

Quantum Computing: Opportunities and Challenges for Computer Science

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Abstract

Quantum computing represents a transformative paradigm in computer science that leverages the principles of quantum mechanics to process information in fundamentally different ways from classical computing. Unlike classical computers, which use binary bits, quantum computers employ quantum bits or qubits that can exploit superposition, entanglement, and quantum interference to perform certain computations more efficiently. This emerging technology has significant potential in areas such as cryptography, optimization, drug discovery, artificial intelligence, machine learning, financial modelling, and complex scientific simulations. However, the development and practical implementation of quantum computing also involve substantial challenges. Quantum systems are highly sensitive to environmental noise and decoherence, which can affect computational accuracy and stability. Other major challenges include quantum error correction, scalability, hardware complexity, limited qubit coherence, and the development of efficient quantum algorithms. In addition, the emergence of powerful quantum computers may challenge existing public-key cryptographic systems, creating a need for quantum-resistant security mechanisms. This paper examines the major opportunities and challenges associated with quantum computing from a computer science perspective. It explores the potential impact of quantum technologies on computational theory, cybersecurity, artificial intelligence, and optimization. The study also highlights the importance of interdisciplinary research, technological innovation, and the development of quantum-ready infrastructure and skills. Understanding these opportunities and challenges is essential for researchers and organizations preparing for the transition toward the next generation of computing technologies.

Keywords: Quantum Computing, Qubits, Quantum Algorithms, Quantum Cryptography, Quantum Error Correction, Artificial Intelligence, Cybersecurity, Optimization, Emerging Technologies.