Genetic Algorithm Based-On the Quantum Probability Representation

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Abstract. A genetic algorithm based on the quantum probability representation (GAQPR) is proposed, in which each individual evolves independently; a new crossover operator is designed to integrate searching processes of multiple individuals into a more efficient global searching process; a new mutation operator is also proposed and analyzed. Optimization capability of GAQPR is studied via experiments on function optimization, results of experiments show that, for multi-peak optimization problem, GAQPR is more efficient than GQA[4].

1 Introduction

Research development in quantum computation presents us not only with a tempting perspective of future computational capability [1], but also with inspirations of improving classical algorithms by reconsidering them from a standpoint of quantum mechanics. Genetic algorithm is a well-known heuristic searching algorithm, and has been proved successful in many applications [2]. Research work on merging genetic algorithm and quantum computation has been started by some researchers since 1990’s. Only two practical models have been proposed till now. QIGA (Quantum-Inspired Genetic Algorithm), proposed by Ajit Narayananam, introduces the theory of many universes in quantum mechanics into the implementation of genetic algorithm [3]. The main contribution of [3] is that it proves the efficiency of the strategy that uses multiple colonies to search in parallel, and uses a joint crossover operator to enable the information exchange among colonies.

Kuk-Hyun Han proposed a Genetic Quantum Algorithm (GQA) [4], in which the probability amplitude of qubit was used for the first time to encode the chromosome, and the formula of quantum rotation gate was used to implement the updating of chromosome. GQA is basically a probability algorithm, not a genetic algorithm. All individuals evolve towards one Contemporary Evolutionary Target (CET). Important genetic operators, such as crossover and mutation, are not adopted in it.

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2 Bin LI is currently a visiting scholar at Information Systems Institute, Technical University of Vienna, Austria.
In this paper, a new Genetic Algorithm based on the Quantum Probability Representation (GAQPR) is proposed, in which each individual has its own Contemporary Evolutionary Target (CET) and evolves independently; a new crossover operator is designed to enable the efficient exchange of evolution information between different individuals. A new mutation operator is also proposed, its effect is studied in experiments. Experiments on two typical function optimization problems prove that, for multi-peak optimization problem, GAQPR is more efficient than GQA.

The remaining part of this paper is organized as follow: section 2 describes the principle and procedure of GAQPR, which includes the introduction of representation and updating strategy of chromosomes, main procedure of GAQPR, and procedures of the new designed crossover and mutation operators. Section 3 is the description of experiment. Section 4 is the conclusion of the whole paper.

2 GAQPR

2.1 Representation and Updating of Chromosomes

In quantum computation, the elementary unit for storing information is a quantum system with two states, called quantum bit (qubit). The key characteristic that makes qubit differ from classical bit is that it can be at the superposition of two quantum states simultaneously. This superposition can be expressed as follow:

\[ \varphi = \alpha |0> + \beta |1>, \]

where \((\alpha, \beta)\) is a pair of complex invariables, called probability amplitude of qubit, which satisfies

\[ |\alpha|^2 + |\beta|^2 = 1, \]

where \(|0>\) and \(|1>\) represent two different states of qubit respectively, so one qubit can store the information of both states at the same time.

In GQA, each gene has only two states, so one qubit is enough for encoding one gene. But it is often the case in applications that one gene may have more than two states. In this paper, following the binary coding methods in classical genetic algorithm, we use more than one qubit to encode gene with more than two states. A chromosome is defined as follow:

\[
q_j = \begin{pmatrix}
\alpha_{11}' \\
\beta_{11}' \\
\alpha_{12}' \\
\beta_{12}' \\
\vdots \\
\alpha_{k1}' \\
\beta_{k1}' \\
\alpha_{21}' \\
\beta_{21}' \\
\alpha_{22}' \\
\vdots \\
\alpha_{2k}' \\
\beta_{2k}' \\
\vdots \\
\alpha_{m1}' \\
\beta_{m1}' \\
\alpha_{m2}' \\
\vdots \\
\alpha_{mk}' \\
\beta_{mk}'
\end{pmatrix},
\]

where \(q_j\) is the jth chromosome in the colony at generation t, m is the number of genes in a chromosome, and k is the number of qubit used to encode one gene, which can be calculated by function

\[ k = \text{ceil}(\log_2^n), \]

where n is the state number of each gene, function \(\text{ceil}(x)\) finds the nearest integer from x towards +\(\infty\).