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Quantum Computing: Recent trend in Computing

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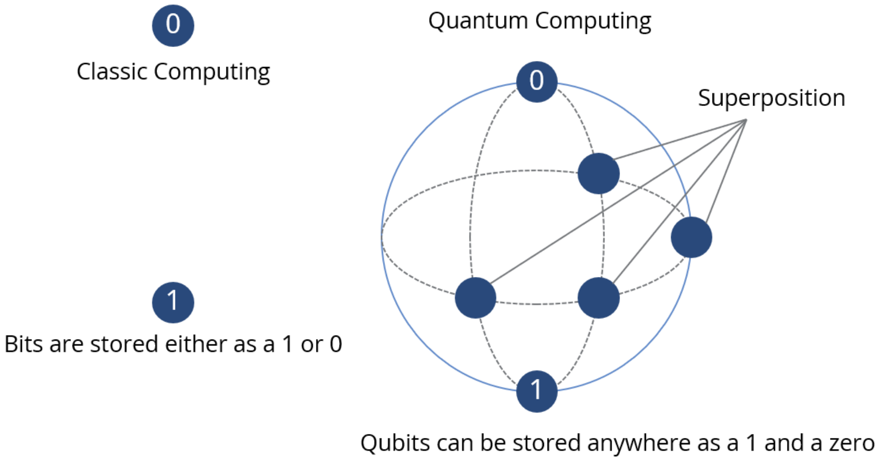
***Abstract*:** Quantum computing uses the laws of quantum mechanics to solve complex problems which is difficult to solve for traditional computers. Quantum computers depends on qubits to run and solve multidimensional quantum algorithms. The quantum computer concept gives entirely different perspective to the traditional computer concept. Quantum computing is the future computing technology which is widely used in the fields from cryptography to material science, agriculture, and computer science. While it's true that our current progress with quantum computers seems promising for the forthcoming few years, but still, we are facing many challenges and major issues in this field of computing to achieve success & quantum supremacy over conventional computers. This paper will be covering the significant concepts of quantum computing like qubits and its characteristics with applications. Besides, it will also emphasise on future advancement and scope of quantum technology. Quantum computing is the future computing technology which uses quantum mechanical phenomena such as superposition and entanglement to perform computation.

Keywords: Quantum technology, quantum computer, qubits, classical computers

I. INTRODUCTION:

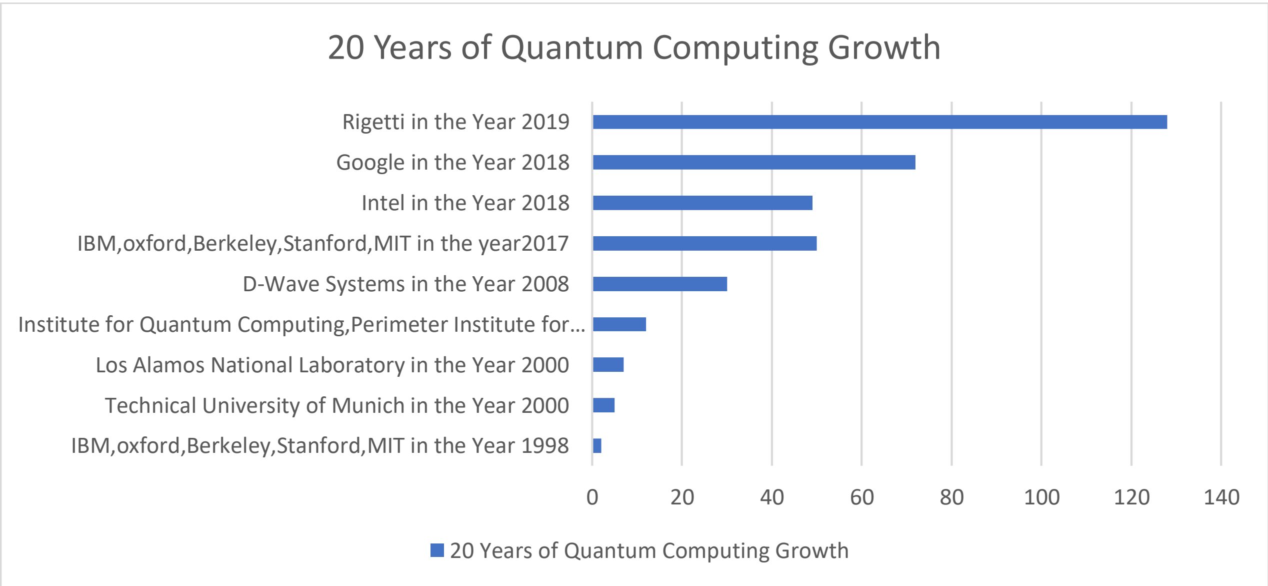
The Quantum computer technology is based on the laws of quantum physics which have high processing using the capability to be in multiple states, and simultaneously perform all possible permutations [1]. Quantum computing is a process that uses the rules of quantum mechanics to solve complex problems for traditional computers. Quantum computers depend on qubits to run and solve multidimensional quantum algorithms. Quantum computing solves scientific problems and use quantum models based on quantum theory which includes photosynthesis, superconductivity and compound molecular formations. To understand the working of quantum computing completely you need to know the concepts of qubits, superposition, entanglement and quantum interference in detail. Quantum computing uses quantum phenomena to perform calculations. Quantum computing is a small part of quantum information technologies which is trying to show how quantum mechanics can be useful in computing, communication, sensing and metrology which is not possible for conventional systems. Quantum computing is an area of computing focused on emerging computer technology based on the principles of quantum theory. Quantum computing is the combination of quantum physics, computer science and the theory of information which has the potential to influence the future of digital professional and security. It is quite different from classic computing because traditional computing uses a base-two numerical system that follows set operations and processes and communicates data using bits. All digital information is stored as a bit in the form of either a zero or a one. A series of bits in combined form is known as binary code. For instance, the letter "B" in classic computing is stored in binary as 01000010. The traditional computing can only run one calculation at a time. It is nearly impossible for classical computer to compute large data set simultaneously which negatively impacts and decreases its computational power.

Quantum computing is fundamentally different because of using quantum bits (qubits), which increase the binary limits by following quantum logic represented as a one or zero of digital data and the logic of superposition in which a qubit is denoted not just by one state but by both a one and a zero at the same time. It exists in an unknown combination which further compiled into one of the definite states as a one or zero. Superposition is the concept which makes qubits more impressive because it decreases the number of operations needed to solve complex problems by doing calculations simultaneously at higher speeds and with fewer power consumption.



II. A BRIEF HISTORY OF QUANTUM COMPUTING:

In 1982, the physicist and 1957 Nobel Laureate Richard Feynman discussed a machine that would operate on quantum mechanical principles to simulate the behaviour of one quantum system using another quantum system — a quantum simulator [2]. In 1985, David Deutsch of Oxford University further advanced the field by proposing a quantum Turing machine (based on the pioneering work of Alan Turing on what constitutes a general computer) and specified an algorithm designed to run on a quantum computer [3]. Beyond the realm of researchers in quantum physics and theoretical computer science, the field really took off in the mid-90s. In 1994, the mathematician Peter Shor proposed an algorithm for a real world “killer application” of quantum computers. It would factorize large numbers into their prime number counterparts exponentially faster than possible with a classical computer [4]. Even though in modern encryption, such as RSA encryption founded on the idea that it is very difficult to factor a large integer that is the product of two large prime numbers. It’s really hard for classical computer to find prime factors of a big number while it is easy to take two primes and multiply them together to form a big number. It is very difficult that a classical computer might take a lifetime or more to perform the calculation.



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However, on a quantum computer, if it can be made to operate with a large number of qubits, finding prime numbers could be done efficiently (mathematically in polynomial time), putting the basis of much of modern encryption used on the internet at risk. A brief history of quantum computing is given below:

• 2012-A group at University of Bristol factored the number 21 with Shor's algorithm [5].

• 2017-D-Wave Systems announced the first sale of its D-Wave 2000Q quantum computer; it is not a general-purpose quantum computer, but can address optimization problems [6].

• 2020-Google accurately simulated the binding of hydrogen chains and isomerization of diazene using Sycamore [7].

The field of quantum technology, especially quantum computing technology, has emerged as an active area of academic and corporate research and development. It has also emerged as an area of heavy investment by companies, governments, and private investors worldwide. For example, worldwide investment in 2021 was estimated at $24.4 billion with the United States appropriating $1.2 billion over five years through the National Quantum Initiative Act [8], [9]. Quantum technologies are the detectors, devices, and communication systems that rely on uniquely quantum resources, and quantum computing is the use of these quantum technologies to speed up or otherwise improve solutions to computational tasks and problems. The encapsulation of quantum mechanics has yielded a number of quantum technologies useful for storing and manipulating quantum information. Taking the position that information is physical [10]. The above chart is describing the growth of quantum computing over the last two decades.

III. QUBITS:

In Quantum computing, the basic unit of information is known as Quantum bits or qubits. Its similar as traditional binary bit in traditional computing. Qubits use superposition to be in several states at one time. Binary bits can be represented only by 0 or 1 whereas qubits can be 0 or 1, or may be any part of 0 and 1 in superposition of both states. Qubits depends on the architecture of quantum systems, as some require very cold temperatures to function accurately. Qubits can be composed of trapped atoms and ions, photons and superconducting circuits whereas binary bits are silicon-based chips. It has the ability to harness the powers of superposition, interference and entanglement which makes qubits more powerful as compared to classical bits. We need quantum objects that will act as qubits to build quantum computers and other quantum information technologies. Scientists and researchers have learned to harness and control many physical systems to act as qubits. This allows us to match the demands of different quantum technologies to the advantages of each type of qubit.

Types of qubits: There are many types of qubits, some occurring naturally and others that are engineered. Some of the most common types include:

• Spin: Most quantum particles act like little magnetic body. This property is called spin. The spin positioning is always pointing either fully up or fully down but never in between. Using the spin states of up and down, we can build a spin qubit.0= pointing up, 1 = pointing down.

• Trapped atoms and ions: We can use the energy levels of electrons in neutral atoms or ions as qubits. In their natural state, these electrons occupy the lowest possible energy levels which can be excited to a higher energy level by using lasers. We can assign the
qubit values based on their energy state. 0 = low energy state, 1 =high energy state.

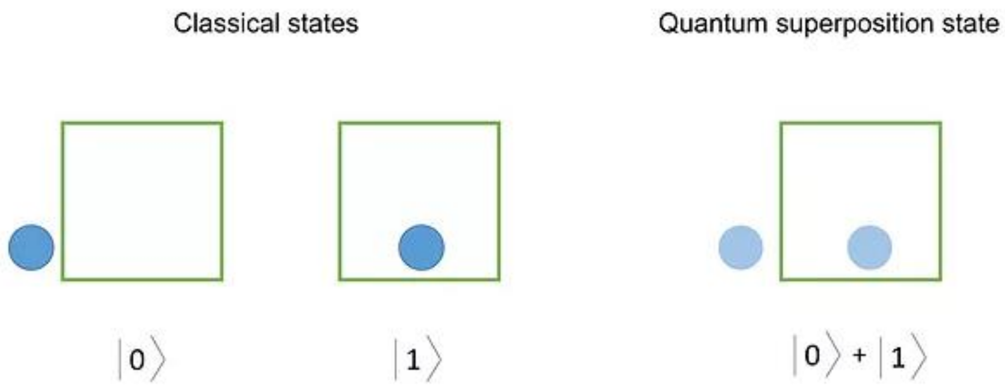
• Photons: We can use photons, which are individual particles of light, as qubits in several ways.

IV. SUPERPOSITION AND ENTANGLEMENT

SUPERPOSITION AND ENTANGLEMENT: Quantum superposition is a state of having quantum particles in all possible combinations. The particles continue to vary and move even though the quantum computer measures and observes each particle. The more fascinating fact about superposition is the ability to look at quantum states in multiple ways. Quantum computers can run vast numbers of parallel computations whereas traditional computer perform tasks sequentially. Entanglement is the state when quantum particles are engaged to correspond measurements with one another. It's like having two members of a pair be in a single state where changing the state of one qubit will definitely change the state of another one. Entanglement supports quantum computers to resolve bigger problems and compute better stores of data and information. Quantum computing algorithms use quantum entanglement for faster data processing.

Quantum superposition and entanglement are fundamental concepts for quantum mechanics and computing. Superposition states that, like waves in classical physics, any two (or more) quantum states can be superposed or added together, and the result will be a valid quantum state. As a result, every quantum state can be represented as a sum of two or more other quantum states. Superposition is a property of the solutions to the Schrödinger equation. And, since the Schrödinger equation is linear, any linear combination of solutions will also be a solution. In quantum computing, the state of a qubit is a quantum superposition of |0⟩ and |1⟩. This means that the probability of measuring 0 or 1 for a qubit is not 0.0 or 1.0, and multiple measurements made on qubits in identical states will not always give the same result.

The inherent parallelism of quantum computers is a direct result of the superposition of qubits. It enables a quantum computer to perform multiple computations simultaneously, whereas a classical computer performs them one at a time. Theoretically, a 30-qubit quantum computer could equal the processing power of a conventional computer capable of running at ten teraflops. But it's not that simple. Quantum entanglement is another factor in quantum computing. Evaluation or measurement of the state of qubits is fraught with problems. Measuring a qubit in superposition to determine its value will cause it to assume a value of either 1 or 0, but not some combination of both. That effectively nullifies the operation of the quantum computer. Indirect measurements are needed to maintain the integrity of a quantum computer. Entanglement provides a possible answer.



V. APPLICATIONS:

Technologies that depend on quantum phenomena are all around us. The first wave of quantum technologies invented the transistor. These devices became the basis of modern computers and digital communication. Further examples of technologies powered by quantum mechanics comprise:

- Magnetic resonance imaging (MRI): It has transformed how we diagnose diseases, providing medical experts with a non-invasive method to produce images inside human bodies. MRI machines working is based on the quantum property of spin, which provides each atom with a predictable magnetic property. We can make 3D images of objects from the outside by exciting these magnets with radio-frequency light. Modern medical MRIs have high resolution to image individual hairs. Researchers are emerging a new MRI technique using defects in diamond as quantum processors that is thousands of times more precise-almost down to the size of an atom.
- Drug development: Quantum computing play a very vital role in drug development, wherein drugs can be tested for stable molecular configuration using molecular modelling processes. Quantum computers can run innovative simulations on several contributing organic molecules which helps us regarding the suitability of the organic molecules for the drug. Quantum computing is typically appropriate for addressing combinatorial optimization problems when specific molecules essential for drug development is not existing. Additionally, simulation-based trials can help deliver drugs to the market in time and save a lot on their research & development.
- Aircraft development: Companies can use quantum computing in the development of aircraft design. The entire aircraft can be modelled and digitized, which enables faster simulation. Currently, aerospace engineers are taking months or years to model the flow of air currents over the aircraft wing. Though, quantum computing can execute mathematical calculations faster, thus enhancing aircraft design proficiency. They can also use quantum principles for optimizing fuel consumption and managing the aircraft's speed, which will fulfil the sustainability goals of the industry.

- Finance: Quantum computing can overcome the problems of traditional algorithms that execute poorly in time-sensitive financial transactions. It can help in stock-portfolio management, investments, and financial trading. Quantum computing can be used for portfolio optimization by banks for processing, scheduling, and prioritizing several financial transactions
- Development of climate models: Climate models used to make weather forecasts are not much accurate because several inputs representing real-world conditions are required to be simulated. Classical computing systems cannot handle large amounts of data inputs. Quantum computers that can accommodate as many inputs can help develop accurate climate models.

VI. **FUTURE SCOPE**: Through the use of cloud computing, companies have already begun offering public access to quantum devices for academic or industrial research purposes. There are mainly two types of services. The first type is cloud services providing access to a single company's collection of quantum devices. The most widely known is the Qiskit cloud services offered by IBM Quantum. The second type are multi-platform services that work as intermediaries to give users options to access quantum devices owned by multiple vendors. A key example of such a service is Amazon Braket offered through Amazon Web Services [11]. Although quantum computing is a relatively new technology, companies such as IBM, Google, D-Wave, Microsoft, and others are making significant growth in this field. In Jan 2019, IBM took a giant leap in quantum computing when it announced the launch of its first commercial quantum computer. On the other hand, in Oct 2019, Google announced that it had developed a quantum machine that could solve a typically complex problem in 200 seconds, which would otherwise take around 10k years for the world's fastest supercomputer to compute.

VII. **CONCLUSION**: Quantum computing is the future of digital world which would be helpful in almost every field. The quantum computer concept brings a completely different perspective to the classical computer concept. Quantum computers can be best option for running simulations and data analyses as they can run complex problems faster. Quantum computing is the upcoming computing technology by using quantum mechanics to perform cryptography tasks with many other potential applications in medical, agriculture, and computer science.

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