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Reducing the size of traveling salesman problems using vaccination by fuzzy selector

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ABSTRACT

At present, no algorithm can solve Combinatorial Optimization Problems (COPs) in polynomial time. The Traveling Salesman Problem (TSP) is an NP-hard COP example widely used as a test problem since it is mathematically equivalent to others in diverse fields. State of the art algorithms provide low quality solutions for large instances at high computational cost. Reducing the TSP size is a heuristic that works well finding solutions at a reduced cost. The Reduce-Optimize-Expand (ROE) methodology allows to solve COPs faster by improving the quality of solutions, however, obtaining optimal reductions is still an open problem since there is no way to determine if the removed nodes are part of the optimal solution without knowing it beforehand. This paper presents an intelligent strategy with a fuzzy logic classifier, based on the ROE, to obtain systematic reductions of TSP instances. The method was tested using TSP instances from the TSPLIB, ranging from 131 to 2924 cities. Comparative experimental results obtained higher-quality reductions, thus improving the overall performance of ROE when using the intelligent selection strategies. Intelligent reductions contribute to improve the performance of existing TSP algorithms, even given solution to many unsolved problems with huge amount of nodes by reducing them to a treatable size.

1. Introduction

Solving optimally large Combinatorial Optimization Problems (COP) is a mathematical challenge since its computational complexity grows exponentially with the problem size. The study of COPs is a very important research topic since they are present in a big diversity of real problems found in industry. The amount of computational resources required to solve these problems by a direct approach of simply considering all the possibilities, and choosing the right one that go beyond a few elements is truly astonishing. Checking modestly sized instances is beyond the capabilities of even the most powerful of recent supercomputers; hence, the emphasis must be shifted to the development and implementation of algorithms that outperform the existing ones, providing us with faster and better solutions (Vazirani, 2001).

The study of famous open problems is still attractive, although they are well known, this is because they remain a challenge for mathematicians since analytic methods that can solve them for the general case are not available. The Traveling Salesman Problem (TSP) is a widely studied COP, which is known to be NP-hard (Garey & Johnson, 1979). The problem consists in finding the optimal arrangement of a tour in which a number of finite cities are visited once and has the same starting and ending city; its importance goes beyond a test problem, as it has a great amount of scientific, industrial and commercial applications. W.R. Hamilton and Thomas Kirkman defined the TSP in 1800, and Karl Menger formulated the TSP as a mathematical problem in 1930 (Crilly, 2005). After more than two centuries, a large number of different approaches to solving it have been published (Fischetti, Lodi, & Toth, 2004; Gilbert, 1992), from which two main points of view have been identified: *Exact solutions*, and *Approximate approaches* (Rajesh, Surya, & Lal, 2010).

Exact solution algorithms range from utilizing brute force to one of the best-performing exact algorithm currently available published under the name “Implementing the Dantzig–Fulkerson–Johnson algorithm for large traveling salesman problems” (Bixby Robert, Vasek, & Cook William, 2003; Dantzig, Fulkerson, & Johnson, 1954). It was an early description of the computer program solver for the symmetric TSP named Concorde (William, 2011). An important improvement is a modified version of the Concorde that uses distributed computers for solving an instance with 85,900 cities (Applegate David, Bixby Robert, Vasek, & Cook William, 2006). A different proposal in this category is the “Branch-and-Bound/Cut” method described in (Eastman, 1958) in 1958, which was finally coined in 1963 in (Little John, Murty Katta, Sweeney Dura, & Caroline, 1963), it is used to obtain the lower bounds

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of the assignment problem, and it is employed by a wide variety of algorithms. The usefulness and success of the exact solution approaches such as the Concorde are very significant; however, solving even a moderate size of the TSP optimally can take a huge computational time or become unsolvable.

Approximate Approaches based on heuristics have made great advances in finding the optimal solution; however, they cannot guarantee to find it, nevertheless, most of the times they can provide suboptimal solutions near to the global optimum that are good enough for some TSP instances. At present, the best-known approximate algorithm was published as "Polynomial Time Approximation Schemes for Euclidean Traveling Salesman and Other Geometric Problems" (Arora, 1998). Some other heuristic examples to solve the TSP are: Lin–Kernighan (Karapetyan & Gutin, 2011; Lin & Kernighan, 1973), Tabu Search (Chuan-Kang, Sheng-Tun, & Chungnan, 2003; Pedro, Saldanha, & Camargo, 2013), Evolutionary Algorithms (Aybars & UGUR, 2008; Jin, 2011; Tsai, Yang, Tsai, & Kao, 2004), Ant Colony Optimization (Escario, Jimenez, & Giron-Sierra, 2015; Jun-man & Yi, 2012; Marco & Maria, 1997; Zhou, 2009), Bee Colony (Marinakis, Marinaki, & Dounias, 2011), Neural Network Algorithms (Johnson & McGeoch, 2003; Wen, Xu, & Yang, 2011), Memetic approaches (Benlic & Hao, 2011; Peter, Botzheim, & Koczy, 2011) and hybrid strategies such as Neural Networks (Mulder & II, 2003), Memetic Algorithms (Wang, Li, Gao, & Pan, 2011) plus Lin–Kerninghan local optimization and ACO plus GA (Dong, Guo, & Tickle, 2012).

The ROE method (Montiel, Díaz-Delgadillo, & Sepúlveda, 2013) consists in reducing the TSP size, perform the optimization using any suitable algorithm that can solve the problem, and finally return the TSP to its original size. The aim of this work is to present an intelligent reduction algorithm based on fuzzy logic concepts that support the ROE method with a better reduction algorithm to improve the quality of solutions at a lower computational cost.

The main contribution of this work is an algorithm that shows how to include the proposed fuzzy reduction method based on a fuzzy expert system, advanced metadata and adaptive heuristics into the ROE methodology with the aim of solving COPs, particularly the TSP. This research is relevant in diverse fields of science and engineering since it provides a solution to the problem of optimizing large instances of TSP, even they do not have a known solution.

This paper is organized as follows: In Section 2 a review of the recent work related with this proposal is presented. In Section 3 the mathematical background of the TSP is explained. Section 4 explains the proposed method and how to integrate it into the ROE methodology. In Section 5 the optimization of a TSP problem using the proposed method is described step by step. Section 6 describes the experiments that were achieved to demonstrate the advantages of the proposal as well as comparisons against other reduction methods. Finally, in Section 7 the conclusion, limitation and future research of this work are presented.

2. Recent related work

Finding novel ways to speed-up algorithms by employing new hardware oriented paradigms is a very important field of research. The increasing development of a very large number of processors available in a computer and the easy access to them, mainly in the form of Multicore CPU and graphics processing unit (GPU) computing, has made a huge portion of researchers to shift their focus to incorporate such up-to-date developments into their work. In the case of COPS, taking existing well-behaved and successful algorithms and parallelizing them has provided great results. For example, in (Chakroun, Melab, Mezmaz, & Tuyttens, 2013) the authors reviewed the Branch-and-Bound algorithms for solving large COPs on GPU-enhanced multi-core machines, a solution based on GPU implementation of the 2-opt and 3-opt local search algorithm was presented in (Rocki & Suda, 2012). Other metaheuristics that were enhanced using GPU are Ant Colony Optimization (Uchida, Ito, & Nakano, 2012; Delvacq, Delisle, Gravel, & Krajecki, 2013) and Genetic Algorithms (Cekmez, Ozsiginan, & Sahingoz, 2013; Hofmann, Limmer, & Fey, 2013).

Another approach is to break down systematically the TSP into smaller subproblems by divide and conquer strategies. Each piece of the fragmented problem must be solved separately, however, to produce valid solutions, these size-reduced subproblems must be interconnected, and so new considerations must be taken into account when solving. Works such as (Khan, Khan, & Iqbal, 2012) describe the effectiveness of this approach and a discussion of multiple algorithms for undertaking the task. A Hybrid Neural Network with local search via modified Lin-Kernighan algorithm that tries to solve a million city TSP was introduced in (Mulder & II, 2003). Although this work proved to be very successful allowing a higher degree of division of this huge TSP instance, thus allowing for more scalability, the next inherent issue was presented in their results: faster solution with lower quality.

In (Montiel et al., 2013), a methodology to reduce the problem size of COPs was presented. In this work, the main idea was to Reduce the problem size, by applying reductions to obtain a new equivalent problem formulation with fewer nodes systematically. Then the method considers using a suitable existing optimization algorithm to perform the optimization task. The last stage of the ROE methodology is to reconstruct the original problem providing the optimal route; the TSP was the case of study. In (Delgadillo, Montiel, & Sepúlveda, 2014) source code to implement the ROE method was included. The experimental results showed big improvements that depend on the TSP size, the quality of reductions, and the solver algorithms. A reduction in computational time in the range of 30–55% was reported, and the obtained solutions consistently remained between 6.48–15.30% far from the global optimum, since at present it is known that any method that make use of reductions cannot guarantee to obtain the global optimum. The ROE method proved to be very proficient; however, more improvements can be achieved using better reductions, hence developing new methods to obtain them is desirable.

A comprehensive survey of the current literature from online repositories such as Scopus database, Science Direct, ACM Digital Library, IEEE Xplore, Springer link, and Google Scholar was achieved in order to find similar methodologies to the ROE and the concept of intelligent reductions of the problem instance, but no other similar methodology proposed by other authors was found.

In the general sense, ROE can be classified as a clustering algorithm because the reduction step requires grouping via classification, and with the presented work, the grouping element shares fuzzy clustering characteristics. Fuzzy clustering has been promoted by other researchers as a valid strategy; however, they do not utilize advanced metadata in the same way as it is done in this proposal, which provides a good degree of intelligence.

Clustering approaches are typically unable to locate global optimum because they assume a certain structure on the underlying data that may be suboptimal, nonetheless, clustering algorithm efforts are very important because, similar to the proposed methodology in this work, their main goal is to improve performance. Fuzzy classification applied to clustering methodologies has been a very powerful strategy that provides two main advantages: utilization of linguistic variables to denote characteristics about the elements of a given problem and knowledge-based classification aided by logical rules derived from human expertise.

While researching the concept of fuzzy logic applied to clustering, it is clear that the most popular approach is using C-Means Fuzzy Clustering techniques as the main form of grouping (Chattopadhyay, 2011). From 2004 to the present, about 40 articles fall within the scope of our research concerning the keywords TSP, COP, Fuzzy clustering, Fuzzy sets, classification, and different variations of them. These articles are the most fitting for comparison with the proposed methodology, yet, they are substantially different because