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Fuzzy logic-controlled diversity-based multi-objective memetic algorithm applied to a frequency assignment problem

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ABSTRACT

One of the most commonly known weaknesses of Evolutionary Algorithms (EAS) is the large dependency between the values selected for their parameters and the results. *Parameter control* approaches that adapt the parameter values during the course of an evolutionary run are becoming more common in recent years. The aim of these schemes is not only to improve the robustness of the controlled approaches, but also to boost their efficiency. In this paper we investigate the application of parameter control schemes to address a well-known variant of the Frequency Assignment Problem (FAP). The controlled EA is a highly efficient diversity-based multi-objective memetic scheme. In this work, a novel general parameter control method based on Fuzzy Logic is devised. In addition, a hyper-heuristic is also considered as an established parameter control scheme. An extensive experimental evaluation of both methods is carried out that includes a comparison to a wide-range of fixed-parameter schemes. The results show that the fuzzy logic method is able to find similar or even better solutions than the hyper-heuristic and the fixed-parameter methods for several instances of the FAP. In fact, this method yielded frequency plans that outperform the best previously published solutions. Finally, the generality of the fuzzy logic-based scheme is demonstrated by controlling different kinds of parameters.

1. Introduction

Many optimisation problems that arise in real world applications require the employment of approximation techniques. Among them, meta-heuristics (Glover and Kochenberger, 2003) have become popular in recent decades. They are high-level strategies that guide a set of heuristics in the search of an optimum. Evolutionary Algorithms (EAS) (Eiben and Smith, 2003) are one of the most popular strategies belonging to this group. They are population-based algorithms inspired on biological evolution.

EAS have shown great promise for calculating solutions to difficult problems. However, in some problems, EAS exhibit a tendency to converge towards local optima, with the likelihood of this occurrence depending on the shape of the fitness landscape (Caamaño et al., 2010). Several methods have been designed with the aim of dealing with local optima stagnation. The reader is referred to Črepinšek et al. (2013) for an extensive survey of diversity preservation mechanisms. One of the methods that has gained some popularity in recent years is based on applying multi-objective schemes to single-objective optimisation problems (Segura et al., 2013a). Several ways of applying the multi-objective concepts have been devised with diversity-based multi-objective algorithms being one of the most promising schemes (Abbass and Deb, 2003). In these schemes, a metric of the diversity introduced by each individual is used as an auxiliary objective. These schemes can better deal with strong optima by being able to alleviate the effects of premature convergence.

Most popular EA variants have several components and/or parameters such as the survivor selection mechanism, or the genetic and parent selection operators, which must be specified. In general, the performance of an EA and, consequently, the quality of the resulting solutions, is highly dependent on these components and parameters. As a result, it is essential that the parameters of an EA be suitably determined. However, finding appropriate parameter settings remains one of the persistent challenges for Evolutionary Computing (Eiben and Smit, 2011).

Parameter setting strategies are commonly divided into two categories: parameter *tuning* and parameter *control*. In parameter *tuning* the objective is to identify the best set of values for the parameters of a given EA, which is then executed using these values, which remain fixed for the duration of the run. In contrast, the aim of parameter *control* is to design control strategies that select the most suitable values for the parameters at each stage of the search process while the algorithm is being executed. In single objective optimisation, it has been empirically and theoretically shown that different parameter values might be optimal at different stages of the search process (Srinivas and Patnaik, 1994;

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Bäck, 1992). Therefore, it is natural to apply control strategies to multi-objective EAS.

In this paper we devise a novel *parameter control* strategy based on the use of *Fuzzy Logic*. Such a strategy, as well as other well-known parameter control methods, is used to control some parameters of a diversity-based multi-objective Memetic Algorithm (MA), which is applied to a set of real-world instances of the Frequency Assignment Problem (FAP). The MA has some components specifically tailored to deal with the FAP. It was selected because it has demonstrated its efficiency against a large set of different meta-heuristics (Luna et al., 2011; Segura et al., 2013c). The contributions of this paper are as follows:

- A novel parameter control method based on fuzzy logic applicable to both continuous and discrete numeric parameters.
- First application of parameter control techniques based on fuzzy logic and hyper-heuristics in order to control the parameters of a mutation operator that has been specifically designed to address the FAP.
- An extensive comparison of fuzzy logic-based schemes vs. hyper-heuristics as methods of parameter control applied to a complex real-world problem.
- A broad comparison between parameter control methods and schemes with fixed parameters that highlights the benefits of parameter control as opposed to parameter tuning.

The paper is organised as follows. In Section 2, an overview of the state of the art in parameter control in EAS is given. Section 3 gives some background on fuzzy logic controllers, which we propose as a parameter control method. The formal definition of the FAP is given in Section 4. Section 5 exposes the diversity-based multi-objective evolutionary engine applied herein and provides some background on related schemes. The proposed control methods are explained in Section 6, followed by a detailed analysis of the experimental results in Section 7. Finally, the conclusions and future lines of work are given in Section 8.

2. State of the art of parameter control in evolutionary algorithms

Finding the most suitable configuration of an EA is one of the most challenging tasks in the field of Evolutionary Computation (Eiben and Smith, 2003). In order to completely define an instance of an EA, two types of information are required (Smit and Eiben, 2009):

- *Symbolic*—also referred to as *qualitative*, *categoric* or *structure* parameters—such as crossover, mutation and selection operators.
- *Numeric*—also referred to as *quantitative* or *behavioural* parameters—such as the population size and the crossover and mutation rates.

For both kinds of parameters, the different elements of the domain are known as parameter values, and a parameter is instantiated by assigning it a value. The main difference between both types of parameters lies in their respective domains. Symbolic parameters, such as the crossover operator, have a finite domain in which neither order is established nor distance metric is defined. In contrast, numeric parameters, such as the mutation rate, have an infinite domain in which a distance metric and an order can be defined for the values. Thus, optimisation methods can readily be used to look for the appropriate values of the numeric parameters of an EA. However, in the case of symbolic parameters, as noted above, distance metrics cannot be applied between two values, meaning optimisation schemes are not able to profit from the definition of these types of metrics for setting such parameters. In this case of this paper, we focus on control methods for *numeric* parameters.

The goal of parameter control is to design a control strategy that selects the most suitable parameter values for every stage of the search process. The ideas of parameter control were first incorporated in early work on EAS (Davis, 1989; Rechenberg, 1973). Nevertheless, recent research has seen a marked increase in proposals for methods that achieve parameter control in EAS (Lobo et al., 2007). In fact, parameter control methods have been successfully applied to a wide range of EAS and other meta-heuristics such as *Evolution Strategies* (ES) (Kramer, 2010), *Differential Evolution* (DE) (Qin et al., 2009) and *Particle Swarm Optimisation* (PSO) (Zhan and Zhang, 2008). Given the large number of proposals, several taxonomies have been proposed. One of the most popular classifications (Eiben et al., 2007) considers the following types of strategies:

- *Deterministic parameter control*: Parameter values are altered by a deterministic rule without using any feedback from the search procedure.
- *Adaptive parameter control*: Parameter values are updated by a mechanism that uses some feedback from the search process. Such a mechanism is externally supplied.
- *Self-adaptive parameter control*: Parameters are encoded into the chromosome and their values are modified by the EA variation operators.

It is worth pointing out that the majority of the work on parameter control is focused on the parameters of a 'standard' EA, i.e. the variation operators (mutation and crossover), the population size or combinations of all three (Eiben et al., 2007; Bäck et al., 2000). In this paper we describe the application of control techniques to the parameters of a mutation operator specifically designed to address the FAP. It is the first time that these parameters are adapted.

3. Background on fuzzy logic controllers for parameter control

Our knowledge of EAS performance has significantly increased in recent years due to the large number of empirical analyses conducted on a wide range of applications in different areas. It would be desirable to profit from this human knowledge by encapsulating it within an algorithm to automate the task of improving the behaviour and performance of EAS. However, this sort of knowledge is usually incomplete, imprecise and/or it is not well organised. Consequently, the application of *fuzzy logic-based methods* would seem to offer a promising approach for dealing with this kind of knowledge.

One application of fuzzy logic is the design of *Fuzzy Logic Controllers* (FLCS). FLCS can be used to define control approaches in which the incorporation of human knowledge is performed intuitively. An FLC consists of the *knowledge base*, the *fuzzy inference engine* and the *fuzzification* and *defuzzification interfaces* (Herrera and Lozano, 2003). The knowledge base has two different parts, a *data base*, which includes the definitions of the membership functions of the linguistic terms for each input and output variable, and a *rule base* constituted by the collection of fuzzy control rules.

The main benefit of using FLCS to adapt the parameters of an EA is that the possible values that can be assigned to certain parameters are infinite, in contrast to other techniques that can only use some values from a finite set. However, the main drawback is that FLCS cannot be directly applied to control the symbolic parameters of an EA. Therefore, in this paper we restrict the application of the FLC to controlling numeric parameters. An