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What Business Managers Should Know About Quantum Computing?

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Abstract: *Business management requires rapid reactions to the changes of business environment effectively. Given quantum computing's game-changing power will bring huge transformation, therefore managers should be aware of how to take the advantage of quantum computing and recognize its potential impacts to the business world. In fact, quantum computing will deliver exponential advantages for various problems, such as factoring very large numbers within very short time, therefore it has dramatic impacts on existing business issues, such as cybersecurity practice, business optimization, investment decision making, search from unstructured data, etc. However, although the topic is emerging, only very limited studies have been conducted with specific focus on the potential impacts of quantum computing on business management. Accordingly, this study was conducted to fill this knowledge gap. In this study, we began with analyzing quantum related investment markets, trends in scholarly publication and keyword search on the internet about quantum computing. In addition, we provided an introduction on what is quantum computing and discussed related quantum algorithms. Finally, we summarized four major potential applications of quantum computing in business management. Hopefully this paper can serve as a reference for researchers, industrial participators and policy makers engaged in future research or practical applications on related topics.*

Keywords: Quantum; quantum computing; business management; quantum application; algorithm

Introduction

Quantum computing is emerging. It is believed that quantum computing will transform many industries, from transportation optimization, improving financial decision making, supporting advanced manufacturing, transforming cybersecurity and more. The importance and emergence of quantum computing can be reflected by relevant investments in the field. According to Needham, (2021), the global quantum computing market could reach USD8.6 billion in 2027. Besides, Hazan et. al., (2020) suggests that the global market value of quantum technology could reach USD 1 trillion by 2035. On the other hand, Bobier et. al., (2020) from Boston Consulting Group estimated that quantum-inspired algorithms can generate up to USD5 billion in operation income for financial institutions. In terms of

government support, Quantum technology is also a key topic, one example can be found in the UK. Being one of the supporting themes, UK research and innovation set average annual budget for related programmes to GBP33 million (UK Research and Innovation, n.d.). In U.S., The Department of Energy (DOE) announced USD61 million in research funding in order to advance quantum information science (DOE, 2021).

Quantum technologies is promising because of its potential computational power. In brief, quantum computer is much faster than existing classical computer (i.e. non quantum computer). For example, in 2019, Google claimed quantum supremacy had been achieved because of their quantum machine performed the target computation in 200 seconds which required 10,000 years to produce a similar output through the world's fastest supercomputer (Arute et. al., 2019).

Given the computational power of quantum computer is overwhelming, quantum computer could be considered as a disruptive technology that will change the business world in many aspects. However, we consider the attention to quantum related topics from the general public is still not at the level it deserves to be. In this regard, the attention to quantum related topics could be reflected by comparing figures 1 and 2 as shown below.

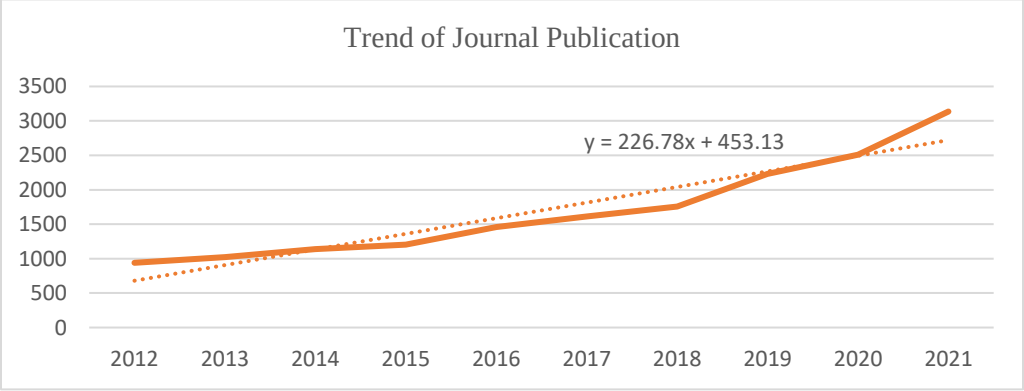

Figure 1: Research publications trend of quantum related topics from 2012 to 2021.

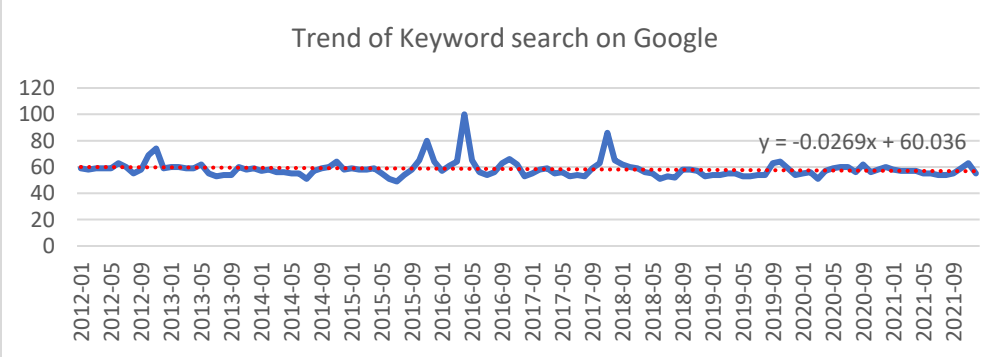

Figure 2: Keyword searching trend of quantum related topics on Google from 2012 to 2021.

Figure 1 indicates the 10-year publication trend of reviewed articles with keyword 'quantum' from 2012 to 2021. The figure demonstrates an obvious increasing trend over the period. On the other hand, figure 2 indicates the searching pattern of keyword 'quantum' on google for the same period. The data was extracted from Google Trends. Google Trends can show how often specific search terms have been queried over a specific period of time. The pattern obtained from Google Trends can be used to understand human behaviour and user interests. The 10-year period from 2012 to 2021 was chosen because the researcher would like to focus on the latest trend to conduct a most current comparison.

Comparison of the two figures demonstrates that the search interest on quantum related topics from the general public did not grow with the upward trend of quantum related publications over the same period.

This situation could be a concern because this may reflect poor awareness of the importance of quantum technologies from the general public. This poor awareness on this emerging topic may hinder economic development in long term. In addition, only very few studies have been conducted with specific focus on the impacts of quantum computing on business management. Therefore, this specific study can fill the knowledge gap of this emerging topic.

In the rest of this paper, we shall introduce what is quantum computing followed by a review of the key quantum algorithms. Furthermore, we shall discuss the possible applications of quantum computing on business management.

What is Quantum Computing

Quantum computing refers to the use of properties of quantum physics to deliver new computing solutions. These properties include superposition, entanglement and interference. A more detailed explanations is provided as follows.

Superposition: Quantum computer is faster than classical computer, one of the key reasons is because it has much richer repertoire of states in terms of basic unit. In classical computer, the basic unit is a classical bit (i.e. binary bit), while in quantum computer, the basic unit is qubit. Unlike a classical bit can only be either 0 or 1, a qubit can represent 0, 1, and a superposition of both the values. Superposition is one of the fundamental properties of quantum mechanics. Given a qubit can hold more information than a classical bit at the same time, this difference helps qubits in quantum computing work faster than classical computers. In fact, the power of quantum computers grows exponentially with more qubits.

Entanglement: Entanglement refers to when two particles (e.g. a pair of electrons) become entangled, they form an unbreakable correlation and remain connected even when separated by a very long distances. In fact, this property creates a lot of potential to improve information transmission and communication (Zou, 2021).

Interference: Interference is an intrinsic behavior of quantum. It can be used to yield more accurate output of a quantum computer by reinforcing or diminishing the quantum computation process.

These 3 major properties make quantum computers much faster, more powerful and accurate than traditional computers. However, without computation logic to tell a computer how to work, no problem can be solved. Therefore, in order to make use of such powerful quantum computers to solve business management problems, computation logic is needed to be designed and implemented. Such computation logic is called algorithm.

Quantum algorithms

An algorithm is a step-by-step procedure or a sequence of instructions to solve a specific problem. On this regard, quantum algorithm refers to the algorithm running on a realistic model of quantum computation for problem solving purpose.
In general, quantum algorithms can be summarized into following categories:

Amplitude amplification

Amplitude amplification is a type of quantum computing technique that generalized from Grover's algorithm (Grover, 1996). Amplitude amplification is a promising research topic because it can be used to achieve quadratic speedup over existing typical classical algorithms. Some widely studied applications of amplitude amplification include cryptography and unstructured database searching.

Quantum Fourier transform (QFT)

The Quantum Fourier transform is the quantum implementation of the Discrete Fourier Transform over the amplitudes of a wavefunction. QFT can be applied in many applications, such as Monte Carlo simulation, principal component analysis and travelling salesman problem, etc. – it depends on how it is applied. Some widely-studied QFT algorithms include Bernstein–Vazirani algorithm (Bernstein and Vazirani, 1997), Deutsch–Jozsa algorithm (Deutsch and Jozsa, 1992), Shor's algorithm (Shor, 1994) and Simon's algorithm (Simon, 1997).

Quantum walks

As per Konno (2008), quantum walks can be viewed as a generalized version of the classical random walk. The two major classes of quantum walks include the discrete-time (or coined) and the continuous-time quantum walks. The potential applications of quantum random walks are many, such as to simulate stock fluctuations, customer behaviors and how messages are spread on social media. In addition, quantum random walks can also be used to help in the design of algorithms.

BQP-complete problems

BQP stands of Bounded-error Quantum Polynomial time. BQP-complete problems relate to the decision problems solvable by a quantum computer in polynomial time. Hamiltonian simulation is a type of BQP-hard problems and the application of Hamiltonian simulation can be used in many business areas such as optimization and diversification.

Hybrid quantum/classical algorithms

Hybrid quantum/classical algorithms refers to the approach that a quantum computer and a classical computer working together to solve a problem. In order words, this is an approach which mixes classical and quantum computing resources in order to achieve a target. This hybrid approach allows researchers and developers to exploit the powers of both type of computers. Some important developments of hybrid quantum classical algorithms include VQE and QAOA.

Although developing or improving quantum algorithms may be the tasks for computer scientists or IT researchers, but business participators and researchers should also understand what insights can be obtained from different quantum algorithms so that applications can be effectively deployed in business management.

Potential applications of quantum computing in business management

In this section, with a focus on business management's point of view, we summarized the potential applications of quantum computing into four major categories, they are i) cybersecurity, ii) data analytics and artificial intelligence, iii) optimization and simulation and iv) data management and searching.

Cybersecurity

Cybersecurity is important in business world because it protects all categories of data from theft and damage. Failure to protect valuable data can impact businesses in various ways, including but not limited to financial losses, reputation damage, etc.

Given quantum computing will deliver an exponential advantage in solving certain problems, such as factoring very large numbers, therefore it has dramatic impacts on existing cybersecurity practice. Nowadays, one of the most common cybersecurity approaches is public-key cryptography, or asymmetric cryptography. However, with quantum computer which builds on its superior computational power can break public key encryption almost instantly, without needing access to the decryption key. Based on this, Shor's algorithm (Shor, 1994) has been widely studied about how to improve existing public-key cryptography (Gerjuoy, 2005; Gu et. al., 2013; Ugwuishiwu et. al., 2020) and it is believed that the applications of Shor's algorithm can be exponentially faster than the existing most efficient factoring algorithm for cryptography. Moreover, the U.S. National Institute of Standards and

Technology (NIST) has evaluated various potential methods for post-quantum cryptography (PQC) (NIST, 2017).

A potential application of quantum computer in cybersecurity for businesses is that managers can use quantum computer to build more reliable and safer cybersecurity measures and systems. For example, using quantum key distribution in cybersecurity not only improved security level, it also enables detection of whether any eavesdropper is presence (Jain et al, 2022). This is particularly useful for companies to protect any strategic digital assets, knowledge and plan which if being known by competitors could lead to irreparable harm. Also, privacy of customer and employee data are also equally important to be protected. Given quantum computing can transform the game rules of cybersecurity, business managers should be aware and get prepared in advance to get ready for such ground-breaking changes to kick in.

Data Analytics and Artificial intelligence

Data analytics refers to the process of analyzing data to find interesting pattens in order to support decision-making. Recent years, data analytics has been considered as one of the most important topics in the business world (Russom, 2011). Data analytics is important because it helps businesses to achieve performance optimization (Au et. al., 2022). In fact, data analytics is important in many aspects such as, understanding consumer behavior (Dhar and Dey, 2019), engineering (McMillan et. al., 2017), finance (Leong and Sung, 2019), health (Akila and Balaganesh, 2021), investment (Jayasree and Jyothi, 2019), tourism (Sahebi et. al., 2022), etc. However, data analytics is challenging because we are living in big data age, the volume, velocity, variety, and veracity of data impose challenges on data analytics. On this, quantum computing has been considered as a promising solution.

Building on its tremendous computing power, quantum computer is able to identify patterns in massive volumes of data instantly. For example, in the finance sector, many decisions are based on complex computations, such as using Monte Carlo simulation to simulate market movements. Quantum computers can help financial decision maker to process much more information in a game-changing speed, as mentioned earlier, it just took 200 seconds in quantum computer to do the work where classical computers took 10,000 years to do a similar job. In fact, speed plays a key role in financial trading. Nowadays, the high-frequency trading industry represents about 50% of trading in US equity markets (Breckenfelder, 2019).

Many studies have been conducted to explore the uses of quantum computing in supporting big data analytics in various ways. For example, applying quantum walks technique to construct quantum artificial neural networks (Schuld et. al., 2014), quantum supervised and unsupervised machine learning (Lloyd et. al., 2013), quantum nearest-neighbor algorithms (Wiebe et. al., 2015), etc. that could take artificial intelligence up into a more supreme dimension.

Quantum computing can help solving problems on a huge scale. Therefore, a potential application of quantum computer in data analytics for businesses is that managers can take quantum advantages to support decision making under more complex scenarios in much quicker speed. Moreover, managers can also use quantum computer to handle more data to achieve more accurate forecasting results in analytics. In addition, the new developments of related quantum data analytics approaches would also help businesses to get new insights. In overall, managers should keep an open mind to any new data analytics approach. Otherwise, their businesses would be disadvantaged over their rivals who are able to generate better insights using quantum computing.

Optimization and simulation

Quantum computers are particularly suitable for solving complex business problems because it can analyze large amounts of data in parallel. Therefore, quantum computers are expected to be good at solving optimization problems because they can sort through many possible solutions almost instantly. In fact, quantum computers can solve Nondeterministic Polynomial (NP) hard problems that classical computers are unable to solve. Some examples of related problems in business world include but not limited to, how to calculate the best routes for transportation, how to find the most fuel-efficient paths for planes, how to effectively arrange materials with various types and sizes, etc. In practice, solving those problems require processing multiple variables or factors. However, existing approaches often not able to use all variables in solving problems due to limited computational power of classical computers. On this, quantum approach would allow taking in more or even all variables into computation and achieve more accurate results (Farhi et. al., 2014; Srinivasan et. al., 2018; Wang and Li, 2007).

Today's business world is more complex and fast-changing than ever. Quantum computer can help managers to evaluate many factors at the same time in order to optimize business operation. For example, scheduling vehicle routing for a public transportation company demands processing a long list of constraints, such as job locations, time windows, and vehicle locations, etc. Using quantum computer can take all inputs and produce an optimal vehicle routing plan that traditional computer cannot produce. In order to make the most of quantum computing, business managers could start to plan how to obtain more data from different sources, the more data, the more complete picture can be known, maybe obtain data through the Internet of Things, that could help managers to generate more insights through quantum computing.

Data management and searching

How to effectively manage and search data is an important practical problem, no matter within a database or on the internet. Data management is important because data is a very valuable resource for business. Good data management can help businesses to reduce the risks related to data processing and to provide timely accurate information to decision makers.

Many existing quantum solutions are developed with the aims to speed up data searching process, in particular on unstructured data. Quantum computing applications could offer game-changing improvements in time and space complexity over existing practices. As an emerging topic, Lavor et. al., 2003; Long and Liu, 2007 and Patel, 2001 have proposed several approaches with the aims to improve database search.

Rapid response allows businesses to seize opportunities. Quantum computers can help business to response more quickly. This is because quantum computing is expected to be able to search very large, unsorted datasets to identify a search target and to uncover patterns or anomalies extremely quickly. Moreover, quantum computer also helps businesses to deliver an effective and faster response to customers which help businesses to develop competitive advantage in today's world.

Conclusion

Quantum computing has become an emerging global topic. In this paper, we comprehensively reviewed the current development of quantum computing and its potential impacts on management in business world. We began with analyzing quantum related investment markets, trends in scholarly publication and keyword search on the internet. Our findings suggested that the attention to quantum related topics from general public has not increased as it was in the investment market and research sector.

Following on, this study introduced what is quantum computing and its 3 key properties (superposition, entanglement, interference). These 3 key properties make quantum computers much faster, more powerful and accurate than traditional computers. However, without computation logic to tell a computer how to work, no problem can be solved. Therefore, related quantum algorithms were reviewed. The review offered the knowledge about why and how the algorithms could affect businesses. Finally, with focus on business management's point of view, we illustrated the potential applications of quantum computing into four major categories, they are i) cybersecurity, ii) data analytics and artificial intelligence, iii) optimization and simulation and iv) data management and searching.

Currently, only very limited studies have been conducted with specific focus on the impacts of quantum computing on business management. Therefore, this study fills the gap of this emerging research filed in business management. With this study, we have shed some lights on future directions of using quantum computing on business management. this study will become one important primary reference for researchers, industrial participators and policy makers engaged in future research or practical applications on related topics.

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