Adapting Metaheuristics to solve Combinatorial Optimization Problems related to transportation

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The transport industry has developed strongly since the industrial revolution. In an economy where consumption needs are growing, its importance has become indisputable in both the public and private sectors. The revenues it can generate and the costs it incurs impose the establishment of a policy and an all but arbitrary system.

To reap the best benefits, a strategy to maximize revenue and minimize costs needs to be developed and optimized. Mathematical models inspired by real problems are designed to allow the scientific community in the field of optimization to implement approaches of different classes, including metaheuristics.

This class of algorithms permits obtaining a solution in a short time, which allows it to be practicable for large instances, unlike exact methods. On the other hand, no guarantee on the quality of the solution can't be given, unlike approximation methods which ensure a lower bound. This constraint has aroused the interest of researchers in order to propose heuristics that can provide good solutions (or even optimal ones) with a very high probability regardless of the topology of the studied instance.

An empirical study of the multi-fragment tour construction algorithm for the travelling salesman problem

Metaheuristics can be divided into two classes, that of improvement methods and that of construction, the latter being used for the first to provide

input solutions. "Multi-Fragment", a construction method for the Travelling Salesman Problem (TSP), more efficient than its competitors, lacked empirical analysis in the literature. The principle of this heuristic is to build a tour by adding at each iteration the smallest edge that has not yet been selected and ensuring the feasibility of the tour.
A work [1] in this direction was carried out in the context of an international conference explaining the method empirically and comparing with the most solicited construction methods in the literature. This study proved useful for some researchers who requested the manuscript and/or wishing to implement this method of construction.

Breakout Local Search for the Travelling Salesman Problem

Metaheuristics are also classified according to their methodologies of resolution. Among the different classes proposed in the literature, local research is one of the most sought after. Its ability to exploit a set of solutions to achieve the best has ensured that it forms the basis or a major component of many successful research projects in a variety of areas.

Breakout Local Search (BLS) is a recent metaheuristic that, as its name designates, is based on the principle of local search and more precisely on the metaheuristics of Iterated Local Search (ILS). BLS has made a major contribution to ILS by introducing the adaptive perturbation principle that allows it to adjust perturbations according to the current state of the search. Thus, and having been applied to many COPs while obtaining solutions of very good qualities, a major interest was given to this metaheuristic during this thesis.

A study and adaptation for the TSP [2] were the first contributions, where variable perturbations in movement types were proposed and introduced to BLS in order to better escape the local optima of strong attraction. This change of movement from one perturbation to another is inspired by the Variable Neighborhood Search (VNS) framework, where at each iteration a neighbourhood structure is randomly selected from a set of structures. On the contrary, this implementation uses these neighbourhoods following the order of increasing perturbation strength.
The comparative results obtained from tests done on the TSPLIB benchmark

instances showed a clear improvement compared to ILS, but at the same time detected a constraining slowness as well on the difficult instances as the big ones. Indeed, the perturbation strategy proposed by BLS requires (whatever the type of perturbation) an exhaustive search of all the movements in order to choose the best possible ones. The quality of the solutions is thus obtained at the expense of the runtime. The tests also revealed that BLS sometimes fails to escape the basins with strong attraction, forcing the exploration of the research space.

A Memetic Algorithm Based on Breakout Local Search for the Generalized Traveling Salesman Problem

To increase the chances of falling on better local optima, a memetic algorithm was proposed during this thesis for the Generalized TSP (GTSP)[1], combining between BLS and a genetic algorithm (AG) with operators (selection, crossover and mutation) from the literature.

Unlike the TSP, where a feasible solution must pass through all cities before returning to the starting one, cities are in this variant (the GTSP) grouped into mutually exclusive and exhaustive clusters that must be visited once through only one city.

BLS is adapted in this case for a problem with two levels/layers of optimization: cluster layer and node layer. Proposing an enhancement to the perturbation strategy in order to reduce its complexity and then the runtime required for BLS was essential in this adaptation to achieve the desired results. The exhaustive search of all feasible movements to obtain the most suitable one(s), initially carried out in the first work as well as in previous works in the literature, has been replaced by a search on a sample of movements. The complexity of the perturbation strategy has significantly decreased from a square to a linear order.

Known for their exploratory features, the GAs will allow BLS to position itself in several points of the search space at the same iteration and to discover new subspaces from one generation to the next one.

The results obtained on the various instances examined in the GTSPLIB benchmark are competitive with the state of the art. The optimal solution (or the

1 Submitted to *Applied Artificial Intelligence* (ISSN: 1087-6545) Impact Factor: 0.587 - https://www.tandfonline.com/uaai20

best-known) being frequently reached. This memetic adaptation based on BLS has thus proved to be more efficient than that proposed in [2].

A novel reduction algorithm for the generalized traveling salesman problem

During the work done on the GTSP in this thesis, especially the one mentioned above, the possibility of reducing the number of cities of an instance was observed. The reduction allows decreasing the search space size by removing some of its solutions.

A pretreatment method has been proposed[2][3] based on the distances between the cities of different clusters. For each pair of clusters, the proposed algorithm selects the couple of cities with the smallest distance then removes at the end of the process the cities that have never been selected.

The reduction rates obtained over a wide range of instances far exceed those of the only competing method of the state of the art we are aware of. The reduced instances were then tested on two local search-based solvers (GLKH and GLNS) and provided faster solutions thanks to a smaller search space, which may not contain the optimal solution(s). This leads to a slight decline in the quality of the produced solutions but remains satisfactory.

A generalization has been proposed making it possible to select for each pair of clusters the cities constituting the k smaller distances. The higher the value of k, the more the number of cities will be preserved, and so the less the reduction rate will be. On the other hand, the provided solutions are better by increasing the value of k.

Using cluster barycenters for the generalized traveling salesman problem

Among the perspectives envisaged in this work, it was proposed to base on the distance between a city and the barycentres of the other clusters. The use of barycentres has been discussed in one [4] of the work of this thesis. The aim is to

2 Submitted to *Operational Research* (ISSN: 1866-1505) Impact Factor: 1.816 - https://link.springer.com/journal/12351

designate each cluster by an imaginary and unique node while taking into account the position of their respective cities.

The aim of this thesis was to propose efficient methods for solving COPs whose applications include the transportation industry. The work done has contributed to the state of the art through various papers in leading conferences and journals.

An efficient (meta)heuristic based on the local search should be aware of the different topologies of the search space of difficult instances. The study of the landscape is an important contribution to the proposition of new approaches that are well adapted to the problem. It makes it possible to identify the neighbourhood functions and the most appropriate operators to predict the difficulties to improve the current solution(s) during the walk. Higher interest in landscape studies will be given in postdoctoral work, a contribution in this regard has already been made to the Traveling Thief Problem [5].

Finding the best configuration for some metaheuristics having several parameters of different types (like BLS) usually penalizes the progress of the work in question, without having the guarantee to find the most suitable. The automatic configuration of algorithms has emerged during the last two decades as an optimization problem. Several techniques have since been proposed giving additional motivation to consider such methods in future work.

Published works

[1] M. El Krari, B. Ahiod, and B. El Benani, "An empirical study of the multi-fragment tour construction algorithm for the travelling salesman problem," in *Advances in Intelligent Systems and Computing*, vol. 552, 2017, pp. 278–287.

[2] M. El Krari, B. Ahiod, and B. El Benani, "Breakout Local Search for the Travelling Salesman Problem," *Computing and Informatics*, vol. 37, no. 3, pp. 656–672, 2018.

[3] M. El Krari, B. Ahiod, and B. El Benani, "A novel reduction algorithm for the generalized traveling salesman problem," *Proceedings of the Genetic and Evolutionary Computation Conference Companion on - GECCO '17*, pp. 105–106, 2017.

[4] M. El Krari, B. Ahiod, and B. El Benani, "Using cluster barycenters for the generalized traveling salesman problem," in *Advances in Intelligent Systems and Computing*, vol. 557, 2017, pp. 135–143.

[5] M. El Yafrani, M. S. R. Martins, M. El Krari, M. Wagner, M. R. B. S. Delgado, B. Ahiod, and R. Lüders, "A fitness landscape analysis of the travelling thief problem," in *Proceedings of the Genetic and Evolutionary Computation Conference on - GECCO '18*, 2018, pp. 277–284.