# 1

# Introduction of Quantum Computing

## 1.1 Introduction

A significant advancement in computer science may take the form of a new algorithm that significantly outperforms the state of the art, or it may provide theoretical evidence that the state of the art cannot be significantly improved. The latter condition imposes a fundamental limit on the complexity of problems that any given computer can solve in a given amount of time. Increasing the computer's processing speed is the only way to increase the number of problems that can be solved. According to Moore's Law, the size of semiconductors (and, by extension, computing capability) has approximately doubled every two years since the 1960s. It is clear that, despite the fact that this development has been going on for decades, it cannot go on forever because of a number of basic physical constraints. As a result, quantum weirdness will dominate the behavior of the circuitry by 2020, and by 2050, the circuits will have achieved the lowest size at which knowledge can be permanently contained [1].

The results of this study have piqued the public's interest in how quantum theory may affect the future of computing over the next several decades. Is it possible, for instance, to make circuits immune to the influence of quantum effects? As an alternative, may quantum phenomena be exploited to do arithmetic? In order to do calculations, quantum computers take advantage of quantum phenomena. However, a quantum computer is not only a device with enhanced performance because of the faster speed of quantum-scale circuits. It is of more interest to the software programmer than to the theoretical physicist. After all, the computational complexity of algorithms executed on a certain CPU remains the same regardless of the CPU's clock speed. Different algorithms may provide better complexity in terms of the new variable P if the computer's architecture is altered

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to include some number P of processors. We may able to reduce the greatest feasible complexity for solving a specific problem from O(N) to O(N/P), if we have a good parallel extraction of processors. However, not all algorithms can be broken down into O(P)-independent portions that can be incorporated and enforced during the algorithm's operating time, therefore obtaining an O(P) complexity reduction is not always possible. To store and manipulate data, for instance, analog hardware and programmable real numbers may replace a discrete set of symbols, which would need a more radical redesign. It is possible that this design will prove to be far more powerful than the classic Turing machine. Because of the limitless precision with which a single physical value may be measured, it is possible to analyze massive amounts of data in parallel by treating them as a single unit cost. This is, of course, completely hypothetical since it assumes infinite precision can be maintained throughout those operations, and there is no reason to believe that such an infrastructure is physically conceivable. The potential of a quantum computer, which relies on the preservation of real, complex values, is underutilized [2].

## 1.2 What Is the Exact Meaning of Quantum Computing?

Large, complex datasets are no match for the speed with which quantum computers can process them. They use the foundations of quantum physics to speed up the process of doing complex computations. Quantum computers' ability to break cryptography and encrypted electronic communications is already changing portions of cybersecurity, and their usage in simulators with a practically endless quantity of variables has implications across fields, from biology to economics. The next large electronics race has already started [3], with some of the biggest names in industry, including Google, Microsoft, Intel, IBM, and Alibaba, exploring quantum computing to improve rates and other applications. Although Google has been studying quantum computing to speed up internet searches since at least 2009, the market for commercialized quantum entanglement is still in its infancy, and it is not yet obvious who will emerge as the market leader.

### 1.2.1 What Is Quantum Computing in Simple Terms?

Figure 1.1 depicts the interactions of matter in the universe at the level of fundamental particles, which provide the basis for special relativity, upon which quantum computing is founded. Bits can only be encrypted in classical computers if they have a value of 1 or 0.

**Figure 1.1** David Deutsch father of quantum computing. Source: Lulie Tanett (https://images.app.goo.gl/CQBoMf7JqWzXfr6r9).

## 1.3 Origin of Quantum Computing

Some types of computations now baffle today's computers and will continue to do so even if Moore's Law is extended indefinitely, although quantum computers may give a stronger correlation boost. Just imagine you have a phone book and need to find a certain number. A conventional computer would have to go through each listing in the phone book to find and provide the appropriate contact information. In theory, a computer system might scan an entire phone book in a fraction of a second, evaluating each line simultaneously and returning the result far faster than a modern computer [4]. The term "complex mathematical optimizing" is often used to describe the process of finding the best possible combination of elements and answers to a problem. Consider the costs of building the tallest building in the world, including machinery, food, labor, and permits. The challenge is in figuring out how to optimally allocate resources like money, time, and manpower. As a result, we may be able to plan for major projects with more efficiency with the aid of quantum computing if these factors are taken into account. Software development, supply chain management, finance, internet-based research, genomics, and other fields all face optimization challenges. The most challenging optimization problems in these fields are inherently well-suited for solution on a quantum machine [4] but stump conventional computers. In contrast to classical

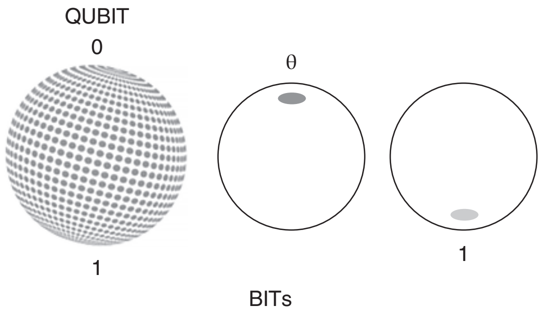


**Figure 1.2** Structure of bits and Qbits. Source: Adapted from https://images.app.goo.gl/DeYCU9A7TeJvV5c16 Last accessed 25 Oct 2022.

computers, which rely almost entirely on technological advances in transistors and microchips, quantum computers may evolve in ways that classical computers cannot. In quantum computers, transistors are not utilized (or classical bits). Substituting qubits for bits. In a quantum algorithm, qubits serve as the basic building blocks for pattern recognition. The example is shown in Figure 1.2.

Qubits may take on the characteristics of either a 0 or a 1, or they can have both at the same time. More choices exist to get accurate results quickly while doing computations. In addition, quantum entanglement and superposition are two important states of matter on which quantum computers depend. When applied to computing, these physical properties have the potential to greatly increase our ability to do very large computations [5].

Although Rigetti Computing's 19-qubit devices are the most powerful in the field of quantum computing, but after 2019, the business is moving on 128-qubit circuit. But as can be seen in Table 1.1, the race to build the most advanced quantum computer with the most qubits has been going on since at least the late 1990s.

**Table 1.1** Quantum computing getting more powerful.

| Year | Labs | Q-bits |
|---|---|---|
| 1998 | IBM, Oxford, Berkeley, Stanford, MIT | 2 |
| 2000 | Technical University of Munich | 7 |
| 2006 | Institute for Quantum Computing | 12 |
| 2008 | D-Wave System | 28 |
| 2016 | IBM | 50 |
| 2018 | Google | 72 |
| 2020 | Rigetti | 128 |

## 1.4 History of Quantum Computing

Conjugate coding was first developed in the 1960s by Stephen Wiesner. In the 1970s, James Park established the no-cloning theorem using his formulation. Alexander Holevo proved what is now known as Holevo's theorem, or Holevo's bound, in a paper that was published in 1973. This theorem states that even though $n$ qubits may store more relevant data than $n$ classical bits, only $n$ conventional bits are obtainable. This is despite the fact that $n$ qubits may store more information than $n$ classical bits.

Research conducted by Charles H. Bennett demonstrates that it is feasible to carry out computing in a backward-compatible manner.

- In 1975, R. P. Poplavskii published (in Russian) thermodynamical models of information processing. This work highlights the computational difficulties of reproducing quantum systems on classical computers owing to the fact that the superposition principle is at play.
- In 1976, the Polish mathematician and physicist Roman Stanislaw Ingarden published Quantum Information Theory in the journal *Reports on Mathematical Physics*. Ingarden's paper "1976 Quantum Information Theory." This study, which was one of the early efforts to build quantum synchronization theory, demonstrates that the traditional Shannon communication theory cannot simply be translated into the quantum situation. This was one of the earliest attempts to establish quantum entanglement theory. However, a quantum entanglement theory, which is a wide expansion of Shannon's theory, is possible to construct within the representation of an expanded subatomic particles of open systems and a generalized idea of explanatory variables that is both broad and imprecise (the so-called semi-observables).

Paul Benioff is credited with developing the very first computer model based on quantum physics in the 1980s. In this paper, Benioff paved the way for further research in quantum computing by laying the groundwork for future work in the field by proposing a Schrodinger equation description of Turing machines. This demonstration showed that a computer could operate in accordance with the rules of quantum physics. The work was first shown to the public in June 1979, and four months later, in April 1980, it was published. Yuri Manin presents a synopsis of the field of quantum computing in this article.

The reversible Toffoli gate, with the NOT and XOR gates, forms the foundation of a universal set that is used for bidirectional classical computing.

In May 1980, the Massachusetts Institute of Technology (MIT) played host to the First Conference on the Physics of Computation. At this conference, prominent figures in the field of computing, such as Paul Benioff and Richard Feynman, explored quantum computing. Benioff's current investigation is an expansion of his earlier work from 1980, which demonstrated the possibility that a computer may function in line with the principles of quantum physics. Quantum mechanical Hamiltonian models of discrete processes that delete their own histories: application to Turing machines," the talk's title said. During his presentation, Feynman said that it seemed to be difficult to properly mimic the evolution of a quantum particle on a regular computer. In addition to that, he laid the foundation for the contemporary quantum algorithm.

Paul Benioff continued to develop his concept of a Turing machine that was based on quantum modeling in 1982. William Wootters, Wojciech Zurek, and Dennis Dieks all independently rediscovered the no-cloning theorem at around the same time.

In 1984, Charles Bennett and Gilles Brassard resort to Wiesner's conjugate coding in order to distribute cryptographic keys in an uncompromised manner.

In 1985, while working at Oxford University, David Deutsch was the first person to conceptualize a universal quantum computer. A universal quantum computer, much like a multiclass support vector machine, has the potential to successfully imitate any other quantum computer with just a polynomial amount of latency (Church–Turing thesis).

Yoshihisa Yamamoto and K. Igeta, two physicists, developed the first practical implementation of a quantum algorithm in 1988. Their algorithm utilized Feynman's CNOT gate as one of its components. Their system utilizes both atoms and photons, which positions it as a forerunner of present quantum computing and networking protocols. These protocols employ photons to transport qubits, while atoms are utilized to carry out two-qubit operations. Gerard J. Milburn demonstrates a quantum-optical variant of the Fredkin gate in his presentation.

- In 1989, researchers at the Saha Institute of Nuclear Physics in Kolkata, led by Bikas K. Chakrabarti, proposed that particle physics activity could be used to learn to navigate rough energy environments by tunneling (rather than trying to climb over using thermal vibrational modes) to escape from local minima of crystalline form systems with tall but thin barriers. This was done in an effort to break free from the local optimal solution of crystallized systems with large but small barriers.
- In 1991, Artur Ekert of the University of Oxford expanded upon the idea of entanglement-based encrypted communication proposed by David Deutsch.
- David Deutsch and Richard Jozsa proposed a number of problems in 1992 that could be quickly solved on a quantum system with the assistance of the predetermined Deutsch–Jozsa automated system, but for which there are no feasible categorical imperatives using classical methodology. This problem was referred to as the "Deutsch–Jozsa algorithm problem." It was the possible first discovery of its kind in the realm of quantum computing, and it demonstrated that qubits

are capable of doing a particular computing job more rapidly and precisely than any conventional computer.

- In 1993, Dan Simon, a professor at the University of Montréal, thought of the concept of an "oracle scenario," in which a computer program would be able to do calculations at a rate that is geometrically faster than a typical computer. The enhancements that were made to Peter were based, in large part, on the core principles that are provided in this method.
- Peter Shor of AT&T's Bell Labs in New Jersey discovered a crucial method via his factorization algorithm. A quantum computer can now quickly factor very large numbers using this method. As a bonus, it also solves the discrete log issue and the factoring problem. Many modern cryptosystems may be vulnerable to Shor's algorithm. Following its discovery, enthusiasm for quantum computers skyrocketed.

In the fall, the first federal government workshop on quantum computing will be held in Gaithersburg, Maryland, hosted by the National Institute of Standards and Technology (NIST).

Isaac Chuang and Yoshihisa Yamamoto, both of whom are physicists, believe that the most effective implementation of Deutsch's method would be to use a quantum computer that was instantiated via quantum optics. A new method of dual-rail encoding for photonic qubits was developed as a consequence of their research.

During the month of December, Ignacio Cirac of the University of Castilla-La Mancha in Ciudad Real and Peter Zoller of the University of Granada got together.

Researchers from Innsbruck University have suggested the controlled-NOT gate as a potential use in the real world. In order to make the gate function properly, the researchers recommend using cold trapped ions.

Three US Army scientists, Charles M. Bowden, Jonathan P. Dowling, and Henry O. Everitt, planned the first US Department of Defense training course in electromagnetism and cryptography in February 1995 at the University of Arizona in Tucson.

Peter Shor is credited with having suggested some of the early quantum error-correcting algorithms.

At the NIST in Boulder, Colorado, Christopher Monroe and David Wineland used trapped ions and the Cirac–Zoller principle to construct the first quantum logic gate. This gate was called the controlled-NOT gate. In 1996, at Bell Labs, Lov Grover developed the first approach that might be considered practically useful for exploring quantum databases. Compared to a quadratic speedup, a factorization, discrete log, or linear speedup comes up more prominently.

Simulations of the physical world are one example. Having said that, the approach may be used to address a far larger range of issues. This speedup by a factor of four is available for use in any activity that can gain an advantage by doing a random brute-force search (in the number of search queries).

The federal government of the United States has just released its first call for research ideas on quantum computing. This request is the result of a collaborative effort between the National Security Agency and the Army Research Office, which is now a branch of the Army Research Laboratory. Steane codes are a kind of error-correcting code that was developed by Andrew Steane. IBM's David P. DiVincenzo sets out the fundamentals that have to be in place before one can build a quantum computer. These fundamentals are required in order to build a computational model.

In 1997 David Cory, Amr Fahmy, Timothy Havel, Neil Gershenfeld, and Isaac L. Chuang were all working at MIT at the same time when they published the first publications establishing gates for subatomic particles based on bulk nuclear spin-responsive or thermal ensembles. These works were published simultaneously. This method makes use of a device known as a nuclear magnetic resonance (NMR) machine, which is relatively similar to magnetic resonance scanners used in the medical field.

Alexei Kitaev has presented topological quantum computing as one technique for lowering the risk of decoherence occurring in a quantum system.

The electrons contained within quantum dots serve as qubits in the Loss–DiVincenzo quantum computer, which was suggested by Daniel Loss and David P. DiVincenzo. Each electron has its own spin-1/2 degree of freedom.

In 1998, a quantum algorithm was successfully realized for the first time in an experimental setting. Jonathan A. Jones and Michele Mosca of Oxford University and Isaac L. Chuang of IBM's Watson Research Center employed a two-qubit NMR quantum computer to answer the issue that was presented by Deutsch. The problem was solved by the computer. Researchers from the Almaden Research Center, directed by Mark Kubinec, collaborated with colleagues from Stanford University and MIT. An NMR computer that has, for the first time, a data storage capacity equal to three qubits. Bruce Kane has developed a computational model for nuclear spins in silicon. In this model, the nuclear spins of certain phosphorus atoms in silicon serve as qubits, while donor electrons are responsible for mediating qubit coupling. The first time Grover's method was ever put into action, it was on an NMR computer. Researchers at the Tokyo Institute of Technology, headed by Hidetoshi Nishimori, have shown that quantum annealing is better than more traditional types of simulated annealing. Daniel Gottesman and Emanuel Knill, two different researchers, separately demonstrate that classical resources may successfully simulate a subset of quantum processes (the Gottesman–Knill theorem).

Isaac Chuang and Yoshihisa Yamamoto, who are both physicists, think that the use of a quantum algorithm that was created by the application of quantum optics would be the way that would result in the most successful application of Deutsch's method. As a direct result of their investigation, a novel approach to dual-rail encoding for photonic qubits was conceived and created.

Ignacio Cirac and Peter Zoller, both from the University of Castilla-La Mancha in Ciudad Real, and Peter Zoller, from the University of Granada, joined together during the month of December.

The controlled-NOT gate has been proposed as a possible use in the real world by a group of researchers from Innsbruck University. The researchers suggest using cold ions that are confined in a vacuum in order to ensure that the gate operates correctly.

The first United States Department of Defense training course on electromagnetism and cryptography is scheduled to take place at the University of Arizona in Tucson in February 1995. The course is being planned by three scientists who are employed by the United States Army: Charles M. Bowden, Jonathan P. Dowling, and Henry O. Everitt. Henry O. Everitt, Charles M. Bowden, and Jonathan P. Dowling are the authors of this work.

Peter Shor is widely acknowledged as having proposed some of the first quantum error-correcting algorithms.

Christopher Monroe and David Wineland built the first quantum logic gate at the NIST in Boulder, Colorado, by using trapped ions and the Cirac–Zoller principle. This gate was known as the controlled-NOT gate at one point in time. In 1996, Lov Grover created the first method that might be regarded as realistically viable for browsing quantum datasets at Bell Labs. This method was the first of its kind. A factorization, discrete log, or linear speedup shows a more significant increase when compared to a quadratic speedup.

One example of this would be simulations of the physical world. Having said that, the strategy may be used to solve a far wider variety of problems than I've mentioned here. This increase in speed by a factor of four is accessible for use in any endeavor that can benefit from carrying out a random brute-force search (in the number of search queries).

The United States federal government has officially issued its first request for ideas pertaining to research on quantum computing. The National Security Agency and the Army Research Office, which is now a part of the Army Research Laboratory, are working together to put out this call for proposals. This request is the result of their joint effort. Steane codes are a kind of error-correcting code that was invented by Andrew Steane. Steane codes were developed in the 1960s. David P. DiVincenzo of IBM lays out the principles that have to be in place before one can develop a quantum computer. These fundamentals are necessary in order to build a quantum computer. To construct a computational model, you will need to have a firm grasp of these foundations.

In 1997, when David Cory, Amr Fahmy, Timothy Havel, Neil Gershenfeld, and Isaac L. Chuang published the first works defining gates for subatomic particles based on bulk nuclear spin-sensitive or thermal ensembles, they were all working at MIT at the same time. These pieces appeared in publications at the same time. This technique makes use of a machine that is referred to as an NMR machine, which is somewhat comparable to magnetic resonance scanners that are used in the area of medicine.

Alexei Kitaev has proposed topological computational methods as a method that may reduce the likelihood of decoherence taking place in a quantum system.

The Loss–DiVincenzo quantum computer, which was proposed by Daniel Loss and David P. DiVincenzo, uses the electrons that are housed inside quantum dots as qubits. Every electron has a degree and a half of spin-dependent freedom individually.

It was not until 1998 that a quantum algorithm was effectively implemented in an experimental environment for the very first time. Jonathan A. Jones and Michele Mosca of Oxford University and Isaac L. Chuang of IBM's Watson Research Center used a two-qubit NMR quantum computer to answer the question that was posed by Deutsch. Deutsch was the one who posed the question. The issue was resolved as a result of the computer's efforts. Researchers from Stanford University and MIT worked with their counterparts at the Almaden Research Center, which is managed by Mark Kubinec. A first-of-its kind NMR computer with a data storage capacity equivalent to three qubits. An innovative computational model for nuclear spins in silicon was created by Bruce Kane. Donor electrons are responsible for mediating qubit coupling in this paradigm. The qubits themselves are the nuclear spins of certain phosphorus atoms in silicon. The NMR computer was the platform on which Grover's approach was first implemented for the first time in history. Researchers at the Tokyo Institute of Technology led by Hidetoshi Nishimori have found quantum annealing to be superior to more conventional kinds of simulated annealing. Both Daniel Gottesman and Emanuel Knill, who are scholars in their own right, show that classical resources may effectively imitate a subset of quantum processes in their own respective studies (the Gottesman–Knill theorem).

In 2007, the development of a waveguide with a sub-wavelength light signal. Creation of an optical fiber-based single-photon emitter. We construct a six-photon, single-direction multicore computer. There is a new suggested material for use in quantum computers. There is now a server for spontaneous emission from a single atom. This is the first instance of Deutsch's algorithm being implemented on a quantum computer with a cluster state. An electron quantum pump has been developed at Cambridge University. Better qubit coupling methods have been developed. Demonstration of qubits with a connection that can be controlled. An important step forward in incorporating spin-based electronics with silicon-based devices. The quantum states of light and matter are shown to exchange with one another by scientists. Making a quantum register out of a diamond. In this scenario, we use a controlled NOT to activate quantum gates implementation of two superconducting quantum bits in a three-dimensional array, scientists may hold and analyse hundreds of individual atoms. The buckyball molecule, which contains nitrogen, is used in quantum computing. Several hundreds of electrons have established quantum connections. The spin-orbit coupling of electrons was quantified. Laser-light-based atomic manipulation at the quantum level. Electronic spins are controlled by pulsing light. Over a range of tens of nanometers, quantum effects have been shown. The evolution of quantum computers is being hastened by the use of light pulses. Plans for quantum random-access memory are now public knowledge. Development of a prototype quantum transistor. Proof of long-range entanglement has been shown. Photonic quantum computing was used to factor numbers in two separate labs. The quantum bus was developed in a joint effort between two separate laboratories. Construction of a quantum cable using superconducting technology. An example of qubit transfer is shown. The development of high-quality qubit material is a major achievement. Electronic memory have single qubit space in the disk. Quantum memory via Bose–Einstein condensation has been realized. D-Wave Systems showcases a 28-qubit processor in action. By decreasing decoherence and increasing interaction distance, a novel cryonic technique improves the efficiency of quantum computers. A proof-of-concept for a photonic quantum computer has been shown. The use of graphene quantum dots as spin qubits has been suggested [6].

In 2008, researchers were able to store a quantum bit in graphene quantum dots, demonstrate three-dimensional qubit–qutrit entanglement, and establish analog quantum computing. Controlling quantum tunneling led to the creation of entangled memory, the invention of a superior NOT gate, the discovery of an optical fiber quantum logic gate, the development of qutrits, and the creation of a better Hall as a result, we may infer that the spin states of quantum dots are stable for a considerable amount of time. A quantum memory based on molecular magnets has been proposed.

The possibility of a reliable quantum computer is improved by the existence of quasiparticles.

It is possible that qubit storage is preferable than image storage.

- Quantum entangled pictures.
- Modified the quantum state of a molecule on purpose.

Microwave photons are pumped into a silicon circuit with the help of a superconducting electronic circuit.

D-Wave Systems claim that it has designed a computer chip with 128 qubits; however, this has not been independently validated.

In 2009, the purity of carbon-12 was improved, which should result in increased coherence over longer periods of time.

Entanglement of the six-photon graph state is used in order to simulate the fractional statistics of anyons that are situated in synthetic spin-lattice models.

Quantum computing: create a photon grenade launcher the development of a quantum algorithm for use with differential equation systems – Presentation of the world's first quantum system, which has completely digital control hardware as well as software. Scientists are able to change the atoms and molecules of electrons using electromagnetic energy. Google, in collaboration with D-Wave Systems, presented a technique for synchronizing the characteristic features of several linked CJJ rf-SQUID flux qubits with a low distribution of electronic resistivity due to manufacturing differences. The spectrum response of hydrogen and helium was correctly calculated by an optical quantum computer with three qubits in 2010; the first semiconductor materials laser brings us closer to electro-optical computing systems. Ions were captured via an optical trap in 2010.

The transmission of subatomic particles across a quantum communications channel may be sped up by architectures that use multiplexing. Quantum state in macroscopic object. Innovative strategy for the cooling of quantum computers. Quantum contact between a single photon and a single atom has been shown to exist using microfabricated planar ion traps in the research. Quantum bits (or "qubits") are handled using electrical current rather than magnets.

Electron quantum states are electrically controlled by scientists.

- A technique for synchronizing the characteristics of several connected CJJ rf-SQUID flux qubits with a minimal spread of electrical characteristics owing to manufacturing variances was shown by Google in collaboration with D-Wave Systems.
- Realization of Universal Ion Trap Quantum Computation with Decoherence Free Qubits 2010
- Ion trapped in optical trap
- Optical quantum computer with three qubits calculated the spectral response of hydrogen and helium with high precision
- First semiconductor materials laser brings us closer to electro - optic computer systems
- Single electron qubit established
- Quantum state in macroscopic object
- New quantum computer cooling method developed
- Quantum interface between a single photon and a single atom proven
- LED quantum entanglement established
- Multiplexed design speeds up quantum information transfer across a quantum communications channel
- Planar ion traps that have been microfabricated Qubits are controlled electricity

In a solid-state spin ensemble, what exactly is meant by the term "entanglement"? In a quantum semiconductor technology that makes use of superconductivity, light from the near-outer radiation (NOON) is used. Quantum antennas are due to multimode quantum interference.

- Atomic racing dual
- Quantum pen

D-Wave one product claims that it discovered quantum annealing. The company claims its product is the world's first quantum computer accessible for purchase. It has been demonstrated that a quantum processor can perform repetitive error correction, that a diamond can be used as a storage medium for a quantum computer, that Modes can be established, that DE coherence can be suppressed, that controlled operations can be streamlined, and that ions can be entangled using microwaves.

- Repetitive error correction performed in a quantum processor
- Diamond quantum computer storage exhibited
- Qmodes established
- DE coherence suppressed
- Simplification of controlled operations
- Ions entangled using microwaves
- Practical error rates attained Quantum Entanglement might aid in the development of photonic processors.

It was reported that a quantum simulator with 300 qubits or particles had been successfully built.

A topologically protected qubit that is entangled with eight photons provides a safe and secure approach to the implementation of real quantum computing [7].

In the beginning, there was 1QB Information Technologies (1QBit). The first software firm in the world to exclusively concentrate on quantum computing. Developed the first system for repeating quantum operations that does not depend on quantum memory.

At room temperature, the use of a laser to manipulate carbon-13 atoms briefly and for a period of two seconds reduced decoherence.

The development of a revolutionary, low-overhead approach for building fault-tolerant quantum logic, which is referred to as lattice surgery. This method is developed on the concept of Bell-based unpredictable expansion and makes a more moderate assumption of measurement being independent.

In 2013, 39-minute coherence times have been measured for ensembles of impurity-spin qubits in isotopically linked systems while the temperature was maintained at room temperature (and three hours at cryogenic temperatures).

The amount of time that a qubit remains in a superimposed state has been multiplied by 10 in order to account for the change.

In 2014, the first ever evaluation of this kind was constructed for factoring in order to determine whether or not it would be possible to implement a large-scale quantum algorithm with explicit fault-tolerant and error-correcting protocols.

The NSA's Penetrating Hard Targets program, which is constructing a computer program for the purposes of cryptanalysis, has received backing as a result of the disclosures that were made public by Edward Snowden.

In a first-of-its-kind development anywhere in the world, researchers from Japan and Austria have made public the designs for a huge quantum computer based on diamonds. Researchers at the University of Innsbruck accomplish quantum numerical computations on a qubit that is topologically encapsulated and password protected in linked states that are scattered among seven trapped-ion qubits.

Using neutrino oscillation, scientists have succeeded in sending data across a distance of 10 feet (3.048 m) with no discernible delay. Percent of inaccuracies, a significant achievement on the way to the construction of a quantum network. Nike Dattani and Nathan Bryans have set a new record for the number 56 153 that can be factored using a quantum device.

In 2015, nuclear spins in a solid, which can have their coherence examined optically, may have coherence periods of up to six hours. A quantum process known as transcription makes use of straightforward electrical pulses, and a quantum error detection code is based on a square lattice of four superconducting qubits as its fundamental building block. On June 22, D-Wave Systems Inc. made the announcement that the company has reached a breakthrough of 1,000 qubits. A silicon logic gate with two qubits has been designed and tested satisfactorily. By simulating its behavior after that of a classical computer and replicating quantum states such as quantum superposition and entanglement using a traditional analog web browser, it is possible to develop a completely classical framework that behaves like a real quantum computer. This is made possible by designing its behavior after that of a quantum computer.

Researchers headed by Rainer Blatt and Isaac Asimov used an ion-trap-based quantum computer to solve the problem. In 2016, Chuang at MIT was successful in running the algorithm developed by Shor. The online interface for IBM's superconducting systems, known as the Quantum Experience, has been made available. After that, the system is put to use in the propagation of cutting-edge techniques in digital signal processing. In order to replicate a hydrogen molecule, Google makes use of an array consisting of nine superconducting qubits. This array was built by the Martinis group at UCSB. In 2017, researchers from Japan and Australia created a quantum version of the communications system known as Sneakernet. D-Wave Systems Inc., claims that the D-Wave 2000Q quantum annealed is now readily accessible for widespread usage in business settings. This apparatus is capable of storing 2000 qubits of information. The blueprint for a quantum computer that operates by entrapping ions in microwaves has been made available to the public. A novel approach to evaluating IBM's 17-qubit quantum computer has been made public by the company. Scientists have devised a device that can produce two entangled qubits, each of which may exist in one of ten distinct states consisting of a hundred different dimensions Visual Studio now comes equipped with Q Sharp, the newest quantum software platform developed by Microsoft. For the purpose of program execution, there is accessibility to both a local 32-qubit simulator and a cloud-based 40-qubit simulator. Intel recently claimed in a news release that it had produced a superconducting test circuit with 17 qubits. The device was used for testing purposes. IBM demonstrates for the very first time a functional model of a quantum computer that has 50 qubits and has the ability to maintain its physical phenomenon for 90 microseconds [8].

In 2018, researchers from MIT discovered evidence of a previously undiscovered kind of light that is composed of three independent photons. The group from Oxford used a technique known as trapped ions. In order to produce logic gates that are 20–60 times speedier than those that are traditionally used, the researchers used a method in which they entangled and superposed two charged atoms obtaining a level of precision of 99.8% in 1.6 milliseconds. QuTech achieves positive results in its testing of a silicon-based two-spin-qubit processor. Google has revealed that it has developed a Bristlecone quantum gadget with a whopping 72 qubits, setting a new record in the process. Intel has started building a silicon-based spin-qubit computer processor at its D1D Fab in Oregon. Tangle Lake, Intel's superconducting test chip with 49 qubits, has been finished, and the company has made the formal announcement. Researchers in Japan have demonstrated holonomic quantum gates that are reliable in every environment. An integrated photonic platform may be useful for quantum systems that rely on a dependent variable. This past Monday, December 17 2018, is the relevant date. The first commercialized trapped-ion functional prototype has been presented by IonQ. This prototype has more than 60 two-qubit gates, 11 fully linked qubits, 55 addressable pairs, and an error rate of 0.03% for one-qubit gates and 1% for two-qubit gates. The National Quantum Initiative Act was signed into law by President Trump on December 21 2018, and it provides an overview of the objectives and prerequisites for a ten-year plan. The objective is to hasten the development of new technologies in the United States that are founded on the study of quantum information.

In 2019, Nike Dattani and his colleagues deciphered the architecture of the D-Pegasus Wave and made it open to the public. IBM also introduced the IBM Q System One, the company's first commercial quantum computer, which was established by the UK's Map Project Office and Universal Design Studio and manufactured by Goppion. Both of these organizations are based in the United Kingdom. Researchers in Austria have demonstrated self-verifying hybrid and variational quantum simulations of lattice structures in crystalline materials and high-energy physics by using a feedback loop between a computing environment and a quantum coprocessor. These simulations are hybrid, self-verifying, and self-variational. At room temperature, the phenomenon of quantum Darwinism may be seen operating in diamonds. In a study that was released at the end of September 2019, the research team working on quantum computing at Google said that the company's project had established itself as the industry leader. IBM has just unveiled its most cutting-edge quantum computer to date, which is comprised 53 qubits. The introduction of the system will officially take place in October of 2019.

In the 2020s, a method for producing "hot qubits," also known as quantum gadgets, that may operate at temperatures as low as 1.5 °C has been developed by researchers at UNSW Sydney. Researchers from Griffith, UNSW, and UTS, in addition to seven other institutions in the United States, have developed a method using pattern recognition to cancel out background noise in quantum bits, thereby reducing quantum device noise to zero. This method was developed in collaboration with researchers from seven institutions in the United States. Researchers at the University of New South Wales have found a way to command subatomic particles inside electronic circuits by using electric nuclear recombination. This feat was accomplished by the researchers. In order to overcome the difficulties associated with experimental wiring, a two-dimensional framework for qubits has been designed and validated by researchers from the University of Tokyo and Australia. This kind of architecture is realizable with the integrated circuit technology of the present day and has far less cross-talk [9].

On the 16th of January, 2019, researchers in theoretical physics said that they have successfully accomplished the first direct dissection of a photon into its constituent pieces. Applications are conceivable in the field of quantum technology, which makes use of spontaneous programmable down-conversion.

It was announced on February 11 that engineers working in the area of quantum computing claim to have built artificial atoms in silicon nanoparticles. These engineers believe that atoms containing more electrons than were previously considered conceivable may be more stable qubits. If silicon-based quantum mechanics can be enabled, there will be a number of benefits, one of which is the potential to reuse traditional manufacturing techniques for computer system chips.

The 14th of February saw the development of a revolutionary single-photon source by quantum scientists. This source might open the way for semiconductor-based quantum machines to communicate with photons by translating the state of an electrostatic interactions. They show that it is possible to generate just a single photon in a controllable environment, without having to resort to completely at random manufactured quantum dots or structural flaws in diamonds.

On February 25, scientists will imagine quantum instrumentation by taking pictures of ion states at separate moments during standard measure by conjugating a trapped ion to the photon environment. They demonstrate that differences in the degrees of superposition, and thus the likelihood of the occurrence of states after measurement, can be observed.

On March 2, scientists revealed repeated quantum inspections of an electron's spin in a silicon quantum dot. These are inspections that do not affect the electron's spin in any way.

The effective manipulation of the nucleus of a single atom using just electric fields was disclosed by quantum engineers on March 11th. The year 1961 marks the beginning of this concept, which might one day be used to study quantum mechanics in silicon. It may have far-reaching ramifications for nanodevices, accurate sensors of electric and magnetic fields, and basic investigations of quantum nature if experiments without oscillating magnetic fields are conducted using single-atom spins.

Researchers at a US Army unit published their experiment on the responsiveness of a Rydberg sensor to different electric fields at frequencies ranging from zero to tens of hertz (the spectrum to 0.3 mm wavelength) on March 19. The Rydberg sensor shows promise as a tool for detecting information components due to its superior performance when compared to other specified electric field wearable sensors such as electro-optic crystallites and dipole antenna-coupled passive electronics. This is due to the Rydberg sensor's ability to detect parts of an organization in a more accurate manner.

On March 23, researchers revealed that they had discovered a method to compensate for signal loss in an early version of a quantum computer. Prototype quantum computer node capable of capturing, storing, and entangling quantum bits. Their proposals might be put into action as essential components of quantum repeaters in quantum networks, which would result in an increase in the potential range of the networks.

Scientists unveiled a proof-of-concept silicon quantum processor unit cell that operates at a temperature of 1.5 kelvin on April 15. This temperature is several times higher than that of commonly constructed quantum computers. It is likely that it will make it feasible to integrate the qubit array with more traditional control electronics, which will result in a large margin reduction in the total price. One of the most challenging obstacles facing the industry is said to be the cooling requirements that must be met by quantum computers.

On April 16, researchers demonstrated that the Rashba effect may be seen in perovskites that are produced in bulk. Despite the fact that it is thought to be related to the material's exceptional electrical, magnetic, and optical capabilities, which make it a regularly used material for solar cells and quantum electronics, this phenomenon has not yet been evidenced in the material. This is despite the fact that it has yet to be made clear in the material.

On the 8th of May, scientists explained their plans to employ quantum phenomena and microwaves to develop a "concrete proof quantum radar." This kind of radar might be important in the development of future radar technology, surveillance scanning, and computed tomography.

Using femtosecond X-ray laser pulses, a team of researchers has discovered a method that allows them to selectively modify the spin state of connected electrons in a multilayer manganite (May 12). As a result, the use of changes in orbital orientations, known as orbitronics, has the potential to work as the basic bit stream in cutting-edge information technology devices.

On the 19th of May, scientists made the exciting announcement that they had successfully manufactured the first silicon on-chip with integrated circuitry. In order to function properly, high-throughput quantum optical communications need just a single, low-noise piece of evidence.

This report on the evolution stage of rubidium Bose–Einstein gaseous hydrocarbons that took place on June 11 at the Cold Atom Laboratory of the International Space Station might be beneficial to investigations into BECs and quantum mechanics, the rules of which are scaled to macroscopic sizes in BECs. This may be of assistance in the ongoing research and pursuit of few-body physics, as well as in the encouragement of the adoption of strategies for atom-wave electric potential between atoms and maybe other benefits.

On June 15, researchers announced the achievement of the world's smallest traditional chemical complex machine. It is comprised 12 atoms and a rotor that is comprised 4 atoms, and it is capable of being obtained by an electromotive force and beginning to rotate even with very low magnitudes of electricity, as revealed by searching transmission electron microscopy light imaging technology in relation to perturbation theory. This discovery was made possible by scanning electron microscope and light microscopy, which were done in relation to quantum tunneling.

On June 17, quantum scientists made public their development of a system that entangles two-photon quantum communication nodes by means of a microwave cable. This enables information to be transferred between the nodes without the photons themselves ever having to travel through or populate the wire. They announced on June 12 that they had employed a technique called delayed-choice quantum erasure to entangle two phonons and remove data from their measurement.

On August 1, it was announced that global coherence protection had been accomplished in a solid-state spin qubit. This is a tweak that will enable quantum systems to preserve their functioning (or coherence) for 10,000 times longer than was previously achievable.

On the 26th of August, researchers suggested that ionizing radiation, which can come from both naturally radioactive elements and cosmic rays, may have a significant impact on the phenomenon known as quantum tunneling.

On June 17, quantum physicists revealed that they had constructed a system that entangles two-photon quantum communication nodes across a microwave cable. This system is capable of conveying information between the nodes even if the photons never travel through or fill the wire. They announced on June 12 that they had employed a technique called delayed-choice quantum erasure to entangle two phonons and remove data from their measurement.

On August 13, it was announced that global coherence protection has been accomplished in a solid-state spin qubit. This is a tweak that will enable quantum systems to preserve their functioning (or coherence) for 10,000 times longer than was previously achievable.

According to research written by experts and published on August 26, the possibility exists that ionizing radiation from cosmic rays and other radioactive elements in the environment may have a significant impact.

## 1.5 Quantum Communication

The possibility of developing a computing model capable of running Shor's algorithm for large numbers is a driving force in the advancement of quantum communication. For a fuller picture of quantum computers, it is important to keep in mind that these machines will bring about significant time savings for just a subset of all possible jobs. Scientists are working to develop techniques to demonstrate that some problems are indeed susceptible to quantum speedups and are also attempting to learn whether or not such problems exist. As optimization plays crucial roles in fields as diverse as the military and the currency markets, it stands to reason that computers would be of considerable help in solving related problems. Several other applications for qubit systems are being actively researched, but they are beyond the scope of this overview since they are not directly related to computation or modeling. Quantum networks and telephony may lead to new, creative methods of exchanging information [10], while quantum detection and measurement leverage qubits' exceptional sensitivity to the environment to realize sensing much beyond the conventional shot noise limit.

## 1.6 Build Quantum Computer Structure

Quantum computers are incredibly challenging to build. Although there are many possible qubit systems in the subatomic particle range, physicists, engineers, and materials scientists who seek to conduct quantum operations on these systems are always challenged by competing requirements. Qubits must first be protected from outside influences that may otherwise destroy the fleeting quantum states necessary for computation. If a qubit can maintain its ground state for a longer period of time, its coherence time will be longer. In this setting, seclusion plays an important role. Second, qubits need to be entangled, movable across physical structures, and programmable on demand so that algorithms may be carried out. These procedures benefit from increased accuracy. It is difficult to achieve the necessary isolation and interaction, but after decades of research, a number of promising systems are emerging as potential candidates for large-scale quantum systems [11].

In order to build a quantum computer, some of the most promising technologies to use include superconducting innovations, trapped molecule ions, and semiconductors. With respect to consistency, accuracy, and, most importantly, scalability to large systems, each has advantages and disadvantages. However, it is obvious that all of these platforms will need some type of error-correcting mechanism in order to be powerful enough to execute large calculations, and how to design and implement these mechanisms is a huge topic of study in and of itself. For a more in-depth introduction of quantum entanglement and its applications in the real world, see [12].

All calculations that make use of subatomic particles have been lumped together under the umbrella term "quantum computing" for the purposes of this chapter. Different types of dynamic programming exist. It is safe to say that logical, gate-based quantum computing is the most well-known kind. Depending on the kind of qubit, they are created in starting states and then put through a series of gate operations, such as current or laser pulses. Similar to AND, OR, and NOT gates in classical computing, the qubits are placed in the quantum mechanical state, entangled, and used in logical operations. Following this, the qubits are measured, and results are obtained.

The study of complicated qubits is also fundamental to the measurement-based computing paradigm. Then, instead of messing with several qubits, a single qubit is measured, locking it into a predetermined state. The outcomes of these tests on additional qubits inform further measurements, which are conducted until a solution is discovered [13].

Finally, a topological computing framework is built on quasiparticles and their intertwining operations, which are the basis for qubits and processes. Theoretically protected against noise that degrades the coherence of other qubits, topological quantum computer chips are intriguing despite the fact that the first demonstration of this technology has yet to be shown.

Quantum simulators, like Feynman's analog computers, are the last option. Emulators of quantum systems are quantum computers designed for this specific purpose. This knowledge might help them solve issues with high-temperature superconductors, the reactions of certain chemicals, or the construction of materials with desired properties.

## 1.7 Principle Working of Quantum Computers

Because quantum computers can determine the state of an item based on its probability rather than just its binary value, they can handle far more information than traditional computers.

Computing devices of the past were able to execute arithmetic and logic on the fixed coordinates of physical objects. Binary systems rely on just two possible locations for their operations, and this limits them to a limited set of uses. To put it simply, a bit is a binary digit.

Instead, a quantum bit (qubit) is created by using an object's quantum state in quantum computing methods. Prior to their discovery, properties like an object's temperature or the spin of its electrons had no name. A photon's polarization.

Quantum states that cannot be measured are not located in one particular place but rather exist in a "superposition," much like a coin that spins in the air before landing in your hand [14].

Since the outcomes of one set of superposition's might get entangled with those of another, we can infer that the quantities associated with the results of both sets of superposition's are related, even if we do not know what those sets of superposition's are.

The complicated mathematics behind these unstable states of entangled "spinning coins" may be fed into novel algorithms to tackle problems that would take a conventional computer a very long time to calculate, if it could compute them at all.

These algorithms might be used to predict the outcomes of complex chemical reactions, create secure passwords, or solve tough mathematical problems.

### 1.7.1 Kinds of Quantum Computing

Different varieties of quantum mechanics exist. How much computing power (qubits) is needed, how well they can be put to use, and how long it will take for them to become commercially viable are all different for each kind.

What is quantum annealing? When dealing with optimization problems, quantum annealing is the most efficient approach. In other words, scientists are looking for the best possible configuration by testing out many possibilities. Recently, Volkswagen (VW) has been experimenting with quantum technology in an effort to improve traffic flow in Beijing, the most populous city in China. Google and D-Wave Systems worked together to do the research.

If the technology is successful in choosing the optimum route for each vehicle, it might drastically reduce traffic, according to VW. In order to find the most economical travel and logistics solutions for everyone, it may be worthwhile to conduct this research on a global scale, optimizing every aircraft route, airport schedules, weather data, fuel prices, and passenger comfort. A typical computer would need thousands of years to provide a best guess at the solution to such a problem. Quantum computers might potentially complete the task in a few hours or less as the number of qubits per computer increases [15].

A wide range of industrial problems may be addressed by annealing. For instance, in 2015, Airbus, a multinational aerospace and defense company best known for producing both military and civilian aircraft, established a quantum information unit at its Newport, United Kingdom, manufacturing facility. The company is looking into the potential applications of quantum annealing in digital modeling and materials science. A classical computer could replicate every subatomic particle of air flowing over a wing at different angles and speeds in a matter of hours or days, allowing for the identification of the best or most effective raked wingtips in a fraction of the time it now takes researchers. The most basic and restricted kind of quantum computing is known as quantum annealing. According to experts, modern supercomputers can handle optimization problems just as well as the quantum annealed devices shown in Figure 1.3.

Quantum modeling: for problems in quantum physics that cannot be solved by traditional means, researchers are turning to computer simulations. Quantum entanglement's potential use in simulating intricate quantum processes is among its most intriguing applications. Simulation of the response of many subatomic particles to a condition that becomes true, or inorganic chemistry, is an exciting area of study (Figure 1.4).

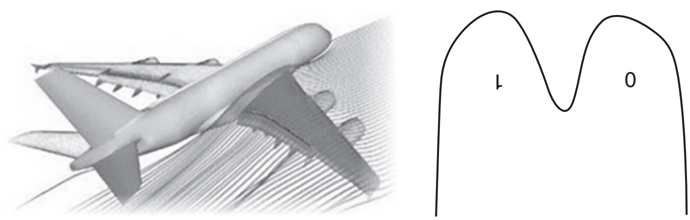

**Figure 1.3** Structure of quantum annealing. Source: Adapted from https://images.app.goo.gl/DeYCU9A7TeJvV5c16 Last accessed 25 Oct 2022.

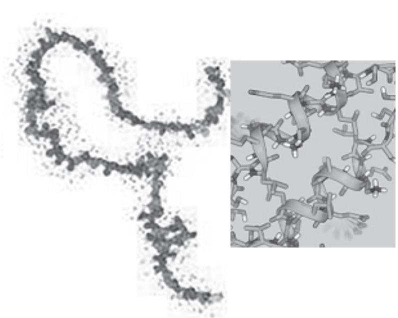

**Figure 1.4** Structure of quantum simulation. Source: Vivien Marx 2021/Springer nature.

Protein folding is a challenging problem in biochemistry that could be replicated with quantum simulations. Researchers testing potential therapeutics for diseases like Alzheimer's and Parkinson's must use stochastic mathematical models to determine which drugs cause reactions for each protein.

Some scientists estimate that it would take longer than the duration of the universe for a protein to fold into its optimal shape if they had to choose among all of the possible drug-induced consequences. If the protein folding sequences could be accurately mapped, it would be a major scientific and medical breakthrough that might ultimately save lives. The vast number of possible protein folding configurations may be calculated with the use of quantum computers, which can speed up the discovery of new and improved pharmaceuticals. In the future, fast designer testing techniques will be possible thanks to quantum algorithms that account for every possible protein–drug interaction.

Quantum computing for all: the most effective and generally applicable kind of computing is quantum, yet it is also the most challenging to build. Some estimates put the minimum number of qubits required for a truly ubiquitous quantum computer at one million. Keep in mind that the current ceiling on available qubits is much below 128 [16].

One of the main ideas underlying the universal quantum system is that it might be put to work on any really difficult problem and quickly provide an answer. Some examples of such work are the solution of the annealing equations stated above and the modeling of quantum events. For a long time now, scientists have been working on algorithms that would need a universal quantum computer to run. Two of the most well-known algorithms are Grover's algorithm for quickly solving equations and Shor's technique for quickly multiplying integers (which may be used for complex code cracking), exploring massive and unstructured data sets (to be used for advanced internet search, etc.)

At now, at least fifty unique algorithms have been developed for implementation on a universal quantum computer. In the distant future, universal quantum computing may radically alter the field of artificial intelligence (AI). It is possible that quantum AI might allow machines to learn at a faster rate than classical computers. While recent research has produced algorithms that might form the basis for quantum machine learning, the hardware requirements need to fully realize quantum AI remain as foreign to us as a general quantum system themselves [17].

## 1.8 Quantum Computing Use in Industry

Despite the hype in Table 1.2, commercial usage of quantum computers is still in its infancy, with just a handful of private enterprises in the sector having raised at least \$50 million (and an even smaller number having raised more than \$100 million).

**Table 1.2** Company funding in quantum technology.

| Country | Quantum technology | Funding in dollars ($) |
|---|---|---|
| Canada | D-Wave | 210 |
| USA | Rigetti | 119 |
| Australia | Silicon Quantum Computing | 66 |
| UK | CQC | 50 |

**Table 1.3** Year-wise investing.

| Years | Dollars |
|---|---|
| 2013 | 10 |
| 2014 | 40 |
| 2015 | 100 |
| 2016 | 40 |
| 2017 | 200+ |
| 2018 | 125 |

D-Wave, the most well-funded private quantum computing startup, has raised $210 million to date, followed by Rigetti Computing ($119 million), Silicon Quantum Computing ($66 million), and Cambridge Quantum Computing (CQC) ($50 million).

Notably, since 2013, 70% of all industry capital has gone toward acquisitions by just these four companies. Table 1.3 also shows that 2018 was the year with the highest volume of sales to private quantum computing companies.

With a six-year increase of more than 200%, from seven in 2013 to twenty-four in 2018, the total number of deals has increased significantly. This year's biggest deal, a $50 million Series C round for Rigetti Computing, closed in August.

With over $200 million invested across 14 deals, 2017 was a record year for funding quantum computing companies. In 2017, Silicon Quantum Computing, Rigetti, 1QBit, IonQ, and D-Wave were the only companies to raise over $20 million in investment.

## 1.9 Investors Invest Money in Quantum Technology

The ecosystem that facilitates the birth of such businesses has been growing in tandem with the increased attention paid to it. Private quantum computing startups have already attracted the attention of major investors in the form of venture capital firms and large enterprises. Investment from Google Ventures (GV), Amazon, and others has helped IonQ toward its goal of developing general-purpose quantum mechanics capable of handling a wide variety of applications. Quantum Circuits, Inc., was backed by the prestigious venture capital company Sequoia Capital (QCI). Rigetti Computing has received a sizeable investment from Andreessen Horowitz (a16z), whereas D-Wave Systems has received many investments from Draper Fisher Jurvetson (DFJ) [18].

In February 2018, South Korean mobile phone carrier SK Telecom entered the fray, joining Germany's Deutsche Telekom in exploring the potential of quantum computing to deliver secure communications. In the wake of a few months for $65 million and a minority stake in the business, the telecom companies have acquired ID Quantique, a provider of quantum-based multi-protocol network cryptography for securing communications. Even the largest companies in the world have their own internal quantum computing projects. An advanced quantum computer made by D-Wave Systems is located at Google's Quantum Artificially Intelligent Lab (QuAIL). The lab is located at NASA's Ames Research Center in Mountain View, California, and is cohosted by NASA and the Universities Space Research Association.

The Alibaba Quantum Computing Laboratory was established in Shanghai, China, in July 2015 by the Chinese Academy of Sciences and Alibaba's Aliyun cloud service. The lab's current focus is on developing quantum data encryption for use in online commerce and data storage facilities. IBM presented the world's first commercial quantum computer at the Consumer Electronics Show (CES) in January 2019. The Q System One from IBM uses 20 qubits and combines classical and quantum features. IBM Q systems are designed to one day overcome difficulties that are presently regarded as being too sophisticated and exponential in nature for conventional systems to handle, but the company's announcement made it clear that commercialized quantum computers would take time to surpass today's conventional machines. Hewlett-Packard, Intel, and Microsoft aren't the only tech giants curious about quantum computing. Companies like Booz Allen Hamilton, Lockheed Martin, and Raytheon, which specialize in the production and development of weapons, have also placed bets on quantum computing as a potential business advantage. The governments of the European Union (EU), the United States (US), Australia (AU), and China (China) are all providing financing for quantum computing research and development [19], in addition to money from corporations.

In the United States, organizations including Los Alamos National Laboratory, the National Security Agency, and NASA are all engaged in quantum computing research and development. Table 1.4: The Chinese government established the first-ever quantum observatory in 2016 to facilitate the development of further methods of secure communication.

**Table 1.4** Companies investing in quantum computing.

| Companies | Quantum technology |
|---|---|
| SK Telecom | ID Quantique |
| Deutsche Telecom | ID Quantique |
| Sequoia | Quantum Circuit |
| Amazon | Ion Q |
| DFJ | D-Wave System |
| Goldman Sachs | D-Wave System, QC Wave |
| Andreessen Horowitz | Rigetti Computing |

## 1.10 Applications of Quantum Computing

- As the price of quantum computing resources decreases, more commercial players will emerge. As more companies join the market, the widespread use of quantum computing will increase, especially in situations where conventional computers are inefficient.
- Its effects are already being seen in many other fields.
- Now is the dawn of the quantum information age. To the best of our knowledge, we are on the cusp of delivering capabilities that are beyond the reach of conventional computers. This sort of computer has this kind of impact in pretty much every field. Vern Brownell, CEO of D-Wave Systems.
- Some potential fields of use for quantum computing range from the medical to the agricultural.
- Healthcare: By analyzing the correlations and effects of numerous medications on a wide range of diseases, quantum computers may facilitate the process of identifying the most effective pharmaceuticals. Furthermore, genetic advancements might be used in conjunction with quantum computing to design individualized treatment plans for each patient. Data generated by next-generation sequencing is so large that it requires a lot of computing power and storage space to represent a single human's whole DNA strand. Although businesses are rapidly decreasing the time and money needed to evaluate genomic data, the use of a quantum computer may make genome sequencing more efficient and scalable on a global scale. An entire generation's worth of sequencing work may be completed in half the time with a quantum computer building and filtering through all possible gene variants simultaneously, discovering all nucleotide pairs swiftly [20]. We may be able to sequence the whole human genome in a single day using the latest rapid quantum generation sequencing technology.

**Figure 1.5** Quantum computing use in healthcare. Source: Bartek Wróblewski/Adobe Stock.

Using quantum computers, we might synthesize patterns in the world's DNA data to learn more about our genetic make-up and maybe even uncover previously unknown illness occurrences, as shown in Figure 1.5.

- The financial sector often uses algorithms constructed from probability and assumptions on future market and investment performance. The use of quantum computing has the potential to help in the eradication of data blind spots and the avoidance of losses brought on by incorrect financial assumptions. In particular, the optimization of investment performance and biometric identification are two areas where quantum teleportation shows the greatest promise for the financial sector. If hundreds of assets with complex relationships are available, quantum computing might be utilized to more efficiently identify fraudulent patterns and build enticing investment portfolios [21].
- Cybersecurity is a concern since quantum computers may be used to decipher the encryption protocols now used to protect sensitive data and documents stored digitally. However, quantum cryptography, which may be performed on quantum computers, might be used to safeguard information from quantum hacking. Quantum cryptography is the idea of securing contact by sending pairs of quantum-entangled particles of light (entangled photons) across long distances in a technique called quantum key distribution (QKD). The most important point is that the encryption system will quickly show signs of failure if quantum encrypted communications are identified, signaling that the interaction is not secure. The reasoning for this is based on the fact that constant observation of a quantum system renders it useless. This is the "measurement effect," as seen in Figure 1.6.
- Agriculture: Fertilizer production might benefit from the use of quantum computers. Almost all fertilizers that are used to grow food for people include

**Figure 1.6** Quantum computing use in satellite for cyber security.

ammonia. Reduced costs and lower energy consumption in fertilizer production would arise from a more efficient means of producing ammonia (or a suitable alternative). Improved access to fertilizers may help both the environment and the world's growing population. Little progress has been made in perfecting the process since there are an infinite number of possible catalyst combinations to create or replace ammonia. Basically, the Haber–Bosch approach, which was created in the 1900s, is necessary for any kind of deliberate imitation of the process. Extreme heat and pressure are needed to convert nitrogen, hydrogen, and iron into ammonia. Digitally testing for the optimal catalysis combination to create ammonia would take years to solve with today's supercomputers. Ammonia production is best optimized with the help of a quantum computer, which can quickly analyze chemical catalytic processes and identify the most effective catalyst combinations. As a matter of fact, we know that tiny bacteria in plant roots perform this same action every day, using a chemical called nitrogenize to do so with a little energy expenditure. Our most powerful supercomputers cannot represent this molecule, but a quantum computer can, as shown in Figure 1.7.

- The cloud: The field of quantum cloud computing is maturing into a commercially relevant field. Access to quantum devices might be made more affordable and programming for them simplified with the help of quantum cloud platforms. QC Ware is a startup in the process of creating a cloud-based quantum computing platform. Investors in QC Ware include Airbus Ventures and Goldman Sachs. Massive corporations like IBM, Google, and Alibaba are all working on quantum cloud computing projects right now.

**Figure 1.7** Ammonia use in agriculture.

## 1.11 Quantum Computing as a Solution Technology

Quantum computers are particularly well-suited to solving problems with an infinite number of variables, encoding and decoding data in a secure manner, and accurately duplicating quantum processes and molecular behavior. To this end, almost all commercially available technology focuses on finding answers to these problems. Notably, security requirements engineering techniques may hold the key to safeguarding our digital future with the help of quantum computers. Automobile and airplane piloting, healthcare provision, economic decision-making, and many other activities are becoming more software dependent. Problems in a codebase may be found and fixed before they have a chance to impact the user experience, thanks to real-time analysis by computer algorithms. Finding bugs in the software that supports these life-or-death processes is becoming more important. Any issue involving nanomaterials can be better tackled with the help of a quantum computer. Potentially, almost any material might be designed using quantum computers. Transportation, building, sensing, the armed forces, medical tools, and many more fields may all benefit. Ultimately, the building blocks of these industries are molecules and atoms, each with its own unique set of quantum mechanical and physical characteristics and linkages.

### 1.11.1 Quantum Artificial Intelligence

In the far future, quantum computers might be used to hasten the development of AI. AI that can carry out complex tasks in a more efficient and human-like manner may one day be created via quantum machine learning. For instance, it enables humanoid robots to make the best possible decisions at the moment, despite the fact that they face uncertainty. The use of quantum computers for AI training might significantly advance the state of the art in several areas, including computer vision, pattern recognition, voice recognition, and computational linguistics. The commercial use of quantum AI is still in its infancy. Zapata Computing, Xanadu, and Qindom are just a few examples of the many companies working to advance the state of the industry via research and innovation.

### 1.11.2 How Close Are We to Quantum Supremacy?

We say that quantum computers have "quantum supremacy" when they can solve problems that classical computers cannot. Keep in mind that the perfect quantum computer would be one that could be used everywhere and would have superior performance to existing computers. Several organizations, some of their government agencies, have claimed to have a quantum computer powerful enough to achieve quantum supremacy. For instance, in March 2018, Google claimed that their 72-qubit processor solved a specially chosen problem faster than conventional computers. Shortly after the announcement, Alibaba's researchers said that they had solved the same issue using conventional methods. This debate exemplifies the critical nature of the race among the world's largest enterprises to become quantum dominant first. Hybrid classical quantum services from companies like D-Wave Systems, Alibaba, IBM, and Rigetti Quantum Computing are at the forefront of today's most advanced quantum computing systems. That is to say, they provide not just robust classical systems but also exceptional quantum capabilities. But things are changing quickly in this industry. By 2030, most industry experts predict, quantum computers will have caught up to, or perhaps surpassed, their classical counterparts in terms of performance. There are still numerous technical obstacles that need to be resolved before computer technology can realize its full potential. Distributing and making available quantum computing power will need the development of more robust hardware, commercial software programming interfaces, and cloud processing capacity.

## 1.12 Conclusion

This chapter addressed the development of quantum computing and suggested that exponential growth in hardware technology is a fair (though not guaranteed) assumption. A quantifiable database documenting successes in the application of quantum computing by various businesses for reasons of security, including the largest physical qubit count and the lowest average two-qubit gate error rates. Consistent with the idea that both measurements are in conflict at a particular stage of technological development, there is a link between the highest qubit counts and the lowest error rates across all technologies.

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