On the study of negotiation strategies

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Abstract. The basic idea behind a negotiation is that the agents make offers that they judge "good" and respond to the offers made to them until a compromise is reached. The choice of the offer to propose at a given step in a negotiation dialogue is a *strategic* matter. In most works on negotiation dialogues, the agents are supposed to be *rational*, and thus propose and accept only the offers which satisfy all their goals. This strategy is very restrictive since in everyday life, it is difficult to find an offer which satisfies all the agent's goals.
The aim of this paper is to propose less restrictive strategies than the one used in the literature. Those strategies are based not only on the *goals* and beliefs of the agents but also on their *rejections*. A three-layered setting is proposed. The properties of each strategy are given as well as a comparative study between these strategies.

1 Introduction

Autonomous agents evolve in a community and because of the interdependences which may exist between them, the agents need to interact in order to exchange information, ask for services, etc. Negotiation is the most predominant mechanism for communicating and also for making deals. The basic idea behind a negotiation is that the agents make offers that they judge "good" and respond to the offers made to them until a compromise is reached. Since the agents' interests are generally conflicting, an offer which is acceptable for one agent is not necessarily acceptable for another agent.
As argued in [9, 10, 12, 11], the choice of the offer to propose at a given step in a negotiation dialogue is a *strategic* matter. Indeed, the acceptability of an offer depends broadly on the *agent profile* and its *mental states*.
There are very few works on negotiation strategies in general if we except the work done by Maudet et al. in [9, 10], and the work done in [1] in the case of argument selection. Concerning the choice of offers, in most works on negotiation dialogues, the agents are supposed to be *rational*, and thus propose and accept only the offers which satisfy all their goals. This strategy is too restrictive since in everyday life, it is difficult to find an offer which satisfies all the agent's goals.
Moreover, recent cognitive psychology studies [6, 5, 3, 13] claim that agents may express and reason on two components: *goals* and *rejections*. Goals describe what the

agent would like to realize, and the rejections describe what is not acceptable for that agent. When both goals and rejections are provided we say that we are in a *bipolar* framework. Beware that *bipolarity* is not *duality* i.e., goals are not simply the complement of rejections. Note however that rejections and goals are related by a coherence condition asserting that what is pursued should not be rejected. A formalization of goals and rejections in a logical setting and reasoning about them have been developed in [2]. We claim that taking into account what an agent rejects, in addition to its goals, in the offer selection enables a more refined selection, and allows to discard rejected offers. Let's suppose, for instance, an agent who has two possible offers x_1 and x_2 to propose at a given step. Suppose also that both offers satisfy all the goals of the agent. In this case, one may say that x_1 is as preferred as x_2 and the agent can propose any of them. However, if x_1 satisfies one of the rejections of that agent, then x_1 will be discarded and the only possible offer is x_2.

The aim of this paper is to propose different strategies allowing agents to select the offers to suggest, and to decide when to accept the offers made to them. These strategies are based on both the goals and the rejections of the agents. We will show that these strategies are less restrictive than the one used in the literature.
This paper is organized as follows: Section 2 presents the different mental states of an agent as well as their role in selecting offers. In fact, the beliefs will delimit the *feasible* offers, the goals will delimit the *satisfactory* ones and finally, the rejections will delimit the *acceptable* offers. In section 3 a general setting for defining strategies is given. In fact, the definition of a strategy consists of fixing three parameters: an ordering, between the goals of and the rejections, which depends on agent's profile, a criterion for defining the acceptability of an offer, and a criterion for defining the satisfaisability of an offer. Section 4 presents different agent profiles, and the way in which the selected offers (called candidate offers) are computed in each case. Section 5 presents a criterion of acceptability, whereas section 6 provides three criteria of satisfaisability. Some strategies are then studied in section 7, and some properties are given in section 8. Section 9 is devoted to some concluding remarks and some perspectives

2 Mental states of the agents

2.1 Logical definition

In what follows, $\mathcal{L}$ will denote a first order propositional language. Each negotiating agent has got a set $\mathcal{B}$ of *beliefs*, a set $\mathcal{G}$ of *goals*, and finally a set $\mathcal{R}$ of *rejections*. Beliefs are *informational attitudes* and concern the real world. Goals are *motivational attitudes* and intrinsic to the agent. They represent what an agent wants to achieve or to get. Like goals, rejections are also *motivational attitudes* and intrinsic to the agent. However, they represent what the agent rejects and considers as *unacceptable*.
Beliefs are pervaded with uncertainty i.e., they are more or less certain while rejections and goals may not have equal priority. More formally, we have:

Definition 1 (Mental states of an agent) *Each agent is equipped with three bases:* $\mathcal{B}$*,* $\mathcal{R}$ *and* $\mathcal{G}$ *such that:*

- $\mathcal{B}$ = $\{(b_i, \alpha_i)$, i = *1, …,* $n\}$, *where* b_i *is a formula of the language* $\mathcal{L}$, *and* α_i *is an element of the interval* $(0, 1]$. *The pair* (b_i, α_i) *means that the certainty degree of the belief* b_i *is at least equal to* α_i. *When* α_i *is equal to* 1 *this means that* b_i *is an integrity constraint which should be fulfilled.*
- $\mathcal{R}$ = $\{(r_j, \beta_j)$, j = *1, …,* $m\}$, *where* r_j *is a formula of the language* $\mathcal{L}$ *and* β_j *is an element of the interval* $(0, 1]$. *The pair* (r_j, β_j) *means that the priority degree of the rejection* r_j *is at least equal to* β_j.
- $\mathcal{G}$ = $\{(g_k, \lambda_k)$, k = *1, …,* $p\}$ *where* g_k *is a formula of the language* $\mathcal{L}$ *and* λ_k *is in the interval* $(0, 1]$. *The pair* (g_k, λ_k) *means that the priority degree of the goal* g_k *is at least equal to* λ_k.

Note that for the sake of simplicity, we use numerical numbers to model the priority/uncertainty degrees. However, a simple ordering on formulas holds as well.

Hypothesis 1 *Throughout the paper, the sets of beliefs and rejections are supposed to be* consistent*. For the sake of simplicity, we suppose that all beliefs are completely certain i.e.,* $\alpha_i = 1$ *for* $i = 1, \cdots, n$. *However this work can be easily generalized to the case where beliefs are more or less certain.*

Since we deal with first order formulas, the satisfaction of formulas is different from the one of classical logic. Suppose that we have a set of some facts $\mathcal{F}$ giving an instantiation of first order formulas. Let x be an offer and $\mathcal{H}_x^{\mathcal{F}}$ be the result of instantiating the set $\mathcal{H}$ by x. Then, x satisfies $\mathcal{H}$ if and only if each formula in $\mathcal{H}_x^{\mathcal{F}}$ is true in the set of facts $\mathcal{F}$.

Example 1. Let $\mathcal{F} = \{\neg promotion(AF), stopover(AF), \neg flexible(BA)\}$ and $\mathcal{H} = \{stopover(x), \neg promotion(x) \vee \neg flexible(x)\}$.
Then $\mathcal{H}_{AF}^{\mathcal{F}} = \{stopover(AF), \neg promotion(AF) \vee \neg flexible(AF)\}$. Each formula in $\mathcal{H}_{AF}^{\mathcal{F}}$ is true w.r.t. $\mathcal{F}$ then AF satisfies $\mathcal{H}$.
Now we have $\mathcal{H}_{BA}^{\mathcal{F}} = \{stopover(BA), \neg promotion(BA) \vee \neg flexible(BA)\}$. Then BA doesn't satisfy $\mathcal{H}$ since $stopover(BA)$ is not true in $\mathcal{F}$.

2.2 Role of beliefs, rejections and goals

Although the three sets are involved in the selection of offers, they should be distinguished since they do not necessarily behave in the same way.

Beliefs play a key role in delimiting the set of *feasible* offers.

Definition 2 (Feasible offers) *Let* $x \in X$. *An offer* x *is* feasible *if it satisfies the set of beliefs.*

Let's take the following example about airline companies.

Example 2 (Airline companies). Suppose that the object of the negotiation is an "airline company". Let

- $X = \{AF, AirLib, BA, KLM\}$,
- $\mathcal{B} = \{(\neg promotion(x) \vee \neg flexible(x), 1)\}$,
- $\mathcal{R} = \{(\neg stopover(x), .9), (dayflight(x) \wedge \neg smoking(x), .4), (\neg flexible(x), .1)\}$,

– $\mathcal{G} = \{(promotion(x), .8), (stopover(x), .5),$
$(dayflight(x), .5)\}$.

Table 1 gives some facts. For example, we have $stopover(AF)$, $\neg promotion(AF)$, etc. Feasible offers are those which satisfy the set $\mathcal{B}$, namely $\mathbb{F} = \{AF, AirLib, BA, KLM\}$.

	AF	$AirLib$	BA	KLM
$stopover(x)$	yes	yes	yes	yes
$dayflight(x)$	no	no	yes	yes
$promotion(x)$	no	yes	no	yes
$smoking(x)$			yes	no
$flexible(x)$	yes	no	yes	no

Table 1. Some facts

Each rejection (r_j, β_j), which should not be satisfied, induces by complementation an integrity constraint $(\neg r_j, \beta_j)$ which should be respected. In what follows, $\mathcal{R}'$ will denote the set of induced integrity constraints from the base $\mathcal{R}$. Such integrity constraints are *intrinsic* to an agent and not "imposed" by the environment. That's why they are not considered as beliefs in $\mathcal{B}$.
The offers which respect the induced integrity constraints will be *acceptable* for the agent.

Definition 3 (Acceptable offers) *Let $x \in X$. An offer x is* acceptable *iff $\mathcal{R}' \Vdash_{c_a} x$. This means that it satisfies the integrity constraints w.r.t. a criterion c_a.*

In the above definition, the acceptability of an offer depends on a criterion c_a. Indeed, one may, for instance, accept an offer which respects all the integrity constrains. Another criterion consists of accepting the offers which respect the most important integrity constraints. In section 5, we will give a criterion for the acceptability of an offer.

Regarding goals, they will delimit the set of *satisfactory* offers. Indeed, the offers which satisfy the goals of an agent according to some criterion will be satisfactory for that agent. The satisfaisability of an offer depends also on the chosen criterion. One may accept the offers which satisfy all its goals. However, it may be the case also that an agent accepts the offers which satisfy at least its most important goals. In section 6, different criteria for the satisfaisability of an offer will be proposed.

Definition 4 (Satisfactory offers) *Let $x \in X$. An offer x is* satisfactory *iff $\mathcal{G} \Vdash_{c_s} x$. This means that the offer x satisfies the goals of the agent w.r.t. a criterion c_s.*

Notations 1
– $\mathcal{R}'_{>\beta} = \{\neg r_j \mid (r_j, \beta_j) \in \mathcal{R}$ *and* $\beta_j > \beta\}$.
– $\mathcal{G}_{>\lambda} = \{g_k | (g_k, \lambda_k) \in \mathcal{G}$ *and* $\lambda_k > \lambda\}$.
$\mathcal{G}_{>\lambda}$ (resp. $\mathcal{R}_{>\beta}$) corresponds to the conjunction of goals (resp. of constraints induced by rejections) having a weight greater than λ (resp. β).

– $\mathcal{G}_{=\lambda} = \{g_k \mid (g_k, \lambda_k) \in \mathcal{G}$ *and* $\lambda_k = \lambda\}$. $\mathcal{G}_{=\lambda}$ *corresponds to the conjunction of goals having a priority degree equal to* λ.
– $\bigvee(\mathcal{G}_{=\lambda}) = \bigvee\{g_k \mid (g_k, \lambda_k) \in \mathcal{G}$ *and* $\lambda_k = \lambda\}$. *This corresponds to the disjunction of all the goals with priority degree equal to* λ.
– *Let* $\succeq$ *be a pre-order between sets. The notation* $\mathcal{H} \succeq \mathcal{H}'$ *means that the* $\mathcal{H}$ *is at least as preferred as* $\mathcal{H}'$. *Let* $\succ$ *be the strict ordering associated with* $\succeq$. *The symbol* $\approx$ *stands for the "equality", i.e. when* $\mathcal{H}$ *and* $\mathcal{H}'$ *are equally preferred by the agent.*

3 General setting for offer selection

Selecting offers is an important decision in a negotiation process since it influences the outcome of the negotiation. This decision follows a three step process:

1. defining a relation $\succeq$ between $\mathcal{B}$, $\mathcal{R}$ and $\mathcal{G}$. The ordering on $\mathcal{B}, \mathcal{R}$ and $\mathcal{G}$ is a determining point in the selection of offers. In the next section, we will show that one may not have the same set of candidate offers when $\mathcal{G} \succeq \mathcal{R}$ or $\mathcal{R} \succeq \mathcal{G}$.
   In [4, 14], it has been argued that beliefs should take precedence over goals in order to avoid any *wishful thinking*. Regarding rejections, beliefs should also take precedence over them since rejections have the same nature as goals. Moreover, the feasibility of an offer is more important than its acceptability. Thus, the following orderings hold: $\mathcal{B} \succ \mathcal{R}$ and $\mathcal{B} \succ \mathcal{G}$. The ordering between $\mathcal{G}$ and $\mathcal{R}$ is not easy to guess and depends broadly on agents' profiles. Different agents' profiles can then be defined according to the precise ordering between $\mathcal{G}$ and $\mathcal{R}$.
2. defining *criteria* for selecting acceptable offers.
3. defining *criteria* for selecting satisfactory offers.

Definition 5 (Strategy) *Let* $\mathcal{B}$, $\mathcal{R}$ *and* $\mathcal{G}$ *be the agent's bases and* X *the set of offers. A* strategy *is a triple* $<\succeq, \Vdash_{c_a}, \Vdash_{c_s}>$. *This system will return a set* $\underline{\mathcal{S}} \subseteq X$ *of* candidate *offers.*

In the above definition, we speak about a *set of candidate offers*. The reason is that it may be the case that several offers will have the same preference for the agent.

4 Different agent profiles

The ordering between beliefs and the other two sets is in some sense imposed by the nature of the different mental states. However, things seem different for fixing the ordering between $\mathcal{R}$ and $\mathcal{G}$. This ordering depends on the agent's profile. Indeed, there are three possibilities for comparing the two sets:

1. the case where both sets have the same preference ($\mathcal{R} \approx \mathcal{G}$).
2. the case where $\mathcal{R}$ is preferred to $\mathcal{G}$ ($\mathcal{R} \succ \mathcal{G}$).
3. the case where $\mathcal{G}$ is preferred to $\mathcal{R}$ ($\mathcal{G} \succ \mathcal{R}$).

Each of the three possibilities corresponds to a specific agent profile. Formally:

Definition 6 (Consensual agent) *Let* $\{\mathcal{B}, \mathcal{R}, \mathcal{G}\}$ *be the bases of an agent* A. A *is* consensual *iff* $\mathcal{R} \approx \mathcal{G}$.

A consensual agent computes separately the acceptable offers and the satisfactory offers among feasible ones w.r.t. some criteria. The candidate offers are those which are both acceptable and satisfactory.

Definition 7 *Let* A *be a consensual agent. The set of* candidate *offers* $\underline{\mathcal{S}} = \mathcal{S}_1 \cap \mathcal{S}_2$ *such that:*

1. $\mathcal{S}_1, \mathcal{S}_2 \subseteq X$, *and*
2. $\forall\, x \in \mathcal{S}_1$, x *is feasible and acceptable, and*
3. $\forall\, x \in \mathcal{S}_2$, x *is feasible and satisfactory.*

This approach is too requiring since it may lead to an empty set of *candidate* offers.

Definition 8 (Cautious agent) *Let* $\{\mathcal{B}, \mathcal{R}, \mathcal{G}\}$ *be the bases of an agent* A. A *is* cautious *iff* $\mathcal{R} \succ \mathcal{G}$.

A cautious agent starts by selecting the acceptable offers among the feasible ones. The candidate offers are the satisfactory (w.r.t. some criteria) offers among the acceptable ones. Formally:

Definition 9 *Let* A *be a cautious agent. The set of* candidate *offers is* $\underline{\mathcal{S}} = \{x \in S'$ *such that* x *is satisfactory*$\}$, *where*

1. $\mathcal{S}' = \{x \in X$ *such that* x *is feasible and acceptable*$\}$.
2. $\mathcal{S}'$ *is maximal for* ($\subseteq$) *among the sets satisfying the first condition.*

This approach is cautious since the agent prefers to select acceptable offers, among feasible ones, even if none of them satisfies any goal.

Definition 10 (Adventurous agent) *Let* $\{\mathcal{B}, \mathcal{R}, \mathcal{G}\}$ *be the bases of an agent* A. A *is* adventurous *iff* $\mathcal{G} \succ \mathcal{R}$.

An adventurous agent selects first satisfactory offers among feasible ones, then among the offers it gets, it will choose those which are acceptable w.r.t. some criteria.

Definition 11 *Let* A *be an adventurous agent. The set of* candidate *offers is* $\underline{\mathcal{S}} = \{x \in S'$ *such that* x *is acceptable*$\}$, *where*

1. $\mathcal{S}' = \{x \in X$ *such that* x *is feasible and satisfactory*$\}$.
2. $\mathcal{S}'$ *is maximal for* ($\subseteq$) *among the sets satisfying the first condition.*

This approach is too adventurous since it may lead the agent to select offers which are not acceptable at all.

5 Acceptability of offers

An offer is acceptable if it respects the integrity constraints induced by rejections. In some situations, one cannot find an offer which satisfies all the constraints, and the set of candidate offers is empty. To relax this criterion, an agent may accept the offers which respects the constraints at a certain level, called *acceptability level*. Indeed, the acceptability level is the complement to 1 of the degree of the less important constraint that should be respected by offers. Formally:

Definition 12 (Acceptability level) *Let $x \in X$. The* acceptability level *of an offer x, denoted $Level_A(x)$ = $1 - min\{\beta$ such that x satisfies $\mathcal{R}'_{>\beta}\}$.*
If x falsifies $\mathcal{R}'_{>\beta}$ for all β then $Level_A(x) = 0$.

This criterion has already been used in possibilistic logic and belief revision [7, 15]. The acceptable offers are the ones with a greater acceptability level. Indeed, such offers satisfy more important integrity constraints.

Definition 13 (Acceptability criterion) *Let $x \in X$ and $\mathcal{R}$ be the set of rejections. The offer x is acceptable, denoted*

$$\mathcal{R}' \Vdash_{Level} x, iff Level(x)_A \geq Level_A(x'), \forall x' \in X.$$

Example 3. In example 2, $\mathcal{R}' \Vdash_{Level} AF$, BA. Indeed, $Level_A(AF)$ = $Level_A(BA)$ = 1 since both AF and BA satisfy $\mathcal{R}'_{>0}$ = $stopover(x) \wedge (\neg dayflight(x) \vee smoking(x))$ $\wedge$ $flexible(x)$, while $Level_A(AirLib) = .9$ and $Level_A(KLM) = .6$.

6 Satisfiability of offers

It is natural that an agent aims to satisfy all its goals. When this is not possible, it may try to satisfy as much as possible prioritized goals. A *cardinality*-based selection mode seems appropriate in this case. Before defining this criterion, let's first introduce some notations.

Let $\beta_1, \cdots, \beta_m$ be the weights appearing in $\mathcal{G}$ s.t. $1 \geq \beta_1 > \cdots > \beta_m > 0$. Let $\mathcal{G}'$ = $\mathcal{G}_1 \cup \ldots \cup \mathcal{G}_m$ be the representation of $\mathcal{G}$ in its well ordered partition. Each $\mathcal{G}_j$, called *layer*, contains formulas of $\mathcal{G}$ having the weight β_j. Let x be an offer and $\mathcal{S}_x$ = $\mathcal{S}_x^1 \cup \ldots \cup \mathcal{S}_x^m$ where $\mathcal{S}_x^j$ is a subset of $\mathcal{G}_j$ containing the goals of $\mathcal{G}_j$ satisfied by x.

Definition 14 (Cardinality-based criterion) *Let $x \in X$. x is satisfactory, denoted*

$$\mathcal{G} \Vdash_{Card} x, \textit{ iff } \forall x' \in X:$$

– $\exists$ k *s.t.* $\forall$ $j = 1, \ldots, k-1$;$|\mathcal{S}_x^j|$ = $|\mathcal{S}_{x'}^j|$ *and* $|\mathcal{S}_x^k| > |\mathcal{S}_{x'}^k|$, *or*
– $|\mathcal{S}_x^j| = |\mathcal{S}_{x'}^j|$ *for* $j = 1, \cdots, m$,

where $|\mathcal{S}_x^j|$ is the number of formulas in $\mathcal{S}_x^j$.

Let's illustrate this criterion on the following example:

Example 4. Recall that $\mathbb{F} = \{AF, AirLib, BA, KLM\}$.
Let's first put $\mathcal{G}$ under its well ordered partition: $\mathcal{G}' = \mathcal{G}_1 \cup \mathcal{G}_2$, where $\mathcal{G}_1 = \{promotion(x)\}$ and $\mathcal{G}_2 = \{stopover(x), dayflight(x)\}$. Then,
$\mathcal{S}_{AF} = \{\} \cup \{stopover(x)\}$,
$\mathcal{S}_{AirLib} = \{promotion(x)\} \cup \{stopover(x)\}$,
$\mathcal{S}_{BA} = \{\} \cup \{stopover(x), dayflight(x)\}$ and
$\mathcal{S}_{KLM} = \{promotion(x)\} \cup \{stopover(x), dayflight(x)\}$.
$\mathcal{G} \Vdash_{Card} KLM$ because it is the only offer which satisfies the maximum of prioritized goals.

The cardinality-based criterion gives priority to the offers which satisfy a maximum of prioritized goals. A weaker version of this criterion consists of choosing the offers which satisfy at least one prioritized goal. Formally:

Definition 15 (Disjunctive satisfaction level) *Let $x \in X$. The disjunctive satisfaction level of an offer x is $Level_{DS}(x) = max\{\lambda$ such that x satisfies $\bigvee(\mathcal{G}_{=\lambda})\}$.
If x falsifies all formulas of $\mathcal{G}$ then $Level_{DS}(x) = 0$.*

Indeed satisfactory offers are those which satisfy at least one prioritized goal. We define now the disjunctive-based criterion:

Definition 16 (Disjunctive-based criterion) *Let $x \in X$. $\mathcal{G} \Vdash_{Disj} x$, iff $Level_{DS} \geq Level_{DS}(x'), \forall\, x' \in X$.*

Example 5. As shown in the previous example, the use of a cardinality-based criterion, only one offer (KLM) is satisfactory for the agent. However, using the disjunctive criterion, we can get more satisfactory offers. Indeed, $Level_{DS}(KLM) = Level_{DS}(Airlib) = .8$ with $\bigvee \mathcal{G}_{=.8} = \{promotion(x)\}$. Consequently, $\mathcal{G} \Vdash_{Disj} AirLib, KLM$.

Another refinement of the cardinality-based criterion can be defined. The idea here is similar to the one behind the acceptability criterion. A satisfactory offer is the one which satisfies as much prioritized goals as possible. A satisfaction level is defined as follows:

Definition 17 (Conjunctive satisfaction level) *Let $x \in X$. The satisfaction level of an offer x is $Level_{CS}(x) = 1 - min\{\lambda$ such that x satisfies $\mathcal{G}_{>\lambda}\}$.
If x falsifies $\mathcal{G}_{>\lambda}$ for all λ then $Level_{CS}(x) = 0$.*

Satisfactory offers are then the ones which have a small satisfaction level, since the smaller this level is, the more important the number of satisfied prioritized goals is. Formally:

Definition 18 (Conjunctive-based selection) *Let $x \in X$. $\mathcal{G} \Vdash_{Conj} x$ iff $Level_{CS} \geq Level_{CS}(x')$, $\forall\, x' \in X$.*

Example 6. We have $Level_{CS}(KLM) = 1$ while $Level_{CS}(AF) = Level_{CS}(BA) = 0$ and $Level_{CS}(AirLib) = .5$. Then $\mathcal{G} \Vdash_{Conj} KLM$.
Note that we get the same result as the one obtained by using the cardinality-based criterion because KLM satisfies all agent's goals but this is not always the case

	$\Vdash_{Level}$, $\Vdash_{Conj}$	$\Vdash_{Level}$, $\Vdash_{Disj}$	$\Vdash_{Level}$, $\Vdash_{Card}$
Consensual ($\mathcal{R} \approx \mathcal{G}$)	- *drastic* - *pessimistic*	*optimistic*	$\times$
Cautious ($\mathcal{R} \succ \mathcal{G}$)	$\times$	*relaxed*	*requiring*
Adventurous ($\mathcal{G} \succ \mathcal{R}$)	$\times$	$\times$	$\times$

Table 2. Different strategies

We can show that if an offer is satisfactory w.r.t the cardinality criterion, it is also satisfactory w.r.t the conjunctive criterion. Similarly, each offer which is satisfactory w.r.t the conjunctive criterion is also satisfactory w.r.t the disjunctive criterion. Formally:

Proposition 1 *Let $\mathcal{B}$, $\mathcal{R}$, $\mathcal{G}$ be three bases of an agent and $x \in X$.*

$$(\mathcal{G} \Vdash_{Card} x) \Rightarrow (\mathcal{G} \Vdash_{Conj} x) \Rightarrow (\mathcal{G} \Vdash_{Disj} x).$$

7 Particular strategies

A strategy for selecting the offers to propose during a negotiation dialogue has three parameters: an ordering between $\mathcal{R}$ and $\mathcal{G}$, an acceptability criterion and finally a satisfaisability criterion. Different systems can then be defined using the criteria suggested in the previous sections. Table 2 summarizes these systems (strategies). This section aims at presenting some of these strategies as well as their properties.

Definition 19 (Drastic strategy) *Let $\mathcal{B}$, $\mathcal{R}$ and $\mathcal{G}$ be the agent's bases and X the set of offers. A* drastic system *is a triple $<\succeq$, $\Vdash_{Level}$, $\Vdash_{Conj}>$, such that*

- $\mathcal{R} \approx \mathcal{G}$*, and*
- $Level_A(x) = Level_{CS}(x) = 1$ *for candidate offers.*

In such a system, an agent computes separately acceptable and satisfactory offers. Acceptable offers are those which falsify *all rejections* while satisfactory offers are those which satisfy *all goals*. Candidate offers are then those which are both acceptable and satisfactory. However the drawback of this approach is that it is too restrictive and may lead to an empty set of candidate offers.

Example 7. Since $Level_A(x)$ should be equal to 1, acceptable offers are feasible ones which satisfy all constraints in $\mathcal{R}'$, i.e. they falsify **all rejections**. They satisfy $stopover(x) \wedge (\neg dayflight(x) \vee smoking(x)) \wedge flexible(x)$. Then the set of acceptable offers is $\mathcal{A} = \{AF, BA\}$.
Satisfactory offers are feasible ones which satisfy **all goals** since $Level_{CS} = 1$. They satisfy $stopover(x) \wedge dayflight(x) \wedge promotion(x)$. Then the set of satisfactory offers is $\mathcal{S} = \{KLM\}$.
Now candidate offers are those which are both acceptable and satisfactory however this set is empty.

Note that if we only consider goals in this example then the candidate offer is KLM which is not acceptable (i.e., rejected) by the agent following the chosen acceptability criterion.

Definition 20 (Optimistic strategy) *Let $\mathcal{B}$, $\mathcal{R}$ and $\mathcal{G}$ be the agent's bases and X the set of offers. An* optimistic system *is a triple* $<\succeq, \Vdash_{Level}, \Vdash_{Disj}>$*, where $\mathcal{R} \approx \mathcal{G}$.*

With an optimistic strategy, one looks for offers which falsify as most as possible prioritized rejections and satisfy as at least one prioritized goal [8]. Formally these offers satisfy

$$\mathcal{R}'_{>\beta} \wedge (\bigvee \mathcal{G}_{=\lambda})$$

s.t. β is as low as possible and λ is as high as possible.

Let $\{\beta_1, \cdots, \beta_n\}$ and $\{\lambda_1, \cdots, \lambda_m\}$ be the degrees appearing in $\mathcal{R}$ and $\mathcal{G}$ respectively. Note that following definition 12, more β_i is close to 1, more offers satisfying the associated rejection are unacceptable. Also following definition 15, more λ_j is close to 1, more offers satisfying the associated goals are satisfactory.

We first put $\beta = 0$ and $\lambda = \lambda_1$. This means that preferred offers are those which satisfy all the constraints induced by rejections (i.e., falsify all rejections) and satisfy at least one goal from the prioritized ones, if possible. If the intersection of the corresponding acceptable and satisfactory offers is not empty then we declare offers belonging to the intersection as the candidate ones otherwise we either increase β or decrease λ. To ensure that we choose β as low as possible and λ as high as possible, we fix the values of β and λ in the following way:

$$\begin{cases} \beta = 0 \text{ and } \lambda = \lambda_2 & \text{if } 1 - \beta_n < \lambda_2 \\ \beta = \beta_n \text{ and } \lambda = \lambda_1 & \text{if } 1 - \beta_n > \lambda_2 \\ \beta = \beta_n \text{ and } \lambda = \lambda_2 & \text{otherwise.} \end{cases} \tag{1}$$

The idea behind the optimistic strategy is to select offers which maximize acceptability or satisfaction. First note that if some offer falsifies all rejections having a weight strictly greater than β but satisfies at least one rejection with a weight equal to β then it is unacceptable to a degree β. Indeed it is acceptable to a degree equal to $1 - \beta$ following definition 12.

Following equation (1), we give up rejections with weight β_n if $1 - \beta_n$ (which represents the acceptability degree of offers satisfying at least one of these rejections following definition 12) is higher than λ_2 which represents the satisfaction degree of offers satisfying one of its corresponding goals following definition 15.

Once the values β and λ are fixed, if there are offers satisfying $\mathcal{R}'_{>\beta} \wedge (\bigvee \mathcal{G}_{=\lambda})$ then we stop otherwise we either increase β or decrease λ, and so on.

Example 8. First we put $\beta = 0$ and $\lambda = .8$. We have $\mathcal{R}'_{>0} = stopover(x) \wedge (\neg dayflight(x) \vee smoking(x)) \wedge flexible(x)$ and $\bigvee \mathcal{G}_{=.8} = promotion(x)$.

Then acceptable offers are feasible ones which satisfy $\mathcal{R}'_{>0}$. They are AF and BA.

Satisfactory offers are feasible ones which satisfy $\bigvee \mathcal{G}_{=.8}$, they are $AirLib$ and KLM.

Indeed the intersection of the two sets is empty.

Now we put $\beta = .1$ and $\lambda = .8$ since offers satisfying the rejection $(\neg flexible(x), .1)$ are acceptable to a degree equal to .9 while those satisfying $(promotion(x), .8)$ are satisfactory to a degree equal to .8. The acceptability degree is greater than the satisfaction

degree.
Now acceptable offers satisfy $stopover(x) \wedge (\neg dayflight(x) \vee smoking(x))$. They are AF, $AirLib$ and BA.
Satisfactory offers satisfy $promotion(x)$. They are $AirLib$ and KLM. Indeed there is only one candidate offer which is $AirLib$.

In the case where we only consider goals, candidate offers are $AirLib$ and KLM however KLM is rejected.

Definition 21 (Pessimistic strategy) *Let $\mathcal{B}$, $\mathcal{R}$ and $\mathcal{G}$ be the agent's bases and X the set of offers. A* pessimistic strategy *is a triple* $<\succeq, \Vdash_{Level}, \Vdash_{Conj}>$*, where* $\mathcal{R} \approx \mathcal{G}$.

With a pessimistic strategy, one selects offers which satisfy as much as prioritized integrity constraints and goals. Formally these offers should satisfy

$$\mathcal{R}'_{>\beta} \wedge \mathcal{G}_{>\lambda},$$

with α and β are as low as possible. We follow the same reasoning as in the optimistic strategy to ensure that α and β are as low as possible.

Example 9. Following the drastic strategy, there is no offer which satisfies all constraints induced by rejections and all goals.
Now we put $\beta = .1$ and $\lambda = 0$. Then acceptable offers are those which satisfy $\mathcal{R}'_{>.1}$. They are AF, $AirLib$ and BA.
Satisfactory offers satisfy $promotion(x) \wedge stopover(x) \wedge dayflight(x)$. There is only one satisfactory offer which is KLM. Again, the set of candidate offers is empty.
Let us now put $\beta = .4$ and $\lambda = 0$. Then acceptable offers satisfy $stopover(x)$. They are AF, $AirLib$, BA and KLM. Indeed there is a candidate offer which is KLM.

Note that we obtain the same result as the case where we only consider goals. However this is not always the case.

Definition 22 (Requiring strategy) *Let $\mathcal{B}$, $\mathcal{R}$ and $\mathcal{G}$ be the agent's bases and X the set of offers. A* requiring strategy *is a triple* $<\succeq, \Vdash_{Level}, \Vdash_{Card}>$*, where* $\mathcal{R} \succ \mathcal{G}$.

Among feasible offers, the agent selects first acceptable offers which falsify as much as prioritized rejections and among acceptable offers, it selects those which satisfy as much as possible goals.
Let $\mathbb{F}$ be the set of feasible offers. According to definition 13, the set of acceptable offers are defined as follows:
$\mathcal{A} = \{x : x \in \mathbb{F}$ and $\mathcal{R} \Vdash_{Level} x\}$.
The candidate offers are: $\underline{\mathcal{S}} = \{x : x \in \mathcal{A}$ and $\mathcal{G} \Vdash_{Card} x\}$. Note that if all acceptable offers falsify all goals then they are equal w.r.t. cardinality-based criterion and then selected as candidate offers.

Example 10. The minimal weight in $\mathcal{R}$ s.t. the set of acceptable offers is not empty is equal to 0. Offers satisfying $\mathcal{R}'_{>0}$ are BA and AF i.e., $\mathcal{A} = \{BA, AF\}$.
BA is preferred to AF following cardinality-based criterion, then there is only one candidate offer which is BA.

Note that if we only consider goals then there is one candidate offer KLM which is not acceptable for the agent w.r.t. the chosen acceptability criterion.

Definition 23 (Relaxed strategy) *Let $\mathcal{B}$, $\mathcal{R}$ and $\mathcal{G}$ be the agent's bases and X the set of offers. A* relaxed strategy *is a triple* $<\succeq, \Vdash_{Level}, \Vdash_{Disj}>$*, where* $\mathcal{R} \succ \mathcal{G}$.

Among feasible offers, the agent selects first those which falsify as most as prioritized rejections and among acceptable offers, it selects those which satisfy at least one prioritized goal as far as possible.
Acceptable offers are computed in the same way as for the requiring criterion. Candidate offers x are now acceptable ones which satisfy $\mathcal{G} \Vdash_{Disj} x$

Example 11. The set of acceptable offers is the same as in the requiring criterion namely $\mathcal{A} = \{AF, BA\}$.
There is no acceptable offer which satisfies the prioritized goal "promotion(x)" then we look for those which satisfy "stopover(x)" or "dayflight(x)". The candidate offers are AF and BA.

Here also, if we only consider goals then candidate offers are $AirLib$ and KLM which are not acceptable for the agent following the chosen acceptability criterion.

8 Properties of the different strategies

We defined in the previous section a three-layered setting where different strategies have been proposed for offers selection. As shown on the running example, these strategies give different results however some of them are related.

Proposition 2 *Let $\underline{S}_1, \underline{S}_2$ and $\underline{S}_3$ be the sets of candidate offers returned respectively by the drastic, requiring and the relaxed strategies. Then,*

$$\underline{S}_1 \subseteq \underline{S}_2 \subseteq \underline{S}_3.$$

This result means that requiring strategy is a weakening of drastic strategy and it is weakened by relaxed strategy. In other words, more we weaken the strategy more there are offers to propose. This is an important point in a negotiation dialogue since the more an agents has a large choice, the more the negotiation has better chance to success (to reach an agreement).

The following proposition states that using requiring and relaxed strategies, the set of candidate offers is not empty as soon as the set of acceptable offers is not empty.

Proposition 3 *Let $\mathcal{A}$ be the set of acceptable offers computed in the requiring (resp. relaxed) strategy. If $\mathcal{A}$ is not empty then the set of candidate offers is not empty in these strategies.*

In contrast to requiring and relaxed criteria, drastic criterion may lead to an empty set of candidate offers even if the set of acceptable offers is not empty. This is shown in example 7. Indeed in negotiation framework, the use of such criteria may lead negotiation to a failure.

As we said in the introduction, existing works on negotiation only consider goals in offers selection. Considering both rejections and goals in this selection enriches the selection process by providing various and different strategies as given in the previous section. Let us consider now the proposed strategies and apply them to a unipolar framework where only goals are considered. Then we have:

Proposition 4 *When we only consider goals, the optimistic and the relaxed strategies are equivalent.*

Readers may wonder whether is it really necessary to distinguish between rejections and goals and not simply use a single set where constraints induced by rejections are prioritized over goals. However this is not possible since we use here first order formulas and in the computation of acceptable offers, we do not look for the consistency of $\mathcal{R}$ (in fact it is supposed to be consistent) but for the *existence* of offers satisfying constraints induced by rejections. Let us consider again our example and put both constraints induced by rejections and goals in the same set. We get $\{(stopover(x), \beta_1), (\neg dayflight(x) \vee smoking(x), \beta_2), (flexible(x), \beta_3), (promotion(x), \lambda_1), (stopover(x), \lambda_2), (dayflight(x), \lambda_2)\}$, with $\beta_1 > \beta_2 > \beta_3 > \lambda_1 > \lambda_2$ however this doesn't make sense for all criteria except the drastic one since candidate offers should satisfy all elements of this set.

9 Conclusion

This paper studies the notion of strategy for selecting offers during a negotiation dialogue. In fact, the choice of the offer to propose at a given step is very important in a negotiation dialogue since this influences the outcome of the dialogue. For example, a too restrictive strategy may lead to an empty set of candidate offers and then the negotiation fails. The more the strategy gives a large choice of offers, the more the negotiation has a better chance to success, and consequently that the agent reach an agreement.

We have proposed a general setting for defining a strategy, which consists of fixing three parameters: the agent's profile, a criterion for defining acceptable offers and finally another criterion for defining satisfactory offers. The three parameters are defined on the basis of three mental states of an agent: its beliefs, its goals and its rejections. The agent's profile consists of determining whether rejections and goals are equally preferred or not.

We have proposed different agent's profiles and different criteria for the notions of acceptability and satisfiability of offers. A combination of an agent's profile, a criterion for selecting acceptable offers and a criterion for selecting the satisfactory ones gives birth to different strategies which are more or less restrictive. We have studied some of these strategies.

At the best of our knowledge, very few works have addressed the problem of offer selection. Moreover all existing works only consider goals in this process. We claim that rejections play also a key role in this problem since they allow to discard rejected offers.

An extension of this work would be to study more deeply the remaining strategies summarized in Table 2, and to compare them to the others. Another interesting work to do consists of integrating these strategies in a more general architecture of a negotiation dialogue. The idea is to study the outcome of the dialogue in the case where all the negotiating agents use the same strategy, and also in the case where they use different strategies.

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