MULTI-CRITERIA NEGOTIATION FOR AGENT-BASED DECISION MAKERS

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ABSTRACT

This paper presents a Multi-criteria Negotiation framework for Agent-based Decision Makers. The negotiation process is represented through a graph introduced in order to manage and to provide efficient solutions for agents. In this framework agents can negotiate everything including the criteria set of Multi-Criteria model used to evaluate the paths, the set of possible actions or even the model itself.

1. INTRODUCTION

Negotiation has long been recognised as a process of some importance for Multi-Agent are research [12]. Generally, it aims to modify the local plans of agent (either cooperative or self-interested) in order to avoid negative (i.e. harmful) interactions and to emphasize the situations where potential positive (i.e. helpful) interactions are possible. Many researchers have proposed different negotiation mechanisms [1] [2] [4] [8] [10] [13]. Generaly such approaches are based on operations research techniques [5]. However the Multi-criteria dimension of the negotiation process is basically ignored in all such approaches. In this paper we propose a framework of a Multi-Criteria based negotiation mechanism for agent-based decision makers. It explores ideas developed in [6] where agents establish a negotiation graph representing efficient solutions for cooperative work. In this context, agents accomplish local goals that are necessary for the global goal achievement, while trying -simultaneously- to optimize private goals (e.g. interests, motivations, etc.). Hence, a negotiation process is started and each of the participants should propose a new efficient solution until a consensus (if ever) is reached. The parameters of the Multi-Criteria model used to evaluate the paths are then negotiated or even the model itself.

In this paper, §2 presents our multi-criteria model, §3 introduces an example used throughout the paper, while §4 presents some possible multi-criteria negotiation strategies. Some conclusions are presented in §5.

2. THE MULTI-CRITERIA MODEL

In conventional decision theory [3] negotiation is seen as an interactive Multi-Criteria Decision Making procedure [12] where the exploration of the set of efficient solutions is performed not just by a single decision maker, but by the whole set of participants the negotiation process. Technically, the procedure is always the same. Begin by an efficient solution and then move to a next by modifying some parameters as the trade-offs, the zenith and/or nadir points, the shape of an utility function. What changes is the type of interaction, since it does not concern just a decision maker and an analyst, but several decision makers. The interaction holds among the different participants each of which may propose a new efficient solution toward a consensus (if ever).

Unlike such a representation, real world negotiation processes do not limit the negotiation to just such issues (the parameters of an already established decision model), but consider more complex objects such as the set of potential actions, the set of criteria under which actions are evaluated and the negotiation scope itself (possibly).

Our claim is that a multi-agent system enabling the participating agents to "negotiate" among them should not limit itself to the possible negotiation objects, but allow each agent to establish what to negotiate for, although this may be against the efficiency of the whole system.

Considering a set **A** of agents α_i following [6], an agent, seen as a dynamic planner, is equipped with the following decision model:

$\alpha_i : \langle T_i, A_i, H_i, P_i, G_i, R_i, S_i, \rangle$ where:

- T_i : a set of tasks to be achieved by the agent (different levels of acheivment may be considered);
- A_i : a set of elementary actions available to the agent;
- H_i : a collection of $H_i^j \subseteq A \times A$, binary preference relations on the set A of the type $\forall x, y \in A, H_i^j(x,y)$: agent *i*, on dimension *j*, considers action *x* at least as good as action *y*;
- P_i : is a set of plans (a sequence of actions) the agent may perform in order to accomplish the tasks;
- G_i : is a collection of binary preference relations $G_i^l \subseteq P \times P$, on the set P of the type $\forall \chi, \psi \in P, G_i^l(\chi,\psi)$: agent *i*, on dimension *l* considers plan χ at least as good as plan ψ;
- R_i : an aggregation procedure enabling to establish a global relation H_i and G_i (if it is the case) and to connect the relations H_i^j to the relations G_i^l;
- S_i: a set of states of the world representing the consequences of each elementary action the agent may perform.

Under such a perspective the agent's problem consists in solving a dynamic programming problem, that is to define the "best path" on a graph whose nodes are the states of the world, the arcs are the elementary actions, paths correspond to plans, and H_i and G_i represent the agent's preferences in order to define what is "best" .

Moving up an abstraction level, the previous decision model may be extended to a community of agents **A** as follows:

$$\mathbf{A}: \langle \mathcal{T}, \Delta, \mathbb{H}, \mathbb{P}, \Gamma, \mathcal{R}\ \mathcal{S} \rangle$$

where:

- $\mathcal{T}$: a set of tasks to be accomplished by the community (different levels of accomplishment may be considered);
- Δ: a set of elementary actions available to the community of agents;
- $\mathbb{H}$: a collection of $H_j \subseteq \Delta \times \Delta$ binary preference relations on the set Δ of the type $\forall$ x, y $\in \Delta$: $H_j(x,y)$: the community, on dimension j, considers action x at least as good as action y;
- $\mathbb{P}$: a set of plans (ordered sets of actions) the community may perform in order to accomplish the tasks belonging to $\mathcal{T}$;
- Γ: is a collection of $G_l \subseteq \mathbb{P} \times \mathbb{P}$ binary preference relations on the set $\mathbb{P}$ of the form: $\forall \chi, \psi \in \mathbb{P}, G_l(\chi,\psi)$ means that the community, on dimension l, considers plan χ at least as good as plan ψ;
- $\mathcal{R}$: is an aggregation procedure enabling to establish a global relation $\mathbb{H}$ and Γ (if it is the case) and to connect the relations H_j to the relations G_l;
- $\mathcal{S}$: is a set of states of the world representing the consequences of each elementary action the community may perform.

Under a conventional negotiation scheme the only object on which the negotiation may hold are the parameters defining $\mathcal{R}$. In such a case it is necessary to consider:

$$\mathcal{T} = \cup_i T_i \text{ and } \Delta = .\cup_i A_i.$$

It is clear that such a perspective is very reductive with respect to the negotiation requirements of a multi-agent system. As already mentioned in [7] the establishment of a collective decision problem for the whole set of agents implies the characterisation of the elementary actions in:

- *conflicting* (actions that induce a conflict among agents; conflicting execution, common scarce resources, conflicting consequences, conflicting plans);
- *cooperative* (actions which performed together may improve their plans);
- *independent* (actions which do not have any consequence on other agents plans).

Moreover the existence of a multi-agent system level may enable actions not foreseen on a single agent level and modify the way by which plans are evaluated (that is each agent G_l).

Under such a perspective we claim that the negotiation objects in a multi-agent system include:

- the establishment of $\mathcal{R}$ and its parameters, considering $\mathcal{T}$, and Δ fixed;
- the establishment of Γ possibly modifying each agent G_i;
- the establishment of $\mathbb{P}$ possibly modifying each agent A_i, T_i and H_i.

In other terms, we consider that there exist three negotiation steps.

1. The first step concerns the definition of the possible plans the community may perform, the set $\mathbb{P}$. Such a set may not just be the union of each P_i (the community graph is not necessarily the merging of each agent graph). In fact, some actions in some A_i may disappear, some new actions may enter directly Δ, the way by which each action is evaluated by each agent (the H_i) may be modified.

2. The second step concerns how the community evaluates $\mathbb{P}$ (the definition of Γ). New criteria may be considered, while some of the criteria used in the different G_i may disappear or may be evaluated differently.

3. The third step concerns how the final decision is taken at the end of the negotiation (the definition of $\mathcal{R}$).

3. AN EXAMPLE

In this section, we present an example which points out our multi-criteria approach and the chosen context. Let us consider a room with a bookcase (C), a table (A) and a heavy piece of furniture (B). This state of the world is presented as: (IN(A), IN(B), IN(C)) (Fig. 1). Two agents (α_1 and α_2) have, as a common goal, to empty the room. This new state of the world will be presented as: (OUT(A), OUT(B), OUT(C)).

The world is described through the following relations:

- Object characteristics: heavy(furniture); light(table); light(bookcase);
- Possible actions associated with agents according to their abilities: wait(z); TR(α_1,x)$\wedge$light(x); TD(α_1,x); TR(α_2,x)$\wedge$(light(x); TR(α_2,x)$\wedge$heavy(x); TR-R(α_2, x, y) $\wedge$ light(x) $\wedge$ light(y), where :

  TR(α,x): agent α transports object x; TD(α,x): agent α takedown object x; TR-R(α,x,y): agent α transports two items x and y
- Private agents' goals : p-goal (α_1, max-profit) ; p-goal(α_2, min-time);
- In this example, local goals are not clearly distinct. Therefore, we do consider that each agent has to use its abilities in order to achieve the global goal, as far as they have complementary abilities.
- Relation between actions: before (takedown (bookcase), transport(bookcase));

We assume that when α_1 performs an action there is a profit of 1 money unit while α_2 , when performing an action, loses 1 time unit. The action wait(z) has no profit.

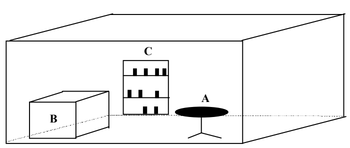

Figure 1: Nil state of the world

4. MULTI-CRITERIA NEGOTIATION STRATEGIES

In the following, we show how, according to our model, the negotiation may be processed as successive steps, representing possible strategies to reach consensus between agents.

Step 1: to begin with, agents establish a negotiation graph where nodes represent the world states as described in §2. Arcs represent n-tuples of actions performed in a parallel way by the negotiating agents. Such a graph is constructed using the sub-graphs of best paths of its negotiating agent. In our example the negotiation graph is represented in Figure 2.

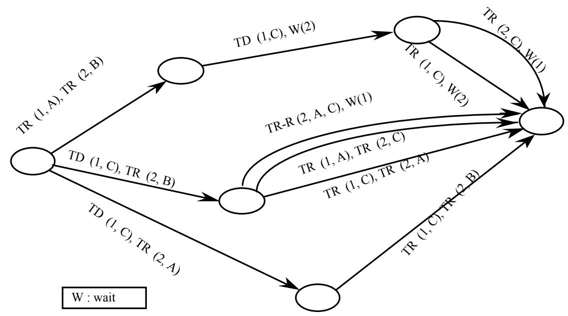

Figure 2: The negotiation graph for agents α_1, α_2

Step2: it concerns how the community evaluates $\mathbb{P}$ (the definition of Γ). For example a new Multi-Criteria model can be settled using the union of the set of criteria of each negotiating agent. There exists two possibilities: the first is to use an hierarchical model of preference aggregation (each agent criteria aggregated to a single criterion and so on), the second is to use a flat model considering all the criteria contempo-raneously. The choice depends on the nature of the criteria and the agent's preferences. In the following we present possible negotiation strategies applied in our example during this step.

First negotiation strategy: it consists in trying to define a compromise solution among the efficient paths of the negotiation graph. Different procedures can be used. For instance establish a global utility function (if the agents accept trade-offs among their criteria), go through direct pairwise comparisons (if the agents accept to simply compare their criteria), and so on. In our example the efficient paths are:

1. (TR(1, A),TR(2, B)),(TD(1, C),W(2)),(TR(1, C),W(2))
2. (TD(1, C),TR(2, B)), (TR(1, A), TR(2, C))
3. (TD(1, C),TR(2, B)), (TR(1, C), TR(2, A))
4. (TD(1, C),TR(2, A)), (TR(1, C), TR(2, B))

For example if a trade-off is accepted such that each time unit is equivalent to 0.2 unit of profit, the path 1 is the best one.

Second negotiation strategy: agents can use this strategy if they fail to find a compromise solution, hence it becomes necessary to re-discuss the model enhancing or contracting the criteria set. Following our approach, negotiation is always possible, but with new criteria set. In this case, the set of efficient solutions may change. In our example each agent could introduce a cost function and a new criterion. So agent α_1 adds to his criteria set the *min-time* criterion while α_2 agent adds *max-profit* criterion. In this case, both agents have to satisfy two new criteria: max-profit and min-time (see Table 1).

α_1 \ α_2	$TR(\alpha_{1/}\alpha_2, A)$	$TR(\alpha_{1/}\alpha_2, C)$	$TD(\alpha_1, C)$	$TR\text{-}R(\alpha_2, A, C)$	$TR(\alpha_2, B)$
C_1 Profit	1 / 1	1 / 1	1 /	/ 1	/ 1
C_2 Time	1 / 1	1 / 1	1 /	/ 1	/ 1

Table 1: New criteria set for agent α_1 , α_2

In this case agents will choose one of the following three paths (i.e. the new set of efficient solutions): (TD(1, C),TR(2, B)), (TR(1, A), TR(2, C)), (TD(1, C),TR(2, B)), (TR(1, C), TR(2, A)), (TD(1, C),TR(2, A)), (TR(1, C), TR(2, B))

Third negotiation strategy: in the case the two previous strategies fail, it could be possible to change again the model introducing a third common criterion; for example pleasure (i.e. to make an action) which in addition can be more important than their previous criteria. We consider that both agents are able to evaluate this criterion according to a value scale [1-5]. So for example, each time α_1 performs an action, he evaluates pleasure criterion by value 3 while α_2 evaluates this criterion by value 1 (he has no really pleasure to make an action). Therefore, α_1 has now max-profit and max-pleasure criteria while α_2 has min-time and min-pleasure criteria respectively, pleasure criterion being the most important for both agents. In this case agents will choose the path (TR(1, A),TR(2, B)),(TD(1, C),W(2)),(TR(1, C),W(2)).

Fourth negotiation strategy: in the case the previous strategies fail, it could be possible to change the model introducing new actions which were not previously considered. If such a situation occurs the criteria set has also to be redefined. The negotiation goes back to the first step and the whole process restarts. In our example a new action that can be introduced is the leave of an agent before the system reaches the final state. In this case new paths are added including such news actions.

Step 3: the stoping condition is either an agreement reached among the negotiating agents (i.e. a compromise solution is accepted) or the negotiation limits are exceeded and the system randomly imposes a solution (one efficient path from the negotiation graph).

5. RELATED WORK AND CONCLUSION

Compared to other relevant works [1] [2] [8] [9] [10] [11] [13] our contribution consists in allowing agents to negotiate the negotiation model (for instance accept or not trade-offs), while other authors impose a priori such a model (implicitly or explicitly). In our approach the multi-criteria model is not fixed, since everything can be negotiated including the criteria set and the set of possible actions. Finally the graph representation gives an explicit representation of the agents' difficulty to compare plans which corresponds to paths. Of course the problems open by the presented approach are more than the ones solved. Work in progress tackles the implementation phase of our algorithms including the multicriteria negotiation strategies presented in this paper.

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