Prof.V.B.Shah Institute of Management & R.V.Patel College of Commerce (Eng.Med.)
&V.L.Shah College of Commerce (Guj.Med.) &

Sutex Bank College of Computer Applications & Science, Amroli

(Accredited 'B' (CGPA 2.55) by NAAC Dec.-2009)

VEER NARMAD SOUTH GUJARAT UNIVERSITY,SURAT

SEMINAR REPORT

ON

Google Quantum Computing

AS A PARTIAL REQUIREMENT FOR THE DEGREE

OF

BACHELOR OF COMPUTER APPLICATION

(B.C.A.)

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SUBMITTED BY:
Mr. Karan M. Kasvala (Ex. No:2942)

GUIDED BY:
Asst. Prof. Nayna N. Mistry

Managed By: Jivan Jyot Trust, Amroli
Prof. V.B. Shah Institute of Management, R. V. Patel College of Commerce(E.M.), V. L. Shah College of Commerce (G.M.) &
Sutex Bank College of Computer Applications & Science, Amroli
Self Financed B.B.A.- B. Com. (Eng. Med. & Guj. Med.) - B.C.A. Programme(Affiliated to VNSGU, Surat)
Accredited By : National Assessment & Accreditation Council with 'B' Grade
Address: College Campus, Amroli, Surat - 394107. Ph: 0261 - 2496478, 2495643,+91 - 6354626492
E-Mail: sbccas.amroli@gmail.com Website: www.amrolicollege.org

Certificate

This is to certify that the seminar presentation and report titled "Google Quantum Computing" is the bonafide work carried out by Mr. KARAN M. KASVALA (Ex. No:2942), students of TYBCA Sem-VI of Sutex Bank College of Computer Application and Science, Amroli, (Surat) affiliated to Veer Narmad South Gujarat University. she has successfully completed her seminar work in partial fulfillment of the requirements for the award of the degree of "Bachelor of Computer Application" during the academic year 2020-21.

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Asst. Prof. Nayna M. Mistry
Seminar Guide

Dr. Mukesh Goyani
In-charge Principal

Date:
Place: **Amroli, Surat.**

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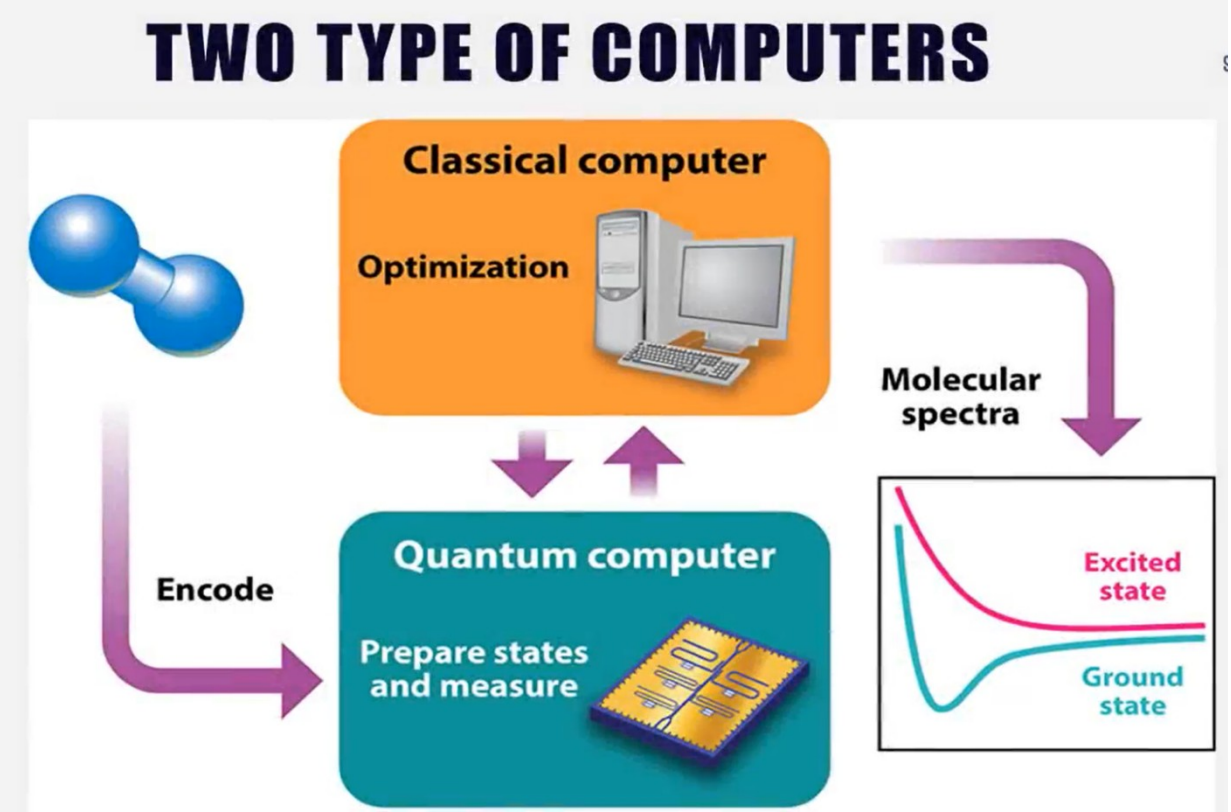
1). Types of Computer

- Basically, we can categorize the computer in 2 types As below,



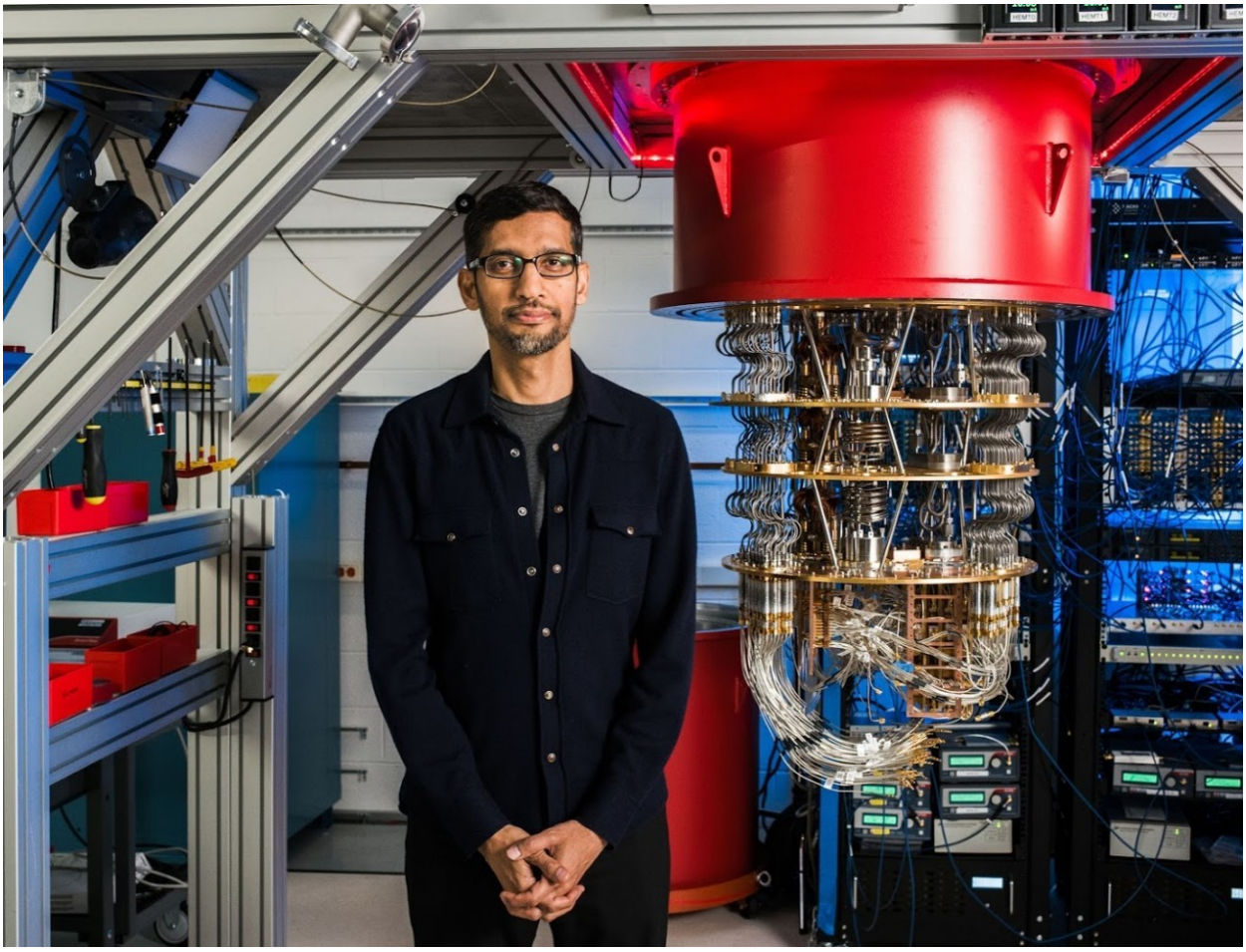
- Classical computers, which we use on a daily basis, are built upon the concept of digital logic and bits. A bit is simply an idea, or an object, which can take on one of two distinct values, typically labelled 0 or 1. In computers this concept is usually embodied by transistors, which can be charged (1) or uncharged (0). For arguments sake, classical coins are also perfectly good bits. A computer encodes information in a series of bits, and performs operations on them using circuits called logic gates. Logic gates simply apply a given rule to a bit. For example, an OR gate takes two bits as input, and outputs a single value. If either of the inputs is 1, the gate returns 1. Otherwise, it returns 0. Once the operations are finished, the information regarding the output can be decoded from the the bits.

- Engineers can design circuits which perform addition and subtraction, multiplications… almost any operation that comes to mind, as long as the input and output information can be encoded in bits. And from these ideas modern computers were developed, and have led to a revolution in both the consumer market and the scientific world. In the latter, because computers can perform calculations so fast that rooms full of people would fall centuries behind in a race. For some applications, however, even computers are not fast enough. Some tasks are so laborious to complete that computers wouldn't be able to do so even given the entire age of the universe.

- The most important characteristics of a computer is how fast it can perform calculations (the clock speed in our domestic PCs is a measure of this). This is determined by two main factors. One is the processor, which determined how many operations can be carried out on bits in a given time interval. The other is the nature of the calculation: how many operations on bits it takes to carry it out.
- This is why it is key to have optimized algorithms; you want to complete a given task in as few steps as possible. The problem is that even the most sophisticated versions of some tasks, like integer factoring, require an enormous amount of operations to be completed. These are the kind of tasks that could take billions of years to complete even on the best computers.
- This inconvenience largely stems from the limitations of bits, forced to be either being in a 0 or a 1 state. This introduces restrictions on what you can do to these units of information. Enter the quantum computer.

2). Introduction of Quantum Computing

- **Quantum computing** is the use of quantum mechanical phenomena such as entanglement and superposition to perform computation. Computers that perform quantum computations are known as **quantum computers**. Quantum computers are believed to be able to solve certain computational problems, such as integer factorization (which underlies RSA encryption), substantially faster than classical computers. The study of quantum computing is a subfield of quantum information science.



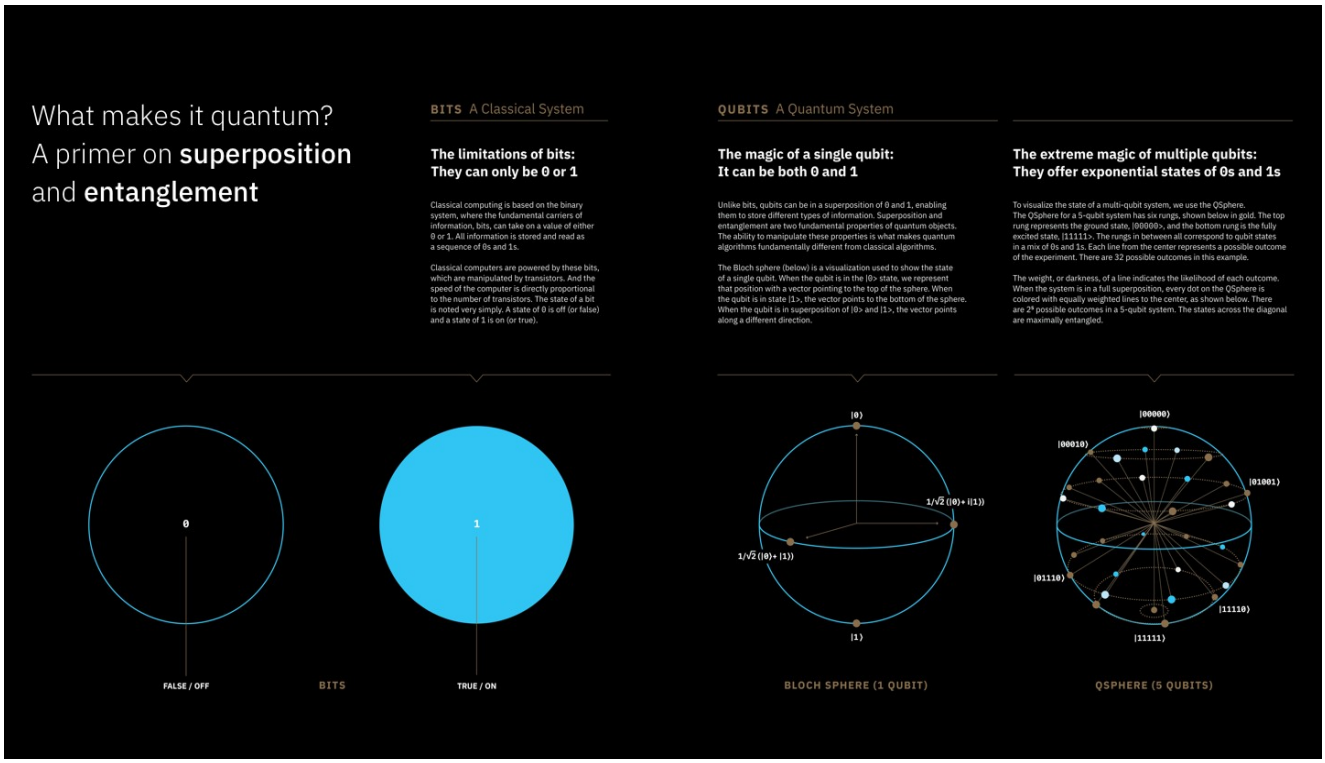
(fig. Quantum computer with Sundar Pichai, who was the CEO of Google)

History

- Quantum computing began in the early 1980s, when physicist Paul Benioff proposed a quantum mechanical model of the Turing machine. Richard Feynman and Yuri Manin later suggested that a quantum computer had the potential to simulate things that a classical computer could not. In 1994, Peter Shor developed a quantum algorithm for factoring integers that had the potential to decrypt RSA-encrypted communications. Despite ongoing experimental progress since the late 1990s, most researchers believe that "fault-tolerant quantum computing [is] still a rather distant dream." In recent years, investment into quantum computing research has increased in both the public and private sector. On 23 October 2019, Google AI, in partnership with the U.S. National Aeronautics and Space Administration (NASA), published a paper in which they claimed to have achieved quantum supremacy. While some have disputed this claim, it is still a significant milestone in the history of quantum computing.

How it differs from Classical Computer

- There are several models of quantum computing, including the quantum circuit model, quantum Turing machine, adiabatic quantum computer, one-way quantum computer, and various quantum cellular automata. The most widely used model is the quantum circuit. Quantum circuits are based on the quantum bit, or "qubit", which is somewhat analogous to the bit in classical computation. Qubits can be in a 1 or 0 quantum state, or they can be in a superposition of the 1 and 0 states. However, when qubits are measured the result of the measurement is always either a 0 or a 1; the probabilities of these two outcomes depend on the quantum state that the qubits were in immediately prior to the measurement. Computation is performed by manipulating qubits with quantum logic gates, which are somewhat analogous to classical logic gates.



(fig. bits representation of classical computer and qubit representation of quantum computer**)**

Approaches

- There are currently two main approaches to physically implementing a quantum computer: **analog and digital**. Analog approaches are further divided into quantum simulation, quantum annealing, and adiabatic quantum computation.

- Digital quantum computers use quantum logic gates to do computation. Both approaches use quantum bits or qubits. There are currently a number of significant obstacles in the way of constructing useful quantum computers. In particular, it is difficult to maintain the quantum states of qubits as they are prone to quantum decoherence, and quantum computers require significant error correction as they are far more prone to errors than classical computers.

3). Introduction of Google Quantum Supremacy

● Introduction

- In quantum computing, **quantum supremacy** is the goal of demonstrating that a programmable quantum device can solve a problem that no classical computer can feasibly solve (irrespective of the usefulness of the problem). By comparison, the weaker **quantum advantage** is the demonstration that a quantum device can solve a problem merely faster than classical computers.
- Conceptually, quantum supremacy involves both the engineering task of building a powerful quantum computer and the computational-complexity-theoretic task of finding a problem that can be solved by that quantum computer and has a super polynomial speedup over the best known or possible classical algorithm for that task. The term was originally popularized by John Preskill but the concept of a quantum computational advantage, specifically for simulating quantum systems, dates back to Yuri Manin's (1980) and Richard Feynman's (1981) proposals of quantum computing.
- Examples of proposals to demonstrate quantum supremacy include the boson sampling proposal of Aaronson and Arkhipov, D-Wave's specialized frustrated cluster loop problems, and sampling the output of random quantum circuits.

● Companies tried to achieve Quantum supremacy

- **Major market player in Quantum computing:**

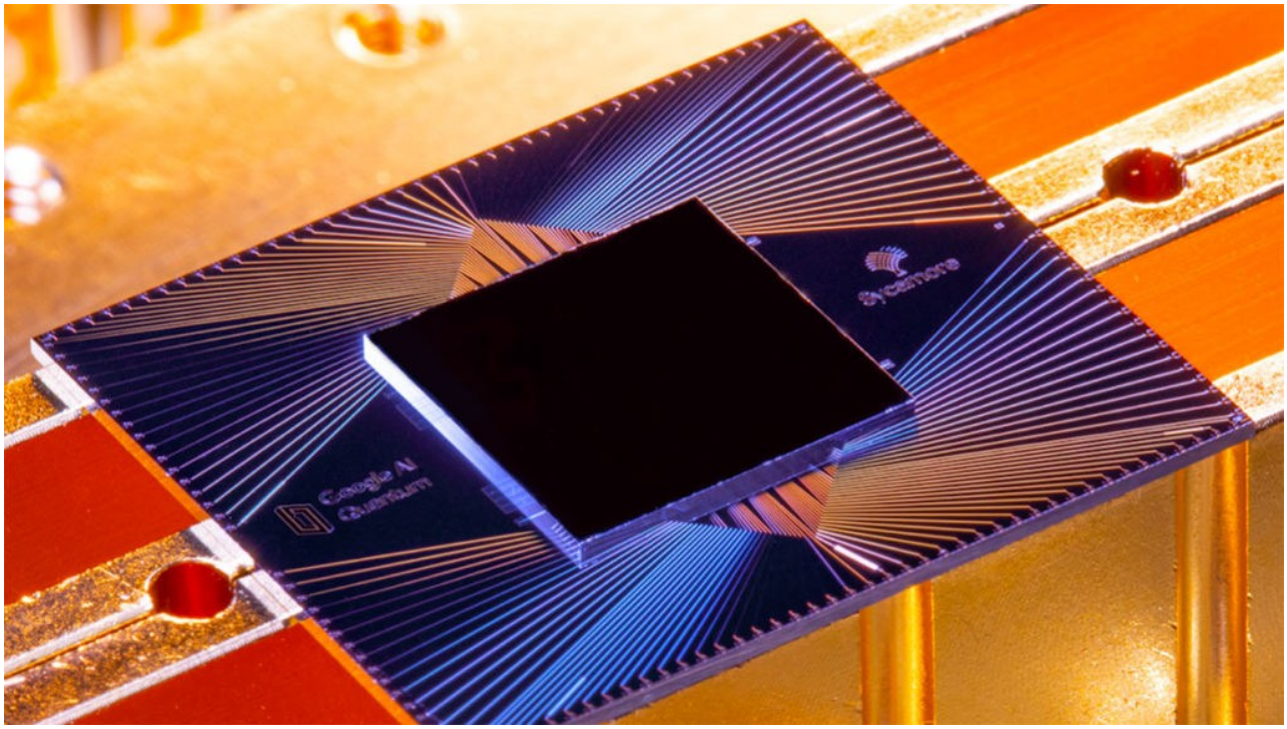
    1. D-Wave Systems Inc.
    2. IBM Corporation
    3. Lockheed Martin Corporation
    4. Intel Corporation
    5. Anyon Systems Inc.
    6. Cambridge Quantum Computing Limited

- Like factoring integers, sampling the output distributions of random quantum circuits is believed to be hard for classical computers based on reasonable complexity assumptions.
- Google previously announced plans to demonstrate quantum supremacy before the end of 2017 by solving this problem with an array of 49 superconducting qubits.
- In early January 2018, Intel announced a similar hardware program.
- In October 2017, IBM demonstrated the simulation of 56 qubits on a conventional supercomputer, increasing the number of qubits needed for quantum supremacy.
- In November 2018, Google announced a partnership with NASA that would "analyse results from quantum circuits run on Google quantum processors, and... provide comparisons with classical simulation to both support Google in validating its hardware and establish a baseline for quantum supremacy.
- Theoretical work published in 2018 suggests that quantum supremacy should be possible with a "two-dimensional lattice of 7x7 qubits and around 40 clock cycles" if error rates can be pushed low enough.
- On June 18, 2019, Quanta Magazine suggested that quantum supremacy could happen in 2019, according to Neven's law. On September 20, 2019, the *Financial Times* reported that "Google claims to have reached quantum supremacy with an array of 54 q[u]bits out of which 53 were functional, which were used to perform a series of operations in 200 seconds that would take a supercomputer about 10,000 years to complete".
- The quantum supremacy experiment was run on a fully programmable 54-qubit processor named "Sycamore."

3.1) Sycamore- Google Quantum processor

● Introduction

- **Sycamore** is the name of Google's quantum processor, comprising 54 qubits.



(fig. Sycamore – Google quantum processor**)**

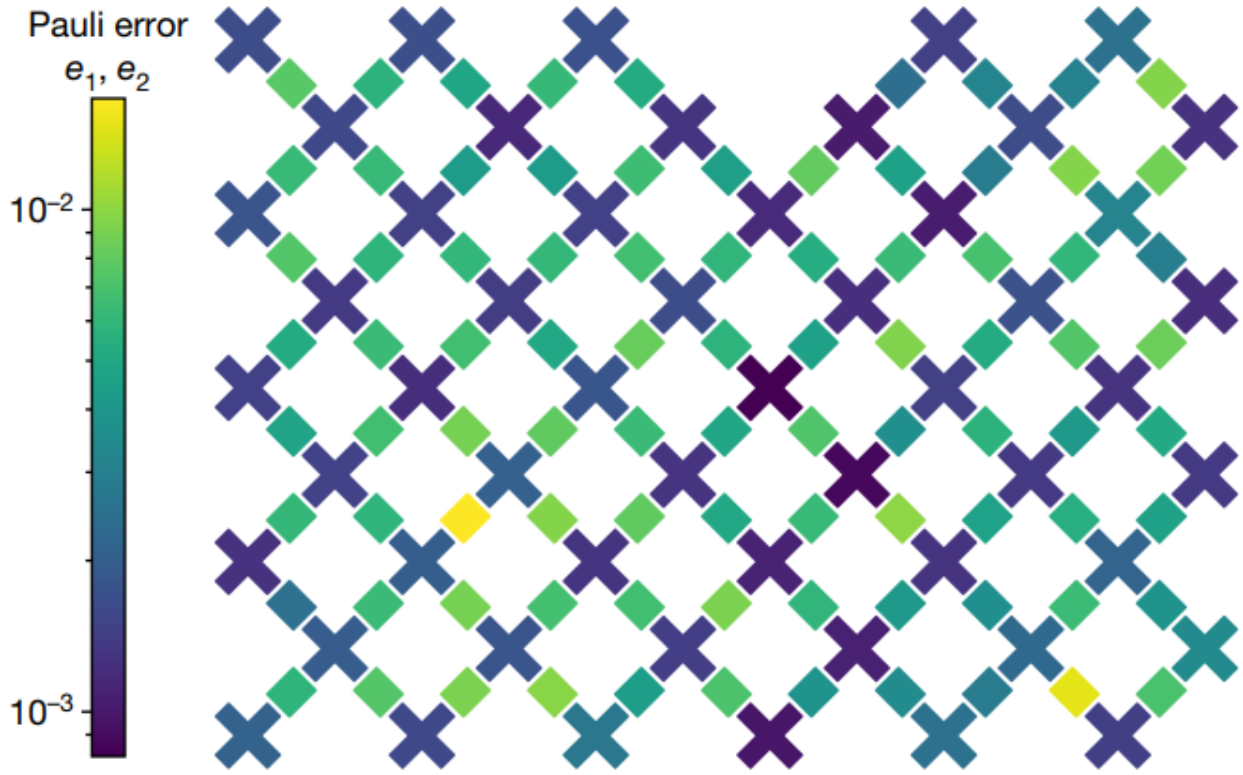
- In 2019, Sycamore completed a task in 200 seconds that Google claimed, in a *Nature* paper, would take a state-of-the-art supercomputer 10,000 years to finish. Thus, Google claimed to have achieved quantum supremacy.
- Google says that its 54-qubit Sycamore processor was able to perform a calculation in 200 seconds that would have taken the world's most powerful supercomputer 10,000 years. That would mean the calculation, which involved generated random numbers, is essentially impossible on a

traditional, non-quantum computer.

(fig. quantum computer with sycamore processor**)**

● How it works

- It's comprised of a two-dimensional grid where each qubit is connected to four other qubits. As a consequence, the chip has enough connectivity that the qubit states quickly interact throughout the entire processor,
- 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. Google achieved this performance using a new type of control knob that is able to turn off interactions between neighbouring qubits. This greatly reduces the errors in such a multi-connected qubit system. They made further performance gains by optimizing the chip design to lower crosstalk, and by developing new control calibrations that avoid qubit defects.



(fig. Heat map showing single- (e1; crosses) and two-qubit (e2; bars) Pauli errors for all qubits operating simultaneously. The layout shown follows the distribution of the qubits on the processor**)**

- We designed the circuit in a two-dimensional square grid, with each qubit connected to four other qubits. This architecture is also forward compatible for 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.

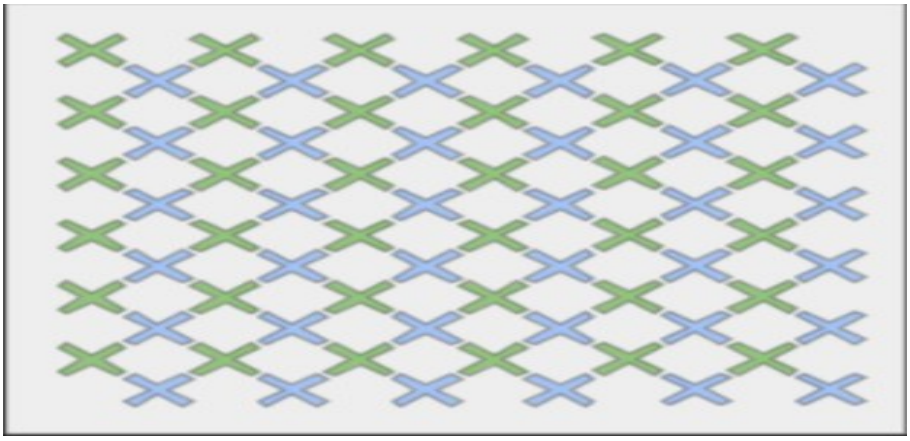
3.2) Bristlecone - Google Quantum processor

(fig. Bristlecone – Google Quantum Processor)

● Introduction

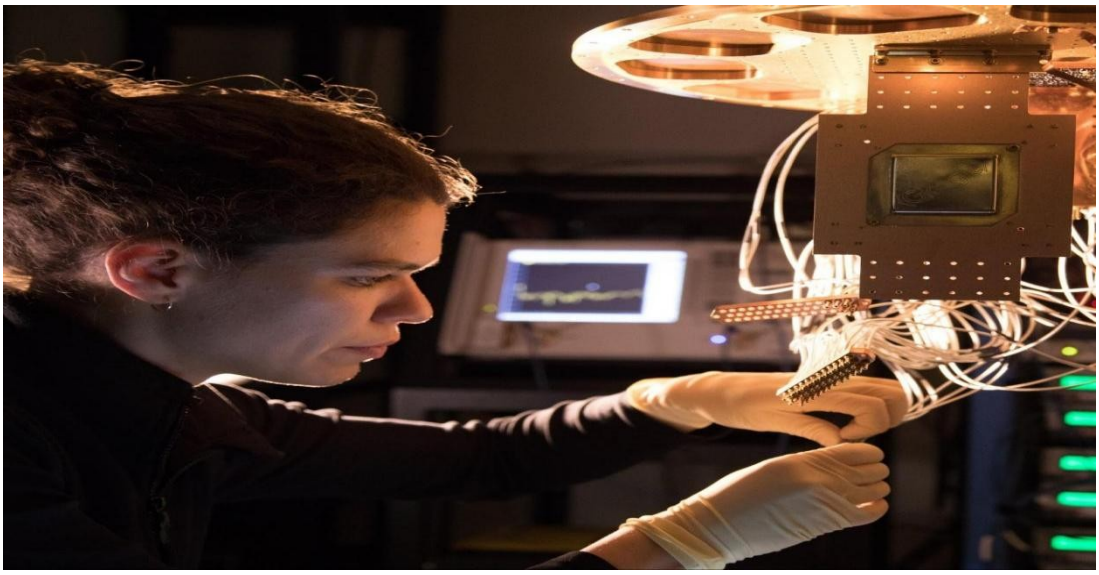
- Bristlecone is the Google's quantum processor which contains 72 qubits for processing.
- The goal of the Google Quantum AI lab is to build a quantum computer that can be used to solve real-world problems. Our strategy is to explore near-term applications using systems that are forward compatible to a large-scale universal error-corrected quantum computer.
- In order for a quantum processor to be able to run algorithms beyond the scope of classical simulations, it requires not only a large number of qubits. Crucially, the processor must also have low error rates on readout and logical operations, such as single and two-qubit gates.
- On 5th march 2018, Google announced their new quantum processor called 'Bristlecone'. At the annual American Physical Society meeting in Los Angeles.
- The purpose of this gate-based superconducting system is to provide a testbed for research into system error rates and scalability of our qubit technology, as well as applications in quantum simulation, optimization, and machine learning.

● How it Works



(fig. cartoon of the device: each "X" represents a qubit, with nearest neighbour connectivity.**)**

- The guiding design principle for this device is to preserve the underlying physics of our previous 9-qubit linear array technology1, 2, which demonstrated low error rates for readout (1%), single-qubit gates (0.1%) and most importantly two-qubit gates (0.6%) as our best result. This device uses the same scheme for coupling, control, and readout, but is scaled to a square array of 72 qubits. We chose a device of this size to be able to demonstrate quantum supremacy in the future, investigate first and second order error-correction using the surface code, and to facilitate quantum algorithm development on actual hardware.



(fig. A Bristlecone chip being installed by Research Scientist Marissa Giustina at the Quantum AI Lab in Santa Barbara**)**

- They are looking to achieve similar performance to the best error rates of the 9-qubit device, but now across all 72 qubits of Bristlecone.

- Google believe Bristlecone would then be a compelling proof-of-principle for building larger scale quantum computers. Operating a device such as Bristlecone at low system error requires harmony between a full stack of technology ranging from software and control electronics to the processor itself. Getting this right requires careful systems engineering over several iterations.

3.3) Sycamore VS Summit

(fig. Summit- World's Most powerful & fastest Supercomputer at IBM**)**

- Summit or OLCF-4 is a supercomputer developed by IBM for use at Oak Ridge National Laboratory, which as of November 2019 is the fastest supercomputer in the world, capable of 200 petaFLOPS.
- As of November 2019, the supercomputer is also the 5th most energy efficient in the world with a measured power efficiency of 14.668 gigaFLOPS/watt.
- Summit is the first supercomputer to reach exaflop (a quintillion operations per second) speed, achieving 1.88 exaflops during a genomic analysis and is expected to reach 3.3 exaflops using mixed precision calculations.

● IBM Challenge to Sycamore processor.

- IBM refuted Google's claim around the same time as Google's Nature paper was published. Google had claimed that IBM's supercomputer, Summit,

would take 10,000 years to solve the problem Google's Sycamore had solved in a mere 200 seconds.

- On October 23, Google officially confirmed the claims. IBM responded by suggesting some of the claims are excessive, and suggested that it could take 2.5 days instead of 10,000 years.
- IBM showed that Summit, with clever programming and using its huge disk space, could actually solve the problem in only 2.5 days.
- Sycamore still beat Summit on this specific problem by solving it 1,100 times faster, but not 157 million times faster, as Google had claimed. According to IBM, this does not establish quantum supremacy as that requires solving a problem a conventional computer cannot solve in a reasonable amount of time. Two and a half days is reasonable, therefore — according to IBM — quantum supremacy is yet to be attained.

4). Application Areas

- **Artificial Intelligence**

  - Artificial intelligence and machine learning are some of the prominent areas right now, as the emerging technologies have penetrated almost every aspect of humans' lives. Some of the widespread applications we see every day are in voice, image and handwriting recognition. However, as the number of applications increased, it becomes a challenging task for traditional computers, to match up the accuracy and speed. And, that's where quantum computing can help in processing through complex problems in very less time, which would have taken traditional computers thousands of years.

- **Cryptography & Cyber security**

  - The online security space currently has been quite vulnerable due to the increasing number of cyber-attacks occurring across the globe, on a daily basis. Although companies are establishing necessary security framework in their organisations, the process becomes daunting and impractical for classical digital computers. And, therefore, cybersecurity has continued to be an essential concern around the world. With our increasing dependency on digitisation, we are becoming even more vulnerable to these threats. Quantum computing with the help of machine learning can help in developing various techniques to combat these cyber security threats. Additionally, quantum computing can help in creating encryption methods, also known as, quantum cryptography.

- **Logistics and Scheduling**

  - Many common optimizations used in industry can be classified under logistics and scheduling. Think of the airline logistics manager who needs to figure out how to stage his airplanes for the best service at the lowest cost. Or the factory manager who has an ever-changing mix of machines, inventory, production orders, and people and needs to minimize cost, throughput times and maximize output. Or the pricing manager at an automobile company who needs to figure out the optimum prices of all the dozens car options to maximize customer satisfaction and profit. Although, classical computing is used heavily to do these tasks, some of them may be too complicated for a classical computing solution whereas a quantum approach may be able to do it.

- **Drug Design & Development**

  - Designing and developing a drug is the most challenging problem in quantum computing. Usually, drugs are being developed via the trial and error method, which is not only very expensive but also a risky and challenging task to complete. Researchers believe quantum computing can be an effective way of understanding the drugs and its reactions on humans which, in turn, can save a ton of money and time for drug companies. These advancements in computing could enhance efficiency dramatically, by allowing companies to carry out more drug discoveries to uncover new medical treatments for the better pharmaceutical industry.

- **Weather Forecasting**

  - Currently, the process of analysing weather conditions by traditional computers can sometimes take longer than the weather itself does to change. But a quantum computer's ability to crunch vast amounts of data, in a short period, could indeed lead to enhancing weather system modelling allowing scientists to predict the changing weather patterns in no time and with excellent accuracy — something which can be essential for the current time when the world is going under a climate change. Weather forecasting includes several variables to consider, such as air pressure, temperature and air density, which makes it difficult for it to be predicted accurately. Application of quantum machine learning can help in improving pattern recognition, which, in turn, will make it easier for scientists to predict extreme weather events and potentially save thousands of lives a year. With quantum computers, meteorologists will

also be able to generate and analyse more detailed climate models, which will provide greater insight into climate change and ways to mitigate it.

5). Advantages of Quantum Computing

- **Faster Execution compare then classical computer.**

  - The main advantage of quantum computing is it can **perform any task faster** as compared to a classical computer. Because atoms move faster in a quantum computer than a classical computer.

- **Exponential Speedup**

  - In quantum computing qubit is the conventional **superposition state** and so there is an advantage of exponential speedup which is resulted by handle number of calculations.

- **Improvement in Drug Development**

  - Quantum computer will **speed up the development of drugs** which will improve the chemical industry and even suck carbon dioxide out of the atmosphere to curb climate change.

- **Better Security System**

  - Quantum computers can be used in **cryptography** for more secure data **encryptions**. Quantum computer can compute the data faster than the classical computer, so it will crack the password and damage the system securities in a moment. If this system will use for the wrong intentions...? The Scientist still continue their research on the quantum computing algorithms for creating a quantum hackproof security system.

- **Easily perform classical and quantum algorithms.**

  - Quantum computing is even classical algorithm calculations are also performed easily which is similar to the classical computer.

- **There are some more advantages of the quantum computing describe as below,**
  - Quantum computers can be used in stock markets for detecting problems. Quantum computers can be used in Mathematical field for better optimization.

- Quantum computers can be used in Mathematical field for better optimizations. Quantum computers can be used for the Google search engine to show the most relevant searches.

6). Disadvantages of the Quantum Computing

- **Costly**
  - The main disadvantage of the quantum computer is its price. Most of the small business may can't afford such an expensive machine.
- **Temperature**
  - Quantum computers need a lot of cooling to work properly. When Qubits changes their state while calculating it will produce the heat, so in that temperature computer doesn't work properly. For example, 460 degrees F.
- **Unbearable sound of Qubits**
  - While Quantum computer works the qubits of the processor constantly change their state i.e. on / off / on-off. At that time qubits produce the noise while changing state and this sound is unbearable.
  - The technology required to implement a quantum computer is not yet available. The reason is that electron (Essential element of quantum computing) is damaged as soon as it is affected by the environment.
- **Consume More power supply**
  - Still, Quantum computer is very big in the size, so it will consume more power supply then the regular classical computer.
- **Damage Today's Security System**
  - According to theoretical research with quantum computing every computer on this planet will become vulnerable even nuclear codes can be hacked with quantum computing. What will happen if it gets in the wrong hands...? The Quantum technology can easily break the today's security system and complex password.

- Scientist still, working on the creating a hackproof quantum algorithms for security system. Otherwise anyone can damage the world's any security system or any device.

- **Lack of quantum algorithms**

  - We Need tons of new Quantum algorithms to reach its full potential. Because without these algorithms a Quantum computer will work only as a classical computer. In short, there will be no advantage to a quantum computer without quantum algorithms.

- There are some other disadvantages of Quantum computing is available described as below,

  - If a result of a computation is not in a base position, the answer is too difficult to understand.

  - Many companies claim they have built quantum computers including IBM and D-wave etc. Even if they have built a quantum computer, we don't have enough experience with Quantum computer. For example, D-wave solved sudoku and many other puzzles using a quantum computer, even a classical computer can do that.

7). Google AI Quantum Research Team

(fig. The Google AI Quantum Research Team member**)**

- Google AI Quantum is advancing quantum computing by developing quantum processors and novel quantum algorithms to help researchers and developers solve near-term problems both theoretical and practical.

- They think quantum computing will help us develop the innovations of tomorrow, including AI. That's why we're committed to building dedicated quantum hardware and software today.

- Quantum computing is a new paradigm that will play a big role in accelerating tasks for AI. They want to offer researchers and developers access to open source frameworks and computing power that can operate beyond classical capabilities.

- There are 39 members in the Google AI Quantum Team.

- The Google AI quantum Research team achieved the quantum supremacy while experiment at the **Santa Barbara, California's,** Google Artificial Intelligence Laboratory.

8). Conclusion

Quantum computing is still in its early stages of development, and many computer scientists believe the technology needed to create a practical quantum computer is years away. Quantum computers must have at least several dozen qubits to be able to solve real-world problems, and thus serve as a viable computing method.

The task performed isn't super important for this milestone. It's much more about the fact that the milestone happened in the first place, the email from Google said. It cites the **Wright Brothers** as an analogy:

"For them to demonstrate that aviation is possible, it didn't matter so much where the plane was headed, where it took off and landed but that it was able to fly at all."

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