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Negotiation support systems: A multi-criteria and multi-agent approach

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Abstract

This research concerns the development of an Negotiation Support Systems (NSS) based on a multi-criteria conceptual framework of the negotiation and developed according to a multi-agent architecture from Distributed Artificial Intelligence (DAI). A first prototype of such a system, NegocIAD, has already been developed [8], but the weakness of its assistance to the negotiation process have led us to revise the conceptual framework in order to define a more relevant assistance to the negotiation process. This paper presents this new conceptual framework defined in order to develop a new prototype. First, we point out the originality of our multi-criteria and multi-agent approach, the general architecture and the limitations of NegocIAD. Then we present the new multi-criteria conceptual framework mainly based on the definition and the use of projection plans (group Gaia plans) emerging from principal component analysis (PCA) already proposed in a single decision maker context in extension of the Promethee method. In the next part, we develop the possible levels of use of these plans during the negotiation process and the type of assistance provided to the mediator. This assistance is mainly based on the elaboration and the interpretation of group Gaia plans for which we propose a set of interpretation rules and the outline of a method to make use of these rules for a relevant support to the mediator in the management of the negotiation process. Finally, we conclude on the perspectives of our future researches and developments for the new generation of our prototype in a multi-agent architecture context. © 1997 Elsevier Science B.V.

Keywords: Negotiation; Decision support systems; Negotiation support systems; Multi-criteria analysis; Multi-agent systems; Distributed artificial intelligence

1. Introduction

Negotiation processes are often characterised by conflicts of interest and a non-cooperation, the existence of various sources of information and rules, proper to each negotiator (that one is not willing to divulge or share), a mutual lack of confidence, a doubt about the sincerity and the good will of the other actors, and finally, exchanges of the 'bargaining' type.

The concept of Negotiation Support System (NSS) is as recent as that of Group Decision Support System (GDSS) [8]. It has taken such an importance in the scientific community that the title NSS has merged with that of GDSS to make only a single field of research: the GDNSS [6]. Several NSS have already been developed [13]. A NSS permits to join

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different points of view and positions, to conciliate differences and to suggest solutions for compromises. It allows to increase the quality and the acceptability of a negotiated agreement, to improve the quality of relationships during the negotiation and finally, to increase the capacity of negotiators to solve the conflict.

As a communication support tool between the opposing negotiators, an NSS reduces the emotional aspect that often characterises exchanges and makes barriers due to influences and/or to inhibitions fall. As an advanced tool in the negotiation process, it helps members of the group to identify their true interests, to place them in the context of the confrontation with the other interests and to help each to evaluate the importance that they grant to their expectations. Being neutral and third parties, these systems allow to develop scenarios taking into account the different positions.

Our research focuses on the development of NSS based on multi-criteria models of the negotiation and developed according to a multi-agent architecture from Distributed Artificial Intelligence (DAI). A first prototype of such a system, NegocIAD, has already been developed [9]. In the first part of this paper, we point out the originality of our multi-criteria and multi-agent approach, and we present the conceptual framework, the general architecture and the limitations of our existing NegocIAD prototype. In the next part, we develop the new multi-criteria conceptual framework that we have adopted for the development of our new prototype. This framework is mainly based on the definition and the treatment of plans which come from Principal Component Analysis (PCA). Such plans have already been proposed in a single decision maker context in extension of the Promethee method. We develop in the next part the possible levels of use of these plans during the negotiation process and the type of assistance provide to the mediator. This assistance is mainly based on the elaboration and the interpretation of group Gaia plans for which we propose a set of interpretation rules and the outline of a method to make use of these rules for a relevant support to the mediator in the management of the negotiation process. Finally, we conclude on the perspectives of our future researches and developments for the new generation of our prototype in a multi-agent architecture context.

2. A multi-criteria and multi-agent approach of the negotiation: NegocIAD

An NSS is often constituted by a set of models and a metamodel federating the exchanges between these models. In general, one associates a specific model to each sub process of the global process of negotiation. These models concern in particular techniques and models from the theory of games. Our research focuses on the development of NSS based on a multi-criteria conceptual framework of the negotiation and developed according to a multi-agent approach. We have already developed a prototype of such a system, named NegocIAD [9].

2.1. A multi-criteria approach

The multi-criteria approach of decision support aims to widen the reflection, on the choice of solutions in selection phase [22], in the development of a set of criteria [2] and solutions in the design phase of Simon's model of the decision process. The multi-criteria approach is extremely relevant for the design of DSS; the implementation of models and multi-criteria techniques allows to design an assistance in the phases of design (possible solution elaboration) and selection (among these possible solutions) of the decision process concerned. Many multi-criteria methods have allowed to develop many operational DSS [18,19,14].

However, a multi-criteria method allowing, for a group of decision makers, to apprehend a process of negotiation does not currently exist. Therefore, we had to develop a multi-criteria method allowing to support such a process, and to serve as foundation to the development of the first version of NegocIAD [9]. This method is largely inspired by the Promethee method (Preference Ranking Organisation METhod for Enrichment Evaluations) proposed by Brans et al. [4] in an unique decision maker context (cf. Appendices A–D for an abstract of the Promethee method in a single decision maker context). Note that concurrently to our research on such a method, other researches are being developed, for example at the VUB – Brussels [16,17].

More precisely, the object of this new method is to support a negotiation process allowing a group of decision makers to find an agreement on a consen-

sual preorder, with the help of a mediator who has to manage the negotiation process. We consider a group of decision makers d_s having to choose among a set of actions a_j, these actions are evaluated according to a set of evaluation criteria c_i. The set of criteria is the same for all decision makers, we are conscious that this is an important restrictive hypothesis. To each decision maker is associated an evaluation matrix, analogous to the matrix proposed by Promethee in the single decision maker context.

The negotiation method we have proposed for the development of our first version of NegocIAD is defined around several phases which are decomposed in stages [9]:

Phase 1. Individual evaluation

stage 1: each decision maker of the group elaborates his own evaluation matrix;

stage 2: for each decision maker, from a flow calculation, we calculate an 'individual preorder' on the actions;

stage 3: decision makers and the mediator agree on, for example, a margin of general negotiation, indicating a maximum adjustment rate accepted for evaluations and weights of criteria (for example $\pm 10\%$);

Phase 2. Collective evaluation

stage 1: from these individual evaluations, the mediator calculates a group matrix or collective evaluation matrix (averages and dispersions);

stage 2: from this collective evaluation matrix the mediator establishes a resulting preorder, called 'collective preorder';

Phase 3. Conduct of the negotiation

stage 1: *test of consensus*: the 'consensus threshold' is obtained in reducing the flow of the best action of the previous collective preorder of the maximum adjustment rate (for example 10%). For each of the decision makers, the mediator isolates all actions of the individual preorder whose total flow is superior or equal to this threshold: if one or more actions are common to all decision makers then there is consensus; if the consensus is not reached, the mediator defines from this preorder a threshold of consensus;

stage 2: *classification of decision makers*: the mediator classifies decision makers according to their distance from the collective preorder;

stage 3: *proposal of adjustments*: the mediator indicates to each decision maker in what directions (increase or reduction) some of his evaluations or weightings of criteria would have to be adjusted so that a consensus can be found;

During this stage, the mediator may adopt several strategies of negotiation. Two possible strategies are [9]:

- *Strategy of reinforcement of the collective preorder*: to bring the decision maker who is the farthest from the consensus, back to the collective preorder;
- *Strategy of change to the collective preorder*: to incite the decision makers closest to the collective preorder, to distance from it and to approach decision makers farthest from the collective preorder.

Return to phase 1. Each decision maker adjusts (or not) his evaluations and weights in the directions suggested by the mediator.

2.2. A multi-agent approach

Our NegocIAD prototype is based on the multicriteria method that we have presented above. For the development of this prototype we have adopted a multi-agent approach, from Distributed Artificial Intelligence (DAI) [1,10,11]. NegocIAD is an NSS for a group of decision makers, managed by a mediator.

2.2.1. General architecture

This prototype has been developed with a multi-agent architecture composed of a population of artificial agents distributed on different machines dedicated to decision makers and to the mediator. The

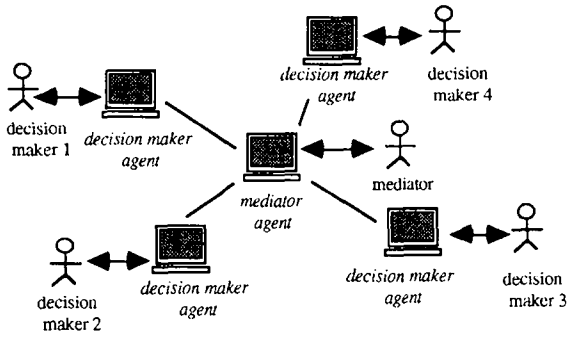

Fig. 1. General architecture of NegocIAD.

main artificial agents are of a cognitive type notably when they are associated to human actors (decision makers and mediator); other agents associated to criteria, actions, weights are of reactive type. Fig. 1 illustrates this multi-agent architecture adopted.

From a technical point of view, NegocIAD has been developed using the Objlog language, extended to the multi-agent context. Objlog is a self-referring language for the development of knowledge based systems (Objlog is itself developed in Prolog). It is based on frames and permits vertical multiple inheritance, horizontal multiple inheritance, management of exceptions, classification and analogy [7]. Decision makers and mediator agents communicate by the Ethernet network, an asynchronous communication (with or without continuation) supported by specific processes developed in C language according to a client-server philosophy.

2.2.2. A negotiation session with NegocIAD

The human Mediator initialises the negotiation by defining, in consultation with the decision makers of the group, the criteria and actions associated to the problem. The formulation of the problem being defined, the mediator communicates it to its artificial agent. This agent communicates the problem formulation to the various decision maker agents. Once the problem defined, each decision maker defines his evaluation values and his criterion weights and he delegates different orders or negotiation strategies to his artificial agent. In our prototype, these orders concern only the definition of evaluation margins and margins of weighting modulations.

After the first individual evaluation (Phase 1) done by each decision maker, the negotiation process can start, managed by the mediator or its artificial agent associated, according to the method presented above. The mediator agent calculates a collective preorder (Phase 2), tests the consensus, ranks the decision makers according to their distance from this collective preorder and finally propose to decision makers agents adjustments in specific ways for their evaluations and weightings (Phase 3). As evoked above in Phase 3 of the method, at the mediator agent level, different strategies of negotiation management can be defined. These strategies can be sophisticated and enrich the knowledge base of the mediator (extent in particular to the concept of belief). In our first prototype these strategies are either a reinforcement of the collective preorder simple or a change of the collective preorder, as already defined in the method.

In response to these adjustment demands expressed from the mediator agent, each decision maker agent modify its evaluations and weightings (Phase 1) in the way of adjustment specified by the mediator agent, and in the respect of the negotiation limits fixed by its human decision makers associated and according to the strategy defined by him. Each decision maker agent communicates these new evaluation and weighting to the mediator agent for the calculation of a new collective preorder, a new test of consensus, a new decision makers ranking and finally the proposition of new adjustments of evaluation and weighting (Phase 2).

Thus, the system manages the negotiation in a semi-automatic manner, through messages exchanged between decision makers and mediator artificial agents, until a consensus is obtained or until margins of negotiation are exhausted. In this last case, the negotiation fails and the system asks all human decision makers to enlarge evaluation and weighting margins, to adjust their evaluations beyond the limits of margins that they had fixed or suggests to continue the negotiation with a meeting with human actors.

2.3. Summary

Our experimentations with NegocIAD have shown that the multi-criteria approach coupled with multi-agent architecture is an worthwhile and operational

way. However, the conceptual framework associated to our multi-criteria negotiation method used in NegocIAD is too poor to define a relevant support to the negotiation process.

Consequently, we have revised our multi-criteria conceptual framework in order to supply a more relevant support to the negotiation process. We have chosen to focus our research on the definition of an assistance dedicated to the mediator. The first aim is to provide assistance tools to the human mediator to help him understand conflict situations and to better manage the negotiation process. The second aim is to permit the human mediator to delegate a part of these tools to an artificial mediator agent. Thus, the object of our research is not to study a possible support to the decision maker in the negotiation process.

3. Conceptual framework for group negotiation

This new conceptual framework is always based on the use of multi-criteria matrices as the main vehicle for the negotiation process. We apply various interpretative analyses to these matrices, based on principal component analysis (PCA) and leading to graphic representations which are projections.

These projections constitute a set of mathematical tools offered to the mediator to help him to understand conflict situations and to better manage the negotiation process. The interpretation of these representations permits an analysis of the current situation of the negotiation and to propose actions for the further conduct of the negotiation.

The usage of such projections has already been proposed in extension of the Promethee method by Brans and his team, under the name of 'Gaia Plan', in a single decision maker context [5], and in an embryonic state for the group negotiation [16] (cf. Appendices A–D for an abstract on Gaia plans in a single decision maker context). In the following part, we develop the mathematical model of our extensions for a multi-decision makers context and the conduct of negotiations.

3.1. Preorders in group negotiation context

Given a group of r decision makers having to choose one action in a set A of n actions. These decision makers have k criteria (belonging to the set C) to evaluate these actions and to make their choice. We introduce a human mediator M who has to manage the negotiation process to reach a consensus in this choice. We make the following preliminary hypotheses:

1. the decision makers have agreed on the items a_j of the actions set A and c_i of the set C of criteria for evaluate these a_j;
2. to each decision maker is attributed a weight w_s, according to his importance within the group;
3. each decision maker does not know the evaluations and the weightings of any other decision makers.

Furthermore, please note:

- j is the index attributed to actions: $A = \{a_j\}$, $j = 1 \ldots n$;
- i is the index attributed to criteria: $C = \{c_i\}$, $i = 1 \ldots k$;
- s is the index attributed to decision makers: $D = \{d_s\}$, $s = 1 \ldots r$.

As in a single decision maker context, each decision maker is associated an 'individual matrix' of n rows and k columns which contains their evaluations and weightings. The mediator M has a 'global matrix' of n rows and $k \times r$ columns elaborated with all the individual matrices. On the global matrix, flows or 'group flows' can be calculated. With these flows we can establish a total or partial preorder. Note that in a single decision maker context, the partial preorder Promethee I points out possible incomparabilities between different actions which result from conflicts of criteria; in a multi-decision makers context, these incomparabilities can also result from conflicts between decision makers.

The flow for a given criterion is equal to the sum of flows of this criterion for each decision maker. It is calculated on the set of individual matrices, weighted by the weight given to each decision maker. If we make the sum of input flows for a criterion c, we obtain the same result as if we calculated it from the global matrix. Therefore, calculations can be made in the same way as in a single decision maker context. With w_{si} the weight associated to each

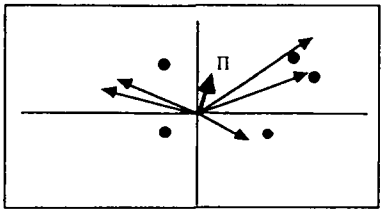

Fig. 2. An example of a group Gaia plan.

criterion i by the decision maker s, the net flow becomes:

$$\phi_g(a) = \sum_{s=1}^{r} w_s \sum_{i=1}^{k} w_{si} 1/(n-1) \sum_{j=1}^{n} P_{si}(a,x_j) - P_{si}(x_j,a).$$

Consequently, we can represent the alternatives of choice in a space of dimension r, axes of which are now, the r decision makers. The decision axis Π is then the vector coordinates of which are the r weights w_s. This leads to the group Gaia plan illustrated in Fig. 2.

In order to provide the mediator with an 'intelligent' support in the conduct of the negotiation, we propose to define a set of group Gaia plans. Now, we present how, starting with the evaluation matrices of all decision makers, we can calculate a relevant set of group Gaia plans.

The net group flow $\phi_g(a)$ for a given action a, can be defined by:

$$\phi_g(a) = \sum_{i=1}^{k} w_{si}\phi_{si}(a),$$

where $\phi_{si}(a)$ identifying the net flow for the action a, the decision maker s and the criterion i:

$$\phi_{si}(a) = 1/(n-1) \sum_{j=1}^{n} \left(P_{si}(a,x_j) - P_{si}(x_j,a)\right). \quad (1)$$

The net flow of the decision maker s for all criteria is:

$$\phi_s(a) = \sum_{i=1}^{k} w_{si}\phi_{si}(a).$$

These flows enable us to elaborate the global matrix G shown in Table 1. The outranking relationship is given by the last column, which represents the outranking flows given by:

$$\phi(a_j) = \sum_{s=1}^{r} w_s \phi_s(a_j).$$

These flows permit to rank the actions according a total preorder (Promethee II).

3.2. Definition of group Gaia plans

Like in a one decision maker context, we can apply the principal component analysis (PCA), it is possible to define plans, group Gaia plans, which are an interpretation of the information contained in this matrix G.

These Gaia plans are the projection of a cloud of points to a two dimensional space. This passage from a space of k dimensions to a plan cannot be made without an impact on the pertinence of the information processed. We can thus define δ, a ratio of pertinence associated to the plan and allowing to measure the inertia preserved by the projection on axes. The δ ratio expresses in percentage the quantity of information preserved. In all cases, the plan chosen for the projection is the one that maximises its pertinence. The plan is qualified as 'perfect' if it preserves 100% of the data during the projection. This corresponds to a particular case in which the cloud of points before projection is defined in a space of dimension 2. This is the case for example for a criteria plan where the multi-criteria matrix comprises only two. We consider that all plans preserving at least 80% of information are usable.

Different projections and consequently different group Gaia plans can be defined. We consider six relevant group Gaia plans to define and support the group negotiation process.

Table 1
Global matrix G

	D_1	...	D_s	...	D_r	
Action						
a_1	$\phi_1(a_1)$		$\phi_s(a_1)$		$\phi_r(a_1)$	$\phi(a_1)$
⋮						
a_i	$\phi_1(a_i)$		$\phi_s(a_i)$		$\phi_r(a_i)$	$\phi(a_i)$
⋮						
a_n	$\phi_1(a_n)$		$\phi_s(a_n)$		$\phi_r(a_n)$	$\phi(a_n)$

Table 2
Global unicriterion flow matrix

Decision maker 1							Decision maker r					
	c_1/D_1	...	c_j/D_1	...	c_k/D_1	...	c_1/D_r	...	c_j/D_r	...	c_k/D_r
	$\phi_{11}(\cdot)$		$\phi_{1j}(\cdot)$		$\phi_{1k}(\cdot)$		$\phi_{r1}(\cdot)$		$\phi_{rj}(\cdot)$		$\phi_{rk}(\cdot)$
a_1	$\phi_{11}(a_1)$		$\phi_{1j}(a_1)$		$\phi_{1k}(a_1)$		$\phi_{r1}(a_1)$		$\phi_{rj}(a_1)$		$\phi_{rk}(a_1)$
⋮											
a_i	$\phi_{11}(a_i)$		$\phi_{1j}(a_i)$		$\phi_{1k}(a_i)$		$\phi_{r1}(a_i)$		$\phi_{rj}(a_i)$		$\phi_{rk}(a_i)$
⋮											
a_n	$\phi_{11}(a_n)$		$\phi_{1j}(a_n)$		$\phi_{1k}(a_n)$		$\phi_{r1}(a_n)$		$\phi_{rj}(a_n)$		$\phi_{rk}(a_n)$

3.2.1. Level 1 (P1) decision makers plan

Fig. 2 illustrated such a plan outcome of the example previously defined. This plan has already been proposed in [16]. It is interesting because it gives a very synthetic comprehension of the negotiation situation. Indeed, the mediator can identify which decision makers are in conflict, and can observe if a decision maker coalition exists and also if the consensus appears easy to achieve or not.

3.2.2. Level 2 (P2) decision makers plan

For each decision maker s and each criterion i, we have already defined (1) the unicriterion net flow $\phi_{si}(a)$:

$$\phi_{si}(a) = 1/(n-1) \sum_{j=1}^{n} \left(P_{si}(a,x_j) - P_{si}(x_j,a)\right).$$

Consider the set of the unicriterion flow matrix of each decision maker. We can gather them in Table 2.

The only remaining task is now to carry out the PCA on the matrix in Table 2. This plan positions the actions not any more in relation to the decision makers, but in relation to the criteria of all decision makers. The actions are positioned in the plan according to the evaluations of all decision makers (see Fig. 3).

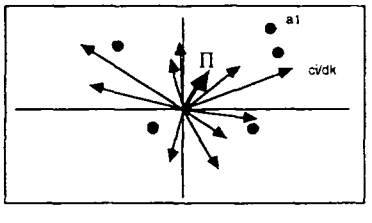

Fig. 3. Level 2 decision maker plan.

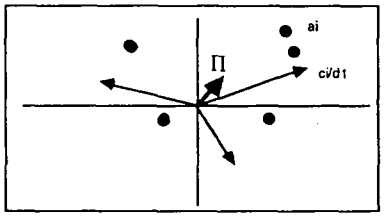

Fig. 4. Level 3 decision maker plan.

3.2.3. Level 3 (P3) decision maker plan

This plan positions the actions seen by all decision makers in relation to the criteria of one decision maker. We have, therefore, as many level 3 decision maker plans as decision makers. The superposition of all these plans equals to the level 2 decision maker plan (see Fig. 4).

3.2.4. Criteria plan (P4)

This plan is obtained by reorganising the information contained in the previous matrices, on the basis of single decision maker, unicriterion flows. We have, therefore, r similar matrices of the kind shown in Table 3.

We then apply PCA to the matrix in Table 3 in order to obtain a criteria Gaia plan without decision

Table 3
Matrix concerned by the criteria plans

	c_1	...	c_j	...	c_k
a_i/d_1	$\phi_{11}(a_i)$		$\phi_{1j}(a_i)$		$\phi_{1k}(a_i)$
⋮					
a_i/d_s	$\phi_{s1}(a_i)$		$\phi_{sj}(a_i)$		$\phi_{sk}(a_i)$
⋮					
a_i/d_r	$\phi_{r1}(a_i)$		$\phi_{rj}(a_i)$		$\phi_{rk}(a_i)$

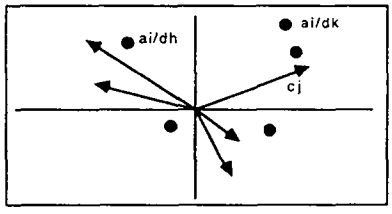

Fig. 5. Criteria plan.

axis. This plan has already been proposed in [6]. We obtain as many criteria plans as there are actions. As matrix for the weighting of individuals (here the a_i/d_s), we use the weight w_s of each decision maker, by taking down the sum of the weights to 1.

Each point in Fig. 5 represents the same action as seen by a different decision maker. This space of criteria allows to compare each decision maker's perception of a given action. This Criteria plan is very relevant for the mediator because in the case of two decision makers strongly disagreeing on a given action, he can identify with this plan if this is due to different weights (preferences) or to different perceptions and manage the negotiation process in consequence.

3.2.5. Weights plan (P5)

Here, we seek to measure the criterion importance according to the decision makers. We summarise the weights attributed to each criterion by each of decision makers in Table 4.

We apply the PCA to the matrix in Table 4 in order to obtain a Gaia plan without a decision axis. Each criterion is assigned the same weight for the PCA (see Fig. 6).

3.2.6. Coalitions plan (P6)

This plan permits the comparison of two coalitions, particularly the comparison of a single decision maker to the group. We can also generalise the method to compare more than two coalitions between themselves. For this purpose, we have chosen to aggregate information in the form of a weighted average. The pertinence of this choice remains to be confirmed. Two decision maker coalitions are noted:

$\mathrm{CO}_1 = \{D_s\}$, $s = 1 \ldots h$ and $\mathrm{CO}_2 = \{D_s\}$, $s = h' \ldots r$

We calculate the net flow of the first coalition for a given action a:

$$\phi_1(a) = \sum_{s=1}^{h} w_s \phi_s(a),$$

where $\phi_s(a)$ is the net multi-criteria flow of the decision maker s. We obtain Table 5. We apply the PCA analysis on the matrix in Table 5 and obtain the plan shown in Fig. 7.

In this section, we have proposed a set of six group Gaia plans. In the following chapter, in order to provide the mediator with an 'intelligent' support

Table 4
Matrix concerned by the weight plan

	D_1	...	D_s	...	D_r
c_1	w_{11}		w_{s1}		w_{r1}
⋮					
c_i	w_{1i}		w_{si}		w_{ri}
⋮					
c_n	w_{1n}		w_{sn}		w_{rn}

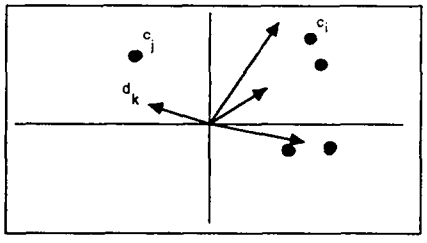

Fig. 6. Weights plan.

Table 5
Matrix concerned by the coalitions plan

	CO_1	CO_2
a_1	$\phi_1(a_1)$	$\phi_2(a_1)$
⋮		
a_i	$\phi_1(a_i)$	$\phi_2(a_i)$
⋮		
a_n	$\phi_1(a_n)$	$\phi_2(a_n)$

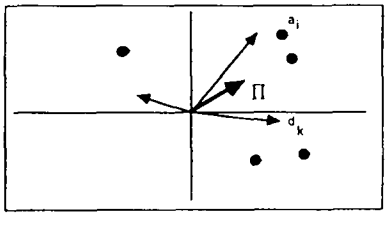

Fig. 7. Coalitions plan.

in the conduct of the negotiation, we propose a set of interpretation rules and the outline of a method to use these rules for a relevant support to the mediator in the management of the negotiation process.

4. Toward an efficient negotiation support system

Our general objective being to design and develop an efficient NSS, we have to define the nature and the place of the assistance that shall be supplied in the negotiation process. This process can be decomposed into two main phases: problem formulation and problem solving phases.

(1) *The problem formulation phase*

This phase concerns the definition of the multicriteria matrix for the group of decision makers, i.e. the definition of potential actions, of criteria according to which these actions will be evaluated and, for each decision maker, his initial weightings between these criteria. During this phase, the mediator's participation may be required to achieve a consensual formulation of the problem: the definition of the sets A (actions) and C (criteria) to be taken into account.

(2) *The problem solving phase*

This phase consists in looking for a consensual solution, i.e. choosing a consensual action for the group. In this step, the mediator's role is fundamental: he manages the negotiation process by suggesting a certain number of concessions, adjustments of the various decision makers in relation to their evaluations of actions, perhaps their weighting of criteria. If a consensus cannot be reached, i.e. a consensual action cannot be chosen, then it becomes necessary to return to the previous phase in order to reformulate the problem. In this reformulation, the role of the mediator is very important; the results of the preceding resolution phase need to be taken into account in order to define new sets of actions and criteria, as well as new weightings of criteria by the decision makers. An assistance has to be provided to the mediator to help him lead this reformulation phase.

The role of the mediator is important during the two main phases of the negotiation process. This role is to lead the group of decision makers to choose a consensual action, neither good, nor bad for each of them, and nevertheless the best possible. By all means, the mediator has to bring the group and thereby the decision makers to define an evaluation of proposed actions which is suitable to find a consensus. While the attitude of each decision maker of the group is quite subjective, we will assume that the mediator is rather objective. This aspect is important because it will allow the mediator to make the most of the information available. Consequently, in this research, our main objective is the assistance to the mediator, particularly during the solving phase of the negotiation process.

4.1. Different support levels given to the mediator

Our research concerns the definition of an assistance dedicated to the mediator in the resolution phase above all and we do not study a possible support to the decision maker in the negotiation process. In this context, the first aim is to provide assistance tools to the human mediator to help him to understand conflict situations and their evolution, and to better manage the negotiation process and even to suggest him apparently pertinent interventions with the decision makers. A second aim could be to permit the human mediator to delegate part of these tools to an artificial mediator agent. This second aim will not be treated in this paper. In this context we have to define:

1. the possible levels of intervention of this assistance during the solving phase of the negotiation process;
2. the type of the assistance our new NSS will provide the mediator with.

As illustrated by Fig. 8, we distinguish four main levels of intervention in the solving phase where support may be provided to the mediator (cf. Fig. 7):

- on the first level (level 0) the mediator has detected a consensus and proposes the validation of a privileged action to the decision makers;
- on the next two levels (level 1, level 2) the mediator proposes adjustments to their evaluations or weightings to the decision makers;
- on the last level (level 4) the assistance provided

to the mediator focuses on a partial reconsideration of the choice of the matrix.

For these four levels of intervention, we define several types of assistance which will be provided by our new NSS to the mediator:

(1) *Calculations and visualisations*

As long as the mediator wants to lead the research for consensus alone, the role of the system is to provide him with a simple way to interpret the information contained in the matrices. The assistance provided by the system consists presenting its results of preorder calculations of groups, as well as the visualisation of group Gaia plans.

(2) *Local analyses on various plans*

The mediator may want to be assisted by a first level of analysis of the information previously provided, but not be guided or influenced by a sharp analysis or suggested actions. Here, the assistance provided by the system is an interpretation of previously provided raw information.

(3) *Global analyses and situation diagnostic*

Up to now, the mediator has used a fragmentary preorder analysis and plans and synthesised himself the information provided by the system. The assistance provided by the tool focuses on results of analyses stemming from successive calculations on different preorders and plans.

(4) *Proposals of interventions for the conduct of the negotiation*

This type of assistance is an extension of the previous type, it consists of suggesting actions to the mediator in order to reach the consensus. The assistance which will be provided to the mediator by the new generation of NegocIAD is largely based on the elaboration and the interpretation of group Gaia plans previously defined. The following paragraphs will develop first of all various interpretation rules for Gaia plans and then the outline of a method for the utilisation of these rules for a valuable assistance in the negotiation. These rules and this method are taken into account in the implementation (currently under way) of the new version of our prototype NegocIAD.

4.2. The use of Gaia plans interpretation for the negotiation

To manage the negotiation and to lead decision makers to a consensus, the mediator has to construct a representation of the negotiation situation. The Gaia plans that we have just defined, more precisely their interpretations, can be used by the mediator to

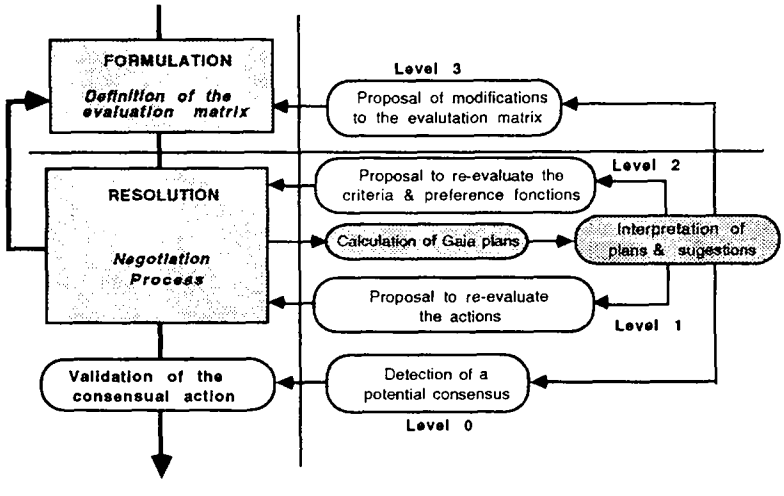

Fig. 8. The levels of intervention for the tool in the negotiation process.

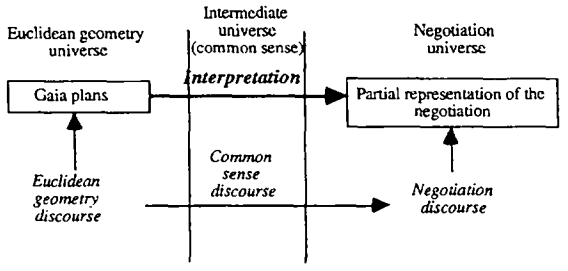

Fig. 9. The Gaia plans interpretation process.

elaborate such a preliminary representation. This partial representation will have to be refined and enriched by other information and knowledge sources available to him. We are in this research exclusively concerned by the elaboration of this preliminary representation of the negotiation obtained from the interpretation of Gaia plans.

To elaborate this representation, the mediator seeks first of all to elicited information from Gaia plans – of geometrical nature – that he has to interpret then in the context of the negotiation. The cognitive process performed by the mediator consists of putting into correspondence two universes, on the one hand the universe of the Euclidean geometry and on the other hand the universe of the negotiation in which the representation we are looking for is developed. To each of these two universes is associated a specific discourse (cf. Fig. 9).

The cognitive process of putting into correspondence these two universes is very complex. However, in order to bring an computerised assistance to the mediator, we make the following operative hypotheses on the Gaia plans interpretation:

Hypothesis 1. The putting into correspondence of the two universes is not direct, there exists at least an intermediate universe corresponding to the common sense discourse.

Hypothesis 2. The negotiation discourse is based on objects associated to the adopted multicriteria model (decision makers, actions, weights, criteria), their description and their relationships.

Hypothesis 3. Gaia plans convey hybrid information due to their elaboration; geometrical objects (not their properties) can be connected with some objects from the negotiation discourse.

Hypothesis 4. Each plan can be interpreted independently from the others in the context of the type to which it belongs: specific plan interpretation.

Hypothesis 5. The global plan interpretation is obtained by combination of the specific plans interpretations.

Hypothesis 6. It is possible to simulate the plan interpretation process according to a declarative approach, with 'Interpretation Rules'.

It is clear that these hypotheses associated to the cognitive process naturally have to be experimentally validated.

4.3. Interpretation rules for Gaia plans

The interpretation of Gaia plans can be very complex. Therefore, the previous hypotheses lead us to distinguish three group rules of Gaia plan interpretation allowing to elaborate a preliminary representation of the negotiation useful to the mediator.

4.3.1. General interpretation rules

These rules are independent of the negotiation discourse, and concerns all types of plans. They allow to elaborate a meaning of plans in the common senses universe (Hypotheses 3 and 6). Premises of these rules concern properties of geometrical objects and their conclusions concern the common sense universe.

We can distinguish several types of general rules related to: the dispersion of points, the dispersion of vectors, the length of vectors and finally the lengths of the II decision axis (see Fig. 10).

Furthermore, we have three types of crossed interpretations according to: the position of the points in relation to vectors; the position of the points in relation to π; and the direction of π in relation to others vectors.

4.3.2. Specific interpretation rules

These rules are associated to each type of Gaia plan, and allow to interpret them in the negotiation

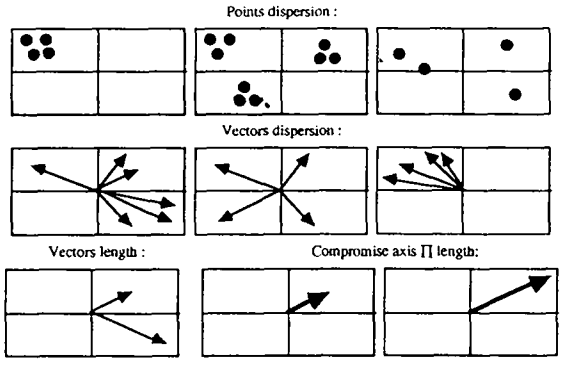

Fig. 10. Different types of general interpretation rules of Gaia plans.

universe. These rules allow to elaborate the specific plan interpretation in the negotiation universe (Hypotheses 2 and 4). Premises of these rules focus on the properties interpretations of geometrical objects (resulting from general interpretation rules) and their conclusions concern the negotiation universe. Specific interpretation rules for each plan concern:

1. decision makers plan, level 1 (P1);
2. criteria plan (P4): each point represents the same action seen by each decision maker. There is no decision axis. This criteria plan allows to compare the perception each decision maker has of an given action;
3. decision maker coalitions plan (P6);
4. weights plan (P5);
5. decision makers plan, level 2 (P2);
6. decision makers plan, level 3 (P3): this plan positions actions in relation to a decision maker's criteria. Therefore, the number of decision maker plans of level 3 is equal to the number of decision makers. On this plan, specific interpretation rules are equivalent to those defined for the Gaia plan in a single decision maker context.

4.3.3. Global interpretation rules

These rules use results of the previously mentioned specific interpretation rules in order to elaborate a preliminary representation of the negotiation (Hypotheses 2 and 5). These rules allow the global Gaia plan interpretation in the negotiation universe. Premises of these rules mainly focus on local plan interpretations (resulting from specific interpretation rules) and their conclusions concern the negotiation universe.

To illustrate this rules typology we present in Appendices A–D some examples of rules illustrating how geometrical, specific and common sense knowledge are used. It is clear that the terminology used in the premises and conclusions expression of these rules would have to be very precisely defined, what we do not make in this paper in particular for its concision. This terminology is currently elaborated in a context of knowledge acquisition relative to the three discourse universes implied in our research (Euclidean geometry, common senses and negotiation universes).

4.4. Toward an global interpretation method of the Gaia plans

In this section, we introduce a global interpretation method which will be used to support a relevant assistance for the negotiation. This method is cur-

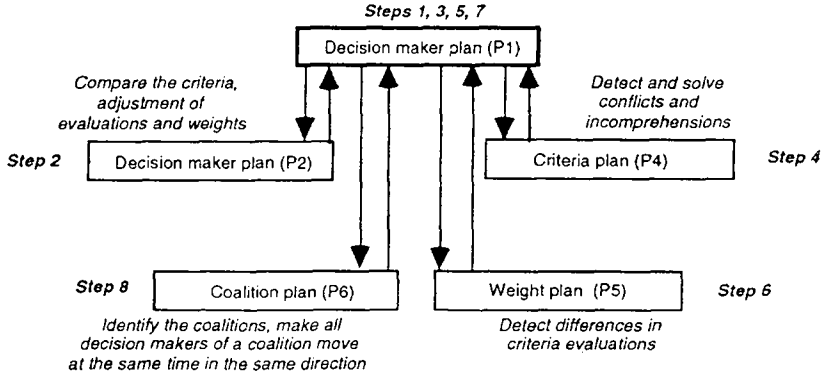

Fig. 11. Interpretation method for group Gaia plans.

rently used in the implementation (under way) of the new version of our prototype NegocIAD and it will have to be validated by an experimental implementation of the tool. The method we propose is composed of 8 steps and illustrated in Fig. 11.

Step 1. Consultation of decision makers plans (P1): In the resolution phase of the negotiation process, the support to the mediator for a good comprehension of the situation must start with the consultation of the decision makers plan of level (1). Indeed, this plan allows to have a global vision of the initial situation and to identify:

1. which are the decision makers in conflict;
2. which are the decision makers that are relatively close;
3. which are the favourite actions for each decision maker;
4. which can be a good compromise.

The analysis begins with the study of the decision makers plans. It allows to detect oppositions and reconciliations, and to explain problems, to identify their causes and to propose actions to solve them. In Appendix D we present some global interpretation rules which can used for this step.

Step 2. Consultation of decision makers plans (P2): This plan allows to identify the criteria on which the decision makers do not evaluate a given action in the same way. It allows to compare decision makers' criteria, to know on which criteria they are opposed and on which criteria they are close. In Appendix D we present some global interpretation rules which can used for this step.

Step 3. Return to the decision maker plan (P1): If the suggested modifications have not permitted to obtain a consensus the mediator passes on to the next step.

Step 4. Consultation of criteria plan (P4): This plan allows to highlight and to solve possible problems related to a conflict of opinion or comprehension. In Appendix D we present some global interpretation rules which can used for this step.

Step 5. Return to the decision maker plan (P1): If the suggested modifications have not permitted to obtain a consensus the mediator passes on to the next step.

Step 6. Consultation of weight plans (P5): This plan permits to know to which criteria the decision maker attaches the most or the less importance. In Appendix D we present some global interpretation rules which can used for this step.

Step 7. Return to the decision maker plan (P1): The mediator can observe if the modifications suggested have permitted to obtain a consensus. If this is not the case, he passes on the next step.

Step 8. Consultation of the coalitions plan (P6): This plan essentially allows to constitute groups of decision makers with close evaluations. Considering this plan rather than the decision makers plans, the mediator will be able to bring the coalitions closer to each other, without taking the risk of moving the decision makers of a same coalition away from each other. The possible actions in case of a conflict between two coalitions are similar to those described for a conflict between two decision makers. The purpose here is to obtain a unique coalition, in which case the consensus is reached. In Appendix D we present some global interpretation rules which can used for this step.

This method will be repeated as long as the consensus is not reached. But we can imagine, for example, that if after one or two passages, no decision maker has accepted to change his evaluations, a consensus will never be reached, and the procedure stops there.

5. Conclusion

The negotiation process treated in this research concerns a group of decision makers, which, under the guidance of a mediator, tends to find a compromise or consensus. This compromise will be obtained by a game of mutual concessions on evaluations or criterion weighting adjustments; this is what we have called the problem solving phase of the negotiation process. If, during the negotiation process, it occurs that a compromise cannot be found, it is advisable to return to the phase preceding the problem solving phase and to reformulate the problem and thus redefine the set of actions and evaluation criteria which will then be taken into account in a new solving phase.

The conceptual framework for a support to the negotiation process which we have proposed in this paper, is mainly based on the definition and the treatment of plans resulting from Principal Compo-

nent Analysis (PCA). The interpretation of these plans is complex, and becomes increasingly complex with an increasing number of criteria. Therefore, we have explicated a set of interpretation rules.

A new generation of our prototype NegocIAD, currently under development, will take into account these interpretation rules to assist the mediator during the conduct of the negotiation. We have implemented the algorithms (as a tool box developed in C + + language) permitting to build the different plans. The accent is currently putting on the cognitive formulation of these rules from the terminology associated to Euclidean geometry, common senses and negotiation discourses, in order to implement these rules through artificial intelligence techniques (production rules in frames environment). This knowledge will be attributed to the artificial agent associated to the mediator as an assistant. This agent will support the mediator at four levels previously defined: calculations and visualisations, local analyses on various plans, global analyses and situation diagnostic, and finally proposals of interventions for the conduct of the negotiation.

Once this support to the human mediator performed, a new perspective may be to create an artificial mediator in charge of the conduct of the negotiation. Another research direction can be to define a support oriented towards the decision maker. This support would be based on the same tools (Gaia plans) but different from the one we are proposing for the mediator, particularly due to the obvious problem of confidentiality. And finally, we can imagine to exceed the rigid multi-criteria framework (rigid matrices) by taking into account new types of exchanges between decision makers (human and artificial agents) during the negotiation process.

We believe it will be possible to absorb this complexification in our system NegocIAD, by even more using concepts (often very theoretical) that currently emerge in the area of multi-agent systems [15]. Thus, we think to make more complex the agents of our system, agents associated to the mediator but also to human decision makers, in particular by providing them with plans and beliefs in order that they could develop increasingly sophisticated behaviours. These behaviours will enable the agents to be very useful assistants in the negotiation process. For example, they will be able to develop strategies, tactics of negotiation. For the implementation of these agents, we intend to change our current environment (Objog) to a more advanced multi-agent environment like AOP/Agent-K, based on Agent 0 developed by Shoham [23], with implementation of the KQML communication protocol. In this Agent-K environment, strongly inspired by the theory of the speech acts, agents are endowed with a characterised mental state defined by beliefs, obligations and capacities.

Acknowledgements

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Appendix A. Promethee method and Gaia plans in single decision maker context

The Promethee method (Preference Ranking Organisation METhod for Enrichment Evaluations) proposed by Brans et al. [4] is one of the most recent outranking multi-criteria decision support methods [3]. These methods have emerged by the end of the 1960s, under the impetus of Roy who proposed the Electre method [21,22]. The Promethee method largely uses the notion of 'pseudo-criterion' or 'generalised criterion' (introduced by Roy et Bouyssou). From the evaluation matrix established by the decision maker, after a flow calculation, the Promethee method proposes a total or partial preorder on possible actions. Having acknowledged this preorder, the decision maker can return to his evaluation matrix and modify there some of his evaluations, as well as the weights he had associated to each evaluation criterion. The newly obtained matrix will result in a preorder that may be different from the preceding one. With the help of this 'simulation', the decision maker will be able to measure the implications of his evaluations and weightings on the resulting preorder. The Promcalc software (PROMethee CALCulation) published by the authors of the method [5], allows to lead this simulation process in an interactive manner.

Now, we will take a brief look at the mathematical model of the Promethee method, emphasising on preorder and Gaia plan calculation.

A.1. Preorders calculation

Given a multi-criteria decision problem of the type: $\mathrm{Max}\{c_1(a_j),c_2(a_j),\ldots,c_i(a_j)\ldots c_k(a_j)$ with $1 \le j \le n\}$ and $A = \{a_1,\ldots,a_j,\ldots,a_n\}$ is the set of the n possible actions, which are evaluated according to k criteria. The set of criteria is $C = \{c_1,\ldots,c_i,\ldots,c_k\}$.

We consider a particular criterion and we suppose that it is to maximise. A comparison by pair of the different actions of A, gives us a structure of preference defining the outranking relationship:

$c(a) > c(b) \Leftrightarrow aPb$ (a is *Preferred* over b for the criterion c);
$c(a) = c(b) \Leftrightarrow aIb$ (a is *Indifferent* to b for the criterion c).

To each criterion, one associates a 'Generalised Criterion' that defines the degrees of preference between actions for each criterion and allows to eliminate scale effects. This 'Generalised Criterion' choice is undertaken interactively with the decision maker. To that purpose, one has the choice between a set of functions of preferences $P(a,b)$ giving the degree of preference of a over b for a criterion c. If we set $d = c(a) - c(b)$:

- $P(a,b) = 0$ if $d \le 0$ *no preference or indifference*;
- $P(a,b) \sim 1$ if $d \gg 0$ *weak preference*;
- $P(a,b) \sim 0$ if $d > 0$ *strong preference;*
- $P(a,b) = 1$ if $d \ggg 0$ *strict preference.*

The generalised criterion related to the criterion $c(\cdot)$ is then defined by the couple $[c(\cdot), P(\cdot,\cdot)]$. Finally, weights are related to the different criteria, showing the importance that the decision maker grants to each of them (weights are numbers belonging to $\mathbb{R}^+$ and the sum of weight is equal to 1). Once the generalised criteria are associated to each criterion and the weights are fixed, a multi-criteria preference of a over b taking into account all the criteria is defined with:

$$\pi(a,b) = \sum_{i=1}^{k} w_i \cdot P_i(a,b),$$

where w_i represents weights related to each criterion. Note that:

- $\pi(a,a) = 0$;
- $0 \le \pi(a,b) \le 1$ for any $a,b \in A$;
- $\pi(a,b) \cdot 1$ implies a good global preference of a over b;
- $\pi(a,b) \cdot 0$ implies a weak global preference of a over b.

Thus, for any pair of actions, we have two arcs of degree of preference: $\pi(a,b)$ and $\pi(b,a)$. In this manner, one builds a valued outranking graph. The calculation of the π allows to calculate the input flow ϕ^+ and the output flow ϕ^- for each action a. The comparison of these flows allows to define a total (Promethee I) or partial preorder (Promethee II):

$$\phi^+(a) = 1/(n-1) \cdot \sum_{j=1}^{n} \pi(a,x_j),$$

$$\phi^-(a) = 1/(n-1) \cdot \sum_{j=1}^{n} \pi(x_j,a).$$

The net outranking flow for action a is:

$\phi(a) = \phi^+(a) - \phi^-(a)$,

$\phi(a) = 1/(n-1)\sum_{i=1}^{k} w_i \sum_{j=1}^{n} (P_i(a,x_j) - P_i(x_j,a))$,

where $\phi(a)$ designates the multi-criteria net outranking flow and can be defined as a weighted sum of net outranking flows $\phi_i(a)$ relative to each criterion i:

$$\phi(a) = \sum_{i=1}^{k} w_i \phi_i(a),$$

$$\text{with } \phi_i(a) = 1/(n-1) \sum_{j=1}^{n} P_i(a,x_j) - P_i(xj,a).$$

The action a is as much better as:

- $\phi^+(a)$ is important;
- $\phi^-(a)$ is weak;
- $\phi(a)$ is important.

Consider the two total preorders S and I:

- $aS + b$ *if and only if* $\phi^+(a) > \phi^+(b)$;
- $aS - b$ *if and only if* $\phi^-(a) < \phi^-(b)$;
- $aI + b$ *if and only if* $\phi^+(a) = \phi^+(b)$;
- $aI - b$ *if and only if* $\phi^-(a) = \phi^-(b)$.

Promethee I is the intersection of these two preorders:

aPb	*if and only if*	$aS+b$ and $aS-b$ or $aS^{+}b$ and $aI^{-}b$ or $aI^{+}b$ and $aS^{-}b$;
aIb	*if and only if*	$aI^{+}b$ and $aI^{-}b$;
aRb		in the other cases; with: P = Preference; I = Indifference; R = Incomparability.

We obtain here a partial preorder where incomparabilities are possible and where the information is reliable. But a total preorder can be obtained with Promethee II.

Promethee II is based only on net flows, removes the incomparabilities, but makes the information slightly less reliable at the same time:

aPb	*if and only if*	$\phi(a) > \phi(b)$;
aIb	*if and only if*	$\phi(a) = \phi(b)$.

A.2. Gaia plans calculation

A development of flow formulae shows that each action is characterised by k unicriterion flows (one can break down $\phi(a)$ in $(\phi_1(a), \phi_2(a), \ldots, \phi_k(a))$. Thus, one can construct a matrix of unicriterion flows (flows relative to a single criterion), that we call 'unicriterion matrix'. The Gaia plan is an interpretation of the information contained in this matrix. It consists of a plan on which the cloud of points from the unicriterion flows matrix is projected. This projection is such that the loss of information is minimal. It is obtained by Principal Component Analysis (PCA). A number δ calculated, giving the percentage of information preserved by the Gaia plan, characterises the quality of the projection. We represent in a Gaia plan:

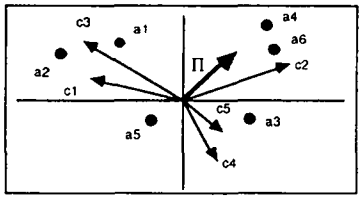

Fig. 12. An example of a Gaia plan in a single decision maker context.

1. *the actions* between which to decide;
2. *the selection criteria* according to axes of direction given by $\phi(a)$;
3. *the decision axis*, given by the projection of the weight vector w: $(w_1, \ldots, w_i, \ldots, w_k)$.

One obtains a cloud of points in the space $\mathbb{R}^k$. The projection of this cloud of points in the Gaia plan is realised by the PCA method. Fig. 12 shows an example of a Gaia plan. These Gaia plans graphically position actions and criteria. They provide the decision maker with some information complementary to the classifications of actions between themselves, provided by the methods Promethee I and II. These plans are relatively easy to interpret by the decision maker and they provide him with very relevant information. They enable him to determine the action to privilege and to find out about those evaluation elements that prevent from bringing out an action to privilege. From the previous Gaia plan, we can thus deduce the following information:

1. the evaluations of criteria C1 and C3 tend to choose the same actions A1 and A2;
2. the evaluations of criteria C4 and C5 privilege action A3;
3. the decision axis II, is rather long; this privileges those actions situated in the direction of this axis

Table 6
Meaning of vectors and points in Gaia plans

	Decision maker plan (1)	Criteria plan	Coalition plan	Weight plan	Decision maker plan (2)
Vector	Decision makers	Criteria	Coalitions	Decision makers	Criteria
Point	Action	An action considered by all decision makers	Actions	Criteria	Decision maker

and the farthest away from the origin of the plan, here the action A4.

Appendix B. General interpretation rules for Gaia plans

Before presenting these interpretation rules, we would like to recall the meaning of vectors and points in each Gaia plan (see Table 6).

Rules related to points

RG1 IF groups of points are observed THEN their meanings bring an equivalent satisfaction level.

RG2 IF two points are opposite THEN their meanings are different.

Rules related to vectors

RG3 IF two vectors are close THEN they represent equivalent information

RG4 IF two vectors are orthogonal THEN they represent independent information

RG5 gaIF two vectors are opposite THEN they represent conflicting information.

Rules related to points and vectors

RG6 IF a vector is directed to a point THEN this point is well explained for this vector.

RG7 The more a point is opposed to a vector, the more this point is badly explained by this vector.

RG8 IF a vector is long THEN the associated information strongly differentiates the information represented by the points.

RG9 IF a vector is short THEN the associated information weakly differentiates the information represented by the points.

Rules related to π length

RG10 IF π is long THEN the decision power of the plan is strong, vectors are not too conflicting, the best choices are those the closer possible to the decision axis π, and the farthest possible of the origin.

RG11 IF π is short THEN the decision power of the plan is weak, vectors are conflicting, the best choices are those the closer possible to the origin, because they do not correspond to any extreme.

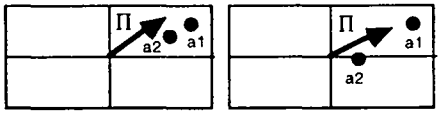

Fig. 13. Examples of use of general interpretation rules on Gaia plans.

Example 1. a_1 will be preferred over a_2 (RG10) (see Fig. 13).

Example 2. a_2 will be preferred over a_1 (RG11) (see Fig. 13).

Then, the notions of proximity and distance, of short and long have to be clarified. We propose some elements (some rules) to approach these notions:

- *two vectors are close* IF the covariance (see matrix V) is > 0 and high, or IF the angle they form is in the interval $[0 + m; 90 - m]$;
- *two vectors are opposite* IF the covariance is $\ll 0$, or IF the angle they form is in the interval $[135 + m; 225 - m]$;
- *two vectors are orthogonal* IF the covariance tends to zero, or IF the angle they form is in the interval $[45 + m; 135 - m]$;
- *a vector is long* IF the variance is strong, or IF its norm is at least equal to 50% m of the average of vector norms of the plan;
- *a vector is short* IF the variance is small, or IF its norm is not more than equal to 50% m of the average of vector norms of the plan;
- *two points are close* IF the distance that separates them is not more than equal to 50% m of the average of distances between all points;
- *two points are distanced* IF the distance that separates them is at least equal to 50% m of the average of distances between all points;
- *a point is close to a vector* IF the distance that separates the point from the extremity of the vector is less than $1/3$ m of the norm of the vector;
- *a point is far from a vector* IF the distance that separates the point from the extremity of the vector is higher than $1/3$ m of the norm of the vector;
- *a point is close to a decision axis* IF its coordinate on the opposite axis is not more than equal

to 50% m of the average of the same coordinate of all points (in absolute value);

- *a point is far from a decision axis* IF its coordinate on the opposite axis is at least equal to 50% m of the average of the same coordinate of all points (in absolute value).

...

It is difficult to quantify such an interpretation which is very subjective, and consequently it is very difficult to automate. To add flexibility to this interpretation, we introduce the parameters m and m'. These parameters have to be fixed by the mediator and/or decision makers before the interpretation.

Appendix C. Specific interpretation rules for each Gaia plan

(1) *Decision maker plan, level 1 (P1)*

RP1.1 IF two vectors (2 decision makers) are close THEN decision makers converge towards the same action;

RP1.2 IF two vectors are in opposed directions THEN the two decision makers are in conflict;

RP1.3 IF two vectors are orthogonal THEN the two decision makers are neither close nor far; there is independence;

RP1.4 IF vectors representing decision makers are close to the decision axis THEN they approach consensus;

RP1.5 IF decision makers are in conflict and the decision axis π is short THEN the good actions are those close to the origin of the plan;

RP1.6: IF π is short THEN the decision power is weak;

RP1.7: IF decision makers are not too conflicting THEN is π long and the best actions are those situated the nearest possible to the decision axis π;

RP1.8: IF π is long THEN the decision power is strong;

RP1.9: IF the vector representing a decision maker is long THEN the decision maker strongly differentiates the actions;

RP1.10: IF the vector representing a decision maker is short THEN the decision maker weakly differentiates the actions;

RP1.11: IF the decision maker weakly differentiates the actions THEN it will be easier to lead this decision maker to the consensus;

RP1.12: IF two projection actions are close THEN these actions obtain the same satisfaction for decision makers;

RP1.13: IF two projection actions are distanced THEN for a given decision maker an action will be preferred to the other;

RP1.14: IF a vector (a decision maker) is close to an action THEN this decision maker is in agreement with this action.

...

(2) *Decision maker plan, level 2 (P2)*

RP2.1: IF vectors representing the same criterion for two different decision makers are close THEN these decision makers have the same perception of this criterion;

RP2.2: IF vectors representing the same criterion for two different decision makers are distanced THEN these decision makers diverge on this criterion;

RP2.3: IF vectors representing the same criterion for two different decision makers are orthogonal THEN this criterion is neither a factor of distance, nor a factor of reconciliation for these two decision makers; there is independence;

RP2.4: IF a vector representing a criterion for a decision maker is long THEN it strongly differentiates actions;

RP2.5: IF a vector representing a criterion for a decision maker is short THEN it weakly differentiates actions;

RP2.6: IF criteria are in conflict THEN π is short and the good actions will be those close to the origin of the plan;

RP2.7: IF π is short THEN the decision power is weak;

RP2.8: IF criteria are not too conflicting THEN π is long and the best actions are those situated the nearest possible to the decision axis π;

RP2.9: IF π is long THEN the decision power is strong;

RP2.10: IF a criterion points to an action THEN this action is good for this criterion;
RP2.11: IF two projection actions are close THEN these actions obtain for decision makers the same satisfaction;
RP2.12: IF two projection actions are distanced THEN for a given decision maker an action will be preferred to the other.

...

(3) *Criterion plan (P4)*

RP4.1: IF points (the same action) are close THEN decision makers have the same perception of this action (i.e. more they are in agreement);
RP4.2: IF two criteria are in the same direction THEN they are similar;
RP4.3: IF two criteria are in opposed directions THEN they are opposite;
RP4.4: IF two criteria are in orthogonal directions THEN they are independent;
RP4.5: IF The vector associated to a criterion is long THEN this criterion strongly differentiates the vision of the actions for the decision makers;
RP4.6: IF The vector associated to a criterion is short THEN this criterion weakly differentiates the vision of the actions for the decision makers;
RP4.7: IF points (the same action) are distanced THEN decision makers have a different perception of this action.

...

(4) *Weight plan (P5)*

RP5.1: IF decision makers are distanced on a same criterion THEN they have not the same perception of this criterion (they do not attribute the same importance to this criterion);
RP5.2: IF a decision maker vector points in the direction of a criterion THEN it has a preference for this criterion;
RP5.3: IF the vector representing a decision maker is long THEN criteria are for this decision maker strongly different;
RP5.4: IF the vector associated to a decision maker is short THEN criteria are for it weakly different;
RP5.5: IF criteria (points) are close THEN they are evaluated in the same way by decision makers;
RP5.6: IF criteria (points) are distanced THEN they are not evaluated in the same way by decision makers.

...

(5) *Coalitions plan (P6)*

RP6.1: IF vectors representing coalitions are distanced from the decision axis π THEN coalitions will have to make concessions;
RP6.2: IF vectors are very close THEN the two coalitions are in phase;
RP6.3: IF vectors of coalitions are close to π THEN they approach a consensus;
RP6.4: IF vectors are orthogonal THEN the two coalitions are neither close, nor far; there is independence;
RP6.5: IF coalitions are in conflict THEN π is short and the good actions will be close to the origin of the plan;
RP6.6: IF π is short THEN the decision power is weak;
RP6.7: IF coalitions are not too conflicting THEN π is long and better actions are those situated the nearest possible to the decision axis;
RP6.8: IF π is long THEN the decision power is strong;
RP6.9: IF the vector representing a coalition is long THEN this coalition strongly differentiates actions;
RP6.10: IF the vector representing a coalition is short THEN this coalition weakly differentiates actions;
RP6.11: IF a coalition weakly differentiates actions THEN it will be easier to lead this coalition to the consensus;
RP6.12: IF two projection actions are close THEN these actions obtain for coalitions the same satisfaction;
RP6.13: IF two projection actions are distanced THEN for a given coalition an action will be preferred to the other;
RP6.14: IF two vector coalitions are orthogonal THEN they are independent (neither close to, nor far from a consensus).

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Appendix D. Global interpretation rules for each Gaia plan

Step 1. Consultation of decision makers plans (P1)

A1.1: IF decision makers (A and B) converge THEN IF the mediator modifies evaluations of decision maker A THEN he must also modify in the same way the evaluations of decision maker B.

A1.2: IF all decision makers converge THEN the consensus is reached and the analysis is ended.

A1.3: IF the mediator perceives that decision makers are in conflict on the choice of an action THEN he must consult the decision makers plan of level 2 to compare their criteria.

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Step 2. Consultation of decision makers plans (P2)

A2.1: IF a criterion C1 for a decision maker A is close to the criterion C1 for a decision maker B THEN decision makers A and B are not in conflict on the criterion C1.

A2.2: IF two decision makers are not in conflict on a same criterion THEN the mediator must not suggest to these decision makers to modify their evaluations on this criterion.

A2.3: IF vectors $V1$ and $V2$, representing the same criterion C1 for 2 different decision makers, are in opposed directions THEN the mediator must ask the decision makers to modify their evaluations on this criterion in order to reduce their appreciation gap (the purpose is to minimise the angle between the two vectors).

A2.4: IF the vector $V1$ representing a criterion C1 for a decision maker A is long and IF the vector V2 representing the same criterion for a decision maker B is short THEN decision maker B (whose vector is short) will be more favourable to a change of his evaluations than decision maker A.

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Step 4. Consultation of criteria plan (P4)

This plan allows to highlight and to solve possible problems related to a conflict of opinion or comprehension.

A4.1: IF the mediator observes that decision makers are in conflict on the choice of an action THEN he can refer to the criteria plan in order to find out if these decision makers diverge on preference functions or on their perceptions of the criteria.

A4.2: IF decision makers have the same perception of a given action THEN their evaluations on this action must not modified.

A4.3: IF decision makers have a different perception of a given action THEN the mediator has to solve conflicts of opinion or comprehension of decision makers.

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Step 6. Consultation of weight plans (P5)

A6.1: IF the decision power of the decision makers plan is weak THEN the mediator will seek to increase it by suggesting the re-evaluation of weights granted to criteria by the decision makers.

A6.2: IF some decision makers do not grant the same importance to a criterion (difference of weight) THEN a decision maker will be more prone to make concessions on a criterion to which it grants a weak weight that on a criterion to which it grants an important weight.

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Step 8. Consultation of the coalitions plan (P6)

A8.1: IF the mediator observes coalitions of decision makers THEN he can interpret the plan of coalitions.

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