Using Visualization Tools to Guide Consensus in Group Decision Making

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Abstract. In the resolution of group decision making problems where the consensus process can not be held *face to face* by the experts it is usually difficult for them to be able to identify the closeness of the opinions of the rest of the experts, and thus, it is difficult to have a clear view of the current state of the consensus process. In this paper we present a tool that creates consensus diagrams that can help experts to easily comprehend the current consensus state and to easily identify the experts that have similar or very different opinions. Those diagrams are based on several new similarity and consistency measures.

Keywords: Consensus, Visualization, Consistency, Group Decision Making.

1 Introduction

Usually, to solve Group Decision Making problems, that is, problems where a set of experts $E = \{e_1, \ldots, e_m\}$ have to choose the best alternative or alternatives from a feasible set of alternatives $X = \{x_1, \ldots, x_n\}$, two different processes have to be carried out: the *consensus process* and the *selection process*. The former consists on obtaining the highest consensus level among experts, that is, to obtain a state were the opinions of the different experts are as close as possible one to another. The latter process consists on obtaining the final solution to the problem from the opinions expressed by the experts in the last round of the consensus process.

While the selection process can be almost fully automatized using different Soft Computing techniques [4,5,9,10,12,17], the consensus process [2,3,11,14,16,22] involves the communication and discussion among experts and between the experts and the moderator, which is usually encharged to guide the consensus process in order to obtain the final solution for the problem with a high level of consensus. Thus, to fully automatize the consensus process is a more difficult task. However, several new different approaches and tools to adapt classical consensus processes

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and models to new environments and making use of new technologies (mainly web-based technologies) can be found in the literature [1,18,19,21].

The application of these new technologies allow to carry out consensus processes in situations which previously could not be correctly addressed. For example, nowadays it is possible to carry out consensus processes among several experts which are located in different countries around the world. Though, it is important to remark that even with the adoption of new communication technologies (video-conference, chat rooms, instant messaging, e-mail and so on) there is still an important need of new collaboration and information tools for the experts being able to solve decision making problems where they cannot meet together with the other experts.

In this work we center our attention in a particular problem that arises in many consensus processes for group decision making when experts do not have the possibility of gathering together: experts may not have a clear idea about the current consensus status among all the experts involved in the decision process. In usual decision making models, where experts gather together to discuss their opinions about the different alternatives, it is relatively easy to determine which experts have similar opinions, and thus, experts may join or form different groups to better discuss and to reason out about the pros and cons of every alternative. Additionally, when experts are able to determine the consensus state of the decision making process it is more easy for them to influence the other experts [8]. However, in the cases where direct communication is not possible, experts will probably need some assistance to stablish connections among them and to obtain a clear view of the consensus process progress.

To ease the perception of the consensus state to the experts, we propose to use a novel visualization tool which generates simple consensus diagrams of the current consensus state in the decision making problem that is being solved by drawing a graph in which the experts are nodes which are separated from each other depending on the affinity of their preferences about the alternatives in the problem. Visual elements do have a great protential to influence experts in decision processes [20] and thus, these consensus diagrams, when presented to the experts, will allow them to have a more profound and clear view about the consensus process and about which experts have similar or different opinions about the alternatives. To develop the visualization tool we take into account several factors as the consistency of the information expressed by each expert and the similarity of the opinions of the experts at three different levels. This visualization tool can be easily integrated into existing consensus models.

The structure of this contribution is as follows: In section 2 we present fuzzy preference relations as the representation model that the experts will use to provide their preferences about the alternatives and some consistency properties and measures about them. In section 3 we present some similarity masures that can be computed from the preferences expressed by the experts. Section 4 describes the visualization tool that using the previous similarity and consistency measures generates some consensus diagrams that can be used by the experts to obtain a clear picture of the current consensus state in the problem. Finally, some conclusions and future works are outlined in section 5.

2 Preliminaries

In this section we present fuzzy preference relations as the representation model that the experts will use to express their preferences about the alternatives in the problem. Additionally, some consistency measures for the preference relations at three different levels (pair of alternatives, alternatives and preference relation levels) are presented.

There exists many different representation formats that can be used by experts to provide their preferences about the alternatives in a group decision making problem. One of the most used formats is *fuzzy preference relations* due to their effectiveness as a tool for modelling decision processes and their utility and easiness of use when we want to aggregate experts' preferences into group ones [13,15,23]:

Definition 1. *A fuzzy preference relation P^h given by expert e^h on a set of alternatives X is a fuzzy set on the product set $X \times X$, i.e., it is characterized by a membership function $\mu_{P^h} : X \times X \longrightarrow [0,1]$.*

When cardinality of X is small, the preference relation may be conveniently represented by the $n \times n$ matrix $P^h = (p^h_{ik})$, being $p^h_{ik} = \mu_{P^h}(x_i, x_k)$ $(\forall i, k \in \{1, \ldots, n\})$ interpreted as the preference degree or intensity of the alternative x_i over x_k: $p^h_{ik} = 1/2$ indicates indifference between x_i and x_k $(x_i \sim x_k)$, $p^h_{ik} = 1$ indicates that x_i is absolutely preferred to x_k, and $p^h_{ik} > 1/2$ indicates that x_i is preferred to x_k $(x_i \succ x_k)$. Based on this interpretation we have that $p^h_{ii} = 1/2 \;\; \forall i \in \{1, \ldots, n\}$ $(x_i \sim x_i)$.

Consistency [13], that is, lack of contradiction, is usually a very desirable property for preference relations (information without contradiction is usually more valuable than contradictory information). In [12] we developed some consistency measures for fuzzy preference relations which are based on the additive consistency property, whose mathematical definition was provided by Tanino in [23]:

$$(p^h_{ij} - 0.5) + (p^h_{jk} - 0.5) = (p^h_{ik} - 0.5) \; \forall i, j, k \in \{1, \ldots, n\} \tag{1}$$

that can be rewritten as:

$$p^h_{ik} = p^h_{ij} + p^h_{jk} - 0.5 \;\; \forall i, j, k \in \{1, \ldots, n\} \tag{2}$$

We consider a fuzzy preference relation P^h to be *additive consistent* when for every three alternatives in the problem $x_i, x_j, x_k \in X$ their associated preference degrees $p^h_{ij}, p^h_{jk}, p^h_{ik}$ fulfil (2).

Additionally, expression (2) can be used to calculate an estimated value of a preference degree using other preference degrees in a fuzzy preference relation. Indeed, the preference value p^h_{ik} $(i \neq k)$ can be estimated using an intermediate alternative x_j in three different ways:

1. From $p_{ik}^h = p_{ij}^h + p_{jk}^h - 0.5$ we obtain the estimate
$$(cp_{ik}^h)^{j1} = p_{ij}^h + p_{jk}^h - 0.5 \tag{3}$$
2. From $p_{jk}^h = p_{ji}^h + p_{ik}^h - 0.5$ we obtain the estimate
$$(cp_{ik}^h)^{j2} = p_{jk}^h - p_{ji}^h + 0.5 \tag{4}$$
3. From $p_{ij}^h = p_{ik}^h + p_{kj}^h - 0.5$ we obtain the estimate
$$(cp_{ik}^h)^{j3} = p_{ij}^h - p_{kj}^h + 0.5 \tag{5}$$

The overall estimated value cp_{ik}^h of p_{ik}^h is obtained as the average of all possible $(cp_{ik}^h)^{j1}$, $(cp_{ik}^h)^{j2}$ and $(cp_{ik}^h)^{j3}$ values:
$$cp_{ik}^h = \frac{\sum_{j=1;i\neq k\neq j}^{n} (cp_{ik}^h)^{j1} + (cp_{ik}^h)^{j2} + (cp_{ik}^h)^{j3}}{3(n-2)} \tag{6}$$

When the information provided is completely consistent then $(cp_{ik}^h)^{jl} = p_{ik}^h \,\forall j, l$. However, because experts are not always fully consistent, the information given by an expert may not verify (2) and some of the estimated preference degree values $(cp_{ik}^h)^{jl}$ may not belong to the unit interval $[0, 1]$. We note, from expressions (3–5), that the maximum value of any of the preference degrees $(cp_{ik}^h)^{jl}$ ($l \in \{1, 2, 3\}$) is 1.5 while the minimum one is -0.5. Taking this into account, we define the error between a preference value and its estimated one as follows:

Definition 2. *The error between a preference value and its estimated one in* $[0, 1]$ *is computed as:*
$$\varepsilon p_{ik}^h = \frac{2}{3} \cdot |cp_{ik}^h - p_{ik}^h| \tag{7}$$

Thus, it can be used to define the consistency level between the preference degree p_{ik}^h and the rest of the preference values of the fuzzy preference relation.

Definition 3. *The* consistency level associated to a preference value p_{ik}^h *is defined as*
$$cl_{ik}^h = 1 - \varepsilon p_{ik}^h \tag{8}$$

When $cl_{ik}^h = 1$ then $\varepsilon p_{ik}^h = 0$ and there is no inconsistency at all. The lower the value of cl_{ik}^h, the higher the value of εp_{ik}^h and the more inconsistent is p_{ik}^h with respect to the rest of information.

Easily, we can define the consistency measures for particular alternatives and for the whole fuzzy preference relation:

Definition 4. *The* consistency level associated to a particular alternative x_i *of a fuzzy preference relation* P^h *is defined as*

$$cl_i^h = \frac{\sum_{\substack{k=1 \\ i \neq k}}^{n} (cl_{ik}^h + cl_{ki}^h)}{2(n-1)} \tag{9}$$

with $cl_i^h \in [0,1]$.

Definition 5. *The* consistency level of a fuzzy preference relation P^h *is defined as follows:*

$$cl^h = \frac{\sum_{i=1}^{n} cl_i^h}{n} \tag{10}$$

with $cl^h \in [0,1]$.

3 Computing Similarity Measures

In this section we present some new similarity measures among experts that can be computed from the fuzzy preference relations expressed by experts. These new measures, as the consistency measures presented in section 2, are computed in three different levels (pair of alternatives, alternatives and preference relations levels) for every pair of experts in the problem.

To do so, for each pair of experts (e_h, e_l) $(h < l)$ we define a similarity matrix $SM^{hl} = \left(sm_{ik}^{hl}\right)$ where

$$sm_{ik}^{hl} = 1 - |p_{ik}^h - p_{ik}^l| \tag{11}$$

Definition 6. *The measure of similarity of the preference experts* e_h *and* e_l *about the alternative* x_i *over* x_k *is* sm_{ik}^{hl}.

The closer sm_{ik}^{hl} is to 1, the more similar is the opinion of the experts about alternative x_i over x_k.

We can now compute similarity measures at the alternatives and preference relation levels:

Definition 7. *A similarity measure for experts* e_h *and* e_l *for a particular alternative* x_i *is computed as:*

$$sm_i^{hl} = \frac{\sum_{\substack{k=1 \\ i \neq k}}^{n} (sm_{ik}^{hl} + sm_{ki}^{hl})}{2(n-1)} \tag{12}$$

Definition 8. *A global similarity measure for experts e_h and e_l (taking into account the whole preference relations) is computed as:*

$$sm^{hl} = \frac{\sum_{i=1}^{n} sm_i^{hl}}{n} \tag{13}$$

4 A Tool to Visualize the Consensus State for Group Decision Making Problems

In this section we present a novel visualization tool that generates consensus diagrams in which the experts on the problem are drawn in different locations depending on the similarity of their opinions, that is, experts with similar opinions will be drawn near to each other, while the experts whose opinions differ greatly will be drawn far away from each other.

To draw the consensus diagrams we use a spring model graph drawing algorithm [7] in which the experts correspond to the nodes of the graph and a similarity measure between each pair of experts act as the length of the spring associated to each edge of the graph. These kind of algorithms simulate a system of springs defined on the graph and output a locally minimum energy configuration.

As we have defined several different similarity measures the tool can use different similarity measures depending on the information that we want to visualize. For example, if we need a general overview of the consensus state for the problem, we can choose to use the global similarity measures sm^{hl}, but if we want to visualize the consensus state about a particular alternative x_i we can choose to use the similarity measures sm_i^{hl}.

As consistency of the information is also an important issue to take into account (inconsistent experts are usually far away from the opinions of the other experts) we have introduced in the visualization tool the possibility of incorporating the consistency measures presented in section 2 to improve the consensus diagrams. This improvements are reflected in two different ways:

- The most consistent experts are drawn bigger. Thus, it is easy to recognize the most consistent experts and those who provide contradictory information.
- The similarity measures are altered according to the consistency of the experts involved:

$$\overline{sm}_{ik}^{hl} = \frac{sm_{ik}^{hl}}{(cl_{ik}^h + cl_{ik}^l)/2} \quad ; \quad \overline{sm}_i^{hl} = \frac{sm_i^{hl}}{(cl_i^h + cl_i^l)/2} \quad ; \quad \overline{sm}^{hl} = \frac{sm^{hl}}{(cl^h + cl^l)/2}$$

In figure 1 we have a snapshot of the tool where the global consensus state is depicted for a group decision making problem with 4 different alternatives and 7 different experts involved. As it can be seen, there are three experts (*Enrique*, *Francisco* and *Francisco C.*) with similar opinions -they are close to each other-. On the other hand, *Sergio*'s opinions seem to be far from all the other experts,

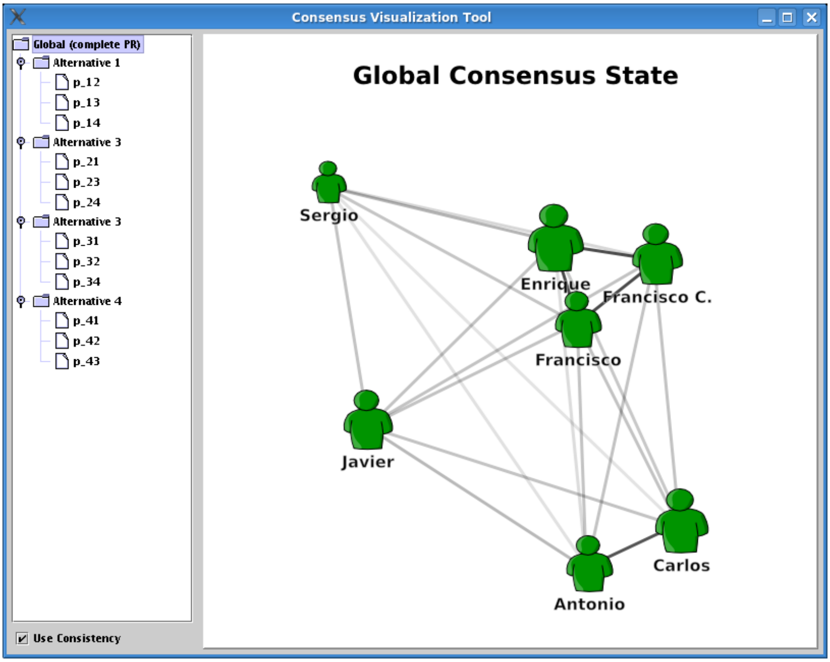

Fig. 1. Snapshot of the Visualization Tool

and moreover, his opinions are the most inconsistent (contradictory) -he is drawn smaller due to that contradictions-. Additionally it can be seen that *Antonio* and *Carlos* have similar opinions about the problem, but these opinions are different than the opinions expressed by all the other experts.

5 Conclusions

In this paper we have presented a tool that allows to visualize the status of a consensus process. It makes use of consistency and similarity measures in order to generate some consensus diagrams were experts are drawn nearer when their opinions are similar. Thus, we provide a powerful tool for experts that participate in consensus processes where there is no possibility of gathering together (for example if the consensus process is held by means of web technologies) and consecuently, where is difficult to obtain a clear overview of the consensus state.

In future works we will improve this visualiztion tool in order to be able to represent more useful information in the consensus diagrams, as the position of the current solution of consensus or the automatic detection of groups of experts with similar alternatives.

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