FIRST DRAFT (Ankit Kumar, ARMY INSTITUTE OF TECHNOLOGY)

Overview

The extraordinary progress in the development of computer technologies is usually summarized in the form of “Moore’s Law”. Put simply, Moore’s Law observes that the computer power available for a given sum of money roughly doubles every eighteen months. Like any form of exponential growth, this doubling soon leads to enormous numbers: computer power increases tenfold every five years, one hundredfold every decade, and so on. Moore’s Law has now held for about forty years, during which time the power of computers has increased by a factor of about one hundred million.

But this further increase in computational power requires miniaturization of circuit components this leads to a fundamental problem. The quantum laws are fundamentally different from physical laws and in an atomic level scenario quantum laws dictate the behavior of elements (electrons, interactions, etc.) currently used silicon MOSFET (transistor) depends on the silicon dioxide layer as a dielectric for blocking the flow of electron. But when these layers get thinner than 1.5 nm electrons start to show tunneling across the layer this leads to leakage current in the transistors. So further miniaturizing of elements is not possible for the current type of transistors.

The above limitation is overcome using quantum computing. QC is fundamentally different from or conventional computing techniques. A classical bit is confined to two basic states, 0 and 1, but a quantum bit (qubit) can also enter superposition states, in which the qubit is effectively in both states at once. A classical register made up of n bits can contain any one of 2^n possible numbers, while the corresponding quantum register can contain all 2^n numbers at the same time.

This has a wide variety of applications, in the medical field the testing of drugs ran via stimulation can now be done in a minimal amount of time, true randomness could be achieved via quantum cryptography methodology and many more discussed in the following paper.

Though quantum computers can't do all the works better than their counterpart but surely they can make many things feasible easily like gene sequencing, true randomness, and many other things which when used along with conventional computers will surely take humanity to its new era.

Outline of Existing Works

1982	Quantum mechanical Hamiltonian models of discrete processes that erase their own histories: application to Turing machines-BY Paul Benioff and Richard Feynman.
1994	Shor’s algorithm was introduced it allows a quantum computer to factor large integers quickly this was groundbreaking as it would lead to decrypting any of the current encryption techniques -BY Peter shor at AT&t’s Bell labs.
1997	The first paper was published on gates for quantum computers based on bulk nuclear spin. -BY David cory, Amr Fahmy, and Timothy Havel at MIT.
1998	First working 2 qubit NMR quantum computer was used to solve Deutsch’s problem -BY IBM and Oxford University.
2000	Arun K. Pati and Samuel L. Braunstein proved the quantum no-deleting theorem.
2001	First execution of Shor's algorithm at IBM's Almaden Research Center and Stanford University.
2005	The University of Illinois at Urbana–Champaign scientists demonstrate quantum entanglement of multiple characteristics, potentially allowing multiple qubits per particle.
2007	Controlled-NOT(CNOT) quantum gates on a pair of superconducting quantum bits realized
2012	D-Wave claims a quantum computation using 84 qubits.
2015	Quantum error detection code using a square lattice of four superconducting qubits
2017	D-Wave Systems Inc. announces general commercial availability of the D-Wave 2000Q quantum annealer, which it claims has 2000 qubits.
2019	IBM unveils its first commercial quantum computer, the IBM Q System One
2020	Experimental proof of quantum spin liquid.

Comparative Review

In 1980 Feynman introduced the idea of the Quantum mechanical Hamiltonian process that erases their own histories which had an application for Turing machines. This started the idea for quantum computing.

The basic requirements for experimental quantum computing were first proposed by DiVincenzo19. Which are listed as follows:

1. Stable qubits

   In a real implementation of a quantum computer, the two logical states of each qubit must be mapped onto the eigenstates of some suitable physical system. For a practical computer, the qubits must have long relaxation times to prevent quantum effects from decohering away.

2. Quantum logic gates

   Coherent quantum processes, such as quantum algorithms, are described by unitary transformations. Fortunately, however, it is not necessary to implement arbitrary unitary transformations, as complex transformations can be built up out of simpler building blocks. Just as classical information processing devices are constructed from networks of classical gates, quantum devices are built from networks of quantum logic gates. It is easy to show that any desired network can be built out of single-qubit and two-qubit gates; thus, only one spin and two spin interactions are necessary.

3. An initialization scheme

   Before a quantum algorithm can be run it is necessary to set the computer to some well-defined initial state. In most proposed designs this is realized by some sort of cooling process, allowing all the qubits to relax back to their energetic ground states.

4. Readout

   The final requirement for practical computation is a method for measuring the state of one or more qubits so that the result can be readout.

1. **NMR(Nuclear Magnetic Resonance spectroscopy) type quantum computers:**

The first type of working quantum computer introduce was made of NMR (nuclear magnetic resonance) type qubits. The basic requirement for a working quantum computing was overcome by using the Zeeman levels of 1/2 spin nuclei in a magnetic field. These levels were treated as eigenstates that occur in the superpositioned state thus acting as qubits. these states altered or read using NMR spectroscopy earlier which was used only in the field of chemical analysis. This type of quantum computing has its restrictions as it can't couldn't achieve fully ground state of qubits which is necessary for the initialization step of any Quantum Computing.

A. Ion trap quantum computing

Ion trap qubits have been around for about twenty years but one of the major setbacks was in grouping in a 3-dimensional array of ion qubit where each ion can be monitored for their respective states. To overcome this a new pair of ions is proposed it was mentioned in a paper of MIT's Lincoln Laboratory. As per their findings, a pair of calcium Ca and strontium Sr were proposed for qubit architecture.

These work as a pair in as a Sr^+/Ca^+ crystal. Sr ion houses qubit for computation now in the process of observing the state of qubit there is the possibility of disturbing the system as a whole to prevent this Ca ion (The helper qubit) With a similar mass to the Sr ion, it takes away extra energy from the Sr ion to keep it cool and help it maintain its quantum properties. Laser pulses then nudge the two ions into entanglement, forming a gate through which the Sr ion can transfer its quantum information to the Ca ion.

B. Electron spin-based quantum computer:

The communication between two distant silicon-based qubits devices builds on previous work by the Petta research team. In a 2010 paper in the journal Science, the team showed it is possible to trap single electrons in quantum wells. In the journal Nature in 2012, the team reported the transfer of quantum information from electron spins in nanowires to microwave-frequency photons, and in 2016 in Science, they demonstrated the ability to transmit information from a silicon-based charge qubit to a photon. They demonstrated the nearest-neighbor trading of information in qubits in 2017 in Science. And the team showed in 2018 in Nature that a silicon spin qubit could exchange information with a photon.

The quantum supremacy test:

Quantum computing integrates the two largest technological revolutions of the last half-century, information technology, and quantum mechanics. If we compute using the rules of quantum mechanics, instead of binary logic, some intractable computational tasks become feasible. An important goal in the pursuit of a universal quantum computer is the determination of the smallest computational task that is prohibitively hard for today's classical computers. This crossover point is known as the "quantum supremacy" frontier and is a critical step on the path to more powerful and useful computations

2. Quantum liquid spins

A recent discovery by the University of Arkansas physicists could help researchers establish the existence of quantum spin liquids, a new state of matter. They've been a mystery since they were first proposed in the 1970s. If proven to exist, quantum spin liquids would be a step toward much faster, next-generation quantum computing.

Quantum spin liquids are defined by their unusual magnetic arrangement. Magnets have a north and south pole, which combined are called dipoles. These are typically produced by the quantum spin of electrons. Inside a magnetic material, dipoles tend to all be parallel to each other (ferromagnetism) or periodically alternate their up and down direction (antiferromagnetism). In the case of hypothetical quantum spin liquids, dipoles aren't as well ordered. Instead, they exhibit unusual ordering within a small distance of each other. Different ordering creates different types of spin liquids.

Scientists have focused attention and research on the Kitaev-type of spin liquid. They have looked extensively at two materials – $RuCl_3$ and Na_2IrO but search for many more new types of materials for the liquid. This is said to be the future of quantum computing.

3. Superconducting type quantum computers:

In a quantum computer, the basic idea is to be able to use the phenomenon of superposition but even if a single photon interacts with it loses its quantum state hence losing the data creating an error. In conventional circuit electrons move randomly interacting with any kernel present in the way, this leads to the generation of unwanted photons. this problem is overcome using superconducting circuit cause in superconductors there no electrical loss and hence no photon generation. For the qubit, a B.C Josephson junction is used, in this junction, a thin layer of an insulator is sandwiched between two superconductors. the electrons tunnel through the insulator thus making a junction.

Here each qubit is made from, lc oscillation of small electrical energy between a capacitor and a non-linear inductor, this allows to break the degeneracy of energy level and thus allowing only two states. The inductor is a squid made from B.C Josephson junctions. These qubits have 2 states one |0> where no energy is present and another where |1> one quanta of energy is present. these 2 states are together in superposition with each other making a functional qubit. Currently, only superconducting type quantum computers can achieve 53 and more than 70 qubit processors.

4. **Google supremacy test:**

The success of the quantum supremacy experiment was due to our improved two-qubit gates with enhanced parallelism that reliably achieve record performance, even when operating many gates simultaneously. We achieved this performance using a new type of control knob that can turn off interactions between neighboring qubits. This greatly reduces the errors in such a multi-connected qubit system. We made further performance gains by optimizing the chip design to lower crosstalk, and by developing new control calibrations that avoid qubit defects. They designed the circuit in a two-dimensional square grid, with each qubit connected to four other qubits. This architecture is also forward compatible with the implementation of quantum error-correction. We see our 54-qubit Sycamore processor as the first in a series of ever more powerful quantum processors.

Conclusions

Though the invention of computers leads humanity to great extents for the better half of the century, they'll hit there a limit of optimization and processing power. Thus, the need for development for quantum computing is of great importance. Currently, we are in the NISQ (Noisy Intermediate Scale) era and the scope of quantum computing is limited but as the error reduction algorithm would stabilize and calibrate a large number of qubits the potential will be much more amazing.