv. (n.d.). Quantum computing preprints.