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Soft-Computing: An innovative technological solution for urban traffic-related problems in modern cities

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ABSTRACT

Urban traffic-related problems are a major point of concern in the majority of cities in the world. These problems arise in many different aspects, such as providing fast congestion-free routes in a city (improving the mobility of its inhabitants), or solving problems caused by the continuous presence of vehicles on the road (reducing thus the levels of noise and CO^2 emission). Many of these problems can be mathematically expressed as optimization, classification or regression models, and involve, in most of the cases, huge search-spaces or hard constraints. In this paper we discuss one of these problems, the so called Reconfiguration One-Way Traffic Optimization Problem (ROWTOP). The problem consists in optimizing the directions of one-way streets in a city, in those cases in which this reconfiguration is needed because of the appearance of a major problem that involves prolonged street cuts. The problem is defined as a multi-objective optimization case and is solved by using a Soft-Computing (SC) approach based on an evolutionary algorithm (the NSGA-II technique). Its performance is discussed in a real problem in a Spanish city, achieving excellent results and showing the feasibility of these techniques as an innovative technology-based approaches, able to upgrade cities without incurring in exorbitant expenditures, helping politicians in making decisions and, ultimately, making cities more sustainable and better places to live.

1. Introduction

Transportation systems play a key role in modern cities. In fact, a transportation system cannot be conceived as an isolated system with no relationship with other urban systems (health, education, telecommunication, water, electric grid, to name just a few of them) that take part in the normal life of a city. This is why it is more appropriate to refer to it as "subsystem" instead of system [1]. The interaction and dependence among those subsystems that make a city work well in delivering services to its inhabitants are very strong, and often, critical. If the transportation subsystem does not work properly, many vital services, such as the distribution of goods (medicines, food, fuel, etc.) will not work as efficient as required by people. Furthermore, the rate at which inhabitants move will be slow (and so will the city as a whole), affecting its competitiveness in our globalized world. As a consequence, it is necessary for all the city subsystems to interact adequately, in the sense that they should be efficient, compatible and synchronized [1]. However, many city subsystems cannot work together optimally, leading to serious problems and inefficiencies in delivering services to inhabitants. And even more, unfortunately some of these systems are evolving unsustainable. Specifically, transportation subsystems are currently being affected by a vertiginous growing volume of road traffic, which is producing a number of severe problems. One of them is the existence of routes suffering from traffic congestions that cause high pollution, CO^2 emission, time delays, noise, and, finally, a degradation of quality of life.

Regarding this point, and considering that there is a fairly wide consensus on the need for a change towards more

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sustainable cities, a great number of prospective works have been carried out aiming at upgrading transportation in cities by means of technology. In turn, because of the fast rate at which technology evolves (and its key impact on society), there is an increasing demand for the use of technology forecasting methods to improve policy planning. For instance, the very recent paper [2] explores those factors which will influence the future development of the transport subsystem until the year 2030, identifying long-range developments of several elements, such as financing, competitiveness, or sustainability. The detailed analysis of traffic management leads to the conclusion that it is much more than the simple optimization of the current system [3]. The relevant question about how the transition to vehicles powered by hydrogen or electricity could take place has been recently tackled [4], since such vehicles seem to exhibit the potential to solve (or, at least, reduce) a number of problems such as degradation of city air quality, climate change, high fuel prices and security of energy supply. Regarding this, the roadmap for integrating the development of transport policies and intelligent transport systems and services has been recently investigated [5]. A multi-level analysis for the sustainable mobility transition in Sweden and in the UK has been carried out in [6], while a model of Canada's economy with six possible scenarios compares alternative technologies for de-carbonizing passenger transportation [7].

More specifically, the use of Soft Computing (SC) techniques (evolutionary, neural and fuzzy algorithms) in problems involving the design of urban road networks has been massive in the last few years. SC techniques allow to find approximate solutions to problems that, like traffic-related ones, would be otherwise intractable. In this regard, several heuristics and meta-heuristic approaches such as genetic and simulated annealing algorithms have been used to design urban roads [8]. The optimization of traffic signals is another problem recently tackled by applying genetic algorithms [9]. Problems of traffic optimization in cities using SC techniques have also been tackled, mainly using evolutionary computing algorithms [10,11]. Multi-objective optimization approaches based on SC algorithms have also been applied to traffic problems in cities [12,13]. The analysis and optimization of transportation networks under resilience conditions (the ability of a transportation network to become stable after a major event such as a disaster or an attack) have been tackled in [14]. Traffic re-structuring in cities based on the so-called one-way traffic organization problem (OWTOP) has been recently proposed and tackled in [15,16]. The OWTOP addresses two different types of urban roads: arterial roads (broad roads with two-way lanes) and branch roads (narrow, one-way circulation). The corresponding problem is formulated as the direction optimization of a given city branch roads, and takes into account several criteria. The OWTOP has been first analyzed as a bi-level optimization problem [15], using a genetic algorithm for minimizing the saturation of branch roads and the saturation excess of arterial roads. Likewise, a Simulated Annealing approach, focused on the avoidance of saturation through the branch roads, has been explored instead [16]. The OWTOP can be updated to a slightly different version by including the construction of alternative routes from an input point *A* to an output point *B* in a given city (and vice-versa). This version of the problem, known hereafter as ROWTOP (Reconfiguration One-Way Traffic Optimization Problem), can be tackled as a multi-objective optimization problem, and solved by using multi-objective optimization algorithms.

In this paper, we explore the feasibility of SC techniques, in particular, those based on evolutionary algorithms (Nondominated Sorting-based Genetic Algorithm II, NSGA-II algorithm), to solve the ROWTOP problem in a real application. It consists reconfiguring the traffic in a medium-size city near Madrid that suffers traffic problems during September celebrations because of the installation of a portable bull-fighting arena in the city center.

The rest of the paper has been structured as follows: Section 2 provides a brief summary of evolutionary computation techniques and multi-objective optimization problems, including a brief description of the NSGA-II algorithm considered in this paper as solver. This will assist us in Section 3 in mathematically describing the ROWTOP problem and in illustrating the potential of evolutionary-based algorithms. Finally Section 4 summarizes the main concluding remarks.

2. Materials and methods

Soft-Computing (SC) is a key part of Artificial Intelligence (AI) focused on the design of robust intelligent systems. SC is formed by many different methods, techniques and algorithms that, as illustrated in Fig. 1, can be conceptually grouped in three main branches: Neural Computation, Evolutionary Computation and Fuzzy Logic algorithms. Many of these methods also belong to the wider knowledge area called Natural Computing (NC). For the sake of clarity, in this paper, we focus on evolutionary computation techniques for tackling the ROWTOP. This problem is an NP-hard multi-objective optimization problem, where it is extremely difficult to successfully apply classical optimization approaches. Instead, as will be shown later on, an evolutionary algorithm adapted to multi-objective problems is able to find very good solutions to this complex problem.

Aiming at making this paper stand by itself, the following subsections describe the basic points of these evolutionary methods (SubSection 2.1), along with the main concepts of multi-objective optimization (2.2), which are in the very-core of the ROWTOP problem solving and in its real application to re-configure traffic in cities.

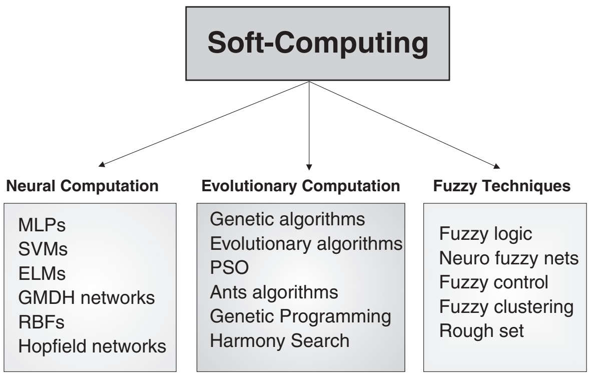

Fig. 1. Scheme of Soft-Computing and its branches.

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