A Modified Binary Crow Search Algorithm for Solving the Graph Coloring Problem

Yassine Meralihi, University of M’Hamed Bougara, Boumerdes, Algeria
https://orcid.org/0000-0002-3735-7797

Mohammed Mahseur, University of Sciences and Technology Houari Boumediene, Bab Ezzouar, Algeria

Dalila Acheli, University of M’Hamed Bougara, Boumerdes, Algeria

ABSTRACT

The graph coloring problem (GCP) is a well-known classical combinatorial optimization problem in graph theory. It is known to be an NP-Hard problem, so many heuristic algorithms have been employed to solve this problem. This article proposes a modified binary crow search algorithm (MBCSA) to solve the graph coloring problem. First, the binary crow search algorithm is obtained from the original crow search algorithm using the V-shaped transfer function and the discretization method. Second, we use chaotic maps to choose the right values of the flight length (FL) and the awareness probability (AP). Third, we adopt the Gaussian distribution method to replace the random variables used for updating the position of the crows. The aim of these contributions is to avoid the premature convergence to local optima and ensure the diversity of the solutions. To evaluate the performance of our algorithm, we use the well-known DIMACS benchmark graph coloring instances. The simulation results reveal the efficiency of our proposed algorithm in comparison with other existing algorithms in the literature.

KEYWORDS

Binary Crow Search Algorithm, Chaotic Maps, Combinatorial Optimization Problem, Crow Search Algorithm, Graph Coloring Problem

1. INTRODUCTION

The graph coloring problem (GCP) is one of the most interesting and difficult combinatorial optimization problems in computer science, mathematics, and operations research. It has been widely used for modeling and solving many significant real-world problems like time tabling (de Werra, An introduction to timetabling, 1985), scheduling (Lotfi & Sarin, 1986), (Dowsland & Thompson, 2005), computer register allocation (Chaitin, Cocke, Hopkins, & Markstein, 1981), (de Werra, Eisenbeis, Lelait, & Marmol, 1999), radio frequency assignment (Gamst, 1986), (Smith, Hurley, & Thiel, 1998), printed circuit board-testing (Garey, Johnson, & So, 1976), communication networks (Woo, Su, & Newman-Wolfe, 1991), and many others. The graph coloring problem consists in assigning a color to each vertex of a given graph with the limitation that no two adjacent vertices gain same colors.

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and the number of different colors used is minimized. The minimum number of colors by which a graph is colored is called its chromatic number, which is denoted by $\chi(G)$. A graph $G$ is $K$-colorable, if it can be legally colored using at most $K$ colors. The problem of finding the chromatic number $\chi(G)$ of any graph is known to be an NP-Hard problem (Garey & Johnson, 1979) and has recently drawn an increasing attention from researchers, so several methods have been adopted for solving this problem including greedy constructive approaches, local search heuristics, metaheuristics, and hybrid approaches.

Constructive approaches are based on greedy approach which color the vertices of the graph one by one using a predefined greedy function. The most constructive algorithms employed to solve the GCP are the Recursive Largest First algorithm (RLF) proposed by Leighton (Leighton, 1979) and the largest satisfaction degree algorithm (DSATUR) developed by Brézaz (Brézaz, 1979). These constructive methods are recently used to generate initial solutions for advanced metaheuristics.

A large number of local search methods have been widely proposed for solving the GCP. The Tabu Search Algorithm proposed by Hertz and Werra (Hertz & de Werra, 1987) was the first local search algorithm applied to solve the graph coloring problem. It is called TABUCOL and has been enhanced by several authors and used as a subcomponent of more other graph coloring algorithms.

Moreover, many efficient metaheuristics such as Genetic Algorithm (GA) (Abbasian & Mouhoub, 2013), (Zhang, Qiu, Li, & Liu, 2014), Cuckoo Search algorithm (CS) (Zhou, Zheng, Luo, & Wu, 2013), (Djelloul, Layeb, & Chikhi, 2014), (Mahmoudi & Lotfi, 2015), Artificial Bee Colony (ABC) (Faraji & Javadi, 2011), (Dorrigiv & Markib, 2012), Particle Swarm Optimization (PSO) (Aoki, Aranha, & Kanoh, 2015), Memetic Algorithm (MA) (Lü & Hao, 2010), and combining algorithms (Mabrouk, Hasni, & Mahjoub, 2009), (Ge, Wei, Tian, & Huang, 2010), (Qin, Yin, & Ban, 2011), (Douiri & Elberoussi, 2015) have been employed to solve the Graph coloring problem.

Abbasian and Mouhoub (Abbasian & Mouhoub, 2013) proposed a Hierarchical method based on Parallel Genetic Algorithms (HPGAs) to solve the graph coloring problem. In this method, an extension of the genetic algorithm, namely the genetic modification (GM) and the parental success crossover operator are proposed. Computational results revealed that the proposed approach is very accurate and faster for solving the graph coloring problem. Zhang et al. (Zhang, Qiu, Li, & Liu, 2014) proposed a new parallel genetic algorithm for solving the graph coloring problem based on Compute Unified Device Architecture (CUDA). The initialization, crossover, mutation, and selection operators are executed in parallel threads. Experimental results demonstrated that the proposed algorithm converges much more quickly than other algorithms and achieves competitive performance for solving the graph coloring problem.

Zhou et al. (Zhou, Zheng, Luo, & Wu, 2013) proposed an Improved Cuckoo Search algorithm (ICS) for solving the planar graph coloring problem. A walking one strategy, swap strategy, inversion strategy and greedy strategy are used to improve the ICS. Experimental results showed that ICS can get smaller average iterations and higher correction coloring rate. Djelloul et al. (Djelloul, Layeb, & Chikhi, 2014) proposed a discrete binary version of cuckoo search algorithm to solve the graph coloring problem. In this approach, a binary representation of the search space is adopted and sigmoid function and probability model are used in order to generate binary values. Simulation results showed the feasibility and the effectiveness of the proposed algorithm. Mahmoudi and Lotfi (Mahmoudi & Lotfi, 2015) proposed a Modified Cuckoo Search Algorithm (MCOA) for solving the graph coloring problem. CAO is discretized by redefining, over discrete space, the standard arithmetic operators such as addition, subtraction, and multiplication that exist in COA migration operator based on the distance’s theory. Experimental results showed the high performance of the proposed algorithm compared with some well-known heuristic search methods in the literature.

Faraji and Javadi (Faraji & Javadi, 2011) proposed a new algorithm based on bee behavior in nature (BEECOL). Simulation results revealed better performances of BEECOL compared to ACO algorithm. The proposed algorithm has the capability of establishing a proper connection between accuracy and speed of coloring the graph. Dorrigiv and Markib (Dorrigiv & Markib, 2012)
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