Analyzing Intra-Team Strategies for Agent-Based Negotiation Teams

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ABSTRACT

An agent-based negotiation team is a group of two or more agents with their own and possibly conflicting preferences who join together as a single negotiating party because they share a common goal which is related to the negotiation. Scenarios involving negotiation teams require coordination among party members in order to reach a good agreement for all of the party members. An intra-team strategy defines what decisions are taken by the negotiation team and when and how these decisions are taken. Thus, they are tightly linked with the results obtained by the team in a negotiation process. Environmental conditions affect the performance of the different intra-team strategies in different ways. Thus, team members need to analyze their environment in order to select the most appropriate strategy according to the current conditions. In this paper, we analyze how environmental conditions affect different intra-team strategies in order to provide teams with the knowledge necessary to select the proper intra-team strategy.

Categories and Subject Descriptors

I.2.11 [**Artificial Intelligence**]: Distributed Artificial Intelligence—*Multiagent systems, Intelligent agents*

General Terms

Algorithms, Experimentation

Keywords

Negotiation, Agreement Technologies, Collective decision making

1. INTRODUCTION

Nowadays, there is an increasing number of applications which, due to their complex nature, require agent-based systems and agreement technologies. The latter allows collaboration, coordination, and conflict resolution among self-interested and independent entities such as agents. Thus, applying agreement technologies brings about the deployment of applications which, otherwise, would not have been possible.

Among agreement technologies, automated negotiation is highlighted as one of the core technologies for collaboration between independent entities. Researchers have put special effort into proposing bilateral negotiation models [4, 6, 10, 12] multi-party negotiation models [3, 7], and argumentation-based negotiation models [15, 18]. Many of these works have focused on scenarios where each party represents a single individual. However, in some real-life situations, a negotiation party may be formed by more than a single individual. For instance, this is the case of a married couple who negotiates with a seller in order to buy a house. In this scenario, despite the fact that both spouses may have a common goal (i.e., buying a house), each one may also have different preferences regarding certain issues involved in the negotiation process (e.g., neighbourhood, price, etc.). One party member should not act blindly on behalf of the others since, it may bring extremely negative consequences (e.g., untrust, tension). Scenarios such as the one presented above, require coordination among party members in order to reach a good agreement for all of the party members. Other real life scenarios such as organizational negotiations, where different stakeholders may be sent to the negotiation table, holiday trip negotiations, where groups of friends may have to negotiate a travel plan with a travel agency, and agriculture cooperatives, which are democratic associations by nature, present the same problem described with the married couple example and, thus, need similar coordination mechanisms.

In social sciences literature, parties of this type have been termed as *negotiation team* [1, 19]. Thompson et al. [1] define a negotiation team as a *a group of two or more interdependent persons who join together as a single negotiating party because their similar interests and objectives relate to the negotiation and who are all present at the bargaining table.* Multi-agent systems' computational capabilities may prove especially interesting because these electronic systems may improve the suboptimal solutions obtained by teams of humans and allow large-scaled simultaneous negotiations. With this purpose in mind, it is necessary to study mechanisms that allow the coordination of negotiation team members. We are interested in distributed mechanisms where

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complete preference revelation is not involved since, it may suppose leaking extremely delicate and important information.

In this paper, we are interested in studying several intra-team strategies for teams that negotiate with an opponent by means of a bilateral bargaining protocol. Intra-team strategies define how communication is carried out inside the team, and when and how decisions are taken (e.g., which offer is sent, if the opponent offer is accepted). We argue that selecting one strategy over others may produce different results. Furthermore, the performance of a specific intra-team strategy may be directly affected by the negotiation environment conditions (deadline lengths, negotiation of the opponent, preference similarity among team members). Thus, prior to the negotiation process, team members should reason about which intra-team strategy is the most appropriate one for the current environmental conditions. This paper aims to analyze how several intra-team strategies are affected by environmental conditions in order to grant teams with the repository of knowledge necessary to select a proper intra-team strategy for the current environmental conditions (as similarly suggested by other authors for scenarios where teams are not involved [9, 14]).

The remainder of this paper is divided as follows. First, we describe the basics of our negotiation model, focusing on the general settings, the negotiation protocol and the opponent strategy. In Section 3, we thoroughly describe the different intra-team strategies studied in this paper. Then, the experiments carried out are described and analyzed in Section 4. Related work is discussed in Section 5. Finally, we include some conclusiones and possible future work.

2. NEGOTIATION MODEL

A negotiation model consists of a negotiation protocol and a negotiation strategy. In our negotiation scenario, a group of agents has formed a team $A = \{a_1, a_2, ..., a_M\}$ whose goal is to negotiate a successful deal with an opponent op. However, each team member a_i may have different preferences about some negotiation issues. In this section, we describe the negotiation protocol employed by the team to communicate with the opponent. The negotiation strategy carried out by the opponent is also described. The strategy carried out by the team and the protocol employed by teammates in order to communicate inside the team will be thoroughly explained in Section 3, since it is the main focus of this paper.

Next, we describe some of the general assumptions of our negotiation model.

- The negotiation domain is comprised of n real-valued attributes whose domain is $[0, 1]$. Thus, the possible number of offers is $[0, 1]^n$.

- The negotiation team has already been formed. Team composition will remain static during the negotiation process.

- The team members and the opponent use linear utility functions to represent their preferences. These functions can be formalized as follows:

$$U(X) = w_1\ V_1(x_1) + w_2\ V_2(x_2) + ... + w_n\ V_n(x_n) \quad (1)$$

  where X is a n-attributes offer, x_i is the value of the i-th attribute, $V_i(.)$ is a linear function that transforms the attribute value to $[0, 1]$, and w_i is the weight or importance that is given by the agent to the i-th attribute. Weights given by the opponent to attributes may also be different. Agents do not know the form of other agents' utility functions, even if they are teammates.

- The opponent has a private deadline T_{op}, which defines the maximum number of negotiation rounds for the opponent. Once T_{op} has been reached in the negotiation process, the opponent will exit the procces and the negotiation end with failure. The team has a private joint deadline T_A which is common information for team members. Once this deadline has been reached, the team will exit the negotiation process and the negotiation will end with failure.

- The opponent has a reservation utility RU_{op}. Any offer whose utility is lower than the reservation utility will be rejected. Each team member has a private reservation utility RU_{a_i}, where a_i is a team member. This individual reservation utility is not shared among teammates. Therefore, a team member a_i will reject any offer whose value is under RU_{a_i}.

2.1 Negotiation Protocol

An alternating offer bilateral protocol [16] is used to allow communication between the opponent and team members. Due to the fact that not all of the teammates can simultaneously communicate with the opponent, it is assumed that a trusted mediator broadcasts opponent decisions to teammates and transmits team decisions to the opponent. As depicted in Section 3, this trusted mediator may have extra functionalities according to the intra-team strategy employed. Nevertheless, in no case is assumed that the complete preferences of the agents are revealed to this mediator.

2.2 Opponent Negotiation Strategy

A negotiation strategy defines the decision-making of an agent in a negotiation process. Next, we describe the negotiation strategy used by the opponent in our negotiation scenario. Given the fact that the goal of this paper is to study several intra-team strategies, they will be described in more detail in Section 3.

- The opponent follows a time-based concession strategy. It can be formalized as follows:

$$s_{op}(t) = 1 - (1 - RU_{op})(\frac{t}{T_{op}})^{\frac{1}{\beta_{op}}} \quad (2)$$

  where t is the current negotiation round and β_{op} is a parameter of the negotiation strategy which determines how concessions are made towards the reservation utility.

- The opponent uses an offer acceptance criterion $ac_{op}(.,.)$ during the negotiation process. It is formalized as follows:

$$ac_{op}(X^t_{A\rightarrow op}) = \begin{cases} accept & \text{if } s_{op}(t+1) \leq U_{op}(X^t_{A\rightarrow op}) \\ reject & \text{otherwise} \end{cases} \quad (3)$$

  where t is the current negotiation round, $X^t_{A\rightarrow op}$ is the offer received from the team, $U_{op}(.)$ is the utility function of the opponent, and $s_{op}(.)$ is the concession strategy of the opponent. Thus, an offer will be accepted if it reports a utility that is equal to, or greater than the utility of the offer that would be proposed by the opponent in the next negotiation round.

In the next section, we introduce the concept of intra-team strategy. Additionally, we introduce several intra-team strategies which will determine the final negotiation strategy carried out by the team.

3. INTRA-TEAM STRATEGIES

An intra-team estrategy defines *what* decisions have to be taken by a negotiation team, *how* those decisions are taken, and *when* those decisions are taken.

In a bilateral negotiation process between a team and an opponent, the decisions that must be taken (*what*) are the team deadline T_A, which offers are sent to the opponent, and whether opponent offers are accepted or not.

Given the fact that a negotiation team is formed by more than a single individual, decisions should take into account the interests of the team members. *How* decisions are taken will determine the satisfaction level of the team with the final decision. Basically, decisions can be taken using a representative, majority rules, or unanimity rules.

Decisions may be taken at different time instants. Nevertheless, we can generally classify *when* a decision is taken based on whether the decision has been taken before or during the negotiation process. Some decisions can be taken before the negotiation process starts since we have some knowledge about the negotiation environment, whereas it is more adequate to take other decisions during the negotiation process due to the fact that the opponent can provide with valuable feedback/new information.

As stated above, we assume that the team deadline T_A has been agreed upon before the negotiation process. Moreover,before the negotiation process starts, team members have agreed to use a time-based concession strategy using an agreed β_A).

Due to the fact that all of the team members seek a common goal, and it is possible that this negotiation case is not their first interaction (e.g., a group of friends who want to arrange a trip with a travel agency, a farm cooperative, etc.), a certain degree of cooperation and truthfulness among teammates is assumed. Despite the fact that a scenario where most of the teammates lie and play strategically is possible, we consider this possibility unlikely in the type of practical situations that we want to solve, since they are cooperative in nature. Nevertheless, it would be interesting to study how strategies behave when a minority of the members play strategically. Therefore, we point this out as possible future work. Next, we describe the intra-team strategies which will be studied during this paper. They have been selected to cover the spectrum of participation in team decisions: the less participative in decision-making (representative); strategies that involve a majority of members (similarity-based simple voting); and strategies that carry out unanimous decisions (similarity-based unanimity borda voting, full unanimity mediated)

3.1 Representative (RE)

The Representative Strategy is probably the simplest intra-team strategy. Team members delegate team decision-making to a representative $a_{re} \in A$, which, in this case, is the trusted mediator. This representative directly communicates with the opponent. He is also in charge of deciding which offer should be sent to the opponent *op*, and whether opponent offers should be accepted or not. In this article, it is assumed that agents have similar negotiation skills and social power.

Given the fact that the representative does not know other teammates' utility functions, he uses his own utility function during the negotiation process to take decisions. The negotiation strategy employed by the representative has been agreed upon prior to the negotiation by team members. A time-based concession strategy is used, using an agreed β_A value as parameter. As for the acceptance criteria, a rational acceptance criterion is used. Therefore, an offer is only accepted if the utility it reports is greater than, or equal to the utility of the offer that will be proposed in the next round. The intra-team strategy can be formalized as follows:

$$\begin{aligned}
&a_{re} = selectRepresentative(A)\\
&s_A(t) = 1 - (1 - RU_{a_{re}})(\tfrac{t}{T_A})^{(\frac{1}{\beta_A})}\\
&X^t_{A\to op} = selectOffer(X^t) \text{ where } U_{a_{re}}(X^t) = s_A(t)\\
&ac_A(X^t_{op\to A}, t) = \begin{cases} accept & \text{if } s_A(t+1) \le U_{a_{re}}(X^t_{op\to A})\\ reject & \text{otherwise}\end{cases}
\end{aligned} \tag{4}$$

3.2 Similarity Simple Voting (SSV)

As opposed to RE, this strategy tries to take into account team members' opinions during the negotiation process. The aim of the strategy is to avoid low quality results when teammates' preferences are very dissimilar. For this purpose, SV relies on voting processes and majority rules in each negotiation round in order to determine whether an opponent offer should be accepted or not, as well as which offer is sent to the opponent. In this intra-team strategy, the trusted mediator has a more important role since it coordinates voting processes.

3.2.1 Offer proposal

Assuming that the negotiation process is currently positioned at round t, the mediator opens an offer proposal process where, firstly, each team members proposes an anonymous offer to the mediator. Each team member uses his own utility function $U_{ai}(.)$ and the agreed time-based concession strategy $s_{a_i}(.)$ with β_A. Nevertheless, it should be pointed out that agents have private reservation utilities. Therefore, despite the fact that β_A is common, the utility of the offers sent by team members at round t may be different. Then, the mediator makes public the set of offers received $XT^t = \{X^t_{a_1\to A}, ..., X^t_{a_M\to A}\}$, and a voting process is opened. Agents anonymously state which offers from the set XT^t they would be willing to send at round t. For that purpose, they employ an acceptance criterion $Vote_{a_i}(.)$ where an offer proposed by a teammate is acceptable if the utility it reports is greater than, or equal to the utility indicated by the concession strategy at round t. The trusted mediator gathers the opinions of all of the team members, and then the most voted offer $X_{A\to op}$ is selected. This offer is broadcasted by the mediator to team members and the opponent. When there is more than a single most voted offer, one of them is chosen randomly. The mechanism employed by team members to determine which offer is proposed to the opponent can be formalized as follows:

$$\begin{aligned}
&Vote_{a_i}(X^t) = \begin{cases} 1 & \text{if } s_{a_i}(t) \le U_{a_i}(X^t)\\ 0 & \text{otherwise}\end{cases}\\
&X^t_{A\to op} = \underset{X^t\in XT^t}{\text{argmax}} \sum_{a_i\in A} Vote_{a_i}(X^t)
\end{aligned} \tag{5}$$

3.2.2 Opponent Offer Acceptance Criterion

The criterion $ac_A(.)$ used to accept an opponent offer $X^t_{op\rightarrow A}$ at round t also follows a majority rule. The trusted mediator receives the offer from the opponent and broadcasts it to team members. Then, a simple voting process is opened, where each team member a_i must anonymously state to the mediator whether they want to accept the opponent offer or not. Once all of the votes have been gathered, the mediator counts positive votes (accept offer). If the number of positive votes is a majority, greater than half the number of team members, the opponent offer is accepted. When there is a draw between positive votes and negative votes, one of the options is chosen randomly. The final decision about the opponent offer is broadcasted to team members and the opponent. Each teammate a_i follows a rational criterion ac_{a_i} to determine if a positive vote is emitted. A positive vote is emitted if the opponent offer reports a utility that is greater than, or equal to the utility of the offer that will be proposed by the agent in the next negotiation round. This acceptance strategy can be formalized as follows:

$$ac_{a_i}(X^t) = \begin{cases} 1 & \text{if } s_{a_i}(t+1) \le U_{a_i}(X^t) \\ 0 & \text{otherwise} \end{cases}$$
$$ac_A(X^t_{op\rightarrow A}) = \begin{cases} accept & \text{if } \sum\limits_{a_i \in A} ac_{a_i}(X^t_{op\rightarrow A}) > \frac{|A|}{2} \\ reject & \text{if } \sum\limits_{a_i \in A} ac_{a_i}(X^t_{op\rightarrow A}) < \frac{|A|}{2} \\ \text{random} & \text{otherwise} \end{cases} \tag{6}$$

Each team member is interested in sending his offer to the opponent, since, that way, he assures that if the offer is accepted, it matches his aspiration level at round t. Additionally, it is also desirable (due to an inherent sense of cooperation) and necessary for the offer to be liked by his teammates. However, the offer needs to be the offer most voted in the voting process. Therefore, the team member needs to propose $X^t_{a_i\rightarrow A}$ in a way that it is acceptable for team members and the opponent. At round t, the expected utility $EU_{a_i}(.)$ of an offer X^t for agent a_i can be defined as follows:

$$EU_{a_i}(X^t) = U_{a_i}(X^t)\; p_{op}(X^t)\; p_A(X^t) \tag{7}$$

where $p_{op}(X^t)$ is the probability for the offer X^t to be accepted by the opponent at round t, and $p_A(X^t)$ is the probability for the offer to be acceptable by teammates. For that purpose, the agent sends $X^t_{a_i\rightarrow A}$ from his iso-utility curve at the current round $C^t_{a_i}$, the offer that maximizes the following equation.

$$\begin{aligned} X^t_{a_i\rightarrow A} &= \arg\max_{X \in C^t_{a_i}} U_{a_i}(X^t)\; p_{op}(X^t)\; p_A(X^t) \\ &= \arg\max_{X \in C^t_{a_i}} p_{op}(X^t)\; p_A(X^t) \end{aligned} \tag{8}$$

where $U_{a_i}(.)$ can be surpressed since all of the offers come from the iso-utility curve. The problem with this proposal strategy is how both probabilities can be calculated in an efficient way. An efficient method for approximating these probabilities consists in using similarity heuristics [5, 12]. On the one hand, when approximating $p_{op}(X^t)$, it can be considered that the more similar X^t is to $X^{t-1}_{op\rightarrow A}$, the more probable it is for X^t to be accepted by the opponent. Thus, we can approximate $p_{op}(X^t) \approx Sim(X^t, X^{t-1}_{op\rightarrow A})$. On the other hand, when approximating $p_A(X^t)$, we can consider that the more similar X^t is to XT^{t-1}, the more probable it is for X^t to be acceptable for team members at round t. We assume that the more similar $X^t_{a_i\rightarrow A}$ is to the most dissimilar offer from XT^{t-1}, the more acceptable it is for the team. Therefore, we can approximate $p_A(X^t) \approx \min\limits_{X_j \in XT^{t-1}} Sim(X, X_j)$.

Then, the offer $X^t_{a_i\rightarrow A}$ proposed by the agent can be formalized as follows.

$$X^t_{a_i\rightarrow A} = \arg\max_{X \in C^t_{a_i}} Sim(X, X^{t-1}_{op\rightarrow A}) \min_{X_j \in XT^{t-1}} Sim(X, X_j) \tag{9}$$

Given our negotiation domain, we employ 1 minus the euclidean distance scaled to [0,1] as a similarity measure between two offers.

3.3 Similarity-Based Unanimity Borda Voting (SBV)

Two problems arose in the previous intra-team strategy. First, the selection rule is still a majority rule. Thus, it is still possible that offers selected do not satisfy every team member. Second, the type of voting system employed does not provide information about which offers are more acceptable than others for team members. In the SBV strategy, majority rules are discarded and unanimity rules are used in order to solve both problems stated above.

3.3.1 Offer Proposal

The communication protocol used within the team to select which offer is sent is similar to the one presented in the SSV strategy. The main difference resides in the fact that Borda Voting is employed to rank proposals. This voting system has the advantage that it usually selects broadly accepted proposals instead of majority proposals.

$$\begin{aligned} &Vote_{a_i}(X^t, XT^t) = |A| - Order_{a_i}(X^t, XT^t) \\ &X^t_{A\rightarrow op} = \underset{X^t \in XT^t}{\text{argmax}} \sum_{a_i \in A} Vote_{a_i}(X^t, XT^t) \end{aligned} \tag{10}$$

where $Order_{a_i}(X^t, XT^t)$ determines the order of the offer X^t in XT^t according to a descending order by utility reported to a_i. Offer are proposed by agents following the similarity heuristic employed in SSV.

3.3.2 Opponent Offer Acceptance Criterion

When it comes to the opponent offer acceptance criteria, the same communication protocol devised for the SSV strategy is used here. However, instead of a majority rule, a unanimity rule is employed. In other words, all of the team members must find the opponent offer acceptable to proceed to accept the offer. Otherwise, the offer is rejected. This criterion can be formalized as follows:

$$ac_A(X^t_{op\rightarrow A}) = \begin{cases} accept & \text{if } \sum\limits_{a_i \in A} ac_{a_i}(X^t_{op\rightarrow A}) = |A| \\ reject & otherwise \end{cases} \tag{11}$$

3.4 Full Unanimity Mediated Strategy (FUM)

The last intra-team strategy aims to be a fully unanimous process. With that purpose, the trusted mediator takes a more active role in the tasks carried out by the team. In fact, the trusted mediator is in charge of building the offer to be sent to the opponent, and observing concessions made by the opponent. It should be pointed out that this strategy is more collaborative in nature, since it requires agents to share some information with the mediator. However, improvements in terms of joint utility and the minimum utility of a team member are expected.

The intra-team strategy can be divided into four different phases: information sharing, observing concessions from the opponent, offer construction, and the opponent offer acceptance criteria. The latter will not be described since the criteria and communication protocol employed is the same one as described in the SBV strategy.

3.4.1 Information Sharing Phase

Building an offer that satisfies every team member each round is a difficult task. If it is not carried out properly, the offer may be too demanding in the eyes of the opponent. The goal of this phase, which is carried out before the negotiation process starts, is to determine which attributes are not interesting for each team member. During the negotiation process, and more especifically during the offer construction phase, agents that have stated x_j as not interesting are not entitled to ask value for that attribute. Therefore, team members must be willing to *sacrifice* some utility for the team welfare and the offer construction process. This cooperative behaviour is governed by a parameter ϵ_{a_i}, which is private for each agent. This parameter determines the set of attributes NI_{a_i} that the team member a_i is not interested in. NI_{a_i} is the largest set of attributes whose sum of weights is lower than, or equal to ϵ_{a_i}. An easy way to calculate NI_{a_i} consists in ordering the attributes by ascending order according to their weights, and then sequentially adding attributes to NI_{a_i} until the sum of the weights in NI_{a_i} is greater than ϵ_{a_i} (the last attribute is not added).

Before the negotiation process starts, the mediator privately asks each agent a_i about N_{a_i}. Then, the agents also respond privately. From this process, the mediator can obtain the set of attributes that are not interesting for any team member, and the set of attributes that are not interesting for each team member.

3.4.2 Observing Opponent Concessions

During the negotiation process, the mediator is also in charge of observing opponent concessions. The goal is to determine which attributes are the most interesting ones for the opponent. A simple mechanism is employed for this task. For each attribute and round, the amount of concession performed by the opponent is observed and accumulated in an array. This process is carried out during k rounds. The general idea behind this mechanism is that those attributes that have accumulated less concession, are those that are more interesting for the opponent. Contrarily, those attributes that have accumulated more concession, are those that are less interesting for the opponent. It is acknowledged that there are more sophisticated methods for guessing opponent preferences. Nevertheless, the goal of this paper is not to propose a sophisticated learning technique, but to test the general behaviour of structurally different intra-team strategies.

3.4.3 Offer Construction Phase

This phase is carried out each time the team has to send an offer to the opponent. The mediator takes a very active role during this phase, where the information gathered from the information sharing phase and the opponent are used. The aim is to build an offer that is unanimously accepted by all of the team members, and that is not too demanding for the opponent.

It should be pointed out, that ϵ_{a_i} also affects each agent's concession strategy as follows:

$$s_{a_i}(t) = (1-\epsilon_{a_i}) - (1-\epsilon_{a_i} - RU_{a_i})(\frac{t}{T_A})^{\frac{1}{\beta_A}} \qquad (12)$$

The offer $X^t_{A\to op}$ is built iteratively in a process where the mediator asks the agents about which value is the most appropriate for each attribute. Next, we detail the algorithm followed by the mediator and team members to build the offer $X^t_{A\to op}$ at round t:

1. First, the list of active agents in the offer construction phase A' is initialized to the set that contains all of the team members. Furthermore, attributes are sorted by ascending order according to the importance for the opponent. The result is placed in an array XOP. Finally, the offer $X^t_{A\to op}$ is initialized to the empty set.

2. The mediator checks which attributes are not interesting for any team member. These attributes are maximized/minimized according to the interests of the opponent. They are also substracted from XOP.

3. The next attribute x_j is substracted from the ordered list XOP. The mediator asks each team member a_i in A' who is also interested in x_j, for a proper value for x_j. More especifically, given $X^t_{A\to op}$, he asks for the value $x_{a_i,j}$ needed by each agent a_i to be as close as possible to the utility defined by his strategy $s_{a_i}(t)$. Among the received values $D=\{x_{a_1,j},...,x_{a_M,j}\}$, the selected value x_j is the one that is the closest to the most demanding value max_{x_j} (e.g. if 1 is the most preferred value in terms of utility, then the most demanding value is 1). x_j is added to $X^t_{A\to op}$. This process can be formalized as follows:

$$\begin{aligned} x_{a_i,j} &= \operatorname*{arg\,min}_{v\in[0,1]} (s_{a_i}(t) - w_j\ V_j(v) - U_{a_i}(X^t_{A\to op}) \\ x_j &= \operatorname*{arg\,max}_{x_{a_i,j}\in D} |max_{x_j} - x_{a_i,j}| \end{aligned} \qquad (13)$$

4. Next, the mediator makes the partial offer $X^t_{A\to op}$ public among teammates. Then, each team member who is still active in A' informs the mediator about whether $X^t_{A\to op}$ reports greater or equal utility than his desired utility $s_{a_i}(t)$.Those teammates whose response is positive are eliminated from A'. If A' is empty or XOP is empty, then the offer construction phase ends. If the construction phase ends and there are still attributes that have not been instantiated, they are maximized/minimized according to the opponent preferences. Otherwise, if the construction phase has not ended, the algorithm jumps to step 3.

This way, the offer $X^t_{A\to op}$ to be sent to the opponent is constructed. This offer is unanimous since the resulting offer complies with the following expression:

$$\forall a_i \in A,\ \ U_{a_i}(X^t_{A\to op}) \geq s_{a_i}(t) \qquad (14)$$

4. EXPERIMENTS AND RESULTS

4.1 Experimental Setting

As stated above, the goal of this paper is to study the performance of different intra-team strategies. More specifically, we check their performance in different environments. Environments differ in team preference diversity (very similar team, very dissimilar team), negotiation time (long deadline, short deadline), and the concession strategy (boulware, conceder[4]). According to these settings, we generated different environmental scenarios, where each one is composed of multiple negotiation cases. Next, we detail how these environmental scenarios were generated:

- 25 different linear utility functions were randomly generated. These utility functions represented the preferences of potential team members for n=4 negotiation attributes, whose $V_i(.)$ is equal and linear for all of the team members. Team size was set to M=4 members. Therefore, 12650 teams were generated. 25 linear utility functions were generated to represent the preferences of opponents. These utility functions were generated by taking potential teammates' utility functions and reversing $V_i(.)$. Therefore, if the value preferred by a team member for attribute i is 1, then the value preffered by the opponent for that attribute will be 0.
- In order to determine the preference diversity in a team, we decided to compare team members' utility functions. We introduce a dissimilarity measure based on the utility difference between offers. The dissimilarity between two teammates can be measured as follows:

$$D(U_{a_i}(.), U_{a_j}(.)) = \sum_{\forall X \in [0,1]^n} |U_{a_i}(X) - U_{a_j}(X)| \quad (15)$$

  If the dissimilarity between two team members is to be measured exactly, it needs to sample all of the possible offers. However, this is not feasible in the current domain where there are an infinite number of offers. Therefore, we limited the number of sampled offers to 1000 per dissimilarity measure. Due to the fact that a team is composed by more than two members, it is necessary to provide a team dissimilarity measure. We define the team dissimilarity measure as the average of the dissimilarity between all of the possible pairs of teammates. For all of the teams that had been generated, we measured their dissimilarity and calculated the dissimilarity mean $\bar{dt}$ and standard deviation σ. We used this information to divide the spectrum of negotiation teams according to their diversity. Our design decision was to consider those teams whose dissimilarity was greater than, or equal to $\bar{dt} + 1.5\sigma$ as very dissimilar, and those teams whose dissimilarity was lower than, or equal to $\bar{dt} - 1.5\sigma$ as very similar. In each case, 100 random negotiation teams were selected for the tests, that is, 100 teams were selected to represent the very similar team case, and 100 teams were selected to represent the very dissimilar team case. These teams participate in the different environmental scenarios, where they are confronted with one random half of all of the possible individual opponents. Therefore, each environmental scenario consists of 100*12*4=4800 different negotiations (each negotiation is repeated 4 times to capture stochastic variations in the different intra-team strategies).
- On the one hand, deadlines T (T_{op}, T_A) for negotiations are selected randomly from a uniform distribution U[30,60] in long deadline scenarios (L). On the other hand, deadlines for negotiations are selected randomly from a uniform distribution U[5,10] in short deadline scenarios (S).
- Time-based concession strategies may be either boulware (B) or conceder (C) depending on the strategy parameter β (β_{op}, β_A) When $\beta < 1$, we set a boulware strategy, where concessions are made slowly at the initial rounds, and faster towards the deadline. For parties who employ a boulware strategy, β is randomly set from a uniform distribution U[0.4,0.99]. When $\beta > 1$ we set a conceder strategy, where concessions are made faster at the initial rounds, and they are slow towards the deadline. For parties who employ a conceder strategy, β is randomly set from a uniform distribution U[20,40].
- Reservation utility is randomly chosen from a uniform distribution U[0,0.25] for both team members and the opponent.
- The representative is randomly chosen in RE.
- ϵ_{a_i} was set to 0.1 for all of the team members when using the FUM strategy.

In each environmental scenario, we want to measure the performance of the different intra-team strategies. We use different quality measures, both economical and computational, for this purpose. Measures are mainly focused on the team performance, leaving aside the performance of the opponent. The selected quality measures are:

- Minimum Team Utility: It is the minimum utility obtained by one of the team members. In some applications, it may be interesting to ensure a certain utility level for the worst case team negotiation scenario.
- Average Team Utility: It is the average of the utility obtained by the team members. It represents the average satisfaction level of the team members.
- Negotiation rounds: It is the number of negotiation rounds employed in obtaining a deal. Note that, in this paper, we assume a similar cost per round since the number of team members is not large.

4.2 Results

The results for the different environmental scenarios can be found in Table 1. Next, we analyze the results obtained for scenarios where teams are very dissimilar. It must be pointed out that results for $s_A = C$ are not included since they always yield worse results than the ones obtained by Boulware in these scenarios.

- **Very Dissimilar. T=L, s_A=B, s_{op}=B :** FUM is able to obtain better results in terms of minimum and average utility. Moreover, the number of rounds is not much different from SUV and SSV, which follow FUM in terms of minimum and average utility.
- **Very Dissimilar. T=L, s_A=B, s_{op}=C :** SSV, SUV, and FUM obtain very similar results in utility. SSV and SUV seem to be the best options since they employ

Very Dissimilar. T=Long. s_A=Boulware. s_{op}=Boulware

Strategy	Minimum	Average	Round
RE	[0.11-0.12]	[0.44-0.45]	[19.07-19.62]
SSV	[0.32-0.33]	[0.56-0.57]	[28.39-28.74]
SUV	[0.39-0.40]	[0.53-0.54]	[30.55-30.88]
FUM	[0.50-0.51]	[0.68-0.69]	[29.87-30.24]

Very Dissimilar. T=Long. s_A=Boulware. s_{op}=Conceder

Strategy	Minimum	Average	Round
RE	[0.38-0.40]	[0.72-0.73]	[6.16-6.45]
SSV	[0.61-0.63]	[0.81-0.82]	[12.49-12.94]
SUV	[0.68-0.69]	[0.81-0.82]	[15.14-15.63]
FUM	[0.68-0.69]	[0.78-0.79]	[21.27-21.80]

Very Dissimilar. T=Short. s_A=Boulware. s_{op}=Boulware

Strategy	Minimum	Average	Round
RE	[0.09-0.10]	[0.41-0.42]	[4.48-4.57]
SSV	[0.33-0.34]	[0.51-0.52]	[5.88-5.95]
SUV	[0.38-0.39]	[0.51-0.52]	[6.22-6.29]
FUM	[0.39-0.40]	[0.58-0.59]	[6.28-6.35]

Very Dissimilar. T=Short. s_A=Boulware. s_{op}=Conceder

Strategy	Minimum	Average	Round
RE	[0.26-0.28]	[0.62-0.63]	[2.48-2.53]
SSV	[0.58-0.59]	[0.77-0.78]	[2.95-3.04]
SUV	[0.62-0.63]	[0.77-0.78]	[3.21-3.30]
FUM	[0.68-0.69]	[0.80-0.81]	[4.13-4.22]

Very Similar. T=Long. s_A=Boulware. s_{op}=Boulware

Strategy	Minimum	Average	Round
RE	[0.47-0.48]	[0.61-0.62]	[23.04-23.47]
SSV	[0.49-0.50]	[0.61-0.62]	[27.56-27.93]
SUV	[0.53-0.54]	[0.61-0.62]	[29.44-29.81]
FUM	[0.61-0.62]	[0.72-0.72]	[25.69-26.12]

Very Similar. T=Long. s_A=Boulware. s_{op}=Conceder

Strategy	Minimum	Average	Round
RE	[0.77-0.78]	[0.86-0.87]	[8.69-9.02]
SSV	[0.76-0.77]	[0.83-0.84]	[15.04-15.49]
SUV	[0.77-0.78]	[0.82-0.83]	[17.25-17.74]
FUM	[0.76-0.77]	[0.82-0.83]	[17.38-17.93]

Very Similar. T=Short. s_A=Boulware. s_{op}=Boulware

Strategy	Minimum	Average	Round
RE	[0.41-0.42]	[0.55-0.56]	[5.05-5.12]
SSV	[0.46-0.47]	[0.55-0.56]	[5.56-5.63]
SUV	[0.48-0.49]	[0.56-0.57]	[5.81-5.88]
FUM	[0.51-0.52]	[0.63-0.64]	[5.56-5.63]

Very Similar. T=Short. s_A=Boulware. s_{op}=Conceder

Strategy	Minimum	Average	Round
RE	[0.70-0.71]	[0.80-0.81]	[2.87-2.94]
SSV	[0.73-0.74]	[0.81-0.82]	[3.23-3.32]
SUV	[0.74-0.75]	[0.81-0.82]	[3.48-3.57]
FUM	[0.77-0.78]	[0.83-0.84]	[3.59-3.68]

Table 1: Results for the different environmental scenarios. Each table shows confidence intervals (95%) for the minimum team utility, the average team utility and the number of negotiation rounds. The results also include cases where no deal was found (minimum utility=0, average utility=0)

fewer rounds. If we analyze the average utility, RE is very close to the rest of the strategies. If the number of rounds is very important during the decision-making process, RE may become the most appropriate option when the team wants to get a good average utility.

- **Very Dissimilar. T=S, s_A=B, s_{op}=B :** SUV and FUM obtain the best results in terms of minimum utility. SUV may be a better option since it requires fewer internal messages. As for the average utility, the results suggest that FUM is a better intra-team strategy.
- **Very Dissimilar. T=S, s_A=B, s_{op}=C :** In terms of minimum team utility, FUM is the best option followed by SUV. However, the results imply that SSV may be the best option for the average utility since it gets similar results to SUV and FUM in fewer rounds.

In general, FUM tends to work better than the other strategies when the opponent is known to use a boulware strategy since it is able to propose a deal that is satisfactory for both parties. Its performance is reduced when the deadline is short. This may occur due to the fact that it is not capable of inferring opponent preferences. When the opponent uses a conceder strategy, SSV and SUV are able to obtain similar results to FUM. The RE strategy gets poor results compared to the other strategies, especially in terms of the minimum utility. This is due to the fact that the representative is not able to account for the preferences of the majority of the team members.

Next, we detail the analysis for the results obtained when teams are very similar. In these scenarios, RE gets closer to the other methods due to the similarities among teammates.

- **Very Similar. T=L, s_A=B, s_{op}=B :** Similarly to the analogous case where teammates were very dissimilar, FUM obtains better results in terms of both utilities.
- **Very Similar. T=L, s_A=B, s_{op}=C :** All of the strategies get very similar results in terms of utility. Thus, RE is suggested as the best intra-team strategy since it requires a significantly lower number of rounds.
- **Very Similar. T=S, s_A=B, s_{op}=B :** SUV and FUM obtain the best results when analyzing the minimum utility. However, regarding the average utility, FUM obtains slightly better results than SUV.
- **Very Similar. T=S, s_A=B, s_{op}=C :** All of the strategies get very similar results. With regard to the minimum utility, SSV, FUV, and FUM obtain slightly better results at a similar number of rounds. Nevertheless, the results are much closer when it comes to the average utility. The results imply that RE is the best option in this case since it requires fewer rounds.

In these cases, FUM still tends to obtain better results when the opponent uses a boulware strategy, and its performance is reduced when the deadline is short. However, when the the opponent uses a conceder strategy, RE may prove to be more useful since it requires fewer rounds and communications. Due to the fact that teammates' preferences are more similar, the representative is able to account for the group preferences.

The variability shown in intra-team strategies' performance under different environmental conditions implies that team members should try to identify such conditions before the negotiation process starts so that they can choose the appropiate intra-team strategy. Analysis such as the one performed in this paper provide agents with the knowledge required to make those decisions.

5. RELATED WORK

As far as we are concerned, the topic of negotiation teams has not been thoroughly studied in agent literature. However, there are some topics which are closely related. Customer coalitions are groups of self-interested agents who join together in order to get volume discounts from sellers [13]. Customer coalitions usually consider scenarios where there is a single attribute that is equally important for every buyer.

Negotiation teams also face the problem of multi-attribute tasks, where teammates may have different opinions about the different negotiation issues.

Most of the works carried out in agent-based negotiation focus on negotiations where parties represent one single individual in a bilateral negotiation process [4, 5, 6, 10, 12], a multi-party process [3, 7] or argumentation processes [15]. However, as far as we know, none of these models take into account the fact that parties may be formed by more than a single individual.

Another agent topic that is closely related is multi-agent teams [2]. Agent teams have been proposed for a wide variety of tasks such as Robocup [17], rescue tasks [11], and transportation tasks [8]. However, as far as we know there is no published work that considers teams of agents negotiating with an opponent.

6. CONCLUSIONS AND FUTURE WORK

From the perspective of agent literature, not much research has been carried to cover the topic of negotiation teams. In this paper, we have studied the performance of several intra-team strategies, which define what decisions are taken by the team during the negotiation process, and when and how these decisions are taken. More especifically, we have analyzed how the performance of the different intra-team strategies is affected in different ways by environmental conditions. The results have shown variability in the strategies' performance depending on the negotiation environment. This fact highlights the need for teams to analyze their environment before choosing a proper intra-team strategy.

Since the topic of negotiation teams is quite novel, there are still several areas that need to be covered. Some of the issues that need to be studied are: the impact of team size on the strategy performance, the impact of other environmental conditions (e.g. different opponent strategies, issue incompatibility among team members, non-static team membership, etc.), additional intra-team strategies, non-flat structured teams where teammates perform different roles, and team formation methods.

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