The Business Perspective of Quantum Computing: An Overview

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Abstract

Quantum computing has the potential to become the next breakthrough disruptive technology in computing, with a profound impact on numerous industries. Quantum computers exploit the principles of quantum mechanics that enable quantum computers to deal with certain types of complex problems significantly faster than regular computers. However, if quantum computing is to achieve its potential, there needs to be a clear understanding from different perspectives of the challenges and opportunities the technology brings to the world. Against this backdrop, this research evaluates application areas of quantum computing and discusses its business prospects. The findings highlight the challenges that should be surmounted to make quantum computing a technology that becomes a reality with a positive societal and business impact.

Keywords

Quantum Computing, Business Model, Business Value

1. Introduction

Computing and communication technologies have repeatedly fundamentally reshaped the software industry by changing the structure and rules of the game. The emergence and evolution over the past decade of the technological phenomena commonly known as quantum computing represents the next revolution of the software and hardware industries with a drastic impact on multiple other software-intensive ones [1]–[3]. While the full implications of quantum computing are most probably decades away, governments and private sectors worldwide have already committed billions of dollars to further advancing quantum computing technology and applications [4]–[7]. As of now, more than 600,000 people are expected to work in the quantum industry by 2040, following the expansion of quantum technology into other industries where breakthrough technologies can bring value. With such great prospects for allocating talent and monetary resources to quantum computing, the progress in scaling up is hard to overestimate [8].

Quantum computing is a computing paradigm centered around the principles of quantum mechanics that distinguish quantum computers from traditional ones. First, quantum computing is not built on bits that are either 0 or 1 but on quantum bits (qubits) that can take on the values of 0 and 1 simultaneously along a probability spectrum. This overlap of the values of 0 and 1 is called superposition. Second, qubits do not exist in isolation and can be connected despite being physically apart. This ability to act as a group is called entanglement. Developing a quantum computer hardware that can create, perform operations on and measure qubits is challenging since any disruption of the qubits' environment may lead to the loss of information stored using them. Leading research organizations and tech companies are actively exploring engineering approaches to building machines based on quantum mechanics. Still, eligible hardware for quantum computing is not fully ready for commercial use and exists only in a laboratory environment where most quantum computers run less than a few thousand qubits [6], [9].

While the bottleneck of the entire quantum revolution still exists and is related to the issue of hardware, where multiple technological challenges still need to be overcome, large IT giants and ambitious start-ups are already thinking about quantum applications to ensure that when the technology comes, these software companies will be ready to take their solutions to market [10]–[14]. There is an equally urgent need to understand the business-related aspects of quantum computing, including

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evaluating the types of problems and application industries, assessing how the ecosystem of organizations and companies involved in the business of quantum computing should be structured and governed, and exploring opportunities and risks quantum computing will create.

2. The Business Landscape of Quantum Computing

Quantum computing can be described as a stack formed by layers [15]. There is no unified approach to the designation of these layers; researchers and practitioners offer various classifications. We suggest differentiating between four quantum computing layers.

Starting from the bottom, the base layer of the quantum computing stack is the Physical Hardware layer responsible for creating infrastructure for qubits building. Above this layer lies the Compilation and Control Systems layer, responsible for regulating qubits status and ensuring qubit operations and measurements. The Software layer runs on top of the Compilation and Control Systems, implements quantum algorithms, and compiles the source code into executable programs. At the top of the stack, the Application and Service layer contains the applications and services that provide complex problems solving solutions.

The proposed stack allows the identification of the following three major categories of quantum computing businesses:

- **Full-stack quantum computing companies** cover the scope of the entire stack and aim to offer generic services to the public. Examples: IBM, Google, D-Wave, Honeywell.
- **Hardware quantum companies** cover the first two layers of the quantum stack and focus on developing the solution to enable quantum mechanics in their computing machines. These companies might expand the scope of their business to the other layers or build an ecosystem of software and service companies around their technological solutions. Examples: Intel, IonQ, QuTech, Quantum Circuits.
- **Software and service quantum providers** cover the top two layers of the quantum stack and focus on enabling quantum technologies to solve complex real-world problems across different industries. Examples: Zapata Computing, 1Qbit, Cambridge Quantum.

Besides these three core categories of companies directly related to quantum computing, a myriad of companies provide focused support to the core quantum companies (e.g., providing cooling technology and error forecasting).

Since quantum computers can achieve an exponentially higher information density than classical computers, they unlock the ability to perform specific complex calculations exponentially faster than traditional computers. This promises exciting opportunities for more advanced applications which rely on complicated mathematics and simulation software. Table 1 provides an overview of the main areas of algorithms where quantum computing might bring breakthrough advances. Table 2 provides an overview of the most promising industrial application areas of quantum computing. Both taxonomies are based on publicly available information on existing quantum computing companies.

All the benefits quantum computing brings come with a cost. The costs here are the challenges and risks related to reshaped software and software-intensive industries due to the appearance and evolution of quantum computing. They include but are not limited to the following ones: (1) Business information security, (2) Digital divide and inequity issues, (3) Artificial intelligence policymaking, (4) Military applications and weapons race, and (5) Qualified labor shortage. Not facing these challenges and risks could undermine the global progress we assume to achieve with the help of quantum computing.

3. Conclusion

Quantum computing requires a coordinated response from all participants of this computing revolution, including government, businesses, and the research community. While the precise roadmap for the evolution of the technology and the industry around it is still unclear, great efforts and significant investments ensure that quantum computing is here to stay. The ongoing research presented is especially relevant as we are still in the early stages of the quantum computing race, while much research is currently taking place in the field of quantum computing technology itself.

Table 1
Quantum computing application areas

Algorithmic area	Quantum computing solution
Linear systems and machine learning	• Quantum computing unlocks the ability to significantly reduce the time for solving equations of linear systems. This would lead to a drastic advance in machine-learning algorithms, including ones for clustering, object recognition, and pattern matching.
Simulation	• Quantum computing enables significantly more sophisticated modeling of complex physical and social systems
Combinatorial optimization	• Optimization algorithms determine the optimal value of a given function and recommend the decision to be made in each combination of internal and external factors.
Unstructured search	• Due to the different way the data is organized using qubits, quantum computing enables searches across a more considerable amount of data with significantly less power and time used
Factorization and encryption	• The decryption of security protocols that rely on the complexity of factoring the product of large prime numbers

Table 2
Quantum computing industrial application

Algorithmic area	Quantum computing solution
Digital services and telecommunication	• Enhancements in performance and speed of search and recommendation algorithms • Emergence and development of quantum communication networks • Advanced marketing and customer analytics and target advertisement optimization solutions
Manufacturing and production	• The improved discovery and design of new materials and compounds • Fluid dynamics simulation for the enhanced aerodynamic design of vehicles and vessels • Production line optimization and process robotization
Logistics and transportation	• Advanced supply-chain and logistic routing optimization solution • Advanced fleet management and transport network scheduling solutions
Cyber and software security	• Post-quantum superior encryption technologies • Advanced solution for software viruses and other malware detection • Enhancements in software code verification and validation
Chemicals and pharmaceuticals	• Improved discovery of new medications and chemical compounds • Performing the analysis of complex multifactorial diseases and the development of treatment protocols
Finance and insurance	• Advancements in Portfolio investment and risk strategy optimization • Enhancements in financial market simulations techniques • Improvements in transaction fraud and anomaly detection
Energy and utilities	• Enhancements in designing and improving the energy efficiency of nuclear and thermonuclear reactors • Improved geological resources exploration and drilling optimization
Science and education	• Providing a better understanding of the functioning of complex physical, chemical, biological and social systems • Advancements in climate and natural disasters forecasting technologies • Enhancements in DNA sequence classification
Military and defense	• Advanced intelligence, surveillance, targeting, and reconnaissance solutions

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