Saarth E-Journal
Saarth E-Journal of Research
E-mail : sarthejournal@gmail.com
www.sarthejournal.com
ISSN NO : 2395-339X
Impact Factor 6.89
Peer Reviewed
Vol.9- issue -2
Article No- 2
April to june- 2024

Quantum Computing: Current Trends and Future Directions

Dr. Haresh H. Kavathia
Assistant Professor,
Shri Matru Mandir B.S.W. College, Rajkot

Abstract

Quantum computing is a new model of computation that provides an exponential speed-up in solving certain classes of problems. This paper gives an overview of state-of-the-art quantum principles and provides a short overview of recent advances and possible applications. It discusses some of the challenges that have been identified in the development and commercialization of quantum computers by providing a way forward for future research activity that would help relieve these challenges.

Introduction

Quantum computing is the area of computation through which performance significantly above any classical computer might in principle be gained by utilizing quantum mechanical principles. In fact, a quantum computer could solve problems that are out of reach for a classical computer, such as those in cryptology, material science, and optimization. This article aims to provide an overview of quantum computing, its key recent trends, possible applications, and present future research directions in this field.

Principles of Quantum Computing

Some of the principles at the base of quantum computing are derived from quantum mechanics, in particular, superposition and entanglement phenomena.

Quantum Bits (Qubits)

In contrast to classical bits having a state of either 0 or 1, qubits are able to be in a superposition state of states. For this reason, quantum computers are able to perform many calculations simultaneously.

Quantum Entanglement

Entanglement is the quantum physical phenomenon in which the state of one qubit depends on the state of another qubit, even if it is far apart. This dependence allows quantum computers to manipulate information in ways that are not physically realizable by classical computers.

Recent Developments

The field of quantum hardware and quantum computation algorithms is rapidly advancing.

Quantum Hardware Developments

Several companies and research institutions have made breakthroughs in developing quantum processors. Considerable examples are Google's Sycamore processor, which achieved quantum supremacy by performing a calculation faster than the fastest classical computer (Arute et al., 2019).

Advancements in Quantum Algorithms

Quantum algorithms, such as Shor's for factoring and Grover's for search, have shown the potentials of quantum computers over their classical counterparts for these specific tasks (Shor, 1997; Grover, 1996).

Potential Applications

Quantum computing is expected to revolutionize several fields by solving current problems that lie beyond the capabilities of classical computers.

Cryptography

Quantum computers can defeat prevalent encryption techniques, requiring the design of quantum-secure cryptographic algorithms. For instance, Shor's algorithm factors large integers exponentially faster compared with classical algorithms, which threatens RSA encryption (Shor 1997).

Drug Discovery

Quantum computing has the power to simulate molecular structures and interactions on a scale not imaginable by classical computing approaches, thus speeding up the drug discovery process. This will enable the development of new drugs and treatment procedures for many diseases (Cao et al., 2018).

Optimization Problems

In logistics, finance, and engineering, quantum computers perform much better at solving optimization problems. Quantum annealing, thus being the most sensitive of all forms of quantum computation, is best done for these tasks.

Challenges

There are several challenges that need to be worked out to facilitate quantum computing to come to its prime.

Technical Limitations

Building and maintaining qubits in a stable state is difficult due to decoherence and noise. These are some of the issues researchers continue to engage with in a bid to find error correction and fault-tolerant quantum computation techniques to mitigate the challenges such as those discussed above (Devitt et al., 2013).

Quantum Error Correction

Quantum error correction plays an essential role in ensuring the reliability of quantum computation. Some developed quantum information-protecting techniques include surface codes to mitigate errors that arise from decoherence and other quantum noise (Fowler et al., 2012).

Scalability

To date, it still remains a big challenge to scale up quantum computers to be able to tackle large-scale, real-life relevant problems. This area has developed in terms of scalable quantum architectures and improved qubit fidelity as noted by Preskill (2018).

Future Research Agenda

To fully realize the potential of quantum computing, future research needs to focus on a few key areas.

Research into Quantum Materials

Developing new materials with appropriate properties for qubit construction is essential for quantum hardware. Work on topological insulators and other exotic materials looks promising for this purpose (Nayak et al., 2008).

Build Quantum Software Ecosystems

Creating strong quantum software tools and quantum programming languages makes it easy to develop and distribute quantum applications. Projects like Qiskit and Google's Cirq in this area are steps in that direction (Gadi & National Academies of Sciences, Engineering, and Medicine, 2019).

Conclusion

Quantum computing is so promising that it is going to blaze a trail in many of the fields by finding answers to problems that are not solvable by classical computation. While significant advances have been made in the past few years, it faces many challenges: technical limitations, error correction, and scalability need to be resolved. Sustained research and collaboration among academia, industry, and government are some of the ways that might overcome these problems to make quantum computing realize its potential.

References

- Arute, F., Arya, K., Babbush, R., Bacon, D., Bardin, J. C., Barends, R., ... & Martinis, J. M. (2019). Quantum supremacy using a programmable superconducting processor. Nature, 574(7779), 505-510.
- Cao, Y., Romero, J., Olson, J. P., Degroote, M., Johnson, P. D., Kieferová, M., ... &Aspuru-Guzik, A. (2018). Quantum chemistry in the age of quantum computing. Chemical Reviews, 119(19), 10856-10915.
- Devitt, S. J., Munro, W. J., & Nemoto, K. (2013). Quantum error correction for beginners. Reports on Progress in Physics, 76(7), 076001.
- Farhi, E., Goldstone, J., Gutmann, S., &Sipser, M. (2001). Quantum computation by adiabatic evolution. arXiv preprint quant-ph/0001106.
- Fowler, A. G., Mariantoni, M., Martinis, J. M., & Cleland, A. N. (2012). Surface codes: Towards practical large-scale quantum computation. Physical Review A, 86(3), 032324.
- Gadi, S. B., & National Academies of Sciences, Engineering, and Medicine. (2019). Quantum Computing: Progress and Prospects. National Academies Press.
- Grover, L. K. (1996). A fast quantum mechanical algorithm for database search. In Proceedings of the twenty-eighth annual ACM symposium on Theory of Computing (pp. 212-219).
- Nayak, C., Simon, S. H., Stern, A., Freedman, M., & Das Sarma, S. (2008). Non-Abelian anyons and topological quantum computation. Reviews of Modern Physics, 80(3), 1083.
- Preskill, J. (2018). Quantum computing in the NISQ era and beyond. Quantum, 2, 79.
- Shor, P. W. (1997). Polynomial-time algorithms for prime factorization and discrete logarithms on a quantum computer. SIAM review, 41(2), 303-332.