Chapter 2

Quantum Learning and Its Related Applications for the Future

Biswajit R. Bhowmik
National Institute of Technology, Karnataka, India

Manjunath T. D.
National Institute of Technology, Karnataka, India

ABSTRACT

Recent advances in high-performance computing have been rapid. On the contrary, experts also know that the Moore's Law prediction of the number of transistors on microchips that would double every 18 months is almost saturated. This calls for new techniques to enhance computational power. Quantum computing is a possible solution that uses quantum mechanical phenomena and employs quantum algorithms to improve performance (accuracy, speed). The emerging technology has many interesting potential applications, including quantum machine learning, quantum computational chemistry, post quantum cryptography, etc. The complexity of applications is ever-increasing. Quantum computing amalgamates various classical machine and reinforcement learning in multiple ways to address different challenges of many complex applications. The state-of-the-art reviews on existing works in the domain show that new learning methods can enhance the achieved performance by quantum computing. The chapter thus provides an overview of quantum learning, its applications, research challenges, and future trends.

INTRODUCTION

In 1965 Moore stated that the number of transistors per unit area of an integrated circuit (IC) would double roughly once every two years. Moore's law has held on very well since it was stated, leading to the fantastic, powerful computers we have today. However, many experts believe it will saturate entirely by 2025 (Eeckhout, 2017; Guria & Bhowmik, 2022) because of a transistor's physical limit. Figure 1 shows the trend on the number of transistors used for CPUs and Moore law. When transistors get smaller

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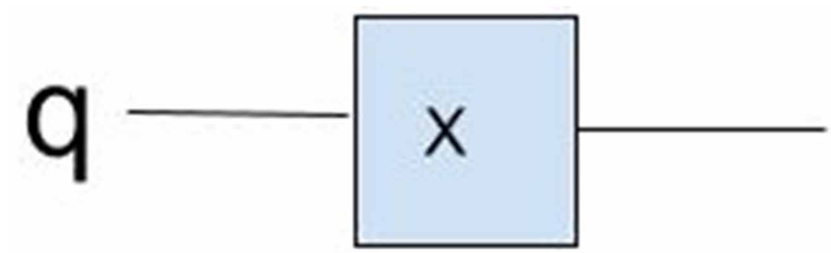
than this physical limit, one needs quantum mechanics to describe the behaviour of electrons. This may hint at looking into quantum computers and quantum information processing. One of the earliest demonstrations where the quantum computer proved significantly faster than the best-known classical counterpart is Shor's algorithm for factoring numbers (Guria & Bhowmik, 2022; Shor, 1999). This was the breakthrough that brought attention to the field of quantum computing. A classical computing system is for general applications and does not meet performance requirements for many complex, large-scale applications (Karali & Bhowmik, 2022; N & Bhowmik, 2021). Subsequently, super-computing or high-performance computing systems is welcomed with quantum computing paradigms.

Figure 1. Number of transistors for CPUs and Moore law



With a wide range of intriguing prospective applications, quantum computing (QC) is a developing area of computer science. Quantum computing is one of the cutting-edge computational methods based on the fantastic phenomena of quantum physics. The combination of information theory, computer science, mathematics, and physics is astounding. It exceeds conventional computers in terms of processing power, energy consumption, and exponential speed by altering the behavior of minuscule physical entities like atoms, electrons, and photons. Quantum computing is the future era of computation. The field continuously explored to solve many real complex problems (Guria & Bhowmik, 2022). Quantum computers make use of quantum mechanical phenomena, which provide an increase in the efficiency of specific algorithms. These algorithms are known as quantum algorithms. For example, Shor's algorithm, Grover's Search algorithm, etc., are well-known quantum algorithms exercised for performance improvement. For instance, Shor's algorithm can factor numbers exponentially faster than classical algorithms. Various quantum computing applications include Quantum Machine Learning, Quantum Computational Chemistry, Post Quantum Cryptography, etc.

This chapter critically situates quantum machine learning (QML), also called "quantum learning" (Q-learning) and its various applications from diverse perspectives. The chapter highlights the limitations of classical computing and welcomes quantum computing. The chapter also presents the necessity of quantum learning over classical machine learning. The work then provides state-of-the-art, relying on current advancements in the domain. The chapter also identifies significant challenges and open issues in quantum using research.

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