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Transgenetic algorithm for the Traveling Purchaser Problem

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ABSTRACT

In this paper an evolutionary algorithm is presented for the Traveling Purchaser Problem, an important variation of the Traveling Salesman Problem. The evolutionary approach proposed in this paper is called transgenetic algorithm. It is inspired on two significant evolutionary driving forces: horizontal gene transfer and endosymbiosis. The performance of the algorithm proposed for the investigated problem is compared with other recent works presented in the literature. Computational experiments show that the proposed approach is very effective for the investigated problem with 17 and 9 new best solutions reported for capacitated and uncapacitated instances, respectively.

1. Introduction

The Traveling Purchaser Problem, TPP, is a generalization of the Traveling Salesman Problem. In this variant there is a set of m markets, vertices of a graph G, and a set of n products that must be purchased. Each product is available, with different quantities, on a subset of markets. The unit cost of each product depends on the market where it is available. The demands for each product and the traveling costs are known. The objective of the purchaser is to buy the whole demand of products, departing and returning to a domicile, so as to minimize the sum of the travel and purchases costs. There is no need of including all markets in the tour. The problem can be stated as follows. Given a domicile, v_0, a set of markets $M = \{v_1, v_2, \ldots, v_m\}$ and a set of products $K = \{f_1, f_2, \ldots, f_n\}$, the TPP is represented in a graph $G = (V,E)$ where $V = \{v_0\} \cup M$ and $E = \{[i,j]: v_i,\ v_j \in V,\ i \neq j\}$. A demand d_k is assigned to each product f_k. The number of units of product f_k at market v_i is denoted by q_{ki} and M_k denotes the set of markets where the product f_k is available, $M_k \subseteq M$. The cost of product f_k at market v_i is denoted by b_{ki} and the cost of traveling from market v_i to market v_j is given by c_{ij}. The objective is to determine a tour in G with v_0 being the starting and the ending point, such that the complete demand is satisfied and the sum of the weights of the edges in the tour and the purchase costs is minimized.

In the uncapacitated version of the TPP (UTPP), it is assumed that if a product is available at a given market, its quantity is sufficient to satisfy the demand. If the availability of, at least, one product f_k is less than the demand d_k at a market v_i, then the problem is said to be capacitated (CTPP). The uncapacitated version is a special case of the CTPP where $d_k = 1$ and $q_{ki} \in \{0,1\}$, $1 \leqslant k \leqslant n$, $1 \leqslant i \leqslant m$.

In the last decade, the TPP has received some attention of the researchers of the Operational Research area. Papers with exact and heuristic approaches proposed for this problem are summarized in Section 2. Although researchers have reported some metaheuristic approaches to tackle the TPP, as far as the authors' knowledge concerns, no competitive evolutionary approach has been proposed for it. Evolution has been a source of inspiration for developing successful problem solving methods for complex optimization problems. The evolutionary algorithms are stochastic search methods that operate on a population of candidate solutions that evolves iteratively by means of variation and selection until a stopping criterion is satisfied (Michalewicz and Fogel, 2000). In this paper an evolutionary algorithm is proposed for the TPP. The proposed heuristic is a transgenetic algorithm (Goldbarg et al., in press). The biological inspiration of the transgenetic algorithms comes from two major evolutionary forces: the horizontal gene transfer (Jain et al., 2003) and the endosymbiosis (Margulis, 1992).

Horizontal or lateral gene transfer refers to the acquisition of foreign genes by organisms. It occurs extensively among prokaryotes (living forms whose cells do not have nucleus) and provides organisms with access to genes in addition to those that can be inherited (Jain et al., 2003). The term "endosymbiosis" specifies the relationship between organisms which live one within another (symbiont within host) in a mutually beneficial relationship. The Serial Endosymbiotic Theory proposed by Margulis (1992) states that a new organism can emerge from the fusion of two or more

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independent beings. Today, researchers recognize the horizontal transfer of functional genes between organisms as a determinant factor of the endosymbiotic origin of specialized cellular parts called organelles (Pierce et al., 2003). Two known vehicles of horizontal gene transfer that are of special interest for this paper, once they inspired search operators for the transgenetic algorithms are: plasmids and transposons. Plasmids, in nature, are mobile genetic particles, DNA rings that can be exchanged between certain cells and that can replicate independently of the chromosome. Transposons or "*jumping genes*" are genetic elements that can spontaneously move from one position to another in a DNA molecule.

Endosymbiotic interactions and lateral gene transfer mechanisms have inspired, separately, the development of evolutionary algorithms (Watson, 2002; Kim et al., 2001). The union of these two biological scenarios, which occurs in nature through the endosymbiotic gene transfer (Timmis et al., 2004) inspired the development of the transgenetic algorithms. The former approaches are fundamentally different from the one proposed in this paper, once they are extensions or versions of genetic algorithms where the information is, basically, restricted to their populations. In the transgenetic algorithms, where a co-evolutionary process is thought to occur between a host cell and its endosymbionts, three contexts of information are considered. The evolutionary search performed by the proposed approach is accomplished by means of information exchanging among individuals of different natures (host and endosymbionts). Agents, called transgenetic vectors, are responsible for the exchanging of information between the host and the endosymbionts. These agents are inspired on natural mechanisms of horizontal gene transfer, such as plasmids and transposons. Therefore, the three contexts of information of the transgenetic algorithms are: the endosymbionts, the host and the transgenetic vectors. The endosymbionts, also called endosymbiont chromosomes or, simply, chromosomes, are the base of the search since they encode problem solutions. Unlike other evolutionary approaches, chromosomes do not share genetic material directly by means of crossover or recombination. Information about the problem being tackled by the algorithm (*a priori* information) and information about the heuristic search (*a posteriori* information) are stored in the host's context. The transgenetic vectors manipulate the chromosomes, modifying their codes and promoting the random variation that is necessary for the exploration and exploitation of the search space.

The paper is organized as follows. Section 2 presents the state-of-the-art of the Traveling Purchaser Problem. Section 3 presents the fundamentals of the proposed approach. The application of a transgenetic algorithm to the Traveling Purchaser Problem is described in Section 4. The results of computational experiments with capacitated and uncapacitated TPP instances are reported in Section 5. Finally, some conclusions and remarks about future works are presented in Section 6.

2. State-of-the-art for the Traveling Purchaser Problem

This problem was first presented by Burstall (1966) in a job shop scheduling context, where a heuristics based on the work of Lomnicki (1996) was utilized to solve the problem. Later, Buzacott and Dutta (1971) utilized a dynamic programming approach to solve the model proposed by Burstall (1966). The first work where the TPP is introduced as it is presently known is due to Ramesh (1981). In that paper, the author presents an exact and a heuristic algorithm. The exact method is based on a lexicographical search and handles instances with $m \leqslant 12$ and $n \leqslant 10$. The heuristic approach is a version of the nearest insertion algorithm for the Traveling Salesman Problem (Bentley, 1992).

Singh and van Oudheusden (1997) developed a branch-and-bound algorithm for the TPP based on a bound for the Uncapacitated Facility Layout Problem. They solved forty symmetric instances with $15 \leqslant n \leqslant 50$ and $10 \leqslant m \leqslant 20$, and sixty-five asymmetric instances with $10 \leqslant n \leqslant 100$ and $10 \leqslant m \leqslant 25$. Laporte et al. (2003) present a branch-and-cut algorithm. Their algorithm was applied to solve instances of the capacitated and uncapacitated versions of the TPP. They were able to handle instances up to 250 markets and 200 products.

A method named "*Generalized Savings Heuristic*" was proposed by Golden et al. (1981) for the TPP. It was modified by Ong (1982) who proposed the *Tour Reduction Heuristic*. Pearn and Chien (1998) suggested some improvements for the heuristics presented by Golden et al. (1981) and Ong (1982). They presented two versions of the *Generalized Savings Heuristic*: the *Parameter Selection Generalized Savings Heuristic* and the *Tie Selection Generalized Savings Heuristic*. The two versions of Pearn and Chien (1998) for the *Tour Reduction Heuristic* are known as the *Adjusted Cheapest Tour Reduction Heuristic* and the *Nearest Cheapest Tour Reduction Heuristic*. Pearn and Chien (1998) propose also the *Commodity Adding Heuristic*. Laporte et al. (2003) propose the *Market Adding Heuristic* which was applied to capacitated and uncapacitated TPP instances. This heuristic is utilized on their exact solution method. This heuristics consists in adding, iteratively, to the route of the traveling purchaser a market that offers some product whose demand was not yet satisfied. A list with the markets where that product is available at the lowest prices is built. The market offering the product at the highest price, among those markets in the list, is chosen to be added to the current route. The market is included in a position that will produce the smallest increase in the route cost.

The first metaheuristic approaches for the TPP were presented by Voß (1996) who developed Tabu Search and Simulated Annealing algorithms. Two dynamic strategies are presented to control the tabu list: the *reverse elimination* and the *cancellation sequence method*. Tabu search algorithms are also proposed by Boctor et al. (2003). In that work the authors propose a set of benchmark instances that has been utilized by other researchers to test their algorithmic ideas for the TPP. Boctor et al. (2003) compare their algorithms with two versions of the *Commodity Adding Heuristic*.

Teeninga and Volgenant (2004) introduce pre-processing and intensification procedures which are utilized in the *Generalized Savings Heuristic* (Golden et al., 1981), the *Commodity Adding Heuristic* (Pearn and Chien, 1998) and in the *Tour Reduction Heuristic* (Ong, 1982).

Riera-Ledesma and Salazar-González (2005) present an iterative local search algorithm where two neighborhoods are utilized. The procedure for the first neighborhood performs an iterative scheme exchanging l consecutive vertices in a given feasible cycle with a set of vertices not belonging to that cycle. The value of l is reduced as soon as a local optimum is achieved. The second procedure inserts as many vertices as possible in a given feasible cycle, whenever each insertion implies a reduction in the objective value. The Lin and Kernighan (1973) procedure is applied to the resultant solutions in order to improve the tour cost. The solution is disturbed and the process is re-started. They test their algorithmic ideas in capacitated and uncapacitated instances proposed by Boctor et al. (2003). An Ant Colony Optimization algorithm is presented by Bontoux and Feillet (2008). They apply their algorithm to the uncapacitated instances of the benchmark proposed by Boctor et al. (2003) and compare their results with the ones obtained by Riera-Ledesma and Salazar-González (2005).

3. The transgenetic algorithm

Transgenetic algorithms are evolutionary computing techniques based on living processes where cooperation is the main evolutionary strategy (Goldbarg et al., in press). Those biological