AN INTRODUCTION TO QUANTUM COMPUTING ALGORITHMS

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ABSTRACT

With the increasing accessibility of quantum computers to the wider population, there is a growing demand for the education and training of a group of quantum programmers. This cohort predominantly consists of individuals who have primarily focused on the development of classical computer programs throughout their professional careers. Although existing quantum computers currently possess fewer than 100 qubits, it is widely anticipated that the quantum computing hardware will experience significant advancements in terms of qubit quantity, quality, and connectivity. The objective of this review is to elucidate the fundamental principles of quantum programming, which diverge significantly from classical programming. This will be achieved through the utilization of concise algebraic expressions, allowing for an optional comprehension of the captivating underlying principles of quantum mechanics. This paper provides an overview of quantum computing algorithms and their practical implementation on physical quantum hardware. In this study, we undertake a comprehensive examination of various quantum algorithms, with the objective of providing concise and self-contained descriptions for each. In this study, we demonstrate the practical implementation of the aforementioned algorithms on IBM's quantum computer. For each algorithm, we thoroughly analyze and compare the outcomes obtained from the implementation on the quantum computer with those obtained from the simulator. This analysis focuses on identifying and discussing any disparities that arise between the results obtained from the simulator and the actual hardware runs. This article serves as an introduction to quantum algorithms for computer scientists, physicists, and engineers, offering a comprehensive guide for their practical implementation.

Keywords: Quantum Computing, Quantum Computing Algorithm.

INTRODUCTION

With the increasing accessibility of quantum computers to a diverse range of individuals, there has emerged a need to establish a program for training a cohort of quantum programmers. Moreover, it is worth noting that the majority of individuals in question have dedicated a significant amount of time to the development of traditional computer programs. Although the present number of qubits in contemporary quantum computers is less than 1100, it is anticipated that quantum computing hardware would significantly advance in terms of qubit quantity, quality, and connection. There exist various quantum algorithms that can be executed using frameworks and libraries offered by multiple companies, such as Microsoft and IBM.

Quantum algorithms can be conceptualized as a mechanism for unlocking further potential in the realm of quantum information technology. The potential number of quantum algorithms is boundless; but, the intricate nature of the multi-valued logic underlying these algorithms restricts the pool of mathematicians capable of effectively developing them in the present day.

The emergence of robust quality control (QC) systems and the growing demand for increased speed will likely lead to the expansion of possible markets in the future. As the hardware efficiency and practicality of quantum machines improve, there is a concomitant development of quantum algorithms. For example, the optimal selection for a Datacentre Company may no longer solely revolve around cost considerations, but rather be contingent upon their ability to efficiently execute the duties associated with your application. The decision between conventional suppliers and a supplier that provides a tenfold increase in operational speed for mission-critical jobs is straightforward, making it an ideal domain for the proliferation of quantum algorithms.

Over the course of time, quantum algorithms have demonstrated their potential for use across various disciplines. The finance sector has several opportunities for compliance, enhancements, cost reductions, and market expansion. In addition to compliance, such as security and cryptocurrency markets, there exists considerable potential in the domains of pattern recognition, real-time risk analysis, and financial forecasting. Moreover, the implementation of enhanced searching quantum algorithms might lead to a reduction in overhead costs for banks that possess extensive client databases.

OBJECTIVE

The rapid advancements in machine intelligence and artificial intelligence have greatly contributed to the significant progress observed in the field of quantum computing. It is customary to ask whether quantum technologies have the potential to increase learning algorithms. The field of study under consideration is commonly referred to as quantum-enhanced machine learning. The primary aim of this paper is to elucidate the advantages that contemporary and prospective quantum technologies can offer to computation, with a specific emphasis on algorithms that present difficulties for classical digital computers. This paper will provide an analysis of quantum computing theories and their corresponding implementations. Additionally, this study will provide insights into the constraints of existing and prospective quantum algorithms. This paper aims to highlight the specific areas of responsibility in which emerging computational intelligence methods surpass or are expected to surpass existing approaches. This paper aims to elucidate the fundamental algorithms and various classifications of quantum computers.

WHAT ARE QUANTUM ALGORITHMS:

In practical terms, a qubit is a quantum system capable of existing in two distinct states, which may include an atom, a photon, an ion, or other such entities. Therefore, the composition of a quantum algorithm's input consists of qubits. In summary, the number of possible configurations that can be simultaneously represented by n qubits is 2^n. Therefore, the implication is that when utilizing 300 qubits, the number of states available is equal to 2^300. From a technical standpoint, the universe contains vast quantities of atoms that are present in large volumes. Quantum computers employ the superposition principle in order to attain these objectives. A limited quantity of pieces in superposition states possess the capability to convey a substantial volume of data. For example, a quantum system consisting of 1,000 elements can exist in a superposition state that represents a range of values from 1 to 21,000. In the context of quantum computing, such a system would enable the simultaneous processing of all these numbers by subjecting the constituent particles to laser pulses. Upon the completion of the computation, it is observed that the states of the elements undergo measurement, resulting in the elimination of all parallel states save for one arbitrary version. Ingenious manipulation of the elements could nonetheless resolve specific problems very rapidly, such as factoring in a large number.

Let's program a quantum algorithm: Qiskit way

Quantum algorithms can be implemented using several frameworks and packages. Various businesses, such as IBM and Microsoft, are offering these tools. An instance of an open-source quantum computing library known as Qiskit has been developed with the support of IBM.

Qiskit enables users to encode and execute programs on either IBM's quantum computers or a local simulator, without the need for the graphical interface. This functionality holds great importance as the graphical interface becomes impractical when the number of qubits becomes big. Qiskit provides users with the capability to access quantum processors featuring a maximum of 16 qubits. There are also processors of lower capability that can be found.

Qiskit is a highly prominent Software Development Kit (SDK) that encompasses multiple components aimed at addressing a wide range of challenges associated with practical quantum computing. Qiskit is further divided into four distinct modules, namely Terra, Aer, Aqua, and Ignis. Moreover, each of these modules is specifically dedicated to a certain aspect of quantum software development.

Qiskit is primarily a Python package designed for the purpose of building quantum circuits. A typical Qiskit code for simple quantum computing tasks consists of two distinct components: circuit design and circuit execution. During the design process, a Quantum Circuit instance is generated with the required number of qubits and classical bits.

How to input data into a quantum computing algorithm using the quantum gate model:

First understand the problem and the requirements. The prerequisite to process 2^n states in the quantum algorithm is the need of the n-Qubit. For instance, the 4 states (00, 01, 10, 11) need two 2 Qubits, and the 8 states need (000, 001, ..., 111) which is the states of 3 Qubits. Now, if we have a great list with millions of items, (for example, a network of bees or travel salesman problems), using the quantum gate model, how to input these items to the algorithm for processing becomes the first bottleneck to proceed further. However, this is not as difficult as it sounds. There are dissimilar methods to access classical data with a quantum computer.

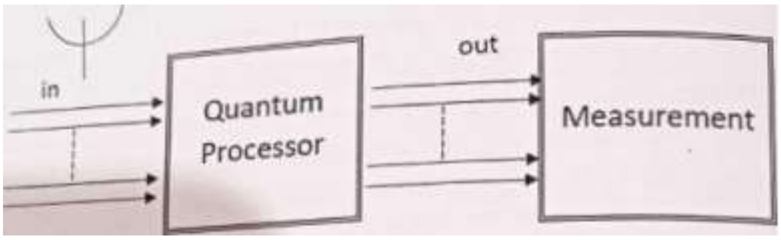
How quantum algorithms work:

During the 1970s and 1980s, significant progress was made in the development of the quantum theory of information, which involves the utilization of quantum systems for information processing. This advancement was influenced by the theories put forth by P. Benioff in 1980 and R. Feynman in 1982. Moreover, the probability of creating computer machines capable of correctly and efficiently simulating a specific quantum system has advanced. This theory proposes more modest solutions for certain uses of contemporary communications and informatics.

Superposition, entanglement, and interference are fundamental characteristics of the quantum realm that enable more efficient solving of specific problems that would require exponential computational time using classical computers. By employing the principles of superposition and interference, it is possible to simultaneously evaluate a function f(x) for all values of x.

The characteristic of quantum computers being referred to in this context is commonly known as quantum parallelism. The significance of an entangled pair lies in the instantaneous correlation between the states of the two particles, regardless of their spatial separation throughout the measurement process.

Another notable aspect of quantum information is the measurement process, which fundamentally alters the state of the system being measured. Every quantum computation process concludes with the measurement of the system.



Prior to implementing quantum algorithms, it is customary to first simulate them on a classical computing system. There are two primary reasons for this phenomenon, namely the identification of design flaws before the production process and the enhanced comprehension of designs.

Due to the basic distinction between quantum computing and classical computing, the construction of algorithms in quantum computing entails inherent differences that have a direct impact on their structure, as well as their function, implementation, and execution. The initial quantum algorithms were designed to leverage the capabilities of quantum computation in order to address computationally challenging problems that include oracles, which are known for their complexity and time-consuming nature. Oracles are devices utilized for the purpose of offering responses to inquiries in a binary format, limited to affirmations or negations.

The big classes of quantum algorithms:

There are multiple types of algorithms. Few important ones are mentioned below:

•**Search algorithms:** This type of algorithm essentially founded on Deutsch-Jozsa, Simon, and Grover.

•**Algorithms that try to find an equilibrium point of a complex system**: Algorithms that hunt for a balance point of a complex system comparable in the training of neural networks, the exploration for an optimum pathway in networks, or procedure optimization.

•**Algorithms founded and take advantage of QFT**: Such as Shor's Integer Factorization, that generated a deliberation among persons who are deficient to produce quantum computers accomplished of violation of public RSA type security keys, and individuals being the ones looking to defend digital communications with algorithms resilient to the reckless factorization of integers

•**Simulation algorithms of quantum mechanisms:** aid in specific to simulate connections among atoms in numerous molecular constructions, and include inorganic and organic structure as well.

Some important quantum algorithms:

It is important to understand the run-time efficiency of the algorithms we use. When takes too long to solve a problem, it costs more money and deprives the of the time to spend on other valuable problems. Plus, if the algorithm is inside a user-facing app, it may result in frustrated users who give up on the app entirely.

We can categorize the run time of an algorithm according to how the number of steps increases as the input size increases. Does it always take the same amount of That's a constant increase, a very fast run time. Does it always require looking at every possible permutation of the input? That's an exponential increase, a very slow run time. Most run times are somewhere between.

•**Constant time**: When an algorithm runs in constant time, it means that it always takes a fixed number of steps, no matter how large the input size increases.

•**Logarithmic time**: When an algorithm runs in logarithmic time, it increases proportionally to the logarithm of the input size.

•**Linear time**: When an algorithm grows in linear time, its number of steps increases in direct proportion to the input size.

•**Quadratic time**: When an algorithm grows in quadratic time, its steps increase in proportion to the input size squared.

•**Exponential time**: When an algorithm grows in super polynomial time, its number of steps increases faster than a polynomial function of the input size.

•**Polynomial versus super polynomial**: Computer scientists often classify run times into the following two classes:

-Polynomial-time describes any run time that does not increase faster than n^k, which includes constant time (n^0), logarithmic time $\log_2$ n, linear time (n^I), quadratic time (n^2), and other higher degree polynomials

-Super polynomial-time describes any run time that does increase faster than n^k and includes exponential time (2^n, factorial time (n!), and anything else faster.

Machine Learning Algorithms:

Machine learning encompasses a diverse range of computing challenges and can leverage many algorithmic methodologies. This post provides a comprehensive overview of quantum algorithmic approaches aimed at enhancing the quality of machine learning outcomes. Quantum algorithms designed for solving linear systems demonstrate efficacy in accelerating cluster-finding processes, exhibit notable performance in principal component analysis, display proficiency in binary classification tasks, showcase exceptional capabilities in training neural networks, and offer utility in various forms of regression analysis, encompassing linear and logical regression. The functionality of the system is contingent upon the fulfillment of specific criteria by the data. However, numerous quantum machine learning techniques that were initially based on linear systems have since been dequantized.

Quantum computing software platforms:

Few famous quantum computing software platforms are Cirq from Google, Rigetti, PyQuil, QISKit, ProjectQ, and Microsoft's Quantum platform. PyQuil is an opensource python library developed from Rigetti computing that constructs program form for the quantum computer. PyQuil produces a program in the quantum instruction language Quil.

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