

Chapter 2

Fundamentals of Quantum Computation and Basic Quantum Gates

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ABSTRACT

Quantum computing plays a major role in modern computation. It can perform operations exponentially faster when compared to classical computation. It has applications in various areas like secure communication, drug design, artificial intelligence, cyber security, etc. Thus, the researchers and students are showing interest to perform experiments in quantum computing to design novel architectures. But to learn/understand quantum computing, one should have strong knowledge of its basics. Because quantum computing performs operations at the atomic level, so the learners need to understand basic concepts like Qubits, superposition, quantum gates, etc. This chapter gives a clear idea about the basic concepts of quantum computing like Qubits, superposition, entanglement, and quantum gates.

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INTRODUCTION

Quantum Computing plays a major role in future computation and also changes the entire paradigm of computation, communication, and encryption. It has applications in various areas like secure communication, Finance, Drug design, simulations, Quantum Chemistry, Smart city transportation, Agriculture, etc. (Gill et al., 2020). A revolution in computing technology i.e., ‘Quantum computing’ is the next big thing that is going to change the whole computing process as we know it today. Quantum computers are highly potential compared to the classical computers (Feynman, 1986). Classical computer deals with the binary information i.e., 0 and 1 but Quantum computer performs the operations on atomic and subatomic particles. An atom performs operations based on principles of Physics. Hence in Quantum computing, the information is represented in the form of qubits and it can store an infinite range of values between 0 and 1 in multiple states so the Quantum computers can perform multiple operations at a time (Benioff, 1982). Due to this, one can say that quantum computers are highly efficient than the world’s best Supercomputers. Efficient quantum algorithms like Shor’s (1995) and Grover’s (Long, 2001) solves the classical security and searching problems in very little time. The advantages of quantum computing are attracting the researchers to work in this area. But the information regarding this technology is very less so it is difficult for the people to understand the concepts especially to work in quantum technology one should have a strong knowledge in quantum basics. Hence this chapter gives a clear idea about the basic concepts of Quantum computing.

QUANTUM BITS (QUBITS)

Qubits are generated from the light beam which is a collection of electrons or photons based on the principles of quantum physics. In classical computation, information is quantified in the form of binary bits i.e., 0’s and 1’s but Quantum information is quantified in the form of Quantum bits or Qubits. A classical bit can be in either state 0 or 1 at a time but a qubit can be superposition of both i.e., it can be in both the states at a time but when we measure it, it will be collapsed into either state 0 or state 1. Quantum bits are represented with bra and ket notation as $|0\rangle$ and $|1\rangle$ and its basis vector representations are $|0\rangle = \begin{pmatrix} 1 \\ 0 \end{pmatrix}$, $|1\rangle = \begin{pmatrix} 0 \\ 1 \end{pmatrix}$. Single qubit system or multi qubit system are implemented by performing tensor operations on quantum states (Jaeger, 2007; Swathi & Rudra, 2022). These operations are performed on the basis vectors of $|0\rangle$, $|1\rangle$. For example to implement two qubit state $|00\rangle$, the tensor operation should be performed on states $|0\rangle$, $|0\rangle$ which is expressed as

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