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A Review on Quantum Circuits: Qubits, Qudits, Reversible Logic Circuits and its Applications

Nilay Awasthi

Department of Quantum Electronics, Amity University Mumbai, India

Abstract

Quantum Computing has already stepped into the world and is also fostering research in many domains. The efficiency and reliability of Quantum efficiency is limited by the Hardware implementation resources existing now. Various domains of qubit implementation have been explored, for coming down to the conclusion, that which is the best implementation of the qubit. Further, the concept of qudits is also been initiated in the research industry and is been explored. In this paper, we explore the various domains of different qubit implementation, shed light on qudits and present the designing of reversible gate which are used for making reversible circuits.

Keywords: Qubits, Qudits, Reversible gate, Reversible circuits

Introduction

Quantum Computing has usage in every other domain, for implementing various algorithms, systems, and many more. It has also drawn interest of many tech giants like IBM, Microsoft, Google. The reason why, quantum computing is exponentially growing is the fact, the phenomenon of superposition which is present i.e. the intrinsic parallelism in the quantum systems. The reason for the development of quantum computer was that the classical computing was reaching its limit and many problems were not solved because through classical computing approach it would take thousands of years to solve. So, there was a need for extension of the current computing scenario. This lead to the development of quantum computers. In this review we talk about various physical implementations of Quantum Bits (qubits). Further we talk about the reversible logic gates and how they are used for implementing reversible circuits.

Quantum Bits (Qubits)

Lie we have classical bit i.e. 0 or 1, in the classical or conventional computer, in a similar fashion, quantum bit or qubit is analogous to classical bit. So, we can say that qubit is nothing but a box which contains information about the quantum system in the quantum computer.

The classical bit and qubit differ on various platforms and one such platform is the property which they offer. The qubits offer the property of quantum superposition and quantum entanglement, when compared with classical bits. The qubit can be in linear combination of all possible states at the same time, for example, it can be in both ground state and excited state at the same time. The two logical states of the qubits must be mapped onto eigenstates of some suitable physical system.

Quantum Superposition

As the classical bit represents data either in one of the states i.e. |0□ or |1 , whereas the qubit's quantum state is in continuous state between "0" and "1" see Figure 1., until it is measured. Therefore the quantum state of a qubit can be defined as |ψ = a|0 + b|1 , where

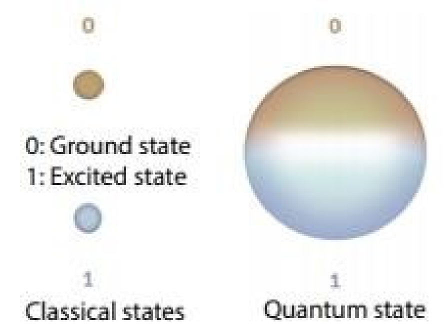

Figure 1: Classical and Quantum State

ψ is the wave function and a and b are complex amplitudes. The outcome of a qubit when measured can be only 0 or 1 with probabilities | |2 and | |2 respectively where | |2 + | |2 = 1. One qubit is in superposition of 2 states, similarly n qubits will be in superposition of 2 states

Quantum Entanglement

When the qubits are entangled together, it means that if one qubit is in particular state, then the other qubit has to be in another particular state i.e. both the qubits are correlated with each other. The usage of this phenomenon helps in quantum information processing and also quantum cryptography.

Qubit Implementation Approaches

There are five traditional requirements called DiVincenzo criteria which qubits in a quantum computer should meet

1. A scalable physical system
2. Ability to initialize the state operation time
3. A universal set of quantum states
4. A qubit-specific measurement capability

Researchers have come with many physical realizations of qubits, each having their own pros and cons.

Nuclear Magnetic Resonance Qubits (NMR)

NMR provides a way to build quantum computer by using the

***Corresponding author:** Nilay Awasthi, Department of Quantum Electronics, Amity University Mumbai, India, Tel: 917559339831, E-Mail: nilay.awasthi13@outlook.com

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spin of atomic nuclei [1]. The NMR system provides long relaxation time and therefore the decoherence is not a major issue, but this system of implementation is restricted on the size that NMR Quantum computers can have, even after fulfilling the above mentioned criteria.

Ion Traps

Ion traps offer great possibilities for building quantum computers [2]. I Iion Trap, the qubit string if implemented by a string which is linear in fashion, in a high electromagnetic field, which is confine in nature. Ions are excellent quantum memories and long coherence times have been demonstrated [2-3].

Superconducting Qubits

Artificial atoms have been made out of superconducting devices [4] e.g. a Josephson Junctions, coupled to a microwave resonator for control and read-out [3]. The Josephson junction introduces non linearity to the system, which increases energy spacing.

Qudits

The general qubits are 2-dimensional system, i.e. there can be only 2 outcomes when a qubit is measured. The qudits provide as a future for quantum computing. The qudits are d- dimensional system and provide possible states greater than 2. Through the usage of qudits, the quantum computing will expand its limit exponentially

Reversible Circuits

The reversible circuits are objective in nature i.e. there is one-to-one mapping between the input and output lines. There is same number of input and output lines. The reason for development of reversible circuits is that, it reduces energy dissipation, which is caused due to information destruction.

Reversible Logic:

As said earlier, the reversible circuits are objective and one-to-one mapping in nature, which means that we can reconstruct input from the output. Through this benefit, reversible logic enables both forward and backward computations possible.

Reversible Gate:

Reversible gate contain equal number of input and output ports, which are mapped in one-to- one fashion. Any reversible circuit should contain the least number of reversible gate possible.

Constant Input:

The inputs which remain constant in terms of their values.

Garbage Outputs:

The number of additional output added to make a function reversible in nature.

Quantum Cost:

It refers to the cost of circuit in terms of cost of primitive gate.

Types of Reversible Gate:

Many types of reversible gates are present with different functionality.

I. NOT Gate:

It is the simplest reversible gate of 1*1 combinations with zero quantum cost.

II. CNOT Gate:

This is 2*2 combination with quantum cost equal to 1.

III. Feynman Gate:

It is 2*2 combination reversible gate with one quantum cost.

IV. Fredkin Gate:

This is a 3*3 gate with quantum cost equal to 5.

Conclusion

In this review, we have discussed certain important aspects related to quantum computing. The introduction to qubit with different physical implementations with each ones pros and cons listed. The parameters which make qubits different from the traditional bits was explained. Further the general information of the reversible circuits was explained and the properties which each reversible circuit should possess along with the need for development

of reversible circuits. The needed definitions related to reversible circuit was explained in order to develop a bred idea about the topic.

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