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Ant colony optimization with immigrants schemes for the dynamic travelling salesman problem with traffic factors

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ABSTRACT

Traditional ant colony optimization (ACO) algorithms have difficulty in addressing dynamic optimization problems (DOPs). This is because once the algorithm converges to a solution and a dynamic change occurs, it is difficult for the population to adapt to a new environment since high levels of pheromone will be generated to a single trail and force the ants to follow it even after a dynamic change. A good solution to address this problem is to increase the diversity via transferring knowledge from previous environments to the pheromone trails using immigrants schemes. In this paper, an ACO framework for dynamic environments is proposed where different immigrants schemes, including random immigrants, elitism-based immigrants, and memory-based immigrants, are integrated into ACO algorithms for solving DOPs. From this framework, three ACO algorithms, where immigrant ants are generated using the aforementioned immigrants schemes and replace existing ants in the current population, are proposed and investigated. Moreover, two novel types of dynamic travelling salesman problems (DTSPs) with traffic factors, i.e., under random and cyclic dynamic environments, are proposed for the experimental study. The experimental results based on different DTSP test cases show that each proposed algorithm performs well on different environmental cases and that the proposed algorithms outperform several other peer ACO algorithms.

1. Introduction

Ant colony optimization (ACO) algorithms emulate the behaviour of real ant colonies when they search for food from their nest to food sources. Ants communicate via their pheromone trails in order to complete this “food-searching” task as efficiently as possible. ACO algorithms have proved to be effective optimization methods in many real-world applications [16,17,20,42].

Traditionally, researchers have focused on ACO to address static optimization problems (SOPs), e.g., the travelling salesman problem (TSP). For SOPs, the environment remains fixed during the execution of algorithms [3,5,34]. However, in many real-world problems, we have to deal with dynamic environments [31]. For dynamic optimization problems (DOPs), the problem may change over time regarding the objective function, decision variables, problem instance, and constraints, etc. Such uncertainties may change/move the optimum, and, thus, the problem becomes more challenging and has much in common with many real-world scenarios. The aim, when solving SOPs, is to obtain an optimal or near-optimal solution efficiently, whereas for DOPs the aim is to track the optimal solution over time with the environmental changes.

ACO algorithms can adapt to dynamic changes since they are inspired from nature, which is a continuous adaptation process [31]. More precisely, they can adapt to dynamic changes by transferring knowledge from past environments [7]. However, traditional ACO algorithms cannot adapt well to dynamic changes once the ants reach the stagnation behaviour, where ants follow the same path, since the pheromone will be distributed into a single trail. Therefore, using the pheromone trails of the previous environment in the new environment will not be sufficient since ants will be biased by the previous path even after a dynamic change. The algorithm loses its adaptation capability since it does not maintain the diversity within the population. A simple way to address this problem is to consider every change as the arrival of a new problem instance which needs to be solved from scratch and re-initialize the pheromone trails. However, this restart strategy is computationally expensive and usually not efficient.

Recently, developing strategies for ACO algorithms to enhance their performance for DOPs and increase their adaptation capabilities has attracted a lot of attention [11]. The strategies developed include: (1) local and global restart strategies [27]; (2) pheromone

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manipulation schemes to maintain or increase diversity [21,35,37]; (3) memory-based approaches [25,28]; and (4) memetic algorithms [36]. These methods have been applied to different types of dynamic TSPs (DTSPs) due to its importance for many real-world applications [39,42].

As we have seen in many evolutionary algorithms (EAs) for binary-encoded DOPs, immigrants schemes are effective when applied to different DOPs [47,49,53,57]. Immigrants enable an EA to maintain the diversity of the population at a certain level, by introducing new individuals into the current population [24]. A good start has been made on ACO algorithms for permutation-encoded DOPs, where immigrant ants are generated to the population [35,37]. In [35], the random immigrants ACO (RIACO) and elitism-based immigrants ACO (EIACO) have been applied on a DTSP where the cities are exchanged with other cities stored in a spare pool over time. In [37], the memory-based immigrants ACO (MIACO) has been applied on a DTSP with traffic factors. The difference between RIACO, EIACO, and MIACO lies on the way immigrants are generated. In RIACO, EIACO, and MIACO, immigrants are generated randomly, using the best ant from the previous environment as the base to generate immigrants, and using the best ant from a memory as the base to generate immigrants, respectively.

In this paper, we further investigate the performance of ACO algorithms with immigrants schemes on different dynamic test cases. RIACO, EIACO and MIACO are applied on two novel variations of DTSPs, e.g., DTSP with random and cyclic traffic factors, and they are systematically constructed from several static TSP problem instances. A series of different DTSPs are generated to investigate the weaknesses and strengths of RIACO, EIACO, and MIACO for solving DTSPs. This paper also carries out experiments on sensitivity analysis with respect to several important parameters, such as the immigrants replacement rate, the size of the memory structures used in the proposed framework and the range of the traffic factors, on the performance of the investigated ACO algorithms for DTSPs. Moreover, the proposed algorithms are compared against several peer ACO algorithms on DTSPs.

The rest of the paper is organized as follows. Section 2 describes the field of dynamic optimization. Section 3 describes the proposed DTSPs variations. Section 4 describes a conventional ACO for DOPs. Section 5 describes existing approaches on different DTSPs. Section 6 first describes the framework of ACO algorithms with immigrants schemes and then describes the proposed algorithms. Section 7 presents and analyzes several experimental studies for different key parameters and compares the proposed algorithms with existing ones. Finally, Section 8 concludes this paper with discussions on the directions for future work.

2. Dynamic optimization

2.1. A brief introduction

A DOP can be intuitively defined as a sequence of several static problem instances that are linked under some dynamic rules. The main aspects of “dynamism” are the frequency and magnitude of environmental changes. The former corresponds to the speed at which environmental changes occur and the latter corresponds to the degree of environmental changes. An environmental change may involve factors like the objective function, input variables, problem instance, constraints, and so on.

Formally, a DOP can be defined as follows:

$$\Pi = (X(t), \Omega(t), f(t))_{t \in T}, \quad (1)$$

where Π is the optimization problem, $X(t)$ is the search space, $\Omega(t)$ is a set of constraints, $f(t)$ is the objective function, which assigns an objective value to each solution $x \in X(t)$, where all of them are assigned with a time value t, and T is a set of time values.

2.2. Approaches to dynamic optimization

Mainly, the research to address DOPs is focused on EAs, which is otherwise known as evolutionary dynamic optimization (EDO). EAs are able to transfer knowledge since the information of previous environment is stored in the population of individuals of the previous iterations. However, the individuals in the old environment may not be feasible for the new one. But, if they are re-evaluated or repaired, they may transfer valuable information. Several surveys are available for EDO [31,41,52].

For DOPs, once the population converges to an optimum, then it is difficult for the population to track the moving optimum after a change. Many strategies have been proposed and integrated with EAs to improve the re-optimization time and maintain a high quality of the output efficiently, simultaneously. The main contributions of these strategies are categorized as: (1) increasing diversity after a dynamic change [12,46]; (2) maintain diversity during the execution via immigrants schemes [24,47,49,53,57]; (3) memory-based schemes [48,56]; (4) multi-population approaches [9,62,45]; and (5) hybrid and memetic algorithms [47,61].

2.3. Immigrants schemes for EAs

Among the approaches described above, immigrants schemes have been found beneficial when applied to EAs for many binary-encoded DOPs [47,49,53,57]. Immigrants schemes work by replacing a predefined portion of individuals in the current population with new immigrants in each generation. Random immigrants were introduced to EAs in order to increase the diversity within the population and enhance their performance for DOPs [24]. According to the experiments in [13], random immigrants perform well when dynamic changes occur frequently and the changing environments are not similar.

Elitism- and memory-based immigrants were introduced to EAs in order to address DOPs with slightly and slowly changing environments [47,49]. For the elitism-based immigrants scheme, the best individual from the previous population is used as the base to generate immigrants via mutation, while for the memory-based immigrants scheme, the best individual from an external memory is used as the base to generate immigrants via mutation. Moreover, hybrid immigrants were proposed [53], where random and elitism-based immigrants are combined to improve the performance of elitism-based immigrants in significantly changing environments, while they degrade the performance in slightly changing environments.

2.4. Benchmark DOPs

Much research on dynamic optimization has been done with EAs on binary-encoded DOPs, such as the one-max problem, royal road problem, plateau problem, knapsack problem etc [47,57]. Usually, the XOR DOP generator proposed in [54] is used to convert any binary-encoded static problem into DOPs with different properties.

On the other hand, the research on ACO for DOPs is focused on permutation-encoded problems, such as TSPs and vehicle routing problems (VRPs). It is fair to say that the research on ACO for permutation-encoded DOPs is still in its infancy when compared with the research on EAs for DOPs. For example, the quantity of contributions on EAs for DOPs is massive, whereas almost all contributions on ACO for DOPs are described in Section 5 (Table 1). **Q3**

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