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An agent-oriented decision support system combining fuzzy clustering and the AHP

Omar López-Ortega *, Marco-Antonio Rosales

Centro de Investigación en Tecnologías de Información y Sistemas (CITIS), Universidad Autónoma del Estado de Hidalgo, Carretera Pachuca – Tulancingo Km. 4.5, C. P. 42084 Pachuca, Hidalgo, Mexico

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ABSTRACT

Decision making is a complex process, particularly when it is carried out by multidisciplinary team. Methods based on the analytical hierarchy process have been widely employed because they provide solid mathematical background. Nevertheless, solutions such as the Aggregation of Individual Judgements (AIJ) and the Aggregation of Individual Priorities (AIP) do not offer sufficient explanatory data in regards with the final decision. We developed an agent-based decision support system (DSS) that employs fuzzy clustering to group individual evaluations and the AHP to reach a final decision. Fuzzy clustering is adequate to determine important pieces of data such as the largest group of evaluations that exist around a centroid value. On the other hand, the MAS paradigm offers capabilities for achieving distributed and asynchronous processing of data. The AHP is used after the individual evaluations are clustered, as if the group were a single evaluator. Altogether, the proposed solution enhances the quality of multi-criteria group decision making.

1. Introduction

As it is suggested in Carmen and French (2003), modern management promotes distributed decision making carried by multidisciplinary teams. Organizations decide to promote group decision making, where experts work together but not necessarily at the same place or time (Soubie & Zaraté, 2005). For example, when it comes to acquire new manufacturing equipment (Rao, 2007), or to select the best personnel, among many alternatives (Metin, in press), not only the opinion of one single person is taken into account. Evaluations from qualified people with different background and perspectives are favored nowadays. Top management must broadcast, to those individuals that will form the decisional group, the evaluation criteria as well as specific data of the alternatives. In turn, the evaluators must judge the alternatives, and top management shall make a final decision based on such judgements.

Thus, decision making refers at selecting, among a finite set of m alternatives, the one that complies best with a finite set of p evaluation criteria. This particular problem has been tackled by Saaty, who developed the well-known Analytic Hierarchy Process (AHP) (Saaty, 1977). Let us suppose, however, that top management decides to gather opinions from p experts. Should the AHP be used as a decision process, a pairwise comparison matrix (PCM) is formed in order to compare the relative importance of the evaluation criteria. Therefore, management will be forced to process z **PCM**'s to determine the group assessments.

To achieve group decision making based on the AHP, three different methods have been proposed. The Aggregation of Individual Judgements (AIJ), and the Aggregation of Individual Priorities (AIP) (Forman & Penitawi, 1998). Also, an optimization method has been proposed by Sun and Greenberg (2006). However, neither of the three mentioned approaches actually provides information on how the group of experts accommodated. For instance, it is not possible to determine how many of the evaluators agree on the resultant priorities. This is so because such techniques are based on geometrical averages.

Hence, to enhance group decision making, we developed a solution based on the combination of Multi-Agent Systems, the fuzzy C-means clustering technique and the Analytic Hierarchy Process. The proposed decision support system (DSS) allows distribution, asynchrony and clusters formation based on fuzzy c-means. Multi-Agent Systems fulfill technological needs related to automating the distribution and processing of large amounts of data. Fuzzy clustering is adequate to determine how many evaluations actually form the group majority. Also, it is established the value around which every single evaluation is close enough to be considered part of the winning cluster. This data is the largest cluster's centroid. Furthermore, it is also possible to determine how compact the clusters are by computing data dispersion. Finally, the AHP is used to reach a final ranking of the alternatives once the experts' evaluations are grouped.

The DSS we present provides the following modules. One module, residing at the management's site, is used to define evaluation

* Corresponding author.
E-mail addresses: lopezo@uaeh.edu.mx, lopezo@uaeh.reduaeh (O. López-Ortega).

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criteria, and broadcast such criteria to the evaluators. They, in turn, possess an evaluation module that helps collecting the judgements of experts. A third module is in charge of clustering the individual evaluations and reach a final decision.

The paper is organized as follows. Section 2 contains the related work tackling multi-criteria group decision making, particularly those techniques based on either fuzzy logic or MAS's. Section 3 presents the mathematical description of the AHP, fuzzy C-means and the algorithm we propose to group the individual evaluations. In Section 4 we describe the Multi-Agent System, which is then shown in Section 5. The calculations are depicted in Section 6. We finish the report showing conclusions and insights about promising future work.

2. Related work

2.1. Fuzzy approaches

It has been acknowledged that in multi-criteria decision making there is a degree of vagueness, either at the moment of making the judgements or when processing the information. On the fuzzy approach, uncertainty is measured by linguistic terms described by a given membership function. The availability of linguistic estimates may be used to evaluate alternatives by using fuzzy relations (Ekel, 2002). Similarly, fuzzy logic has been used to solve a multi-criteria problem, comparing results obtained with those of classical statistics (Kangas, Leskinen, & Kangas, 2007). An overview on how fuzzy logic has been introduced into multi-criteria decision making can be found in Wang (2000), where different proposals are set in order to employ fuzzy mathematics into the AHP. In Chan and Kumar (2007), for instance, the original scale proposed by Saaty is computed by using fuzzy numbers. Also, in Fenton and Wang (2006) the evaluator's risk and confidence attitudes are defined by a linguistic scale of triangular fuzzy numbers. Similarly, trapezoid fuzzy numbers are used to model linguistic terms on which criteria are measured, and a fuzzy distance is developed to calculate the difference between two trapezoid fuzzy numbers (Li, 2007). Fuzzy numbers are also employed to compute linguistic information provided by a group of experts (Jiang, Fan, & Ma, 2008). A fuzzy distance measure is proposed as part of a fuzzy clustering methodology for linguistic opinions when evaluations are expressed vaguely (Chakraborty & Chakraborty, 2007). A fuzzy AHP system has been developed to select machine tools by evaluating criteria with fuzzy numbers (Ayag & Ozdemir, 2006). These approaches follow earlier attempts to model the vagueness of the evaluators' judgement (Cuong, 1999). Although such proposals are highly valuable, we intend to establish patterns that come up naturally when individual evaluations form clusters, and by establishing to what degree of membership they belong to one cluster. Fuzzy C-means is suitable for our goals because it considers that any given value (crisp evaluation, in our approach) might reside on two clusters at the same time. So, to establish to what cluster such value belongs to, the higher membership degree is considered. We consider that it is entirely possible to measure the proximity of the evaluators' judgement via their membership degree to a group of similar measures within a well-defined cluster. An interesting upgrade of our MAS is to allow evaluators to express linguistic opinions rather than crisp values.

2.2. The Multi-Agent approach

As it has been stated before in this paper, in real-world situations data are acquired asynchronously, at geographically dispersed sites, and processed by decision making algorithms. On this line of research (Lee, Ghosh, & Nerode, 2000) developed a Mathematical Framework that permits the description of centralized decision making algorithms and facilitates the synthesis of distributed decision making. Even though the concept of Agency is not explicitly used in the sense of FIPA-based MAS, entities capable of establishing communication are developed. However, such communication is described in the form of signals, and intelligent behavior is not granted to such entities. Instead, utility functions are considered to synthesize the final decision. This obviously contrasts with our approach, since we are using the theory of speech acts to model conversations, and we synthesize a soft-computing technique to promote approximate reasoning. On the other hand, the usage of argumentation-based MAS has been proposed as an approach to multiple criteria group decision making. An overview of such approach is presented by Matsatsinis and Tzoannopoulos (2008). However, emphasis is placed on the argumentation and negotiation mechanisms, rather than on the agent's intelligent capabilities to reach a solution. A cooperative knowledge-based system has been designed to support decision makers who are not in the same place at the same time, enabled by cooperation processes (Soubie & Zaraté, 2005). A decision support system, enabled under web services, has been developed in order to promote distributed decision making (Yuen & Lau, 2008). Recent proposals support our claim that fuzzy clustering and MAS lead to high quality decisions (Yu, Wang, & Keung Lai, 2008). In their model, agents are given fuzzifying capabilities so that crisp evaluations are transformed into fuzzy opinions. Such fuzzified opinions are then compared and aggregated into a single group opinion. However, such approach differs from ours because they do not present a distributed solution based on the AHP, and we do not use linguistic labels to make the evaluation.

3. Methods' presentation

3.1. The analytical hierarchy process

It consists of three major stages. First, an evaluator judges the relative importance of evaluation criteria on a pair-wise basis. This leads to a pairwise comparison matrix (**PCM**), possessing the following structure:

$$PCM = \begin{vmatrix} 1 & c_{12} & \dots & c_{1p} \\ c_{21} & 1 & \dots & c_{2p} \\ \vdots & \vdots & \vdots & \vdots \\ c_{p1} & c_{p2} & \dots & 1 \end{vmatrix}, \tag{1}$$

where c_{ij} is a numeric value that shows the relative importance of criterion c_i to criterion c_j. This first stage completes with the calculation of the eigenvector of the **PCM**.

$$eigenCriteria = \begin{vmatrix} e_1 \\ e_2 \\ \vdots \\ e_n \end{vmatrix}, \tag{2}$$

Eigenvector **eigenCriteria** defines the actual priority obtained by each criterion.

On a second stage, the evaluator decides to what extent one alternative over another complies with a given criteria.

$$PCM^{criterion}_{alternative} = \begin{vmatrix} 1 & a_{12} & \dots & a_{1m} \\ a_{21} & 1 & \dots & a_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ a_{m1} & a_{m2} & \dots & 1 \end{vmatrix}, \tag{3}$$