A Negotiation Support System based on a Multi-agent System

specificity and preference relations on arguments

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Abstract. In this paper, we propose a Negotiation Support System based on a Multi-agent System. Each agent assists a user in multi-criteria decision making and negotiates according to this decision-modelling with other agents, each of them representing a user. Moreover agents assist users in the debate to negotiate a joint representation of the problem and automatically justify proposals with this joint representation.

1 Introduction

In this paper, we present a Group Deciding Support System which could be used in environment planning by the elect, civil society and experts. This software, a groupware, drives rational decisions according to governance principles. More pluralistic than hierarchic, it guarantees the readability in the choice made by all between creative solutions. Moreover, users are really assisted and need no ability in Computer Science.

A Negotiation Support System provides three kinds of functionality. Firstly, it facilitates the exchange of information among users (ex: Zeno[1]) Secondly, it provides decision-modelling or group-decision techniques to reduce the noise and uncertainty that occur in the process of asynchronous telecooperation (ex :GDSS-DMI[2]). Finally, it provides negotiation support. The field of Artificial Intelligence in particular multi-agent methods can be useful for negotiation support. In this paper, we use these technics to detect the sources of conflict. Interaction between users is used to clarify conflicts.

This system is inspired by the group choice design support system which was proposed by Takayuki Ito and Toramatsu Shintani [3, 4]. It is based on multi-agent negotiation. Figure 1 shows the system architecture. Each agent assists a user in the multi-criteria decision making and negotiates according to this decision-modelling with other agents, each of them representing an user.

[1] http://www.ais.fraunhofer.de/MS/results/results-zeno.html
[2] http://gdss-dmi.uqam.ca/gdss-dmi/

All agents are registered by a middle agent transmitting proposals and counter-proposals to other agents. This system provides addition functionalities to negotiate a joint representation of the problem and to automatically justify proposals based on this joint representation.

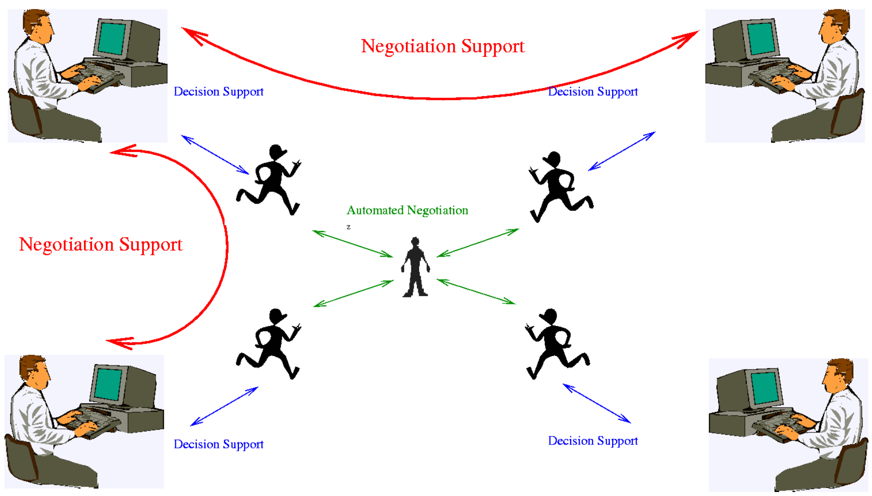

Fig. 1. System Architecture

The decision support tools are described in section 2. The multiagent negotiation is presented in section 3. Section 4 explains how negotiation is supported.

2 Decision support

Multi-criteria analysis is useful for land-use management. The Analytic Hierarchy Process (AHP) [7] is a powerful and flexible decision making process to help people set priorities and make the best decision when both qualitative and its quantitative aspects of a decision need to be considered.

The agent assists user in the three steps of this procedure: the definition of the problem structure, the pairwise comparison between elements and the synthesis of preferences.

2.1 First step: constructing decision hierarchy

To obtain a good representation of a problem, it has to be structured into different components called **activities**. Figure 2 shows that the **goal** of the problem ($G =$"to lay out a highway") is addressed by some **alternatives** ($A = a^1, a^2, a^3$) i.e. possible solutions. The problem is split into sub-problems (c_1, c_2) which are

criteria evaluating alternatives. These criteria (C) are split in sub-criteria and, recursively split to finally obtain the **leaf criteria** of a **decision hierarchy** i.e. a taxonomy of criteria. A specificity relation over criteria is defined as: $c_{k1} \lhd c_{k2}$ iff c_{k1} is a sub-criterium of c_{k2}. The corresponding transitive closure is noted by $\lhd^*$.

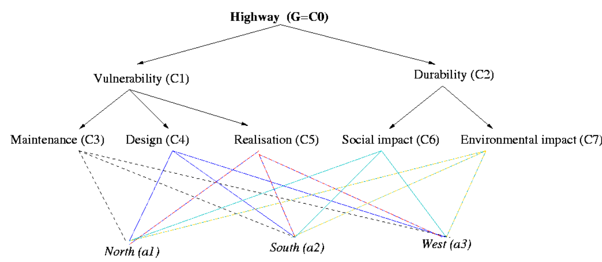

Fig. 2. Decision hierarchy to lay out an highway

After develop the hierarchy using the graphical user interface, the user weights the relative importance of all elements.

2.2 Second step: making judgments

The user have to make pairwise comparisons between similar activities on the same level with respect to the activity on the upper level to evaluate the relative importance of one element over another with respect to a property. The relative importance could be: equal (1), moderate (3), strong (5), very strong and demonstrated (7) or extreme (9). Sometimes one needs compromise judgments $(2, 4, 6, 8)$ or reciprocal values $(1/9, 1/8, 1/7, 1/6, 1/5, 1/4, 1/3, 1/2)$. For pairwise comparisons between n similar activities with respect to the criterium c_k, a matrix $A_{c_k} = (a_{ij})_{i,j \leq n}$ is a preferred form. Each element evaluates the relative importance of one activity i over another activity j ($a_{ij} = \frac{w_i}{w_j}$).

Some proprieties of this pairwise comparison matrix: identity, reciprocity, default values reduce user's effort to inform all pairwise comparisons. The next step synthesizes judgments and allows to know how good the consistency is.

2.3 Third step: judgments synthesis and consistency measurement

If n is the size of the pairwise comparison matrix $A_{c_k} = (a_{ij})_{i,j \leq n}$, and $\lambda_{\max}$ the max eigen-value, the eigenvector which is associated represents the priorities of the activities with respect to c_k ($W_{c_k} = (w_i)_{i \leq n}$).

Of course, a minimal degree of consistency in setting priorities for elements with respect to some criteria is necessary to get valid results in the real world. The **consistency index** of a pairwise comparison matrix A_{c_k} is defined as follows: $\mathrm{CI}_{A_{c_k}} = \frac{\lambda_{max} - n}{(n-1)}$. RC_n is the **random consistency** for n-order pairwise comparison matrix where values are randomized. The AHP measures the overall consistency of judgments by means a **consistency ratio**: $\text{CR}_{A_{c_k}} = \text{CI}_{A_{c_k}}/\text{RC}_n$. The higher consistency ratio is, the less consistent preferences are. The value of the consistency ratio should be 10% or less (in fact 5% for a 3×3 matrix, 9% for a 4×4 and 10% for a larger matrix) [7].

Under condition of consistency, the priorities can be calculated.

– I, the priority of a criterium with respect to the criterium on the upper level:

$$\begin{aligned} I : C - \{c_o\} \times C &\rightarrow [0;1] \\ (c_i, c_j) &\longmapsto I(c_i|c_j) = w_i \in W_{c_j} \text{ if } c_i \lhd c_j \\ &\quad\; I(c_i|c_j) = 0 \text{ else} \end{aligned}$$

According to its definition, I verifies: $0 \leq I(c_i|c_j) \leq 1$ and $\forall c_j$ criterium which is not a leaf
$\sum_{c_i \lhd c_j} I(c_i|c_j) = 1$;

– J, the priority of an alternative with respect to a leaf criterium:

$$\begin{aligned} J : A \times C &\rightarrow [0;1] \\ (a_i, c_j) &\longmapsto J(a_i|c_j) = w_i \in W_{c_j} \\ &\quad\;\; \text{with } c_j \text{ leaf criterium} \\ &\quad\; J(a_i|c_j) = 0 \text{ else} \end{aligned}$$

According to its definition, J verifies: $0 \leq J(a_i|c_j) \leq 1$ and $\forall c_j$ leaf criterium $\sum_{a_i \in A} I(a_i|c_j) = 1$;

The extension of these functions corresponding to the transitive closure of the specificity relation ($\lhd^*$) is deduced as follows:

– I^*, the priority of a criterium with respect to the criterium on the upper level:

$$\begin{aligned} I^* : C \times C &\rightarrow [0;1] \\ (c_i, c_j) &\longmapsto I^*(c_i|c_j) = 0 \text{ if } \neg(c_i \lhd^* c_j) \\ &\quad\; I^*(c_i|c_j) = I(c_i|c_j) \text{ if } c_i \lhd c_j \\ &\quad\; I^*(c_i|c_j) = I(c_i|c_k).I^*(c_k|c_j) \\ &\quad\;\; \text{with } c_i \lhd c_k \text{ else} \end{aligned}$$

We immediately deduce that: $0 \leq I^*(c_i|c_j) \leq 1$ and $\forall c_j$ not a leaf criterium $\sum_{c_i \lhd c_j} I^*(c_i|c_j) = 1$

– J^*, the priority of an alternative with respect of a criterium:

$$\begin{aligned} J^* : A \times C &\rightarrow [0;1] \\ (a_i, c_j) &\longmapsto J^*(a_i|c_j) = J(a_i|c_j) \\ &\quad \text{if } c_j \text{ is a leaf criterium} \\ &\quad J^*(a_i|c_j) = \sum_{\substack{c_k \lhd^* c_j, \\ c_k \text{ leaf criterium}}} J(a_i|c_k).I^*(c_k|c_j) \text{ else} \end{aligned}$$

We immediately deduce that: $0 \leq J^*(a_i|c_j) \leq 1$ and $\sum_{a_i \in A} J^*(a_i|c_j) = 1$

This decision-modelling measures the consistency of judgments and synthesizes them by providing the following utility function:

$$\begin{aligned} \pi : A &\rightarrow [0;1] \\ a_i &\longmapsto \pi(a_i) = J(a_i|c_0) \end{aligned}$$

This utility function is used by the autonomous agent representing user in automated negotiation.

3 Automated negotiation system

Negotiation could be considered as a process of distributed rational decision making following a protocol. In this context, we define the autonomy of negotiating agents and show the limits of this approach.

3.1 Distributed rational decision making

Game theory defines the economic rationality of agent as making decisions optimizing their individual payoff, through an utility function π^i which maps each model of the state of the world to a real number. A non-cooperative negotiation is a framework where agents may have different goals, and each agent tries to maximize its own good with no concern for the global good.

Definition 1. *Formally, a* ***non-cooperative negotiation*** *consists in the four components* $< I, A^I, s, \Pi^I >$ *specialized by the following:*

– *a* ***set of*** N ***agents****:* $I = \{1, 2, ..., N\}$*;*
– *a* ***set of alternatives*** $A^i \subseteq Sol$ *considered by the agent* i*:* $a^i \in A^i$ *is the advocated alternative. Alternatives are represented by the vector* $A^I = (A^1, A^2, ..., A^N)$*;*
– *a* ***global decision*** s*, the majority alternative or if some of the alternatives are equals, determined by lexicographic order;*
– *for each agent* i*, a* ***utility function*** π^i*, evaluating the payoff of the agent* i *with respect to the global decision. Utility functions are represented by the vector* $\Pi^I = (\pi^1, \pi^2, ..., \pi^N)$.

This approach respects the cognitive scheme of each agent which is determinated by the reference system of its user. The comprehension and judgments of the problem are subjective.

In this system, negotiation consists in an exchange of proposals between agents. The agent i proposes its advocate alternative to agent j. This alternative should be the most preferred alternative for agent j (with the highest priorities with respect to the goal) to be immediately accepted. If not, agent j tries to change the preference order of alternatives by adjusting judgments in pairwise comparison matrixes (cf section 3.2). If the proposal is not accepted, it will send a counter-proposal. The negotiation will be stopped, when an alternative is approved unanimously.

3.2 Strategy of negotiating agents

Takayuki Ito and Toramatsu Shintani [3] propose a method to increase the support of an alternative within the limits of consistency. In the system, an agent increases the value of elements of the rows of this alternative in the matrix where this alternative is evaluated except for the diagonal element, within two intervals of the nine point scale in order to increase the weight of the alternative and change the preference order. Table 1 shows an example of such an adjustment. Agent increases by 1 interval the value of elements of the alternative a_2 over the alternatives a_1 and a_3. Figure 3 shows by this adjustment that a_2 become more preferable.

	a_1	a_2	a_3	w_i
a_1	1	1	1	1/3
a_2	1	1	1	1/3
a_3	1	1	1	1/3

$\Rightarrow$

	a_1	a_2	a_3	w_i
a_1	1	1/2	1	1/4
a_2	2	1	2	1/2
a_3	1	1/2	1	1/4

Table 1. Adjusting judgments in the matrix A_{c_3}

The rationality of negotiating agents is implemented with a utility function given by the AHP. Within the limits of the uncertainty of this decision-modelling, the agent is autonomous of its user for the decision [1].

3.3 The limits of this approach

Arrow's impossibility theorem [8] shows that no social choice exists with more than three alternatives ($\|\text{Sol}\| \geq 3$). This impossibility to satisfy desiderata conditions (possible aggregation of individual preferences, pareto efficiency, independence of irrelevant alternatives, no-dictatorship) justify the need of negotiation support tools to help users during the debate (cf section 4).

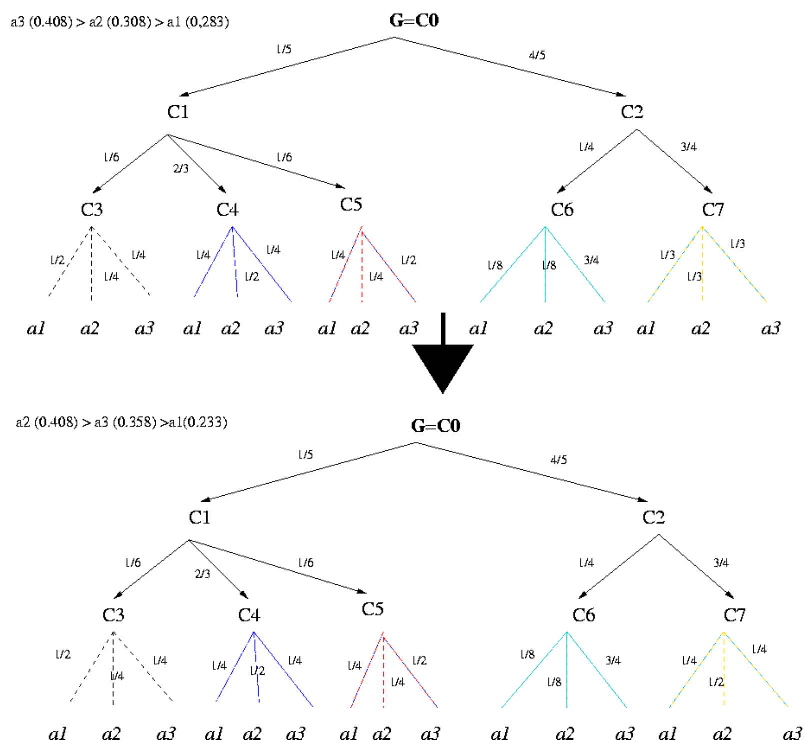

Fig. 3. Adjusting judgments in a decision hierarchy

Moreover, the process of adjusting judgments which is called persuasion [3, 4] is not oriented by a heuristic to find an acceptable alternative. The process can neither justify the modifications on judgments nor justify the order of these modifications. Compromises are not relaxations on preferences but help to find acceptable alternatives which are not found by the AHP.

According to N.R. Jennings [5], argumentation is a way to improve the efficiency of a negotiation process. This assertion can not be formally demonstrated. The presence of explicit justifications in argumentation could fail to improve convergence and may degrade performance due to processing overheads [6]. Instead of speeding up the rate of converging to a solution, argumentation can explain conflicts.

4 Negotiation Support

The system takes advantage of the interaction between users. It provides functionalities to negotiate a joint representation of the problem and to automatically justify proposals based on this joint representation.

4.1 Collaborative development of decision hierarchy

The AHP can be used successfully with a group. The greater the number of people involved in the hierarchy construction is , the greater the range of ideas is. The enumeration of alternatives and the development of decision hierarchy help the group to debate the problem. This computer-mediated work increases the comprehension, the readability and, the objectivity of the decision-making. However judgments remain subjective.

This system provides addition functionalities to negotiate a joint representation of the problem. All agents ($i \in I$) share the same goal ($G = c_0$) but each of them has its own set of activities, alternatives (A^i) or criteria (C_i). The sets of activities can move, expand and, retract during negotiation. When a user takes into account a new alternative, this alternative is proposed to all users by agents. A user group is associated with a sub-hierarchy. When a user takes into account a new criterium, this criterium is proposed to the corresponding group. In the previous example, "the social impact" (c_6) is a criterium proposed to all users taking into account "the durability" (c_2). The middle agent registries agents and their sets of activities.

The problem structure help users to argue their choices. Common criteria can be used to justify proposals.

4.2 Automated justification

The relative **confidence** in a criterium taken into account for a decision could be estimated by the following function:

$$\begin{aligned} V : C - \{c_o\} &\rightarrow [0;1] \\ c_i &\longmapsto V(c_i) = I^*(c_i|c_0) \end{aligned}$$

We immediately deduce that a more general criterium than another is more confident: if $\forall k_1, k_2\ c_{k1} \lhd c_{k2}$ then $v(c_{k2}) \geq v(c_{k1})$.

According to Bayes'relation, the **contribution** of a criterium to an alternative could be estimated by the following function:

$$\begin{aligned} S : C - \{c_o\} \times A \ &\rightarrow\ [0;1] \\ (c_i, a_j) \longmapsto S(c_i|a_j) &= \frac{J^*(a_j|c_i).V(c_i)}{\pi(a_j)} \end{aligned}$$

We deduce that a more general criterium than another have a greater contribution:
if $\forall k_1, k_2\ c_{k1} \lhd c_{k2}$ then $\forall a_i \in A\ S(c_{k2}|a_i) \geq S(c_{k1}|a_i)$.

An agent can justify its proposals. Each proposed alternative is supported by a criterium in accordance with a force. The set of arguments have two kinds of relations:

- a specificity relation over criteria not depending on the alternative is defined as: $c_{k1} \lhd c_{k2}$ iff c_{k1} is a sub-criteria of c_{k2};
- a set of preference relations over criteria depending on the alternative: $c_{k3} \succ_{a_l} c_{k4}$ iff $P(c_{k3}|a_l) \geq P(c_{k4}|a_l)$.

Example 1. The second decision hierarchy in the figure 3 have the following specificity relation:
$c_1 \lhd c_0, c_2 \lhd c_0, c_3 \lhd c_1, c_4 \lhd c_1, c_5 \lhd c_1, c_6 \lhd c_2, c_7 \lhd c_2$ The preference relation depending on a_2 is such as:

$$\begin{aligned} c_0[P(c_0|a_2) = 1] \succ_{a_2} c_2[P(c_2|a_2) = 0.795] \succ_{a_2} \\ c_7[P(c_7|a_2) = 0.734] \succ_{a_2} c_1[P(c_1|a_2) = 0.204] \succ_{a_2} \\ c_4[P(c_4|a_4) = 0.163] \succ_{a_2} c_6[P(c_6|a_2) = 0.061] \succ_{a_2} \\ c_3[P(c_3|a_2) = 0.02] \simeq_{a_2} c_5[P(c_5|a_2) = 0.02] \end{aligned}$$

A message to make a proposal consists of an alternative and the set of arguments supporting it. The middle agent filters and transmits this message to agents sharing the same activities. If agents share some criteria, the strongest criterium, except for roots, is selected. This argument is transmitted by agents to users in order to explain the conflict. It points at the criterium from which the conflict comes from.

5 Conclusions

The functionalities for negotiation support take advantage of interactions between users. When a criterium is pointed by a conflict, the system encourages users to split criterium in sub-criteria.

As Florania Grasso [2], we think that conflicts are not only beneficial but also necessary and welcomed to make a better choice. Despite advices [2], the arguing agent does not base its justification on the audience's beliefs. It uses common criteria in accordance with a force determined by its own judgments. The relevance of arguments is based on the preferences of the arguing agent.

An implementation and an empirical assessment must come to valid the adequacy and the significance of our approach.

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