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QCF, A useful tool for Quantum Neural Network implementation in Matlab

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ABSTRACT

Most proposals for quantum neural networks have skipped over the implementation of the Qubit, superposition, entanglement and measurement in order to be used in MATLAB environment. Quantum computing uses unitary operators acting on discrete state vectors. Matlab is a well-known (classical) matrix computing environment, which makes it well suited for simulating quantum algorithms. The Quantum Computing Function (QCF) library extends Matlab by adding functions to represent and visualize common quantum operations. On the other hand a new mathematical model of computation called *Quantum Neural* Networks (QNNs) is defined, building on Deutsch's model of *quantum* computational *network*. The *Quantum Neural Network* (QNN) model began in order to combine quantum computing with the striking properties of neural computing. In this paper the use and importance of those functions is illustrated with the help of few examples. This paper presents a brief overview of QCF that how it can be useful in Quantum Neural Network simulation.

INTRODUCTION

The research interest in Artificial Neural Networks comes from the networks' ability to mimic human brain as well as its ability to learn and respond. The neural networks have a large number of applications. Fields where ANN performed effectively are Pattern Recognition, classification, vision, prediction and control systems. A major focus of ANN research is its ability to learn or adaptation, which provides a degree of robustness to the neural network model. The power of ANN is due to its massively parallel, distributed processing of information and also due to the non-linearity of the transformation performed by the Network. Nodes (neurons) in spite of rules are for determining optimal architectures, limited memory capacity, and catastrophic forgetting due to the pattern interference.

On the other hand, Quantum Computer (QC) is quantum information processing unit. It is relatively new discipline and not yet completely understood, however, provides an excellent introduction to many of key ideas. Richard Feynman examined the role quantum mechanics can play in the development of future computer hardware and demonstrated [1] that time evolution of an arbitrary quantum state is intrinsically more powerful computationally than the evolution of logical classical state. Since then, quantum computing has attracted wide attention and soon became the hot topic of research, especially after Shor's quantum prime factoring algorithm[2] and Grover's random data base search algorithm[3] were proposed. Simon[4] demonstrated the power of quantum computation and proved quadratic reduction of the amount of quantum data required if quantum states rather than classical states are transmitted and Vetura[5] demonstrated potential of quantum system to exhibit correlations that cannot be accounted classically.

Quantum Neural Network (QNN) is a burgeoning new field built upon the combination of classical neural networks and quantum computation. There are two main motivations for applying capabilities of quantum computation to neural networks: to compensate the ever decreasing scale in hardware development and to produce computational capability not available in classical neural computation. Zak[6] combined classical and quantum neural networks and developed quantum decision maker and Bshouty and Jackso demonstrated superiority of quantum learning algorithm over classical one in certain situations like Quantum Hopfield Networks and Quantum Associative Memories (Qu.AM). Quantum entanglement[8] is one of the most interesting features of quantum mechanics and it provides promising and wide applications in quantum information processing such as teleportation[9], dense coding[10,11], geometric quantum computation[11,12], quantum neural computing[13-15], universal quantum computing network[16-18] and quantum cryptography[19-21]. Measurement and manipulation of entangled state of many particles system becomes a far reaching consequence of quantum information processing. Qubit is the basic building block of quantum computation and hence the experimental creation and measurement of qubit and entangled states is of crucial importance for various practical implementations of algorithms. The generation of quantum entanglement among spatially separated particles requires non-local interactions through which the quantum correlations are dynamically created [22] but our present knowledge of quantum entanglement is not at all satisfactory[23].

Qubit; a basic building block

A simple two- state quantum system is the basic unit of quantum computation: quantum-bit (qu-bit) where we rename two states as 0-state, and 1-state . Smallest unit of information stored in a two-state quantum computer is called a qu-bit. If there is a system of m qu-bits, it can represent 2^m states at the same time.

Qubit is simply a two-level system with generic state as

|ψ> $=a\,|\,0> \ +b\,|\,1>$,

a two-dimensional complex vector, where a *and* b are complex coefficients specifying the probability amplitudes of corresponding states such that

$$|a|^2 + |b|^2 = 1$$

Quantum Computation (QC) can be defined as representing the problem to be solved in the language of quantum states and producing operators that derive the system to a final state such that when system is observed there is high probability of finding a solution. QC consists of state preparation; useful time evolution of quantum system; and measurement of the system to obtain information. Upon measurement system will collapse to a single basis state. Object of QC is to ensure that measured basis state is with high probability.

Basic notation

There are three basic quantum state notations that are frequently used in the literature: integer kets, binary kets, and vectors. For example, the following are all representations of the same state (in a 2-qubit space):

|3> |11> $[0\ 0\ 0\ 1\ ]^T$

Starting with the theoretical basis of quantum computing in the present paper, Quantum Computing Functions have been explored as one of the key resources required for implementation of Quantum Neural Network using MATLAB.

The simulator uses vectors as its primary internal representation, but provides functions to convert between notations:

phi = bin2vec(bin)

Converts a single binary string state representation to a state vector.

For example:

```
>> C1=bin2vec('11')
0
0
0
1
>> Q1=bin2vec('011')
0
0
0
1
0
0
0
0
```

phi=dec2vec(dec,n)

Convert single decimal state representation to state vector.

n is number of qubits in the vector space.

```
>> C2 = dec2vec(1, 2)
0
1
0
0
```

```
>> Q2 = dec2vec(1, 3)
0
1
0
0
0
0
0
0
```

Handling superposed states:

```
>>QSP= 1/sqrt(2)*C1 + 1/sqrt(2)*C2
0
0.7071
0
0.7071
```

The pretty-print functions:

str = pretty(psi, [bin])

Gives a pretty-printed ket string for a (possibly superposed) state vector *psi*.

By default the integer ket representation is used. The optional *bin* flag gives the binary version.

```
>>pretty(QSP)
0.7071|011> + 0.7071|101>
>>pretty(QSP, 1)
0.7071|3> + 0.7071|5>
```

Measurement of state

Measuring a state with respect to the standard basis causes it to collapse into one of its standard basis eigenstates, with an eigenstate's probability given by the modulus of its squared amplitude. This non-deterministic process is simulated by the *measure* function:

```
>>MQB = measure(QSP)
```

Measure QSP with respect to the standard basis.

```
>> QSP = 1/sqrt(2)*C1 + 1/sqrt(2)*C2;
>> MQB = measure(QSP)
```

As |*C1*> and |*C2*> both have amplitude 1/sqrt(2), this measurement will result in the new |MQB> collapsing to |*C1*> or |*C2*>, each with probability ½.

CONCLUSION

In this paper, the concept of Quantum Computing is described and the concept of Quantum Computing is inherited from Quantum Mechanics phenomena. This paper also elaborates the representation of Qubit with its operators. The paper also highlights the implementation details of Qubit with MATLAB environment. The examples are also presented for support. In future the idea of Quantum Computing and Qubit representation will be used for the implementation of Quantum Gates and for development of Quantum Neural Network. The Quantum Neural Network will be used for various real world applications such as Pattern Recognition Task.

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Web-Resource

www.robots.ox.ac.uk/~parg/pubs/qcf.pdf

Quantum Computing Functions (QCF) for Matlab, Charles FoxDept. of Engineering Science, University of Oxford, UK