Pseudo Implementation of Quantum Gates using Verilog

by Bhavam Vidyarthi

Submission date: 28-Oct-2019 07:12PM (UTC+0800)
Submission ID: 1201918017
File name: paper_bhavam.doc (125K)
Word count: 1089
Character count: 5674

Pseudo Implementation Of Quantum Gates Using Verilog (October 2019)

Bhavam Vidyarthi, Rohit Sanjay

Abstract— **Quantum Gates provide a deep insight into how we can overcome bounds set by Moores Law or Silicon based computers. Here in this paper we realize a succinct demonstration and implementation of Quantum gates using Verilog HDL and by real time simulation of reversible gates like Toffoli , Hadamard ,CNOT . Here we use the matrix multiplication method of implementing these gates and hence simulate them on given inputs. We also look into a basic implementation pipeline to develop Quantum Circuits for multiple applications.**

Index Terms—**Quantum Computing , Reversible Gates , Quantum Circuits ,**

I. Introduction

Quantum computation is a computational method in which we simulate the Quantum Mechanical effects we observe in the real world like superposition , entanglement , EPR paradox , Bells Experiment etc. Basic structure of representing these processes entails use of reversible gates which perfectly captures the Quantum Logic needed to simulate queries in its equivalent form . On how Quantum Circuits outperform classical computational algorithm we observe utilizing two particular Quantum Mechanical effects namely superposition and entanglement which use the probability factors of each qubit to ascertain its state without collapsing the state function or variable of the qubit offer an unprecedented advantage in terms of time complexity and computational power.

In this research we applied these concepts to simulate these operations in its binary equivalent form so that we can implement Quantum Gates on silicon based computers , primarily there are two methods used by the development community in general which are Matrix transformation and state transition table methods both of these methods are for representation purposes only they have no physical significance as such. But these methods map the quantum counterparts perfectly , allowing us to test inputs without having a Quantum Computer at hand .Three gates namely CNOT, Toffoli and Negation gates form the universal set which are used in developing quantum circuits , we confine ourselves to discussion of their working and implementation.

II. Quantum Gates

Quantum circuits utilize operations which have no binary equivalent but can be mapped using matrices which allows us to use the higher dimensionality they offer . These matrices themselves act as gates and can operate on qubits (here we use the term qubit to represent the bit in quantum entanglement , but for our demonstration purposes it is a two bit long register which can assume four values).

The vector representation of a single qubit is:

$$|a\rangle = v_0|0\rangle + v_1|1\rangle \rightarrow \begin{bmatrix} v_0 \\ v_1 \end{bmatrix},$$

The vector representation of two qubits is:

$$|ab\rangle = |a\rangle \otimes |b\rangle = v_{00}|00\rangle + v_{01}|01\rangle + v_{10}|10\rangle + v_{11}|11\rangle \rightarrow \begin{bmatrix} v_{00} \\ v_{01} \\ v_{10} \\ v_{11} \end{bmatrix},$$

These matrices then are matrix multiplied with the product state of the qubit which is represented as a 4 bit register each having value 0 or 1.

|00> = (1 0 0 0)
|01> = (0 1 0 0)
|10> = (0 0 1 0)
|11> = (0 0 0 1)

These product states are then fed as inputs to the CNOT module which uses matrix multiplication to output corresponding product state which is then mapped to its equivalent qubit value.

This mechanism represents the basic functionality of one spin of an entangled electron affecting its pair by assigning it the complimentary spin or retaining the original spin.

Hadamard Gate is used to obtain entangled values of bits , this is the most basic gate required for quantum computers to apply binary computation to qubits and all the gates are reversible i.e.each gate if cascaded in series with itself produces the original input thus being its own inverse this sets Q gates apart from classical gates like AND , OR , XOR etc.

The CNOT matrix and the Hadamard gate is represented as-

One-qubit gates	Multi-qubit gates
$H = \begin{pmatrix} 1/\sqrt{2} & 1/\sqrt{2} \\ 1/\sqrt{2} & -1/\sqrt{2} \end{pmatrix}$	$\mathrm{CNOT} = C_X = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$

EXAMPLE CASE :

C{|10>} = C{(0 1).*(1 0)}

= (1000 0100 0001 0010)*(0010)

= (0001)

Thus we observe how the qubits are processed by CNOT gate which we observe in the Verilog HDL implementation of this project.

III. Proof of superiority

Concept of Deutsch Oracle dictates given a categorical problem in form of F(n):{0,1..n-1} it works by assigning probabilities to the set by eliminating other answers by passing the input to a circuit which collapses the input function into a form where a single value assumes maximum value which is given or interpreted as the answer . This process uses quantum superposition to accordingly compute four different states in single unit of time. This generalizes to a n bit function which is mapped to a query such as find prime factors of a given large number (Shor's Algorithm) , thus computes or processes four different values at a single instance instead of computing two different binary responses of a circuit hence giving an advantage in terms of time complexity. This proves that the Quantum Circuit uses half the time taken to process a problem compared to the equivalent classical circuit .

However some techniques don't gain superiority over classical equivalent such as AND, OR , Comparison etc. so there is a subspace of circuits which utilize both classical and quantum gates to achieve peak performance.

An example quantum circuit is visualized by using these basic gates is as follows(this is the famous Shor's Algorithm Circuit) -

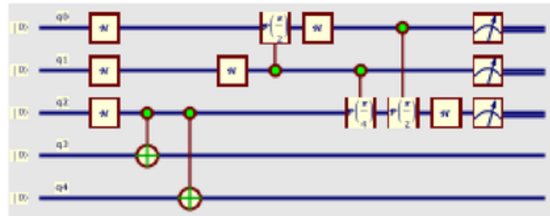

FIG. 9: Circuit for Shor's algorithm for $N = 15$ and $x = 11$.

Primary workflow pipeline to map any query to its quantum circuit equivalent is detailed as –

Algorithm 2 Solution to the hidden subgroup problem (for finite abelian groups)

Input:
- Two quantum registers.
- Elements of the finite abelian group A (or the generating set).
- A function g, such that $g : A \to X$, with $a \in A$ and $h \in X$.

Output:
- The generating set for the hidden subgroup K.

Procedure:

Step 1. Create initial state.
Step 2. Create superposition between resisters.
Step 3. Apply unitary operation (U) for function $g(a)$.

$$\to \frac{1}{\sqrt{|A|}} \sum_{a \in A} |a\rangle\, |g(a)\rangle$$

Step 4. Apply inverse Fourier transform.

$$\to \frac{1}{\sqrt{|A|}} \sum_{l=0}^{|A|-1} e^{2\pi i l a/|A|}\, |\hat{g}(l)\rangle$$

Step 5. Measure the phase from first register.

$$\to l/|A|$$

Step 6. Sample K from l / | A |.

IV. Applications

The primary purpose of developing these primitives representing quantum gates is to help advance public interest and participation in Quantum Computing , providing a framework to test and develop some classical understanding of how they work and also allow people with no access to Quantum Computers to achieve growth and traction in this field . Existing state of the art frameworks exist such as IBMs IBMQ and Quantum Katas developed by people at Microsoft and also allowing cutting edge development to be available open source to the public domain . Scaffold is also an ongoing project at Stanford which aims to develop Quantum Primitives in C .

V. Conclusion

Thus this project entails the creation of CNOT gate which is one off the primary gates used in this fields and also provides some background information collected and assembled by the authors to impart a layman's understanding of Qcomputing.

References

[1] arXiv:1804.03719v1 [cs.ET] 10 Apr 2018 Patrick J. Coles, Stephan Eidenbenz,∗ Scott Pakin, Adetokunbo Adedoyin, John Ambrosiano, Petr Anisimov, William Casper, Gopinath Chennupati, Carleton Coffrin, Hristo Djidjev, David Gunter, Satish Karra, Nathan Lemons, Shizeng Lin, Andrey Lokhov, Alexander Malyzhenkov, David Mascarenas, Susan Mniszewski, Balu Nadiga, Dan O'Malley, Diane Oyen, Lakshman Prasad, Randy Roberts, Phil Romero, Nandakishore Santhi, Nikolai Sinitsyn, Pieter Swart, Marc Vuffray, Jim Wendelberger, Boram Yoon, Richard Zamora, and Wei Zhu Los Alamos National Laboratory, Los Alamos, New Mexico, USA

Pseudo Implementation of Quantum Gates using Verilog

ORIGINALITY REPORT

0%	0%	0%	0%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

Exclude quotes	On	Exclude matches	< 10 words
Exclude bibliography	On		