# Quantum Computing: Introduction and Application Areas

Er. Purva Paroch*, Er. Rishabh Sharma

**Abstract:**

Quantum computing is an emerging technology that uses quantum physics to address issues that are too difficult for traditional computers to solve. Quantum computers utilize the properties of quantum physics, such as superposition, entanglement, and quantum interference, to perform computing. Traditional programming methods are introduced to new notions in this way.

Keywords: Quantum computing, quantum physics, superposition, entanglement, quantum interference.

## 1. Introduction:

Quantum computing is a technology that is based on creating computers that implement the concepts of quantum physics that deal with the behavior of matter and energy on atomic and subatomic levels. The commonly used traditional computers make use of bit values 0 and 1 to encode data, which ultimately limits the capabilities of traditional systems. Quantum computing was introduced in the 1980s and later on it was established that quantum algorithms performed more efficiently for solving certain problems, as compared to classical ones. The 'quantum' in quantum computing is used to refer to quantum physics concepts that are employed by the system to perform operations. A quantum is the smallest unit of a physical attribute. It usually refers to electrons, neutrinos, and photons, which are atomic or subatomic particles. The quantum-bits or qubits are the fundamental units of data and are used to perform operations and make use of the special property of subatomic particles due to which the can exist in multiple states at the same time. Qubits serve the same purpose as bits in classical computing, but they act quite differently. Qubits may retain a superposition of all conceivable states, unlike traditional bits, which are binary and can only hold a position of 0 or 1. A quantum computer is a sort of computer that uses the collective features of quantum states to accomplish calculations, such as superposition, interference, and entanglement. They must be situated in extremely cold environments and they are quite expensive and difficult to build. They make use of quantum physics concepts like superposition and entanglement. This enables quantum computers to perform tasks at speeds that are orders of magnitude faster than conventional computers while using far less energy. Quantum computers process data very differently from traditional computers. Traditional computers use transistors that give only two values, 0 and 1, one at a time. Quantum computers use qubits that can be 0 or 1 or even both simultaneously. Computational power in case of quantum computers increases exponentially when more qubits are added to the system. On the other hand, adding more transistors to the system increases the computational power linearly.

## 2. Need for Quantum Computers:

In order to perform common tasks, traditional computers are ideal. To step up the performance of a classical machine, we can increase memory to

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 06 Issue: 06 | June - 2022 Impact Factor: 7.185 ISSN: 2582-3930

speed up the processing time. For more complex tasks like carrying out simulations or performing data analytics, quantum computers are preferred. Quantum computing has found its use for a variety of things, like secure transfer of data, developing radar, identify missiles and planes and producing new medicines for a range of health issues.

Whenever difficult problems are encountered, scientists use supercomputers. A supercomputer is a large traditional computer that has thousands of classical CPU and GPU cores. However, there are some problems with a high degree of complexity that cannot be solved by supercomputers. These problems contain a large number of variables that interact with each other in a complicated manner. For example, modeling the behavior of an atom in a molecule. This is a complex problem because each electron in an atom interacts with the other electrons. It is ideal to use a supercomputer for solving tasks like sorting through a large database. However, a supercomputer will not be able to detect patterns to see how data values behave and interact. Quantum algorithms solve such kinds of problems by creating multidimensional spaces where the patterns of data values can be detected. Traditional computers cannot create such multidimensional spaces thus; they cannot find and identify these patterns. Quantum computers can process exponentially more data because they carry out calculations depending on the probability of an object's state before measuring it.

## 3. Terminology:

**3.1. Superposition:** Qubits can be represented as a number of possible combinations of 1 and 0 simultaneously. This ability of qubits to be in multiple states at the same time is known as superposition. In order to achieve superposition, qubits are manipulated using precision lasers or microwave beams. Due to this contradictory process, a quantum computer having numerous qubits will be able to go through a large number of possible outcomes simultaneously. The final result is then calculated after all the qubits are measured. This causes the quantum state of the qubits to collapse to either 1 or 0.

**3.2. Entanglement:** It is possible that pairs of qubits are generated that are existing in a single quantum state. This basically means that two qubits of a pair can correlate their measurements. This property is known as entanglement. If the state of one of the two qubits is changed, then the state of the other one will also change in a predictable manner. This is possible even if the two qubits are separated by a large distance. Entanglement cannot be precisely explained but it is the driving force behind the power of quantum computers. In a traditional computer, the doubling of bits doubles the processing power. In quantum computers, due to entanglement, addition of qubits will result in an exponential increase in the processing power.

**3.3. Quantum interference:** The intrinsic behavior of a qubit is called quantum interference. It is affected by superposition and it influences the probability of a qubit collapsing in one out of two ways. The role of quantum computers is to reduce interference to the maximum to ensure more accurate results.

**3.4. Decoherence:** Quantum machines are more error-prone than traditional computers due to decoherence. Qubits have extremely fragile quantum state and they interact with their environment which causes their quantum behavior to decay and disappear ultimately. This is known as decoherence. Even the slightest disturbance or 'noise', like change in temperature or vibration is enough to cause qubits to fall out of superposition before properly completing their task. This is the reason why qubits are stored in super cooled environments and vacuum chambers, although noise still causes a lot of errors during calculations. This can be avoided by implementing smart quantum algorithms and also by adding more qubits.

**3.5. Quantum Supremacy:** Quantum supremacy refers to a point in time at which a quantum computer is able to solve a mathematical problem that is conclusively beyond the reach of the most powerful supercomputers. The number to qubits needed to achieve this is not known yet because new algorithms to boost performance of classical machines are constantly being developed, along with the development of better hardware.

## 4. Quantum computing in the real world:

Google is in the process of building its quantum computer by 2029 which will cost billions of dollars. A campus has been opened in California, called Google AI to achieve this goal. Other companies like Honeywell International (HON), JPMorgan Chase, Visa and International Business Machine (IBM) are also expected to make a breakthrough in the near future. A few companies have built personal and expensive quantum computers but still no commercial quantum computers have been made available. Google might launch a quantum computing service through the cloud. Sycamore is the quantum computer developed by Google and it claims to perform calculations in 200 seconds. This is better performance than one of the fastest supercomputers in the world, IBM Summit. Currently, IBM provides access to quantum machines if they are part of the quantum network. This includes research organization, universities and laboratories. Microsoft, like Google, also offers quantum technology service through the Azure Quantum platform. However, unlike Google, Microsoft does not sell access to its quantum computers.

## 5. Operating Conditions:

Quantum computers are smaller in size and require less energy than supercomputers. They are also extremely sensitive and are maintained at specific pressure and temperature. A quantum computer has three main parts: an area to store the qubits, a method to transfer signals to the qubits and a classical computer to run programs and send instructions. The quantum computer architecture requires components like superconductors and super fluids, to keep the quantum processors cold. In order to store qubits, the storage unit is kept at a temperature just above absolute zero in order to maximize their coherence and reduce interference. Another way to store qubits is to use a vacuum chamber to minimize vibrations and stabilize qubits. Qubits receive signals by methods like microwaves, laser and voltage. Quantum computers operate for short intervals of time. If any damage occurs to the data, it is lost and data cannot be recovered.

## 6. Application areas:

Quantum computers cannot entirely replace the traditional computers but there are certain fields where quantum computers can make a positive impact.

**6.1. Optimization:** Optimization refers to the process of finding the best possible solution to a problem according to its preferred outcome while also keeping in mind the constraints. Some metrics for taking critical decisions are cost, quality, production time etc. Optimization is performed with respect to metrics like these. Quantum based optimization algorithms can be run on classical computers to solve such problems. This has other implications in complex systems like managing package deliveries, traffic flows, airplane gate assignments and energy storage.

**6.2. Cryptography:** Cryptographic algorithms like RSA algorithm are commonly used for securing data transmission. These cryptographic algorithms rely on the intractability of problems like integer factorization and discrete logarithms. A lot of these problems can be solved more efficiently by making use of quantum computers.

**6.3. Search algorithms:** It was observed that a quantum algorithm developed in 1996, when implemented to perform search operations on unstructured data, sped up the process dramatically. The overall steps executed during this process also were fewer than when any classical algorithm was used.

**6.4. Quantum machine learning:** Using classical computers to implement machine learning is revolutionizing the world in terms of science and business. Training machine learning models has a high computational cost which obstructs the scope and development of this field. Researchers are exploring the ways to devise and implement quantum software to enable faster machine learning, keeping in mind the hindrances encountered while using traditional computers.

**6.5. Quantum simulation:** Quantum computers are exceptionally good at modeling other quantum systems. This is because they can handle the complexity and ambiguity of systems that cannot be handled by a classical computer. They are used for simulating the behavior of matter down to the molecular level. Some examples for the systems that can be modeled by quantum computers are photosynthesis, complex molecular formations and superconductivity, due to the use of quantum phenomena in the computation. They are being used to simulate the chemical composition of electrical-vehicle batteries by auto manufacturers like Daimler and Volkswagen. Pharmaceutical companies use quantum computers to analyze and compare compounds that might ultimately lead to development of new drugs.

## 7. Conclusion:

Quantum computing and classical computing are different on the basis of operation and application areas. However, in some situations, quantum computing is much more powerful and can be used for solving more complex problems. A commercial quantum computer is not available for the general public yet. Currently, traditional technology is able to handle and manage some of the tasks that are being thrown at a quantum computer. Companies like IBM and Google claim that we are close to quantum supremacy, which is the ability of a quantum computer to outperform its traditional counterparts. Some mathematicians are of the opinion that quantum computers are not worth the effort and some obstacles are practically impossible to overcome. With research going on in this field, with time, it is possible to get a clearer idea of computational power of quantum computing that can be harnessed.

## 8. References:

[1] https://azure.microsoft.com/en-us/overview/what-is-quantum-computing/#introduction

[2] https://www.investopedia.com/terms/q/quantum-computing.asp#toc-real-world-example-of-a-quantum-computer

[3] https://www.iberdrola.com/innovation/what-is-quantum-computing

[4] https://www.technologyreview.com/2019/01/29/66141/what-is-quantum-computing/