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Acceleration Based Particle Swarm Optimization for Graph Coloring Problem

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Abstract

The graph coloring problem is one of the combinatorial optimization problems. Although many heuristics and metaheuristics algorithm were developed to solve graph coloring problem but they have some limitations in one way or another. In case of tabu search, the algorithm becomes slow, if the tabu list is big. This is because lots of memory to keep the list and also a lot of time to travel through the list, is needed in each step of the algorithm. Simulated annealing has a big handicap when applied to graph coloring problem because there are lots of neighboring states that have the same energy value. The problem with ant colony optimization is that the number of ants that must be checked is n times bigger than other algorithms. Therefore, there will be a need of a large amount of memory and the computational time of this algorithm can be very large. A swarm intelligence based technique called as particle swarm optimization is therefore employed to solve the graph coloring problem. Particle swarm optimization is simple and powerful technique but its main drawback is its ability of being trapped in the local optimum. Therefore, to overcome this, an efficient Acceleration based Particle Swarm Optimization (APSO) is introduced in this paper. Empirical study of the proposed APSO algorithm is performed on the second DIMACS challenge benchmarks. The APSO results are compared with the standard PSO algorithm and experimental results validates the superiority of the proposed APSO.

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Keywords: Acceleration based Particle Swarm Optimization ; Combinatorial optimization problem; Graph coloring problem;Particle swarm optimization.

1. Introduction

Optimization is a challenging field that concerns with the finding of minima or maxima of functions. Today, optimization covers a wide variety of techniques from Operations Research, artificial intelligence and computer science, and is used in both scientific and industrial worlds. Optimization problems can be of different types such as multi objective optimization, multimodal optimization and combinatorial optimization [1]. Many optimization problems of both theoretical and practical importance relates them with the selection of best configuration of a set of finite object to achieve certain goals. Such problems are basically divided into two categories one is those where solutions are programmed with real valued variable and the other is those where solution is programmed with discrete variable. Combinatorial Optimization Problems are the one that belongs to the second category. A Combinatorial Optimization Problems (COP) [2] can be stated as among a finite set of possible solution we look for the best one minimum or maximum.

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The graph coloring problem is one of the combinatorial optimization problems and is NP hard [3]. It can be defined as for a given graph, find the least number of colors needed for coloring of graph such that no two adjacent vertices bear the same color. The least number of colors for coloring a graph G is called its chromatic number denoted by χ (G). Application of graph coloring includes map coloring, scheduling, radio frequency assignment, register allocation, pattern matching, Sudoku, timetabling and many more.

The paper is organized as follows, Section 2 reviews about the research works related to the graph coloring problem. In section 3, a brief discussion about the standard PSO is presented and section 4 describes the proposed APSO algorithm. The experimental results on the benchmark functions are given in Section 5 and conclusion of the paper is given in Section 6.

2. Literature Survey

Various approaches used by many researchers to solve the graph coloring problem are described as follows:

2.1. Heuristics Methods

Approaches based on heuristic methods were developed due to the high computational complexity of the graph coloring problem. Heuristic methods determine the suboptimal solutions in polynomial time because of their characteristics of accuracy and level of complexity of the graph. They can be of the certain types based on the idea of choosing a vertex first and then assigning an appropriate color. Welsh and Powell [4] proposed Largest-Fit (LF) method in which vertices of a high degree are colored in first priority. Despite of its simplicity this method is very effective. Matula et al. [5] proposed a heuristic method alike the LF method named as Smallest Last (SL) method. It is also based on the idea of color vertices with high degree first but it does not have certain faults of LF algorithm such as SL optimally color trees, cycles, unicyclic graph, wheels, complete bipartite graph. Although both the methods are easy to implement and fast by nature but they are quite inefficient in optimal coloring. To improve the efficiency of these sequential algorithms, interchanges are executed. By performing interchanges, a previously colored vertex is switched to another class, by allowing the current vertex to be colored without adding new color [5]. By performing interchanges, performance was improved but it is more time consuming. Another heuristic method proposed by Johnson [6] known as greedy independent sets (GIS) method which is an implementation of the maximum independent set algorithm. In this method, the vertices of graph are analyzed in a certain order. The vertex is assigned a color if the vertex is not adjacent to any vertex with the same color. Another technique introduced by Brlaz [7] was based on the idea of reordering the nodes at each stage known as Degree of Saturation (DSATUR) or Saturation LF (SLF). In this, saturation degree is the term by which next vertex to color is chosen. A vertex with maximum saturation degree is given the priority to be placed in the first legal color class. All the methods discussed above are based on the idea of choosing a vertex first and then assigning an appropriate color. However there is a more successful method proposed by Leighton [8] known as Recursive Largest Fit (RFL) which is based on the idea where each color is completed before introducing a new one. In this method, vertices of one class got selected at a time. Randomization is also carried to improve the performance of simple heuristics. This concept is reflected in the work proposed by Johnson [9] who introduced the XRLF method. In this method, for each color many candidate classes are created and one is selected with the least degree in the remaining graph.

2.2. Metaheuristic

Metaheuristic is another way to solve graph coloring problem. Metaheuristic can be defined as high level strategies for exploring search space by using different methods. In the context of graph coloring we can have two types of metaheuristic one is local search method and another is population based method. The local search method includes simulated annealing, tabu search and population based method includes genetic algorithm, ant colony optimization, particle swarm optimization.

2.2.1. Local Search Methods

Local search is a metaheuristic method for solving computationally hard optimization problems. Local search methods start with a complete assignment of a value to each variable and try to iteratively improve this assignment by improving steps, by taking random steps, or by restarting with another complete assignment. Local search methods can be of different types such as simulated annealing [29], tabu search [17], variable neighborhood search [34], variable search space [21], iterated local search [7] and large scale neighborhood search [40].

2.2.1.1 Simulated Annealing

In 1987, Simulated annealing (SA) was first applied to graph coloring problem by Chams, Hertz and Werra [31]. In this, initially a neighboring solution is selected. If the neighboring solution is better than the current solution it will be accepted as the starting solution. If it is not better it will be accepted with a certain probability that gradually decreases with a global parameter