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Granulating linguistic information in decision making under consensus and consistency

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ABSTRACT

This study is concerned with group decision making contexts in which linguistic preference relations are used to provide the evaluations of results. On the one hand, granulation of linguistic terms, which are used as entries of the preference relations, is carried out for the purpose of dealing with the linguistic information. Formally, the problem is expressed as a multi-objective optimization task in which a performance index composed of the weighted averaging of the criteria of consensus and consistency is maximized via an appropriate association of the linguistic terms with information granules formed as intervals. On the other hand, once the linguistic terms are made operational by mapping them to the corresponding intervals, a selection process, in which the consistency achieved by each agent is also considered, is employed with intent to construct the solution to the decision problem under consideration. An experimental study is reported by demonstrating the main features of the proposed approach. Furthermore, some drawbacks and advantages are also analyzed.

1. Introduction

A general group decision making scenario, as considered here, is composed of various agents (experts, decision makers, individuals, etc.) and a collection of alternatives being possible solutions to the considered decision problem (Capuano, Chiclana, Fujita, Herrera-Viedma, & Loia, 2017; Evangelos, 2000; Hwang & Lin, 1987; Liu, Dong, Chiclana, Cabrerizo, & Herrera-Viedma, 2017). The objective of this kind of decision problem is to arrange the alternatives that are considered as possible solutions ranking from best to worst according to the testimonies provided by the agents. For the characterization of the value of each alternative, we consider the use of linguistic terms. This should make easy the expression of human assessments and judgments (Cabrerizo et al., 2017; Herrera, Alonso, Chiclana, & Herrera-Viedma, 2009; Montero, 2009).

Each individual agent evaluates qualitatively how good an alternative (possible solution) is with respect to each other. In particular, linguistic pairwise comparisons are assumed to represent the agents' preferences, that is, preference degrees between two particular alternatives are provided using linguistic terms. The alternatives are classified subjectively in the sense that they are assessed by the agents (human beings) and for this reason these evaluations can be given in an intuitively appealing way by using linguistic terms (Zadeh, 1973), that is, values expressed in natural language that should allow an ease of usage and a required human consistency (Golunska & Kacprzyk, 2016; Montero, 2009). For example, linguistic terms like Bad, Good, Very Bad, and so on, could be considered (Zadeh, 1973). It is assumed that each agent is capable of providing such an assessment via a linguistic preference relation (Herrera & Herrera-Viedma, 2000). Preference relations are assumed here because they are more accurate than preference elicitation approaches based on non-pairwise comparisons (Millet, 1997).

Several computational linguistic models, that is, approaches for dealing with linguistic information in computing with words (Herrera et al., 2009), have been developed, say the model based on membership functions (Zadeh, 1975), the symbolic model based

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on ordinal scales (Cabrerizo, Morente-Molinera, Pérez, López-Gijón, & Herrera-Viedma, 2015; Herrera & Herrera-Viedma, 2000; Morente-Molinera, Mezei, Carlsson, & Herrera-Viedma, 2017), the 2-tuple linguistic model (Herrera & Martínez, 2000; Martínez, Ruan, & Herrera, 2010), the model based on discrete fuzzy numbers (Massanet, Riera, Torrens, & Herrera-Viedma, 2014), among many others. Recently, a new approach making the linguistic information operational through information granulation was proposed (Cabrerizo, Herrera-Viedma, & Pedrycz, 2013; Cabrerizo, Ureña, Pedrycz, & Herrera-Viedma, 2014; Pedrycz & Song, 2014). In contrast, in this new approach, both the semantics and the distribution of the linguistic terms, instead of being established *a priori*, are obtained as reported by an optimization task where a certain performance criterion is maximized or minimized by an appropriate association of the linguistic values with a certain family of information granules. An information granule is a complex information entity that has to be efficiently treated in the computing setting appropriate to the information granulation framework that is assumed (Wang, Pedrycz, Gacek, & Liu, 2016).

The individual consistency (Herrera-Viedma, Herrera, Chiclana, & Luque, 2004) of the assessments provided by an agent was considered as performance index by Cabrerizo et al. (2013) and Pedrycz and Song (2014). Consistency is related to contradictory opinions provided by an individual agent. However, the problem of consistency itself implies another question: when all the agents are said to be consistent, that is, when they have similar opinions, which is known as consensus (Cabrerizo et al., 2015; Herrera-Viedma, Cabrerizo, Kacprzyk, & Pedrycz, 2014; Zhang, Dong, & Herrera-Viedma, 2018). Consensus requires that a majority of the group of agents agree on the solution achieved, but that the minority of the group of agents approve to go along with the solution. Because obtaining a consensus solution is essential, it is an important objective in group decision making contexts and, therefore, many authors have studied this area (Cabrerizo, Alonso, & Herrera-Viedma, 2009; Cabrerizo, Moreno, Pérez, & Herrera-Viedma, 2010; Kacprzyk & Zadrozny, 2010; del Moral, Chiclana, Tapia, & Herrera-Viedma, 2018; Palomares, Estrella, Martínez, & Herrera, 2014; Xu, Cabrerizo, & Herrera-Viedma, 2017).

The underlying objective of this study is to propose a general approach to modeling, and then support, the resolution process of a group decision making situation in which the agents' assessments are represented via linguistic preference relations. The proposed approach is composed of two steps. The first one becomes indispensable to make the linguistic information operational so the final solution can be achieved. In this step, the linguistic terms are transformed into formal constructs of information granules, which are then handled within the computing setting that is appropriate to the given information granulation framework. Here, the granulation formalism being considered pertains to intervals and two optimization criteria are used to arrive at the formalization of the linguistic terms through intervals, namely consistency and consensus. This helps transforming linguistic information into meaningful intervals in such a way that the final ranking of alternatives with highest consistency and consensus is achieved. To accomplish high flexibility when formulating this optimization task, the Particle Swarm Optimization (PSO) framework (Kennedy & Eberhart, 1995) is used as a viable technique of global optimization. Once the linguistic information is made operational, the second step consists in applying a selection process (Cabrerizo, Heradio, Pérez, & Herrera-Viedma, 2010; Herrera-Viedma, Chiclana, Herrera, & Alonso, 2007) that obtains the solution according to the assessments given by the group of agents. In this step, the consistency achieved by each agent is used with the aim of assigning higher significance to the most consistent agents.

The main originality of the proposed approach is that both the semantics and the distribution of the linguistic terms are not established *a priori*, but they are obtained according to an optimization task where a optimization criterion, which is based on both consistency and consensus, is maximized by a suitable mapping on the linguistic terms on the information granules. Therefore, solutions with higher levels of consistency and consensus are obtained using this approach and, as a consequence, better results in GDM scenarios are derived.

The study is organized as follows. Section 2 is related to a granulation of the linguistic information, which forms a core component of the proposed approach. Then, the PSO framework is described as it is used as an optimization technique, and some aggregation operators are introduced as they are utilized in the selection process. We formally introduce a general approach to support the resolution process of a group decision making situation (Section 3). An experimental setting and its results are illustrated in Section 4. Then, the characteristics of the developed proposal are analyzed in Section 5. Finally, Section 6 covers main conclusions and future studies.

2. Preliminaries

This section introduces a granulation of the linguistic terms that are used in the linguistic preference relations. This guides us to the operational version of additional processing producing the rank of alternatives. Next, the PSO framework is described. Lastly, both the Ordered Weighted Averaging (OWA) operator (Yager, 1988) and the Induced Ordered Weighted Averaging (IOWA) operator (Yager & Filev, 1999) are introduced.

2.1. Granulation of linguistic information

The pairwise comparison between alternatives is provided via a linguistic value belongings to a linguistic terms set $S = \{s_1, s_2, \ldots, s_g\}$, being g its granularity (Herrera et al., 2009). It is usually assumed that there exists a linear order $\prec$ among the linguistic terms, such that $\forall s_i,\ s_j \in S,\ s_i \prec s_j$, being $j > i$, means that the linguistic term s_j denotes a better evaluation than the linguistic term s_i. As example, a linguistic term set S, with granularity equal to five, could be composed of the following linguistic terms: MW (Much Worse), W (Worse), E (Equal), B (Better), and MB (Much Better).

Each linguistic term itself is not operational, which signifies that no further processing can be carried out. This means that a granulation (Song & Pedrycz, 2011), which is defined as the process of forming something into granules, of the linguistic terms is required. A number of formalisms of information granulation may be considered here including shadowed sets, fuzzy sets, rough sets, intervals, just to cite to some options (Pedrycz, 2013).

A certain optimization task, where a certain performance criterion is optimized, may be formulated with the aim of arriving at the operational realization of the granules of information. For instance, the consistency of individual agents was used as performance index in Pedrycz and Song (2014) and Cabrerizo et al. (2013).

2.2. PSO framework

Kennedy and Eberhart (1995) proposed the PSO framework, which is a population-based meta-heuristic algorithm. It is included in the class of swarm intelligence algorithms inspired by the social dynamics and the emerging behavior in organized colonies by social norms as, for example, colonies of ants, swarms of bees, flock of birds, schools of fish, and even human social behavior (Gou et al., 2017; Zhou, Gao, Liu, Mei, & Liu, 2011).

In contrast to other evolutionary methods, PSO is an iterative algorithm starting with an initial population of individuals, called