Tactics and Concessions for Argumentation-based Negotiation

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Abstract. Argumentation-based negotiation has gained increasing prominence in the multi-agent field over the last years. There is currently a long literature on the use of argumentation in negotiation and especially the modeling of negotiation protocols or decision making mechanisms. However the study of strategic issues that define the behavior of an agent during the negotiation has been largely neglected. This work fills this gap by providing, profile, behavior and time constraints based tactics that can be combined together to implement complex strategies similar to those studied in game-theoretic negotiation. These different tactics lead to different types of concessions. An experimental evaluation shows how tactics and concessions may influence the negotiation length and outcome, under the assumptions of deadlines and the availability of information on the opponent.

Keywords. Argumentation, Negotiation, Tactics

Introduction

Argumentation-based negotiation is an important approach to automated negotiation that has gained increasing prominence in the multi-agent field over the last years (see [8] for a recent overview of the domain). In the literature many works propose generic or specific argumentation-based negotiation frameworks (see e.g. [2], [14]) or focus on specific aspects of the use of argumentation in negotiation such as the modeling of protocols (see e.g. [15], [13]) or decision making mechanisms (see e.g. [1], [14]). However, the study of strategic issues concerning the main decisions an agent has to make during a negotiation, has been insufficient (see e.g. [13], [11], [7], [4]). Such decisions relate to the acceptance or the rejection of an offer, the level of concession in the case an offer is rejected, or the selection of the best offer to be proposed next. All these decisions depend on different parameters such as the time, the profile, and the behavior of the opponent during the negoti-

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ation. To the best of our knowledge there is a lack of work that address the above issues, namely the use of tactics and strategies taking into account the time, the profile or the behavior of an agent during the negotiation as this is done in game theoretic negotiation (see e.g. [12]). The aim of this work, which is a follow-up of [13], is to fill this gap by providing methods for defining tactics that take into account deadlines, as well as the profile and the exchanged arguments between agents during the dialogue. Two of the proposed tactics simulate, in argumentation based negotiation context, the *Boulware* and *Conceder* behavior proposed in [12]. A third tactic, called $LastMinuteTactic$, helps agents, negotiating under time constraint (i.e. with a deadline), to propose an offer in the last round when the time limit is attainted, that is very likely to be accepted by his opponent. For the proposed tactics we present several experimental results concerning more than 4000 negotiations we ran on randomly generated negotiation theories. These results show that the proposed tactics have a positive impact on the negotiation wrt four criteria: a) the length of the negotiations, b) the number of the optimal solutions found by at least one of the agents, c) the number of Pareto optimal solutions and d) the number of disagreements avoided in the last round by applying the $LastMinuteTactic$. These tactics can be combined together to implement complex strategies, similar to those studied in game-theoretic negotiation and yield different types of concessions for the agents during the dialogue.

1. The Negotiation Framework

The negotiation framework we use in this paper is the one of [13]. We assume two agents, α and β engaged in a bilateral negotiation over a set of offers (options) $O = \{o_1, o_2, ..., o_n\}$ that are identified from a logical language $\mathcal{L}$. The options are mutually exclusive, therefore each agent can choose only one at each time.

As in [13] we distinguish two types of arguments namely *epistemic* and *practical*, that are both taken into account (see [3]), in the reasoning mechanism used by the agents. *Practical arguments* A_p support offers (or decisions) by justifying those offers. *Epistemic arguments* A_e represent what the agent believes about the world. Epistemic arguments are denoted by variables γ_1, γ_2,..., while practical arguments by variables δ_1, δ_2,... When no distinction is necessary between arguments, we use variables a, b, c...

In what follows, we are not interested in the construction of these arguments. Furthermore, we assume that $Args(\mathcal{L})$=$A_e \cup A_p$, and $A_e \cap A_p = \emptyset$. Let $\mathcal{F}$ be a function that maps each option to the arguments that support it, i.e., $\forall o \in O$, $\mathcal{F}(o) \subseteq A_p$. Each argument can support only one option, thus $\forall o_y, o_z \in O, o_y \neq o_z, \mathcal{F}(o_y) \cap \mathcal{F}(o_z) = \emptyset$. When $\delta \in \mathcal{F}(o)$, we say that o is the conclusion of δ, noted Conc $(\delta) = o$.

As in [13], [3], we assume three binary preference relations on arguments. A partial preorder $\succeq_e$ on the set A_e, and a partial preorder $\succeq_p$ on the set A_p. Finally, a relation $\succeq_m$ (m stands for mixed relation) on the sets A_e and A_p, such that $\forall \gamma \in A_e$, $\forall \delta \in A_p$, $(\gamma,\delta) \in \succeq_m$ and $(\delta,\gamma) \notin \succeq_m$. Therefore, any epistemic argument is assumed stronger than any practical argument.

In the following, $\succ_x$ with $x \in \{e, p, m\}$ denotes the strict relation associated with $\succeq_x$. It is defined as $(a, b) \in \succ_x$ iff $(a, b) \in \succeq_x$ and $(b, a) \notin \succeq_x$. Moreover, when

$(a, b) \in \succeq_x$ and $(b, a) \in \succeq_x$ we will say that the arguments a and b are *indifferent*, denoted by $a \sim_x b$.

Conflicts between arguments in $\mathcal{A} = A_p \cup A_e$ are captured by the binary relation $R = R_e \cup R_p \cup R_m$ [3], where $R_e \subseteq A_e \times A_e$, $R_p = \{(\delta, \delta') \mid \delta, \delta' \in A_p, \delta \neq \delta'$ and $Conc(\delta) \neq Conc(\delta')\}$, and $R_m = A_e \times A_p$. We assume that practical arguments supporting different offers are in conflict. Thus for any two offers o_y, o_z, $o_y \neq o_z$, $\forall \gamma \in \mathcal{F}(o_y)$ and $\forall \gamma' \in \mathcal{F}(o_z)$, it holds that $(\gamma, \gamma') \in R_p$ and $(\gamma', \gamma) \in R_p$.

Each preference relation $\succeq_x$ (with $x \in \{e, p, m\}$) is combined with the corresponding conflict relation R_x to give a *defeat relation* between arguments $Def_x = \{(a, b) \mid (a, b) \in R_x$ and $(b, a) \notin \succ_x\}$. We have $Def_{global} = Def_e \cup Def_p \cup Def_m$.

We assume that the reader is familiar with basic notions related to the acceptability semantics of [10]. This work, assumes that the agents reason under the *stable extension* semantics. For theories with a defeat relation as defined above, stable extensions always exist [9].

As in [13], we assume that each agent engaged in a negotiation has an argumentation theory containing arguments $\mathcal{A}$ that are exchanged during the negotiation. In addition to that, this work introduces the profiles of the opponents of an agent, a new element in the argumentation-based negotiation theory. More specifically, an agent has in his disposal a set of profiles $P^{ag}=\{p_{ag_1}, ..., p_{ag_n}\}$, where $p_{ag_i} \subseteq \mathcal{A}^{ag} \times \mathcal{A}^{ag}$, for $1 \leq i \leq n$. The profile associates each opponent of an agent with a *defeat relation*, that provides information about the negotiation behavior of this agent. This behavior is associated with the particular role the agent has (e.g. seller, buyer) in the negotiation context. This information may be incomplete and given before the start of the negotiation or acquired during the negotiation as it is shown later on. Formally, a negotiation theory is defined as follows.

Definition 1 *[Negotiation Theory] Let O be a set of offers, $ag \in Ag$ an agent and Ag the set of negotiating agents. The negotiation theory $\mathcal{T}^{ag}$ of agent ag is a tuple $\mathcal{T}^{ag} =< \mathcal{A}^{ag}, \mathcal{F}^{ag}, Def^{ag}_{global}, P^{ag} >$, where $Def^{ag}_{global} = Def_e \cup Def_p \cup Def_m$, $\mathcal{A}^{ag} = A^{ag}_p \cup A^{ag}_e$, $P^{ag}=\{p_{ag_1}, ..., p_{ag_n}\}$ is a set of profiles of the possible opponents $ag_1, ..., ag_n$ of agent ag as specified above, and $\mathcal{F}^{ag} : O \rightarrow 2^{A^{ag}_p}$ a mapping that associates practical arguments to offers. It holds that $\bigcup_{1 \leq y \leq n} \mathcal{F}^{ag}(o_y) = A^{ag}_p$.*

2. Negotiation Tactics

Negotiation Tactics have been largely used in game theoretic negotiation. In that context they are a set of functions (see [12]) that determine how to compute the values of an issue (e.g. price, volume) for a next offer based on a *single* criterion (e.g. time, recourses). Based on existing tactics agents can build *strategies* which correspond to different combination of tactics. Tactics have been ignored in argumentation-based negotiation. This work is the first attempt to adapt the notion of tactic to the argumentation context, and relate it to two different criteria, *time* and *opponent behavior*.

2.1. Time Dependent and Behavior Tactics

Time dependent tactics are used by agents when there is a deadline by which the negotiation must end. The goal is then to progressively move closer to offers that are likely to be accepted by the opponent. This becomes critical when the time deadline approaches, and a disagreement is a worse outcome than an agreement on a less preferred offer. A competent negotiating agent needs to concede in an informed way, a quality that presupposes some kind of knowledge on the theory of the opponent. In the following, $T = \{1, \ldots, t_{max}\}$ denotes the set of time periods (or rounds) in the negotiation, and $o^t_{\alpha \to \beta}$ the offer that agent α proposes to agent β at time $t \in T$.

2.1.1. Aggregate Theories Method

It is well known that in all kinds of negotiations, when agents seek to reach an agreement, they have to *concede*. We assume that when agent α makes a *concession* at time (round) t, he proposes an offer $o^t_{\alpha \to \beta}$ that is more preferred for agent β, w.r.t. a preference relation $\trianglerighteq_\beta$ (see e.g. [3], [2] for such a preference relation), than the offer $o^{t-2}_{\alpha \to \beta}$ proposed in the preceding round $t-2$, i.e. $o^t_{\alpha \to \beta} \trianglerighteq_\beta o^{t-2}_{\alpha \to \beta}$. Therefore, the more an agent concedes the closer he gets to an offer that is likely to be accepted by his opponent.

To exhibit such behavior in conceding, an agent has to take into account information that he has acquired from his opponent during the negotiation. One such kind of information is the *defeat relation* used by the opponent agent. More precisely, when an agent β sends arguments for defending or attacking an offer (through the defeat of $\alpha's$ arguments) he implicitly reveals to α elements of his defeat relation Def^{β}_{global} and therefore part of his *profile* (see definition 1).

The *dialogue-based profile,* $\mathcal{DBP}$ of agent α about agent β, denoted as $\mathcal{DBP}^{\alpha,\beta}_{d,t}$, is a subset of the defeat relation of its opponent agent β, that has been received by α in the rounds preceding round t in the course of a negotiation dialogue d between the two agents. The $\mathcal{DBP}$ may be used when a profile p_{ag} of the opponent agent ag is not available. However, a combination of the two is also possible. Here we adopt the definition of a dialogue of [13].

Definition 2 *[Dialogue] A dialogue d between two agents α, β is a non-empty sequence of rounds $d = \{r_1, ..., r_\lambda\}$ between α and β.*

The definition of a round is that of [13]. In the definition that follows, $m_{t,g}$ denotes a move g uttered at time (or round) t, $Agent(m_{t,g})$ is a function that returns the sender of $m_{t,g}$, $Argument(m_{t,g})$ is a function that returns the argument sent in $m_{t,g}$ and $Argument(Targ(m_{t,g}))$ is a function that returns the target of this argument (see [13]).

Definition 3 *[Dialogue-Based Profile] Let d be a negotiation dialogue between two agents $\alpha, \beta \in Ag$. Then the* dialogues-based profile *accumulated by agent α on agent β till time period (or round) t of the negotiation dialogue d is $\mathcal{DBP}^{\alpha,\beta}_{d,t} = \{(a, b) | \exists m_{t,g} \in d,\ Agent(m_{t,g}) = \beta,\ Argument(m_{t,g}) = a$ and $Argument(Targ(m_{t,g})) = b\}$.*

An agent α that wishes to make informed concessions needs, along with his negotiation theory $\mathcal{T}^\alpha$, to take into account the dialogue-based profile $\mathcal{DBP}_{d,t}^{\alpha,\beta}$ about his opponent β. This can be accomplished through the aggregation of $\mathcal{DBP}_{d,t}^{\alpha,\beta}$ and Def_{global}^α, and more specifically through the aggregation of the underlined preferences. This yields a defeat relation Def_{Cons}^α that α will be using for making concessions. The aggregation for agent α is done as follows. For two *indifferent arguments* a, b, i.e. $a \sim_\alpha b$, such that $a \succ_\beta b$ (or $b \succ_\beta a$), agent α can harmlessly select any of a and b. In order to favor the opponent agent, the aggregation is defined as the *intersection* of the sets $\{(a,b),(b,a)\} \subseteq Def_{global}^\alpha$ and $\{(a,b)\} \subseteq \mathcal{DBP}_{d,t}^{\alpha,\beta}$ (or $\{(b,a)\} \subseteq \mathcal{DBP}_{d,t}^{\alpha,\beta}$). In the case of a strict preference for both agents, i.e. $a \succ_\alpha b$ and $b \succ_\beta a$ (or vice-versa), the aggregation operator he uses is the *union* of the sets $\{(a,b)\} \subseteq Def_{global}^\alpha$ and $\{(b,a)\} \subseteq \mathcal{DBP}_{d,t}^{\alpha,\beta}$, so that strict preference is transformed in indifference allowing agent α to take into consideration simultaneously his preferences and those of his opponent β. More formally:

Definition 4 *[Aggregated Theory] Let d be a negotiation dialogue between agents $\alpha, \beta \in Ag$, $\mathcal{T}^\alpha =< \mathcal{A}^\alpha, \mathcal{F}^\alpha, Def_{global}^\alpha, P^\alpha >$ the negotiation theory of α and $\mathcal{DBP}_{d,t}^{\alpha,\beta}$ the dialogue-based profile of α on β. The* aggregated theory *of α is $\mathcal{T}_{agg}^\alpha =< \mathcal{A}^\alpha, \mathcal{F}^\alpha, Def_{Cons}^\alpha, P^\alpha >$, where Def_{Cons}^α is defined as follows*

- *if $(a,b) \in Def_{global}^\alpha$, $(b,a) \in Def_{global}^\alpha$, $(a,b) \in \mathcal{DBP}_{d,t}^{\alpha,\beta}$ and $(b,a) \notin \mathcal{DBP}_{d,t}^{\alpha,\beta}$, then $(a,b) \in Def_{Cons}^\alpha$*
- *if $(a,b) \in Def_{global}^\alpha$, $(b,a) \notin Def_{global}^\alpha$, $(b,a) \in \mathcal{DBP}_{d,t}^{\alpha,\beta}$ and $(a,b) \notin \mathcal{DBP}_{d,t}^{\alpha,\beta}$, then $(a,b) \in Def_{Cons}^\alpha$, and $(b,a) \in Def_{Cons}^\alpha$.*

Finally, an alternative way of building the aggregated theory $\mathcal{T}_{agg}^\alpha$ is to use Def_{global}^α and p_β (see definition 1) (instead of $\mathcal{DBP}_{d,t}^{\alpha,\beta}$) in order to build Def_{Cons}^α.

$\mathcal{T}_{agg}^\alpha$ and $\mathcal{T}^\alpha$ can be combined together to simulate the *Boulware* and *Conceder* tactics, originally introduced in game theoretic negotiation ([12]). In the *Boulware tactic* an agent maintains the offer it has made until the deadline is almost reached, and then it concedes down to its reservation value. In argumentation-based negotiation an agent α exhibits a Boulware like behavior when he generates offers based on his theory $\mathcal{T}^\alpha$ until the negotiation deadline t_{max} is almost reached, and then selects its last offer(s) using theory $\mathcal{T}_{agg}^\alpha$.

In the *Conceder tactic* an agent goes quickly to its reservation value. In argumentation-based negotiation a Conceder like tactic can be realized by an agent α that first employs $\mathcal{T}^\alpha$, but very quickly switches to theory $\mathcal{T}_{agg}^\alpha$. Alternatively, agent α can use $\mathcal{T}_{agg}^\alpha$ from the start of the negotiation. However, as the dialogue-based profile $\mathcal{DBP}_{d,t}^{\alpha,\beta}$ which is used for building $\mathcal{T}_{agg}^\alpha$, can be very incomplete (especially if the dialogue is short), the use of P^α for building $\mathcal{T}_{agg}^\alpha$ seems a better option.

2.2. Last Minute Tactic

In a negotiation under time constraints (i.e. with a deadline) an agent may wish employ a tactic that, when the deadline is reached (i.e. in the last round), it favors offers that are very likely to be accepted by his opponent. Information about such offers at time t can be obtained either from the dialogue-based profile $\mathcal{DBP}_{d,t}^{\alpha,\beta}$ or the profile $p_\beta \in P^\alpha$ of agent β. If dialogue-based profile $\mathcal{DBP}_{d,t}^{\alpha,\beta}$ is used, the set of *best offers* is defined as follows (the case of p_β is similar).

Definition 5 *Let d be a negotiation dialogue between two agents $\alpha, \beta \in Ag$, O be the set of possible offers, and $E_1, \ldots, E_n$ the extensions of theory $\mathcal{T}_{LMT}^{\alpha} =< \mathcal{A}^\alpha, \mathcal{F}^\alpha, \mathcal{DBP}_{d,t}^{\alpha,\beta}, P^\alpha >$ under a given semantics. The set of* best offers *for agent β at time t is $O_t^\beta = \{o \mid o \in O$ and $\exists a \in \cup_{i=1}^{n} E_i$ and $a \in \mathcal{F}^\alpha(o)\}$.*

When agent α applies the last minute tactic it selects offer from O_t^β. Obviously, if this set is empty the tactic does not apply. If the set is not empty, α employs one of two preference relations, $\trianglerighteq_{pref}$ and $\trianglerighteq_{ind}$ defined below, on the the set of epistemic arguments that attack the practical arguments supporting the offers in O_t^β.

For each practical argument δ, we define the set $Att(\delta)$ of epistemic arguments that defeat it. Thus $\forall \delta \in A_p, Att(\delta) = \{\gamma \mid (\gamma, \delta) \in Def_m\}$. An offer o_x is preferred to an offer o_y, denoted as $o_x \trianglerighteq_{pref} o_y$, if for each epistemic argument that defeats a supporting argument of o_x, there exists a more preferred epistemic argument that defeats a supporting argument of o_y. In other words, the agent chooses the offer that is attacked by the less important epistemic arguments or, said differently, that "violates" the less "essential" beliefs of the agent.

Definition 6 *[Preference Pref] Let O be a set of offers and $o_x, o_y \in O$. Then $o_x \trianglerighteq_{pref} o_y$ iff $\exists \delta \in F(o_x), \exists \delta' \in F(o_y)$ s.t $\forall \gamma \in Att(\delta) \backslash Att(\delta')$, $\exists \gamma' \in Att(\delta') \backslash Att(\delta)$ and $\gamma' \succ_e \gamma$.*

The preference relation $\trianglerighteq_{ind}$ takes into account the cardinality of Att.

Definition 7 *[Preference Ind] Let O be a set of offers and $o_x, o_y \in O$. Then $o_x \trianglerighteq_{ind} o_y$ iff $\exists \delta \in F(o_x), \exists \delta' \in F(o_y)$ s.t $\forall \gamma \in Att(\delta) \backslash Att(\delta')$ and $\forall \gamma' \in Att(\delta') \backslash Att(\delta)$ it holds that $\gamma \sim \gamma'$ (i.e they are indifferent) and $\mid Att(\delta') \mid \geq \mid Att(\delta) \mid$*

3. Experimental Evaluation

The experimental evaluation presented in the next section is carried out by means of a system that has been implemented in JAVA, using the JADE platform (Java Agent Development Framework). The problem of computing the stable extensions of the theories is translated to propositional satisfiability and solved by precosat [6]. Since sizeable argumentation theories coming from real applications are rather rare, one of the components of the system generates random argumentation theories.

3.1. Random Theory Generation

Argumentation theories build on facts and arguments. The *facts* of the theory represent knowledge that an agent has about the world. They are the premises of the arguments, and are randomly assigned a truth value. In the two theories that represent the two agents engaged in a negotiation, the same fact may be assigned different values. Obviously, one of the agents has false information, or makes a wrong assumption. The agent that is assumed to assign the correct truth value is called the "owner" of the fact. The owner of a fact is selected randomly. This treatment of facts reflects the incompleteness or the falsity of the information that the agents may have or assume.

A number of epistemic (practical) arguments between 10 and 100 (10 and 50) is generated randomly. Each offer is supported by only one, randomly selected, practical argument. To encode that fact p is a premise of an argument a, we introduce an attack from $\neg p$ to a. Each argument is attacked by at least one and at most four facts that are randomly selected. This relation is the same for the two agents. When an agent receives an argument from its opponent he updates the truth value of the facts that are premises of that argument, provided that the receiving agent is not the owner of the fact.

The conflict relation on the set of epistemic arguments is generated randomly for both agents. The conflicts between epistemic and practical arguments are randomly generated for one of the two agents. For the second agent two cases are studied. Either the other agent has exactly the same conflict relation R_m as the first, or 50% of his relation R_m is the same as his opponent's. The other 50% is generated randomly.

Preferences over epistemic arguments are also generated randomly. Moreover, each epistemic argument is strictly preferred to each practical argument. The preferences between the set of practical arguments are generated following the seller-buyer scenario, i.e. one agent is a seller agent and the other the buyer. The buyer and seller agent have opposite preferences over the set of options O. For example, for three offers o_1, o_2, o_3 if for the buyer holds that $\mathcal{F}(o_1) \succ \mathcal{F}(o_2) \succ \mathcal{F}(o_3)$, the preferences of the seller are $\mathcal{F}(o_3) \succ \mathcal{F}(o_2) \succ \mathcal{F}(o_1)$.

In order to evaluate the quality of the outcome of our negotiation framework, we used the notion of optimal solution of a negotiation problem as it is defined in [5].

3.2. Experimental results

The system that has been used for the experimental evaluation implements the tactics described in the preceding sections, as well as the framework presented in [13] that employs no tactics. Hereafter, runs where both agents apply the same tactic are denoted by T, whereas negotiations where the agents do not employ any of the tactics are denoted by $\neg T$.

The randomly generated negotiation experiments are grouped together according to the similarity between agent theories and the completeness of the knowledge of the opponent profile. Theory similarity is determined by the similarity of the *facts* (parameter F), the *preferences* (P) on the epistemic arguments, and the *conflicts* (C) between the epistemic and the practical arguments. The possible values for each of these three similarity parameters are 50 and 100 with the following meaning. The value 100 for F means that both agents have the correct truth value of all the facts, whereas 50 designates the case where each agent

		Boulware			Conceder		
	Aggregated Theories	$r_T < r_{\neg T}$	$r_T = r_{\neg T}$	$r_T > r_{\neg T}$	$r_T < r_{\neg T}$	$r_T = r_{\neg T}$	$r_T > r_{\neg T}$
P1: Profile=100%	$F100P100C100$	43	8	0	43	8	0
	$F50P100C100$	16	5	0	16	5	1
	$F100P50C50$	32	5	0	31	5	1
	$F50P50C50$	22	6	0	21	7	0
P2: Profile=50%	$F100P100C100$	22	16	0	21	17	0
	$F50P100C100$	9	4	0	6	4	1
	$F100P50C50$	22	10	0	20	12	1
	$F50P50C50$	10	8	3	11	7	1
P3: Profile=X%	$F100P100C100$	24	13	0	22	17	0
	$F50P100C100$	8	10	0	7	10	1
	$F100P50C50$	26	7	0	18	15	2
	$F50P50C50$	22	4	4	18	4	3
DBP: Dialogue-based	$F100P100C100$	2	46	2	2	45	2
	$F50P100C100$	0	19	3	0	21	4
	$F100P50C50$	1	32	3	1	32	4
	$F50P50C50$	2	23	0	3	26	0

Table 1. Influence of tactics on negotiation length

has the correct truth values of 50% of the facts owned by his opponent. Similarly, a value 100 for P designates the same preference relation for both agents, and 50 means that 50% of the pairs of the relations is common to both agents. The meaning of the two values is analogous for parameter C. In the following, the string $FX1PX2CX3$ denotes a set of experiments on theories with a specific combination of values for the parameters F, P and C, where $X1$ is the value of F, $X2$ the value of parameter P, etc. Conflicts between epistemic arguments are the same in both agents' theories.

As for the completeness of the information of an agent on the profile of his opponent, the following cases have been studied experimentally:
-Both agents have complete knowledge of the profile p_{ag} of their opponent (designated by Profile=100% in the Tables)
-Each agent has a percentage x of the profile (defeat relation) of his opponent, with $x \in \{50\%, 100\%\}$ or ($30\% \leq x \leq 65\%$ and $65\% < x < 100\%$) (designated by Profile=X% in the Tables)
-Agents use the dialogue-based profile $\mathcal{DBP}$ accumulated during the negotiation.

We ran a total of 4148 negotiations covering all possible combinations of the four possible structures $FX1PX2CX3$ and the three possible cases related to the knowledge an agent has on his opponent. For each possible combination 61 negotiations were ran. The *Boulware* and *Conceder* tactics are based on the aggre-

		Boulware		Conceder		Preferences Pref		Preferences Ind	
	Optimal Solutions	$\neg T$	T	$\neg T$	T	$\neg T$	T	$\neg T$	T
S1: Profile=100% Two Agents	$F100P100C100$	19	23	19	23	19	29	19	29
	$F50P100C100$	7	6	8	7	6	11	6	11
	$F100P50C50$	12	20	12	20	12	27	12	27
	$F50P50C50$	10	8	10	10	7	11	6	10
S2: Profile=50% Two Agents	$F100P100C100$	12	13	12	13	16	21	12	16
	$F50P100C100$	4	5	4	4	7	7	9	14
	$F100P50C50$	7	8	9	11	12	23	12	22
	$F50P50C50$	8	9	6	9	7	10	6	10
S3: Profile=X% Two Agents	$F100P100C100$	16	16	16	17	18	23	17	21
	$F50P100C100$	9	11	9	11	6	8	4	6
	$F100P50C50$	16	21	16	21	17	20	17	22
	$F50P50C50$	13	10	11	8	15	20	12	18
S4: Dialogue-based Two Agents	$F100P100C100$	19	20	20	21	15	19	15	19
	$F50P100C100$	10	9	11	10	10	12	8	9
	$F100P50C50$	20	19	19	19	18	23	19	25
	$F50P50C50$	13	13	14	14	13	16	13	17

Table 2. Effect of tactics on the number of optimal solutions

gated theories that are built either on the profile that belongs to the negotiation theory of the agents from the beginning or the profile that is acquired during the dialogue. In Boulware, reasoning with the aggregated theory is triggered at round $T_{max}/2$, where T_{max} is the negotiation deadline, while in Conceder at the second round, unless $T_{max} = 1$ in which case it initiates in the first round.

Boulware and Conceder tactics were first evaluated wrt the *length of the negotiation* they yield. Table 1 compares the length of negotiations for which an agreement has been found both with and without the application of the tactics. Entries under $r_T < r_{\neg T}$ (resp. $r_T > r_{\neg T}$) refer to the number of runs the negotiation with the tactic is shorter (longer) than the negotiation without. $r_T = r_{\neg T}$ denotes dialogues of equal length. It is evident that, when information on the profile of the opponent is available, both tactics yield improvements in a significant number of cases. For Boulware the $r_T < r_{\neg T}$ cases (first column for P1,P2,P3) are 71,30% of the total (i.e. sum of the first 3 columns for P1,P2,P3), whereas for Conceder 65,73%. It is interesting to note that the negotiation shortening occurs irrespectively of the completeness of the profile of the opponent. Moreover, the portion of known facts has a bigger influence on this criterion than the similarity between the agents' preferences. However, the tactics seem not to have a real impact on the first criterion in the cases where the agents apply the tactics based on the dialogue-based profile (nevertheless this may depend on the dialogue length).

The percentage of negotiations that finish earlier when agents apply a tactic compared to those when they do not, is overall higher in the case the agents apply the Boulware tactic. However, a more refined analysis shows that this essentially holds when the incompleteness of the profiles increases (i.e. $P2(60,57\%$ vs $57,42\%)$ and $P3(67,79\%$ vs $55,55\%)$. However when the agents use a complete profile ($P1(82,48\%$ vs $80,43\%)$) the difference is marginal.

		Boulware		Conceder		Preferences Pref		Preferences Ind	
	Pareto Optimal	$\neg T$	T	$\neg T$	T	$\neg T$	T	$\neg T$	T
O1: Profile=100% Two Agents	$F100P100C100$	4	4	5	4	1	2	2	2
	$F50P100C100$	2	1	2	1	0	1	0	1
	$F100P50C50$	3	3	3	3	1	2	1	3
	$F50P50C50$	3	1	3	2	0	0	0	0
O2: Profile=50% Two Agents	$F100P100C100$	1	1	1	1	0	2	0	1
	$F50P100C100$	0	0	0	0	1	0	1	1
	$F100P50C50$	0	0	0	0	0	2	0	3
	$F50P50C50$	0	0	0	1	0	0	0	0
O3: Profile=X% Two Agents	$F100P100C100$	3	3	3	3	2	0	2	0
	$F50P100C100$	0	1	0	1	0	0	1	0
	$F100P50C50$	3	3	3	3	1	2	1	3
	$F50P50C50$	4	3	3	2	0	3	0	3
O4: Dialogue-based Two Agents	$F100P100C100$	0	0	0	0	1	1	1	1
	$F50P100C100$	1	0	1	0	0	0	1	0
	$F100P50C50$	1	0	0	0	1	4	1	4
	$F50P50C50$	0	0	0	0	2	3	2	3

Table 3. Pareto Optimal solutions

Table 2 shows the impact of the tactics on the *solution optimality* criterion. It concerns the negotiations where an agreement is found with (entries under T) and without (entries under $\neg T$) the application of a tactic and refer to the same test cases as Table 1. More particularly this table shows that the application of tactics increases the number of solutions that are optimal for one or both agents, irrespectively of the applied tactic. The increase in the number of the optimal solutions is more significant for the test case groups $S1$, $S2$ and $S4$ and less significant for group $S3$. Note that the $LastMinuteTactic$ ($Perf$ or Ind) has a higher impact than the Boulware or Conceder tactics and the Conceder tactic a higher impact than the Boulware.

Pareto optimality is another solution quality related criterion that has been used in the evaluation of the tactics. According to this criterion an outcome o is better than o' if o is preferred to o' for one of the agents and it is not less preferred than o' for the other agent. Table 3 presents the experimental results for Pareto optimality on the test cases that are the same with those of the two previous

		Preferences Pref		Preferences Ind	
		$\neg T$	T	$\neg T$	T
P1: Last Minute Profile=100%	$F100P100C100$	9	51	9	51
	$F50P100C100$	3	23	10	23
	$F100P50C50$	7	55	6	55
	$F50P50C50$	17	22	7	21
P2: Last Minute Profile=50%	$F100P100C100$	17	42	24	35
	$F50P100C100$	12	23	12	20
	$F100P50C50$	19	41	13	41
	$F50P50C50$	9	26	16	24
P3: Last Minute Profile=X%	$F100P100C100$	20	42	18	42
	$F50P100C100$	18	20	18	19
	$F100P50C50$	13	47	13	46
	$F50P50C50$	13	30	13	30
DBP: Last Minute Dialogue-based	$F100P100C100$	24	40	23	36
	$F50P100C100$	17	22	18	17
	$F100P50C50$	17	46	16	44
	$F50P50C50$	15	31	15	28

Table 4. Last Minute tactics

tables. This table shows that, even though agents find solutions faster when they negotiate under time limits and apply the tactics (see Table 1), the number of Pareto optimal solutions do not significantly decrease wrt the number of such solutions found when agents negotiate without applying tactics and time limits (i.e. the negotiation ends when an agreement is found or after a withdrawal). Table 3 shows that the decrease of Pareto optimal solutions is indeed very marginal when agents apply the Boulware or Conceder tactics and use the profile (i.e. $23(\neg T)/20(T)$ for Boulware and $23(\neg T)/21(T)$ for Conceder). The number of such solutions even increases when a time limit is fixed for both sub-systems and the $LastMinuteTactic$ is applied by the agents using the sub-system T (i.e. $6(\neg T)/14(T)$ for $Pref$ and $8(\neg T)/17(T)$ for Ind).

The fourth criterion is used for evaluating the *Last Minute Tactic*. This criterion concerns the number of agreements reached in a number of negotiations run with the two sub-systems, with a fixed time limit (the same for both systems) and where the agent who proposed an offer in the last round has applied the *Last Minute Tactic* when using the sub-system T. For this tactic we evaluate both options, $Pref$ and Ind (see Definitions 6 and 7).

Table 4 presents the results we have obtained for 1952 (i.e. 61 negotiations for each row and each option in Table 4) such negotiations. It turns out that the application of this tactic (option $Pref$), significantly increases the number of agreements compared to the number of agreements reached when agents negotiate by using the sub-system $\neg T$. Thus the ratio $agreements/negotiations$ for the case where no tactic is applied is $230/976(23,56\%)$ while this ratio becomes $561/976(57,47\%)$ where the LMT is applied. The same holds with the option Ind. The corresponding ratios are $231/976(23,66\%)$ and $532/976(54,59\%)$.

4. Conclusion

In this paper we presented negotiation tactics that simulate the *Boulware* and *Conceder* behavior (see [12]) in the argumentation based negotiation context as well the $LastMinuteTactic$ that helps agents to propose an offer in the last round, when there is a time limit, that is very likely to be accepted by his opponent. These tactics take into account time constraints, the profile and the behavior of the agents during the negotiation while they enable agents to make consequential concessions. To the best of our knowledge, time and profile based tactics have not been previously addressed in argumentation based negotiation. We also presented several experimental results that show the impact of those tactics on the negotiation according to four criteria. The test cases were generated randomly, as there are no publicly available real-life negotiation problems that could have been used instead. Our future work concerns devising additional tactics that, along with the current ones, will implement complex strategies.

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