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The Viability of Quantum Computing

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In the past few decades a digital revolution has ushered in a new era of innovation. Although classical computers have been dominating for the past few decades, a new form of computational technology is on the verge of arriving, quantum computing. Quantum computing refers to a new type of computer that, unlike a classical computer which operates on 1s or 0s (bits), can operate in a superposition of these states called qubits. This allows the quantum computer to exceed every capability of the classical computers currently available.

Quantum computing is a major ongoing conversation in the field of computer engineering with national governments and even military agencies trying to fund research. Svore and Troyer's article "The Quantum Future of Quantum Computing" (2016), provides an in-depth look at potential applications of quantum computing including economic, industrial, and academic uses. Biswas' article "Quantum Computers: A Review Work" (2017) makes bold predictions indicating the first fully functioning quantum computer will arrive in the year 2030. Although the technology is still in its infancy, the future looks bright as prominent researchers in the field predict the first quantum computers to arrive in the next decade or two. If such a feat were to become a reality, the world would be affected on industrial, trade, and civilian levels. Quantum computing would allow for significantly faster data processing, quicker solving of current algorithms, and a myriad of applications in the medical, engineering, and defense industry.

The purpose of this study is to explore quantum computing and whether it has potential to replace classical computing. One major problem in the computer industry encouraging the development of quantum computer technology is Moore's law. Researchers define Moore's law as the ability to double transistors in an integrated circuit every two years (Cumming, Furber, & Paul, 2014, 1). Because Moore's law is merely an observation, and not a physical law, this doubling of transistors every two years cannot continue forever. As the limits of Moore's law are reached, stagnation in the computer industry is inevitable. The rapid advancement of the past few decades will continue to slow as creating faster and more efficient technologies using current methods climbs in difficulty. With these problems becoming more prominent every year, the computer industry faces a unique challenge that it has not faced since the inception of transistors. Effectively, the industry is back at square one, and must create an entirely new approach or fester in an era without innovation. Taking these major issues into account, it is reasonable to state quantum computing will be a viable alternative to the classical computers of today.

Research Design

Research was conducted using a variety of science and technology databases to find relevant sources that pertained to the computer field. Specifically, I considered peer reviewed journal articles, as they provided the most reliable and up to date information. Additionally, these peer reviewed journal articles were from 2009 or later since this technology is a relatively new topic. The databases that I used to find these articles included IEEE Xplore, SCOPUS, ACM Digital Library, and Google Scholar. These databases all pertain to computer and electrical engineering and provided relevant results that strengthened my research paper. I searched these databases using terms such as *quantum computing*, *applications of quantum computing*, *Moore's law*, and *classical vs. quantum computing*. Sources that pertained to the history of quantum computing or the physics of quantum mechanics were ignored. The sources found in these databases have provided sufficient information on the topic and allowed me to come to a conclusion on the viability of quantum computing.

Overcoming the Limits of Moore's Law

In the past few decades the rapid progress in electronics has been nothing short of astonishing. While this unprecedented advancement changed the course of history, the end of this innovative era is near. Currently the computer and electronics industries face the hurdle known as Moore's law. The economic and physical repercussions of Moore's law are two major factors that constrict development. Researchers have noted that "this exponential growth in complexity cannot continue forever, and there is increasing evidence that, as transistor geometries shrink towards atomic scales, the limits to Moore's law may be reached over the next decade or two" (Cumming, Furber, and Paul 2014, 1). Cumming and his team offer a description of Moore's law that illustrates the limits of physics and what is possible using current methods. They go on to say that to deliver better performance and grow in a variety of new markets, a new approach must be developed. While these startling facts suggest a bleak future for computers and electronics, the Moore's law hurdle can be conquered with new emerging technologies. This only further strengthens the argument for pursuing quantum computing.

Cumming and his team's assertion on Moore's law is shared by Robison, another prominent researcher in the field. Robison indicates that "although the marginal cost of producing a single silicon chip has remained stable or decreased over time as the number of components per chip has exponentially increased, the cost of research and development and of manufacturing infrastructure has increased exponentially, in what has been dubbed Moore's Second Law" (Robison 2012, 402). Robison's research demonstrates that physical limits are not the only thing holding innovation back. Economic limits are just as important, and rising costs for development of technologies will also slow innovation. Robison (2012) further indicates that to progress past the age of silicon, new emerging technologies such as quantum or molecular computers must arrive. With the rising cost of development for microelectronics, it is easy to see that further progress will be limited. All research seems to indicate that quantum computing could be the breakthrough needed to overcome Moore's law. While there are other technologies, such as molecular computing, quantum computing is the most attractive option as there has already been concrete research and prototypes developed.

Quantum Computing versus Classical Computing

As the era of classical computing begins to slow, viable alternatives must be examined to compare the advantages and disadvantages of the two. One of the main advantages quantum computing has is its exponential increase in processing power. Biswas indicates in his research that "the proposed quantum computer can exponentially speed-up the processing capabilities of the processors over that of the classical computing capabilities of the existing processors" (Biswas 2017, 1472). The significantly improved processing power of quantum computers allows it to process data at a much faster rate than even supercomputers currently available. Using this processing power to solve some of the best-known algorithms gives quantum computing a massive advantage over classical computers.

Svore and Troyer (2016) note that quantum computers can solve a range of problems exponentially faster than even the most famous classic algorithms. This is because quantum computers can use quantum algorithms, which use superposition and are superior to classical methods in terms of speed and efficiency. These significantly faster quantum algorithms can solve many issues including database searching, finding periodic functions, solving linear systems, sampling from a distribution, and probability distribution (Svore and Troyer 2016). With improved processing power and algorithms, these proposed quantum computers can run simulations and calculations much faster. Use of calculations and simulations are vital to engineering and science fields, and quantum computing could fundamentally change how scientists analyze and manipulate data.

Biswas and Svore and Troyer all highlight the advantages of quantum computing over classical; however, other prominent researchers in the field, such as Moller and Vuik, doubt that it could be a viable option. Moller and Vuik's research illustrates that "a common challenge of most of today's quantum devices is the need for extremely low operating temperatures near absolute zero, which suggests quantum computing as a cloud service as most promising business model to bring this technology to the end-users" (Moller and Vuik 2017, 2). The current need for extreme cooling solutions presents a unique challenge for the development of quantum computers that its classical counterpart has already solved.

Moller and Vuik (2017) go on to say that the immense costs of development may discourage researchers from pursuing development if the costs outweigh the benefits. The high cost and unconventional cooling requirements may give classical computers an advantage here, but quantum computers are very much still early in their development and have room for improvement. Perhaps quantum computers will not be available for consumer use at first, but they could realistically be used in large data centers and still have immense benefits. As with any new emerging technology, the initial cost of development is high. However, continued development and research will drive the cost of production down as quantum computing becomes the norm. The immense improvements in processing and algorithms alone make it a worthwhile and viable alternative to the classical technologies of today.

Applications and Viability of Quantum Computing

When examining the applications of quantum computing, there are thousands of different applications that promise to improve over what the classical computer can do. Although there are lots of different uses for quantum computers ranging from medicine to artificial intelligence, researchers are mostly interested in its ability to decrypt data and simulate models. These applications are vital to science and could potentially revolutionize how data is analyzed. Computer scientists have noted that "this subroutine is at the core of Peter Shor's seminal quantum algorithm for factoring large numbers, which is one among several quantum algorithms that would allow modestly sized quantum computers to outperform the largest classical supercomputers in solving the specific problems required for decrypting encoded information" (Ladd et al. 2009, 2). Because quantum computers can potentially decrypt much better than classical computers, governments and military agencies are pushing for development to use this power to hack into sensitive enemy information and learn more about securing important data. The attractive prospect of having unstoppable decrypting power has driven several countries to pursue quantum computing, effectively creating a new race-to-the-moon scenario.

While decrypting is a major application of quantum computing, quantum simulation is another highly important application that could allow for discovery of new and previously unsuspected phenomena. Simulations can be run on classical computers; however, they are inaccurate and cannot compare to the simulations attainable with a quantum computer. Preskill (2012) highlights the importance of this application, saying quantum computers will be able to simulate highly entangled matter including antiferromagnets, superconductors, complex biomolecules, nuclear matter, and spacetime singularities. Using these powerful simulations, it is hoped new information regarding the universe can be uncovered (Preskill 2012). Such a proposition has the potential to validate or refute predictions made by theorists and allow for learning about the universe. The applications of quantum computing are highly enticing and only strengthen the need to pursue quantum computing. The payoff of researching this new technology could be huge and allow for a new generation of decrypting tools and simulation models, which in turn will allow for an expanded knowledge of the universe and its laws.

Discussion

"Technological progress has often faced seemingly fundamental barriers. When viewed from a new perspective, these barriers can be transformed into opportunities for innovation" (Morton et al. 2011, 345). This in depth look into the viability of quantum computing has revealed the need for a new computing technology that is able to deliver revolutionary performance and data processing to help advance the computing industry past the age of silicon. The impacts of such an achievement would undoubtedly be far reaching and would shape the computer engineering field for years to come. The design of quantum computers is a completely new approach that features a new architecture, newly designed components, and a major shift from the classical fundamentals currently available. The computer engineering field will have to start from square one and effectively relearn how to construct a computer. The way fundamentals of computing logic is taught in universities would also need to be reinvented to incorporate the quantum design. Others outside the computer engineering field would see noticeable effects as well. Quantum computing would affect the world on industrial, trade, and civilian levels by delivering exponentially faster performance. Breakthroughs in physics, advanced decryption and encryption techniques, and extreme simulation models would all become a reality with the development of quantum computers. Improved processing power would lead to a faster computer, which in turn would lead to faster devices such as phones, processors, and video cards. These devices are crucial and are depended on every day.

While the impact of quantum computing would be far reaching, it is not without its limitations. The initial cost of production would be quite high considering this is a brand-new technology. This should not be a major issue considering major military agencies and countries are already pursuing this technology and the price of development will decrease over time. The other major limitation is the cooling issue. Currently quantum computers can only operate in subzero conditions. While this could be a roadblock for consumer production, architecture and cooling optimizations could be developed in the future. Nevertheless, these widespread impacts present the importance of developing such a quantum computer and demonstrate the need for further research and development of this exciting technology.

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