NOVEL QUANTUM-INSPIRED GENETIC ALGORITHM
BASED ON IMMUNITY

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Abstract A novel algorithm, the Immune Quantum-inspired Genetic Algorithm (IQGA), is proposed by introducing immune concepts and methods into Quantum-inspired Genetic Algorithm (QGA). With the condition of preserving QGA's advantages, IQGA utilizes the characteristics and knowledge in the pending problems for restraining the repeated and ineffective operations during evolution, so as to improve the algorithm efficiency. The experimental results of the knapsack problem show that the performance of IQGA is superior to the Conventional Genetic Algorithm (CGA), the Immune Genetic Algorithm (IGA) and QGA.

Key words Genetic Algorithm(GA); Quantum-inspired Genetic Algorithm(QGA); Immune operator; Knapsack problem

I. Introduction

Genetic Algorithms (GAs)\cite{1,2} are principally stochastic searches and optimization methods based on principles of natural biological evolution. Compared to the traditional optimization methods, such as calculus-based and enumerative strategies, GAs are robust, global and can be generally applied without recourse to domain-specific heuristics. But GAs have several disadvantages such as poor balance ability of exploration and exploitation, and absence of individual's past history. In other words, the characteristics of population diversity and selective pressure are not easy to be implemented in GAs simultaneously: A strong selective pressure supports the premature convergence of the search; a weak selective pressure can make the search ineffective. And there is no history information of evolving individuals in GAs. Therefore, various improved methods have been proposed. Recently, a novel evolutionary algorithm called Quantum-inspired Genetic Algorithm (QGA) was presented in Refs.\cite{3-5}. QGA is based on the concept and principles of quantum computing\cite{6} such as qubits and superposition of states. By adopting qubit chromosome as a representation, QGA can represent a linear superposition of solutions due to its probabilistic representation.

Compared to GAs, QGA has many advantages such as automatic balance ability be-

\footnote{Manuscript received date: September 15, 2003; revised date: April 26, 2004. Supported by the National Natural Science Foundation of China (No.60133010 and No.60141002). Communication author: Li Ying, born in 1969, female, Ph.D., associate professor. P.O. Box 756, School of Computer, Northwest Polytechnical University, Xi'an 710072, China. lybyp@163.com}
between global search and local search, inclusion of individual's history, having fewer individuals without degrading performance, etc. QGA evolves the qubit chromosomes by applying some quantum gates, and makes the binary solutions by observing the states of qubit chromosomes. Because it is a probabilistic operation process which makes individuals change randomly and indirectly during the whole process, it not only gives the individuals the evolutionary chance but also causes certain degeneracy. On the other hand, there are many basic and obvious characteristics or knowledge in a pending problem. But QGA neglects the assistant function of the characteristics or knowledge. The loss due to the negligence is sometimes considerable in dealing with some complex problems.

Therefore, this paper introduces immune concepts proposed in Ref.[7] into QGA, and presents a novel genetic algorithm called the Immune QGA (IQGA). With the condition of preserving QGA's advantages, IQGA utilizes the characteristics and knowledge in the pending problems for restraining the repeated and ineffective operations during evolution, so as to improve the algorithm efficiency. The effectiveness and applicability of IQGA are demonstrated by experimental results on the knapsack problem.

II. The Immune Quantum-inspired Genetic Algorithm(IQGA)

1. Quantum-inspired Genetic Algorithm(QGA)

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 bit or qubit[6]. A qubit may be in the state '1', the state '0', or in any superposition of them. The state of a qubit can be represented as

$$|\Psi\rangle = \alpha|0\rangle + \beta|1\rangle$$  \hspace{1cm} (1)

where $\alpha$ and $\beta$ are complex numbers that specify the probability amplitudes of the corresponding states. $|\alpha|^2$ gives the probability that qubit will be found in state '0' and $|\beta|^2$ gives the probability that qubit will be found in state '1'. Normalization of the state to unity guarantees

$$|\alpha|^2 + |\beta|^2 = 1$$  \hspace{1cm} (2)

If there is a system of $m$-qubits, the system can contain information of $2^m$ states. However, in the act of observing a quantum state, it collapses to a single state.

QGA uses a new representation that is based on the concept of qubits. One qubit is define with a pair of complex numbers, $(\alpha, \beta)$, which is characterized by Eq.(1) and Eq.(2). An $m$-qubits representation is defined as

$$\begin{bmatrix}
\alpha_1 & \alpha_2 & \cdots & \alpha_m \\
\beta_1 & \beta_2 & \cdots & \beta_m
\end{bmatrix}$$  \hspace{1cm} (3)

where $|\alpha_i|^2 + |\beta_i|^2 = 1$, $i = 1, 2, \cdots, m$. QGA with this qubit representation has better characteristics of diversity than classical approaches, since it can represent superposition of states.

Convergence can also be obtained with the qubit representation. As $|\alpha_i|^2$ or $|\beta_i|^2$ approaches to 1 or 0, the qubit chromosome converges to a single state and the property of diversity disappears gradually. That is, the qubit representation is able to possess the two characteristics of exploration and exploitation, simultaneously.

The basic structure of QGA is described in the following.