WEB-BASED COLLABORATIVE MULTI-CRITERIA DECISION MAKING

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Abstract

This paper describes a web-based environment for collaborative (group) multi-criteria decision making and semantical analysis. The environment is built on top of a web-meeting tool that facilitates both synchronous and asynchronous discussions, data collection, and results analysis. While there are a number of tools available that support web-based collaboration and decision making the results analysis in this system is unique. The back-end for the decision making environment is a multi-criteria decision engine based on fuzzy set and fuzzy integration theories.

INTRODUCTION

Within a number of existing organizational structures it has become a necessity to develop distributed multi-criteria decision making tools. For example, if the executive board of a company has to make a decision regarding the next year's budget, it can not be expected that all members are present on a particular day, due to hectic schedules. Using multi-criteria decision making software, they can meet and participate not only from different locations, but also at different times (synchronous and asynchronous access).

From a multi-criteria decision making point of view, recent techniques have been developed, that offer much more than simple classification of the alternatives or consequences. These techniques are based on fuzzy integrals (or non-additive integrals) such as the Choquet integral on which we will focus here, or the Sugeno integral. With such aggregation operators, we can define the notions of importance of criteria, and also interaction between the criteria. These are key elements in decision making as they allow us to understand and explain the behavior of a decision maker, and therefore to give a semantical explanation of the results. The application of these methods to a group decision making problem is the case we are interested in here.

The fuzzy multi-criteria decision making tool is built on top of the ZingThing groupware tool (see http://www.anyzing.com) which is introduced in the next section of the paper. This software allows a group of decision makers to participate in the group decision making process from different locations, potentially at different times. The remainder of the paper introduces the basics of decision making from a fuzzy integral perspective and explains how to interpret the results.

The decision making environment in this project is built on a group-ware product called "ZingThing". ZingThing is a text-based, web-meeting tool that has its genesis in a face-to-face meeting system called "Grouputer" (see http://www.grouputer.com). Grouputer facilitates face-to-face meetings through a timer controlled, text-based environment where a group of up to 12 participants, or stake-holders, meet. Each participant has a standard keyboard which is connected via multiplexing hardware to a single computer. The Grouputer software provides a graphical user interface where each participant has a "playspace" in which their ideas and thoughts are typed. These thoughts can then be promoted by the participant to a common "teamspace" area where meeting discussion takes place. Meeting agenda templates can be loaded, minutes are automatically generated, and timers can be used to keep meetings within strict time constraints.

A Java version of Grouputer has been implemented in which the keyboards are replaced by separate clients connected to a central meeting server. This product is called "WebGrouputer" and in what seems like a bizarre reversal of technology a system that is conceptually like the Unix "talk" command and Internet Relay Chat (IRC) was taken back to the Internet. ZingThing is the descendant of WebGrouputer.

ZingThing's star-shaped network topology is shown in Figure 1. Using the Java Communications API (see http://java.sun.com/products/javacomm/) support for the multiplexer hardware has been "re-incorporated" into the system. This allows for three decision making scenarios:

(1) Up to 13 participants can meet in one physical location using a single computer, the multiplexer hardware and a video projector.

(2) A maximum of 16 participants per meeting can connect to a central server and meet remotely via the Internet.

(3) Any combination of multiplexed and stand-alone clients can meet. For example, 13 participants could meet in one location and a colleague who is in another city or another country can join them remotely.

The client software can be run as a stand-alone application or as an applet within a web-browser. Participants can join a meeting simply by pointing their browser at the meeting server which then presents them with a list of possible meetings to join. New meetings can be created by uploading extensible XML agenda templates to the meeting. Currently, for each agenda item a template specifies the item text, a GIF or JPEG image, a URL to be displayed, the voting criteria and an enumeration of the voting scale.

Figure 2 presents a client screen-shot during the voting phase of a meeting with 3 participants. The top quarter of the screen contains the meeting topic, current agenda item text, an image related to the agenda item and the meeting timer. Images are loaded on demand via HTTP. The next quarter of the screen is the teamspace where ideas, comments or discussion points are submitted by participants. The remaining half of the screen holds the participant playspaces.

Playspaces for participants currently connected to the meeting are shown with a blue title-bar and a white background. The grey playspaces are inactive. As individual keystrokes are typed they are displayed in the participant's playspaces. A lower latency word-at-a-time update mode is also available for participants using low speed connections.

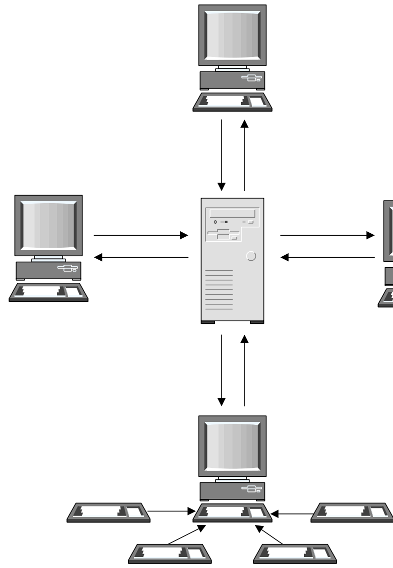

Figure 1: The star-shaped ZingThing network topology.

Multiple meetings can be run concurrently on the server with up to 16 participants per meeting. An embedded HTTP server is also incorporated which allows virtually any computer to host meetings with minimal configuration. The embedded HTTP server can serve up the required client applet files, agenda images, and minutes or results pages. Alternatively the software can be configured to use an external web-server.

At any point during the meeting the minutes can be generated in HTML. These detail client name and connection information as well as documenting the participants discussion for each agenda item. Currently the minutes are threaded by the agenda item number and then the time of receipt. At the conclusion of voting, summary and analysis reports from the decision engine are also generated by the server in HTML format. The client software then launches the participant's web-browser to display the results. Vote data from each meeting is also saved in CSV (comma separated value) format so it can be easily imported into spreadsheet software for further analysis. To help solicit unbiased responses for potentially delicate or controversial meetings an anonymous option is available. Fictitious names can be specified in the meeting template to replace the participant's log-on name which normally appears in the title-bar. Connection details are also removed so all discussion and voting during the meeting remains anonymous.

While it may be advantageous to hold synchronous meetings that are geographically distributed it may also be convenient at times to hold meetings that are temporally distributed. An asynchronous meeting mode provides this flexibility allowing groups that cannot find a meeting time that is mutually convenient to join and leave a meeting a number of times over a longer period. In this mode the participants effectively log into the meeting to read the discussion, submit their votes, and provide comments to rebut or support the views of other participants.

The meeting environment that has been described provides no support for audio, video, white-boards or file-sharing - features that are available in other systems that support group communication and collaboration (see http://www.microsoft.com/windows/NetMeeting/, http://www.icq.com). However, this text-based system provides timer-driven synchronous and asynchronous discussion,

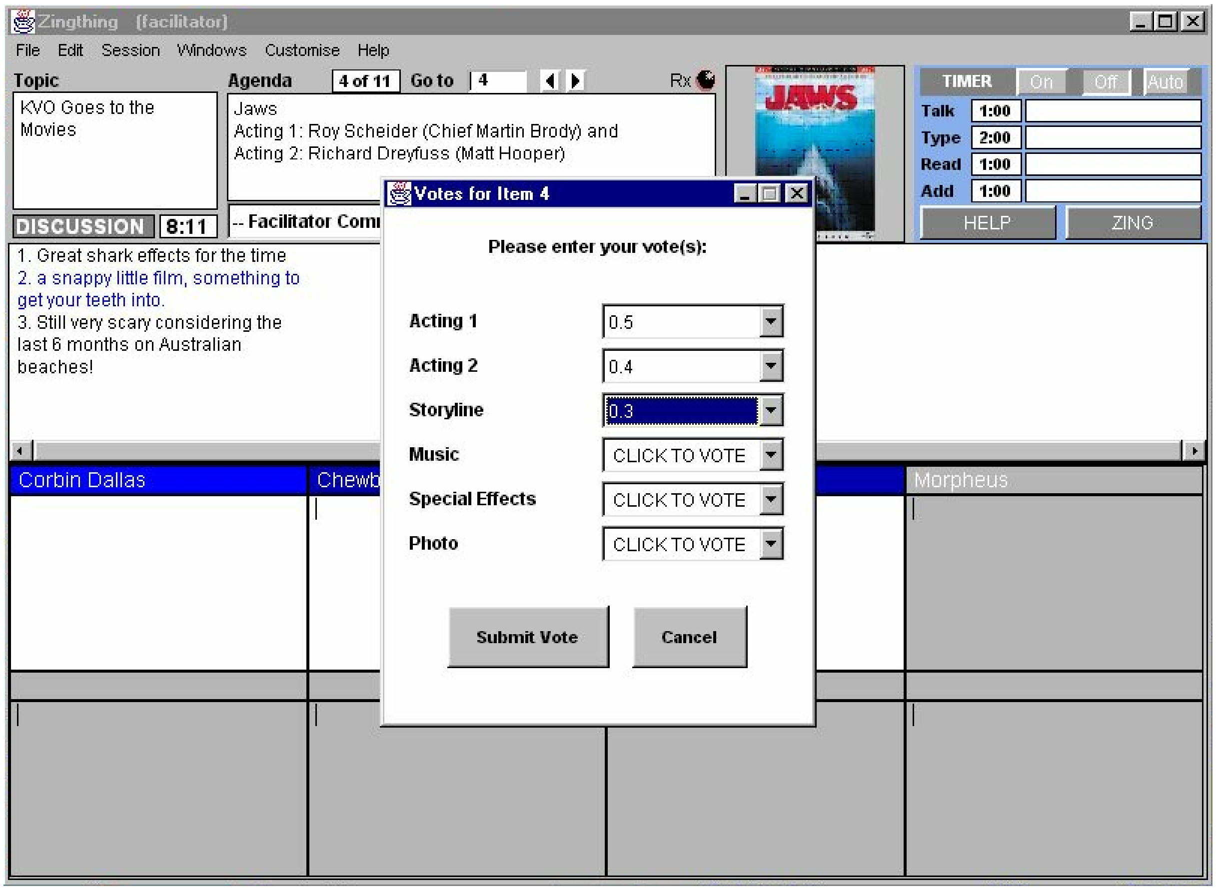

Figure 2: Screen-shot of the ZingThing interface in voting mode.

data collection, voting facilities and automatic minutes and report generation that are simple and flexible. Having introduced the meeting and voting environment, the next section describes the voting process.

FUZZY MULTI-CRITERIA DECISION MAKING

PROBLEM

A multi-criteria decision making problem is usually seen as a 2-tuple $(X, \succeq)$, where

$$X = \times_{i \in I} X_i$$

is a multidimensional set of consequences or alternatives among which the decision maker can choose, $I = \{1, \cdots, n\}$ is the set of criteria or attributes being considered to evaluate alternatives, and $\succeq$ is a preference relation on X.

Usually, one can give her/his preferences among elements in a set of values of attributes X_i, that is a partial preference, but can not give a global preference over X. In short, partial preferences $\succeq_i$ (read "is preferred to") are available on each set X_i, but $\succeq$ is not obvious.

Therefore, we try to find a numerical representation (though qualitative approaches can also be considered) $u : X \to \mathbb{R}$ such that

$$\forall x, y \in X \ , \ x \succeq y \Leftrightarrow u(x) \geq u(y).$$

The solution should be obtainable from the partial preferences, so we are looking for an operator $\mathcal{H} : \mathbb{R}^n \to \mathbb{R}$ such that

$$u(x) = \mathcal{H}(u_1(x_1), \cdots, u_n(x_n))$$

where $x = (x_1, \cdots, x_n)$ and for all $i \in I$, $u_i : X_i \to \mathbb{R}$ such that $x_i \succeq_i y_i$ is equivalent to $u_i(x_i) \geq u_i(y_i)$. The operator $\mathcal{H}$ is called an aggregation operator.

When found, this operator allows us to give a global preference among alternatives. A general decision engine should, however, also provide an explanation of why an alternative was chosen as well as a semantical interpretation of the results. These results should include importance and interaction of criteria.

TRADITIONAL APPROACH

The classical way to deal with such an aggregation procedure is to use the weighted sum as the aggregation operator:

$$u(x) = \sum_{i \in I} \alpha_i u_i(x_i)$$

with $\sum_{i \in I} \alpha_i = 1$. The coefficient α_i represents the importance/weight of criterion i given a priori by the decision maker.

Although such a method is very simple to use and to compute, it has some major drawbacks shared by any additive procedure of aggregation in a multi-criteria decision making context.

- the weights are chosen in a ad hoc way.
- one can not explain the results precisely because the weights are chosen by the decision maker and not obtained from the available data.
- there is no way to define interaction between criteria when assuming the aggregation operator is a an additive operator.
- considering an additive method is equivalent to assuming the criteria are independent (see [8]).

THE DELPHI METHOD

The Delphi method has also been proposed for decision making in a group setting. It is a refinement of the weighted sum process, adapted to group decision making.

Assume a group of people have to choose the best alternative with respect to several criteria. The first step is for each decision maker to assign a weight to each criterion, and a utility function on each set of values of attributes. Then, he/she can decide which alternative/choice is the best with respect to their weights and utility functions.

In a second step, the participants in the voting procedure discuss their respective choices and why they assigned these particular weights in an attempt to influence the vote of other participants.

After the discussion, a second round of voting is organized, similar to the first one. The process can go on until a consensus is reached, or until there is no significant change, and the individual choices are aggregated. Aggregation can use a simple average sum, if all participants are assumed equal, or with a weighted sum if participants are not of the same importance. This can be the case for example, when deciding what is the optimal strategy to apply in a military setting where participants are officers of different ranks.

Although such a method is extremely simple, and actually leads to non-additive choices, (this is due to the fact that the discussions following the voting rounds "erase" in some way the independence between criteria) it does not permit us to understand the decision process as the importance and interaction between criteria is somehow hidden in the discussion rounds.

For these reasons, it is necessary to develop a non-additive procedure to aggregate partial preferences into a global one.

THE CHOQUET INTEGRAL AS AN AGGREGATION OPERATOR

We briefly introduce the tools of non-additive (fuzzy) integration theory before explaining how to use them as aggregation operators in multi-criteria decision making (see [5] for a thorough investigation, as well as [7], [2], for the links with uncertainty problems, and [9]).

Definition 1 *A Non-additive measure on* $S = \{s_1, \cdots s_n\}$ *is a set function* $\mu : \mathcal{P}(I) \to [0, 1]$ *such that*

(i) $\mu(\emptyset) = 0$, $\mu(S) = 1$

(ii) $A \subset B$ *implies* $\mu(A) \leq \mu(B)$

With respect to such measures (that encompass the notion of probability measure and is therefore a generalization of the additive method presented in the previous section) it is possible to define generalized non-additive integrals. Though, we will present here only the Choquet integral in the finite case [1].

Definition 2 *The Choquet integral of* f *w.r.t* μ *is defined by*

$$(C) \int f d\mu = \sum_i (f(s_{(i)}) - f(s_{(i-1)}))\mu(A_{(i)})$$

with $f(s_{(1)}) \leq \cdots \leq f(s_{(n)})$*, and* $A_{(i)} = \{x_{(i)}, \ldots, x_{(n)}\}$*.*

We can also define other fuzzy integrals such as the Sugeno integral [10] which has a similar structure to the Choquet integral and where the sum operator is replaced by a $\vee$ maximum operator, and the $\times$ operator is replaced by a $\wedge$ minimum operator.

Definition 3 *Let* μ *be a non-additive measure, and let* f *be an application* $f : X \to [0, +\infty]$*. The Sugeno integral of* f *w.r.t* μ *is defined by:*

$$(S) \int f \circ \mu = \vee_{i=1}^{n}((f(x_{(i)}) \wedge \mu(A_{(i)})))$$

with the same notations and conventions as above.

Despite similar structures these integrals are rather different. The Sugeno integral does not restrict to a classical Lebesgue integral when the fuzzy measure considered is in fact additive. Besides, the Sugeno integral appears to be better suited for qualitative problems, and the Choquet integral is best used for quantitative problems.

The Choquet integral can be used as an aggregation operator in the following way. If a fuzzy measure on the criteria is available, then the Choquet integral of the mono-dimensional utility functions, with respect to the fuzzy measure defined on the criteria is used as the aggregation operator. In this case:

$$u(x) = \sum_i [u_{(i)}(x_{(i)}) - u_{(i-1)}(x_{(i-1)})]\mu(A_{(i)})$$

with $A_{(i)} = \{(i), \cdots, (n)\}$.

Disadvantages:

- the cost is 2^n but this problem can be easily solved by using so-called 2-additive measures that reduce the cost to the power 2 (see [4])
- it may not be optimum for purely qualitative problems. In this case an other integral the Sugeno integral [10] would be a better aggregating tool

Advantages:

- it relies on the data given by the decision maker(s)
- it encompasses most aggregation operators
- it is semantically interpretable

Semantic interpretation:

- The measure μ is used to represent the importance of a criterion i through the Shapley index (Game Theory):

  $$v_i = \sum_{K \subset X \setminus \{i\}} \gamma_{|K|}(n)(\mu(K \cup \{i\}) - \mu(K)).$$

  where γ is defined such that the Shapley indices sum up to 1.

- The Shapley index of criterion i represents the average added information/importance of i to all coalitions not containing i

- The measure μ can also express the interaction between two criteria:

  $$\begin{aligned} I_{ij} &= \sum_{K \subset X \setminus \{i,j\}} \xi(|K|)[\mu(K \cup \{i,j\}) \\ &- \mu(K \cup i) - \mu(K \cup j) + \mu(\{i,j\})]. \end{aligned}$$

  that represents redundancy when negative and complementarity when positive as can be seen when studying the following expression taken by the Choquet integral when evaluated with respect to 2-additive measures

$$(C)\int_S f d\mu = \sum_{I_{ij}>0} (f(i) \wedge f(j)) I_{ij} + \sum_{I_{ij}<0} (f(i) \vee f(j)) |I_{ij}| + \sum_{i=1}^{n} f(i)(I_i - \frac{1}{2}\sum_{j\neq i} |I_{ij}|). \tag{1}$$

Eventually, in a group decision making problem, if a panel of experts is available, it is possible to extract a non-additive measure and to evaluate a Choquet integral to be used as an aggregation operator in a distributed multi-criteria decision making problem.

A "good" operator would be an operator minimizing the difference between the subjective global evaluation given by the expert and denoted by $g(x_j)$ and the computed global evaluation given by aggregating the partial evaluation, denoted by $\hat{g}(x_j)$. That is

$$E^2 := \sum_{j=1}^{m} [\hat{g}(x_j) - g(x_j)]^2$$

the minimization being on $\hat{g}$, where for every criterion x_j, for $j = 1, \cdots, m$:

$$\hat{g}(x_j) := \mathcal{H}(p(x_j, 1), \cdots, p(x_j, n)).$$

where $p(x_j, i)$ represents the partial evaluation of alternative x_j with respect to criterion i.

Though, the problem is ill-conditioned and therefore can be rather slow even for small problems with 10 decision makers, 10 criteria, and 10 objects (up to 7hrs).

An alternative method was proposed by Michel Grabisch in [3]. Despite not being optimal, the method is much faster, as it does not go through every edge of a hypercube as is the case when solving quadratic problems under constraints. Besides, in the case where the decision makers have very little information, the fuzzy measure given by the algorithm is close to a probability measure which is expected.

MULTI-CRITERIA DECISION MAKING AND ZINGTHING

To place the decision engine in the ZingThing context, we give a short summary of how the ZingThing and the multi-criteria decision engine are linked. The panel of experts or decision makers meet using ZingThing in a synchronous or asynchronous way. They criteria to be considered during the voting process is agreed upon before the meeting. The meeting then guides the participants through the alternatives, for which each participant gives a partial preference with respect to each criterion, as well as a global evaluation. These values can be real numbers as well as linguistic, as fuzzy set theory allows us to map these linguistic values into a subset of the real numbers. We can, therefore, restrict ourselves to real numbers without loss of generality. Once all the values have been obtained, they are sent to the decision engine which generates a fuzzy measure, a ranking, and Shapley and interaction indices for the criteria. The Shapley values and interaction indices can be used as a feedback to the decision makers.

CONCLUSION

This paper has briefly introduced a Web-based distributed meeting environment that can be used to gather votes from participants who may be distributed both geographically and chronologically. From a Multi-criteria decision making perspective, we have introduced non-additive (or fuzzy) tools to avoid the drawbacks encountered when trying to deal with such problems using additive methods such as the weighted sum, or even refinement of additive methods in a group decision setting such as the Delphi method. As we have seen, the Choquet integral is a very interesting aggregation operator to solve multi-criteria decision making problems, as it offers a way to classify alternatives as well as a way to interpret the results, and provide a semantic interpretation of the results. The Choquet integral is generated only from the data really available to the decision maker or group of decision makers which makes the Choquet integral both a practical and theoretical tool.

In purely qualitative problems, the Choquet integral may not be the best aggregation operator, from a measurement theory perspective [6]. In this case the Sugeno integral would be a better tool. Therefore, it is important to show in what case a utility function can be represented as a Sugeno integral, and also to define importance and interaction indices in a qualitative problem.

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