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Real-coded chaotic quantum-inspired genetic algorithm for training of fuzzy neural networks

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ABSTRACT

In this paper, a novel approach to adjusting the weightings of fuzzy neural networks using a Real-coded Chaotic Quantum-inspired genetic Algorithm (RCQGA) is proposed. Fuzzy neural networks are traditionally trained by using gradient-based methods, which may fall into local minimum during the learning process. To overcome the problems encountered by the conventional learning methods, RCQGA algorithms are adopted because of their capabilities of directed random search for global optimization. It is well known, however, that the searching speed of the conventional quantum genetic algorithms (QGA) is not satisfactory. In this paper, a real-coded chaotic quantum-inspired genetic algorithm (RCQGA) is proposed based on the chaotic and coherent characters of Q-bits. In this algorithm, real chromosomes are inversely mapped to Q-bits in the solution space. Q-bits probability-guided real cross and chaos mutation are applied to the evolution and searching of real chromosomes. Chromosomes consisting of the weightings of the fuzzy neural network are coded as an adjustable vector with real number components that are searched by the RCQGA. Simulation results have shown that faster convergence of the evolution process in searching for an optimal fuzzy neural network can be achieved. Examples of nonlinear functions approximated by using the fuzzy neural network via the RCQGA are demonstrated to illustrate the effectiveness of the proposed method.

1. Introduction

Recently, quantum genetic algorithms (QGA) have been proposed for some combinatorial optimization problems, such as the traveling salesman problem [1], knapsack problem [2,3], and filter design [4]. However, QGA is based on the concepts of qubits and superposition of states of quantum mechanics. The smallest unit of information stored in a two-state quantum computer is called a quantum or Q-bit. A Q-bit may be in the 1 state, in the 0 state or in any superposition of the two. In the act of observing a quantum state, it collapses to a single state. It is evident that to apply QGA to multi-parameters optimization and high precision in calculation is not felicitous. The paper proposes a real-coded chaotic quantum-inspired genetic algorithm (RCQGA) based on the chaotic and coherent characters of Q-bits. In this algorithm, real chromosomes are inversely mapped to Q-bits in the solution space. Q-bits probability guided real cross and chaos mutation are applied to real chromosome's evolution and searching; Simulation shows that the proposed RCQGA not only avoids the shortcoming of binary system coding based QGA prematurely but also reduce the optimizing complexity with faster convergence speed more powerful optimizing ability. Much research combining fuzzy logic with neural network have been developed to

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improve the efficiency of function approximation. In fuzzy set theory, the selection of an appropriate membership function is an important issue for engineering problems. It is important that the fuzzy membership functions are updated iteratively and automatically, because a change in fuzzy membership functions may alter the performance of the fuzzy logic system significantly. Traditionally, fuzzy neural networks are trained by using gradient-based methods, which may fall into a local minimum during the process. Unfortunately, such techniques also suffer from difficulties, such as the choice of starting guess and convergence. Moreover, since the cost function generally has multiple local minima, the attainment of global optimum by these nonlinear optimization techniques is difficult thanks to a probabilistic search procedure based on the concept and principles of states. Unlike binary, numeric, symbolic representation, the QGA are highly effective and robust over a traveling salesman problem [1]. This promotes its use to overcome the problems encountered by the conventional learning methods for fuzzy neural networks. However, it is well known that the searching speed of the conventional quantum genetic algorithms is not suitable. Such conventional quantum genetic algorithms are inherently incapable of dealing with a vast number of adjustable parameters in fuzzy neural networks. Thus, we propose a framework to automatically tune the adjustable parameters, including both the center points of the RBF and the weightings of the fuzzy neural network [5] to approximate nonlinear functions using a real-coded chaotic quantum-inspired genetic algorithm (RCQGA). First, quantum chromosomes consisting of adjustable parameters of the fuzzy neural networks are coded as a vector with real number components searched by the RCQGA. The fitness value of each quantum chromosome is obtained via mapping from the error function, which is the difference between the outputs of the fuzzy neural network and the desired outputs. With the use of RCQGA, faster convergence of the evolution process to search for an optimal fuzzy neural network can be achieved. The details of the proposed RCQGA are given in Section 2, Section 3 give the construction of the fuzzy neural network. Several examples are illustrated in Section 4 to show the effectiveness of this approach. Conclusions are drawn in Section 5.

2. Real-coded chaotic quantum-inspired algorithm

To overcome the problems encountered by conventional quantum-inspired algorithms, we propose a real-coded chaotic quantum-inspired algorithm to deal with the complicated situation where a vast number of adjustable parameters are to be searched in the fuzzy neural network

2.1. Overview of quantum-inspired genetic algorithm

QGA is a probabilistic algorithm that is similar to a genetic algorithm. QGA maintains a population of qubits chromosomes. It is based on the concept and principles of quantum computing such as qubits and superposition of states, and exploits Q-bit chromosomes as a presentation. The smallest unit of information stored in two-state quantum computer is called a quantum bit, which may be in the 1 state, or in the 0 state, or in any superposition of the two. The state of a quantum bit can be represented as

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle \tag{2.1}$$

where α and β are complex numbers that specify the probability amplitudes of the corresponding states. $|\alpha|^2$ and $|\beta|^2$ give the probabilities that the Q-bit will be found in the "0" state and "1" state, respectively. Normalization of the state guarantees it is set to unity. A Q-bit individual as a string of m Q-bits is defined as

$$\begin{pmatrix} \alpha_1 & \alpha_2 & \cdots & \alpha_m \\ \beta_1 & \beta_2 & \cdots & \beta_m \end{pmatrix} \tag{2.2}$$

where $|\alpha_i|^2 + |\beta_i|^2 = 1, i = 1, 2, \ldots, m$ Q-bit representation has the advantage that it is able to represent a linear superposition of states. In QGA a rotation gate $U(\theta)$ is employed to update a Q-bit individual as variation operator. (α_i, β_i) if the ith Q-bit is updated as follows:

$$\begin{pmatrix} \acute{\alpha}_i \\ \acute{\beta}_i \end{pmatrix} = \begin{pmatrix} \cos(\Delta\theta_i) & -\sin(\Delta\theta_i) \\ \sin(\Delta\theta_i) & -\cos(\Delta\theta_i) \end{pmatrix} \cdot \begin{pmatrix} \alpha_i \\ \beta_i \end{pmatrix} \tag{2.3}$$

where $\Delta\theta_i, i = 1, 2, \ldots, m$, is a rotation angle of each Q-bit. $\Delta\theta_i$ should be designed in compliance with the application problem. At the present time, many scholar's research is base on cooperative Q-bit encoding, but cooperative encoding only is expedient strategy that solve existing computer cant processes quantum information. Some studies have demonstrated that cooperative Q-bit coding can availability ensure individual diversity and evolution direction but Cooperative Q-bit coding can not fit for complexity function optimize due to complexity coding and limit computational accuracy.

2.2. Evolutionary process of real-coded chaotic quantum-inspired algorithm

2.2.1. The real quantum chromosome denotes

The quantum-inspired algorithm used in this paper is real-coded. Real number encoding has been confirmed to have better performance than either binary or gray encoding for Multi-parameters optimization problems [6]. RCQGA adopted a