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An Introduction to the Process of Quantum Computing

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Abstract:

Quantum information processing is the result of using the physical reality that quantum theory tells us about for the purposes of performing tasks that were previously thought impossible or infeasible. Devices that perform quantum information processing are known as quantum computers. Quantum theory has emerged as an advancement in scientific thoughts which helps in analysing inconceivable situations. Like various laws in physics, information can be processed in various ways in computer. At present, there are various algorithms which enhances the advantages of quantum computers. In this paper, we will study about the basics of quantum computing,. If we believe the hype, this nascent technology embodies the promise of the future and has the potential to revolutionize our lives with its turbo-charged computation.

Keywords — **Quantum computing, Entanglement, Superposition**

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I. INTRODUCTION

Before we can even begin to talk about the potential applications of quantum computers we need to understand the fundamental physics that drives the theory of quantum computing. We will need to dive into another dimension , smaller and more alien than anything we intuitively understand : the subatomic world of quantum mechanics. Feynmans's Idea in the 1980's , one of the most important physicists of 20^{th} century encountered a major roadblock. Quantum systems by nature are fragile and the information they hold hides from us. [1]As , Feynman could not directly observe quantum events, he wanted to design a simulation. A he added particles to the quantum systems, he was modeling, the cost of computation began to rise exponentially. He concluded that classical computers just cannot scale up fast enough to keep pace with the growing complexity of quantum calculations. After this, he started to build a bridge between quantum physics and computer science.

To understand how quantum computing works, it's essential to start by understanding what makes it quantum. [2]It is the classical rule of probability that tell us about getting tails if we toss a coin. Before measuring a subatomic particle, we can think about it as a wave of probability that exists in a kind of black-box – a quantum system with many different chances of being in different places.

Next is how can quantum computers use amplitudes to store and manipulate information quantumly? This is qubit, a basic computational unit in quantum computing. Qubits are like bits but qubits are madeup of subatomic particles so they operate according to subatomic logic. Qubits can be 0,1 or linear combination of 0 and 1. Before we measure a qubit, it exists in a state called superposition. It can be considered as a quantum version of a probability distribution. Problem is when a quantum system is measured, it collapses into a classical state. Scientists can harness interference by creating a deterministic sequence of qubit gates. These qubit gates causes the amplitudes to add up constructively. Since 1994, there have been a few major breakthroughs in quantum algorithms, with theoretical applications in fields such as cyber security and search optimization.

II. STRUCTURE OF QUANTUM COMPUTERS

The register R of a quantum computer holds n input qubits and the register W represents n output qubits:

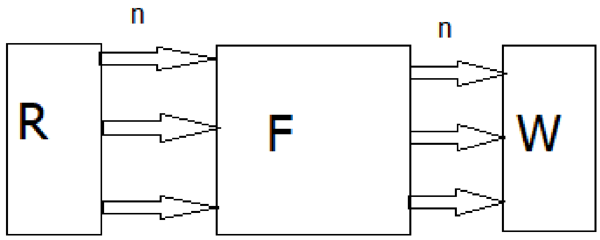

Fig 1: Structure of quantum computer

The input register can be setup as a superposition of states, such as superposition of all the numbers from 0 to 2^n . The function applied to all 2^n integers is then calculated in parallel by the computer. According to the quantum measurement postulate, every bit from the output register is assigned a Boolean value when we measure W based on the entangled wave of qubits that results. We must construct F in order to increase the likelihood that the desired answer and the output we are measuring are same.[3]

III. QUANTUM COMPUTING PRINICPLES

A. Superposition State

In conventional computers, electrical signals like voltages represent 0 and 1 states as one bit information. Two bits can represent four states. The bits 00, 01, 10 and 11 can represent 2n states and 2n states can be represented by n bits. Quantum computers represent 1-bit data by two state quantum bit called 'qubit'. Spin up of an electron reflects two states, 0 and 1 respectively via spin down. A photon representing both vertical and horizontal polarization can be used as a qubit. With the help of qubits, a quantum computer can perform arithmetic and logical operations. Superposition principle denotes the ability of a quantum system to be in multiple states at the same time until it is measured.

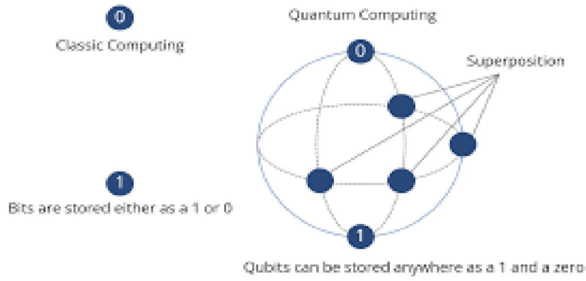

Fig 2: Superposition in quantum computing

Recommended font sizes are shown in Table 1.

B. Entanglement

It means two members of a pair exist in a single quantum state. If there is change in the state of one qubit, it will simultaneously change the state of another one. Using a pair of entangled quantum systems, it is possible to carry out computing and cryptographic operations that are impractical for conventional systems. A pair of set of particles is said to be entangled when each particle's quantum state cannot be independently represented from the quantum state of the other. The system's overall quantum state can be expressed even while its component pieces are not in clear state. When two qubits are entangled, they have a unique relationship. Depending on how each qubit is tested, the result could be 0 or 1. [4]However, the outcome of a measurement on one qubit will always be compared to the outcome of a measurement on the other qubit. It can be represented with the help of a Bell state example :

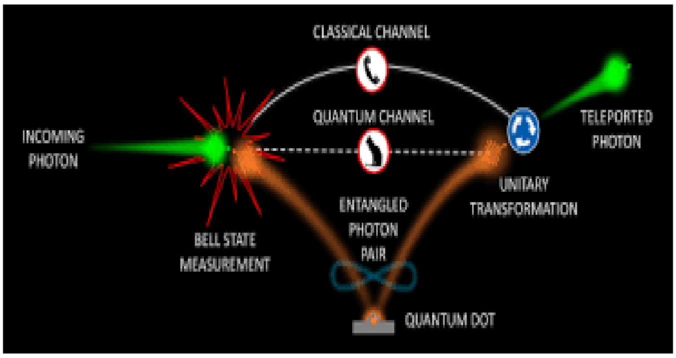

Fig 3 : Entangled photons

IV. VARIOUS QUANTUM COMPUTING ALGORITHMS

A. *Quantum Factoring to find hidden sources*

A significant advancement in the field of quantum algorithms was made by Shor's discovery of polynomial time algorithms for factoring and computing discrete algorithms. This was due to both apparent speedup for classical algorithms and the ramifications of this speedup for existing applications.

Shor initially transformed the issue of determining the components of a number into a problem that involves determining a repeating pattern exactly what the FT detects- in order to be able to utilize the capabilities of the QFT. Finding the period in a sequence of numbers is equal to the factoring problem, even though the length of sequence of numbers is exponentially greater than the number of bits in the corresponding number to be factored.

B. *Grover's Algorithm*

This algorithm looks for a marked entry in an unstructured database(or an unordered list) with N entries using O(sqrt(n)) only instead of O(N) queries. Grover's approach specifically addresses the issue of identifying the distinct inputs to a given function that would produce a particular outcome. This is a classic example of an NP Hard problem meaning that there are no known polynomial time solution to the problem.

The drawback of the traditional exhaustive search approach method is that each response is systemically tested as blind and guess check with no information about the answer being revealed until it is actually located. Grover's algorithm moves forward by repeatedly performing a pair of two operations on the qubits. By altering the sign of its coefficient, the first effectively flags the state corresponding to the right response. The amount of this coefficient can then be slightly increased by the second also known as Grover diffusion operator. [5]

V. PROBLEM BASED ON QUANTUM WALKS

The quantum equivalent of a classical random walk is a quantum walk, which can be characterized by a probability distribution over a set of states. A quantum superposition over states can be used to describe a quantum walk. For some black- box issues, quantum walks are known to provide exponential speedups.[6]

A. *Element distinctness problem*

It is the problem of finding out whether each member in a list is distinct or not. A randomized algorithm that inserts each item into a hash table and compares only those elements that are placed in same hash table cell can also solve the problem in linear expected time. The problem can also be solved by sorting the list and then checking if there are any consecutive equal elements.

B. *Triangle Finding Problem*

It is the problem of finding whether a given graph contains a triangle. Algorithm is frequently required to output the three vertices that makes up a triangle in the graph when it does exist.

C. *Formula Evaluation*

Each internal node of a formula has a gate and each leaf node has an input bit. Given Oracle access to the input, the challenge is to assess the formula, which is the root node's output.

VI. CHALLENGES

Two types of challenges are there in building a quantum computer : Physics and engineering.

The primary physics issues include defining techniques to improve the precision of the qubit and to make up for errors that occur during quantum operations, as well as the coherence time of output bits in superposition state. The phrase "scalability" best describes the engineering challenge. Numerous articles demonstrates that in order to accomplish any significant quantum action, we will require a very large number of qubits due to aforementioned physical difficulties.

Other challenges are fabrications, verification and architecture. The ability of quantum computing to store a complicated state in single bit is what gives it its power. This is also the reason why designing, building and verifying quantum systems is challenging. Because quantum states are delicate, production must be exact and bits frequently need to operate at extremely low temperatures. Verification is challenging as it may not be possible to measure the full state precisely.

The small size of the components and the accuracy with which they must be arranged in the system is perhaps the most evident challenge in the fabrication of quantum computers. Another challenge is the temperature of the device. The device needs to be cooled to less than 1 degree kelvin for the quantum bits to stay stable for respectable amount of time.

There are two primary architectural challenges in this. First, the design must be altered to allow classical circuits to operate at very low temperatures because quantum computing demands very low temperatures and classical circuits are designed for higher temperatures. Second, a trustworthy communication method is necessary due to the high mistake rate of quantum processes and the size of error correction circuits itself.

VII. CONCLUSION

In principle, issues that are practically intractable by classical computers can be solved using quantum computation. Although the quantum promise still has a long way to go before becoming practical realization. In this paper, principles, algorithms and hardware considerations have been addresses. Using various resources, several research teams are examining qubits and quantum logic circuits. It is necessary to conduct more study , for instance, through simulation on quantum computers that use classical computers. Such a simulator needs to be capable of handling quantum computers that use large number of qubits. [8] Undoubtedly, we need to conduct more thorough research on the physical realization of quantum computer components.

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