Assumption-based argumentation for the minimal concession strategy of agents engaged in resource negotiation[1]

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Résumé :
De récents travaux s'intéressent au modèle informatique de l'argumentation pour la négociation multi-agents. Toutefois, cette approche logique ne propose pas de stratégie d'agent efficace pour la négociation. Dans cet article, nous présentons une réalisation de la stratégie de concession minimale et nous l'illustrons à l'aide d'un exemple intuitif de négociation de ressources. Nous affirmons ici que le résultat d'une négociation, dont on garantit l'arrêt, est un accord optimal (si possible), lorsque les agents adoptent notre stratégie.

Mots-clés : Comportement d'agent, Négociation, Argumentation, Théorie des jeux, Allocation multi-agents de ressources

Abstract:
Several recent works in the area of Artificial Intelligence focus on computational models of argumentation-based negotiation. However, even if computational model of arguments are used to encompass the reasoning of interacting agents, this logical approach does not come with an effective strategy for agents engaged in negotiations. In this paper we present a realisation of the Minimal Concession (MC) strategy. The main contribution of this paper is the realisation of this intelligent strategy by means of assumption-based argumentation illustrated by an intuitive scenario of resource negotiation. Moreover, we claim here that the outcome of negotiations, which are guaranteed to terminate, is an optimal agreement (when possible) if the agents adopt the MC strategy.

Keywords: Agent behaviour, Negotiation, Argumentation, Game theory, Multiagent Resource Allocation

1 Introduction

In negotiations, the aim for all parties is to "make a deal" while bargaining over their interests, typically seeking to maximise their "good" (welfare), and prepared to concede some aspects while insisting on others. Negotiations can be delegated to a multiagent system responsible for reaching agreements automatically [9]. As pointed by [15], there is a need for a solid theoretical foundation for negotiation that covers algorithms and protocols, while determining which strategies are most effective under what circumstances.

Several recent works in the area of Artificial Intelligence focus on computational models of argumentation-based negotiation [12, 1, 5]. In these works, argumentation logic serves as a unifying medium to provide a model for agent-based negotiation systems, in that it can support : the reasoning and decision-making process of agents [12], the inter-agent negotiation process to reach an agreement [1] and the definition of contracts emerging from the negotiation [5]. However, even if computational model of arguments are used to encompass the reasoning of interacting agents, few works are concerned by the strategy of agents engaged in negotiations and its properties. A first attempt in this direction is the Minimal Concession (MC) strategy proposed by [7]. However, the latter does not show how to fill the gap between the argumentation-based decision-making mechanism and its realisation for computing this negotiation strategy. Moreover, some assumptions are too strong such as the fact the agents know the preferences and the reservation values of the other agents. In this paper we present our realisation of the MC strategy [17]. Moreover, we consider it for the specific case of resource negotiation. Argumentation logic is used to support the intelligent strategy of negotiating agents, to guide and empower negotiation amongst agents and to allow them to reach agreements. With the support of assumption-based argumentation, agents select the "optimal" utterances to fulfil the preferences/constraints of users and the requirements imposed by the other agents.

The paper is organised as follows. Section 2 introduces the basic notions of assumption-based

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argumentation in the background of our work. Section 3 introduces the walk-through example. Section 3 outline the dialogue-game protocol we use. Section 5 defines our framework for decision making. Section 6 presents our realisation of the MC strategy. Section 7 highlights some properties of our protocol and strategy. Section 8 discusses some related works. Section 9 concludes.

2 Assumption-based argumentation

Assumption-based argumentation [3] (ABA) is a general-purpose computational framework which allows to reason with incomplete information since certain literals are assumptions, meaning that they can be assumed to hold as long as there is no evidence to the contrary. Moreover, ABA concretise Dung's abstract argumentation [6] (AA). Actually, all the semantics used in AA, which captures various degrees of collective justification for a set of arguments, can be applied.

An ABA framework considers a deductive system augmented by a non-empty set of assumptions and a (total) mapping from assumptions to their contraries. In order to perform decision making, we consider here the generalisation of the original assumption-based argumentation framework and its computational mechanism, whereby multiple contraries are allowed [8].

Definition 1 (ABA) *An **assumption-based argumentation framework** is a tuple* $\mathsf{ABF} = \langle \mathcal{L}, \mathcal{R}, \mathcal{A}sm, \mathcal{C}on \rangle$ *such that :*
- $(\mathcal{L}, \mathcal{R})$ *is a deductive system where,*
  - $\mathcal{L}$ *is a formal language consisting of countably many sentences,*
  - $\mathcal{R}$ *is a countable set of inference rules of the form* $r : \alpha \leftarrow \alpha_1, \ldots, \alpha_n$ $(n \geq 0)$ *where* $\alpha \in \mathcal{L}$*, called the **head** of the rule (denoted* $\mathtt{head}(r)$*),* $\alpha_1, \ldots, \alpha_n \in \mathcal{L}$ *, called the **body** (denoted* $\mathtt{body}(r)$*), and* $n \geq 0$ *;*
- $\mathcal{A}sm \subseteq \mathcal{L}$ *is a non-empty set of **assumptions**. If* $x \in \mathcal{A}sm$*, then there is no inference rule in* $\mathcal{R}$ *such that* x *is the head of this rule ;*
- $\mathcal{C}on : \mathcal{A}sm \to 2^{\mathcal{L}}$ *is a (total) mapping from assumptions into set of sentences in* $\mathcal{L}$*, i.e. their **contraries**.*

In the remainder of the paper, we restrict ourselves to finite deduction systems, i.e. with finite languages and finite set of rules. For simplicity, we restrict ourselves to flat frameworks [3], i.e. whose assumptions do not occur as conclusions of inference rules, such as logic programming or the frameworks considered in this paper.

We adopt here a tree-like structure for arguments.

Definition 2 (Argument) *Let* $\mathsf{ABF} = \langle \mathcal{L}, \mathcal{R}, \mathcal{A}sm, \mathcal{C}on \rangle$ *be an ABA framework. An **argument*** $\bar{a}$ *deducing the **conclusion*** $c \in \mathcal{L}$ *(denoted* $\mathtt{conc}(\bar{a})$*) supported by a set of **assumptions*** A *in* $\mathcal{A}sm$ *(denoted* $\mathtt{asm}(\bar{a})$*) is a tree where the root is* c *and each node is a sentence of* $\mathcal{L}$*. For each node :*
- *if the node is a leaf, then it is either an assumption of* A *or* $\top$[1] *;*
- *if the node is not a leaf and it is* $\alpha \in \mathcal{L}$*, then there is an inference rule* $\alpha \leftarrow \alpha_1, \ldots, \alpha_n$ *in* $\mathcal{R}$ *and,*
  - *either* $n = 0$ *and* $\top$ *is its only child,*
  - *or* $n > 0$ *and the node has* n *children,* $\alpha_1, \ldots, \alpha_n$*.*

We write it $\bar{a} : \mathsf{A} \vdash c$*. The set of arguments built upon* ABF *is denoted by* $\mathcal{A}(\mathsf{ABF})$*.*

In the remainder of the paper, we restrict ourselves to finite deduction systems, i.e. with finite languages and finite set of rules. For simplicity, we also restrict ourselves to flat frameworks [3], in which assumptions do not occur as conclusions of inference rules.

In an assumption-based argumentation framework, the attack relation amongst arguments comes from the contraries which capture the notion of conflicts.

Definition 3 (Attack relation)_ *An argument* $\bar{a} : \mathsf{A} \vdash \alpha$ ***attacks*** *an argument* $\bar{b} : \mathsf{B} \vdash \beta$ *iff there is an assumption* $x \in \mathsf{B}$ *such as* $\alpha \in \mathcal{C}on(x)$*. Similarly, we say that the set* $\bar{S}$ *of arguments attacks* $\bar{b}$ *when* $\bar{a} \in \bar{S}$*.*

According to the two previous definitions, ABA is clearly a concrete instantiation of AA where arguments are deductions and the attack relation comes from the contrary relation.

We have defined the attack-relation to adopt Dung's calculus of opposition [6].

[1] $\top$ denotes the unconditionally true statement.

Move	Speaker	Proposal
$\mathtt{mv}_1$	ag_1	grab r_3
$\mathtt{mv}_2$	ag_2	grab r_1 and r_2
$\mathtt{mv}_3$	ag_1	none swap
$\mathtt{mv}_4$	ag_2	swap all the resources
$\mathtt{mv}_5$	ag_1	swap r_2 and r_3
$\mathtt{mv}_6$	ag_2	grab r_2
$\mathtt{mv}_7$	ag_1	swap r_1 and r_3
$\mathtt{mv}_8$	ag_2	swap r_2 and r_3

TAB. 1 – Negotiation dialogue

Definition 4 (Semantics) *Let* $AF = \langle \mathcal{A}(ABF), \mathtt{attacks} \rangle$ *be our argumentation framework built upon the ABA framework* $ABF = \langle \mathcal{L}, \mathcal{R}, \mathcal{A}sm, \mathcal{C}on \rangle$. *A set of arguments* $\bar{S} \subseteq \mathcal{A}(ABF)$ *is :*

- ***conflict-free*** *iff* $\forall \bar{a}, \bar{b} \in \bar{S}$ *it is not the case that* $\bar{a}$ *attacks* $\bar{b}$ *;*
- ***admissible*** *iff* $\bar{S}$ *is conflict-free and* $\bar{S}$ *attacks every argument* $\bar{a}$ *such that* $\bar{a}$ *attacks some arguments in* $\bar{S}$.

For simplicity, we restrict ourselves to admissible semantics.

3 Walk-through example

In order to present informally our negotiation strategy, we consider a scenario where two agents seek to swap discrete, non-divisible and non-shareable resources. The negotiation of the allocation is a complex task due to the number of possible allocations, their characteristics and the preferences of the users. It makes this use-case interesting enough for the evaluation of our strategy.

In our scenario, the initial allocation is such that the agent ag_1 has the resources r_1 and r_2 while the agent ag_2 has the resource r_3. While the agent ag_1 is empowered to collect as much resources as possible whatever the resources are, the agent ag_2 is responsible for collecting r_2 and eventually as much other resources as possible. Taking into account these goals/preferences, the agent ag_1 (resp. the ag_2) needs to interactively solve a decision-making problem where the decision amounts to a deal it can agree on. Moreover, some decisions amount to the moves they can utter during the negotiation.

We consider the negotiation performed through the moves in Tab. 1. A move at time t has an identifier $\mathtt{mv}_t$ and it is uttered by a speaker. According to the MC strategy, the agents start with the proposals which are "optimal" for themselves. Each of them suggests to take all the resources. In the third step of the negotiation, the agent ag_1 adopting the MC strategy must concede minimally : either with the empty deal where none resource is exchanged, or the swap of the resources r_2 and r_3, or the swap of the resources r_1 and r_3. Arbitrarily, it suggests the empty deal, and so implicitly it rejects the previous proposal of the agent ag_2. It is rational for the agent ag_2 to reject the empty deal since it does not allow the agent ag_2 to take the resource r_2. The agent ag_2 is ready to concede r_3 in order to get r_2. Adopting the MC strategy, the agent ag_2 concedes minimally by suggesting to swap all the resources. It is rational for the agent ag_1 to reject this deal for which the number of its resources decreases. The agent ag_1 implicitly rejects this deal by suggesting the swap of the resources r_2 and r_3. The agent ag_2 prefers and so suggests to take the resource r_2. Since this deal is still irrational for the agent ag_1, the latter suggests the swap of the resources r_1 and r_3. Since the previous proposal put forward by the agent ag_2 has been previously (implicitly) rejected, the agent ag_2 must concede minimally. For this purpose, the agent ag_2 suggest the proposal which is preferred and which has not been yet rejected, i.e. the swap of the resources r_2 and r_3. Since this proposal has been previously put forward by the agent ag_1, the agent ag_2 accepts it and the dialogue is closed.

4 Protocol

A negotiation is a social interaction between self-interested parties intended to resolve a dispute by verbal means and to produce an agreements upon a course of action. In this section, we briefly present our game-based social model to handle the collaborative operations of agents. In particular, we present a dialogue-game protocol for bilateral bargaining.

According to the game metaphor for social interactions of [20], agents are players which utter moves according to social rules.

Definition 5 (Dialogue-game) *Let us consider* $\mathcal{L}$ *a common object language and* $\mathcal{ACL}$ *a common agent communication language. A* ***dialogue-game*** *is a tuple* $DG = \langle P, \Omega_M, H, T, \mathtt{proto}, Z \rangle$ *where :*

- P *is a set of agents called* ***players*** *;*

- $\Omega_M \subseteq \mathcal{ACL}$ *is a set of well-formed moves ;*
- *H is a set of histories, the sequences of well-formed moves s.t. the speaker of a move is determined at each stage by the turn-taking function T and the moves agree with the protocol* `proto` *;*
- *T : H $\rightarrow$ P is the turn-taking function ;*
- `proto` *: H $\rightarrow 2^{\Omega_M}$ is the function determining the legal moves which are allowed to expand an history ;*
- *Z is the set of dialogues, i.e. the terminal histories.*

DG allows social interaction between agents. During a dialogue-game, players utter moves. Each dialogue is a maximally long sequence of moves. Let us now specify informally the elements of DF for bilateral bargaining.

In bilateral bargainings, there are two players, the initiator `init` and the partner `part`, which utter moves each in turn. The **syntax** of moves is in conformance with a common **agent communication language**, $\mathcal{ACL}$. A move at time t : has an identifier, $\mathtt{mv}_t$; is uttered by a speaker ($\mathtt{sp}_t \in$ P) and the speech act is composed of a locution $\mathtt{loc}_t$ and a content $\mathtt{content}_t$. The possible locutions are : `assert`, `reply`, `standstill`, `concede`, `accept` and `reject`. The content consists of a sentence in the common object language, $\mathcal{L}$.

Given an history, the players share a **dialogue state**, depending on their previous moves. Considering the step $t \in \mathbb{N}$, the dialogue state is a tuple $\mathtt{DS}_t = \langle \mathtt{ll}_t, \mathtt{lo}_t(\mathtt{init}), \mathtt{lo}_t(\mathtt{part}), \mathtt{nbss}_t \rangle$ where :
- $\mathtt{ll}_t$ is the last locution which has been uttered, eventually `none` ;
- $\mathtt{lo}_t(\mathtt{init})$ (resp. $\mathtt{lo}_t(\mathtt{part})$) represents the last offer of the initiator (resp. partner), i.e. the content of its last move ;
- $\mathtt{nbss}_t$ is the number of consecutive `standstill` in the last moves.

Fig. 1 represents our dialogue-game protocol with the help of a deterministic finite-state automaton. A dialogue begins with a first offer when a participant (the initiator or the partner) makes an `assert`. The legal responding speech act is `reply`. After that, the legal responding moves are standstills, concessions, acceptations and rejections. The legal responding moves to a concession/standstill are the same. An history is final and : i) the dialogue is a failure if it is closed by a `reject` ; ii) the dialogue is a success if it is closed by an `accept`.

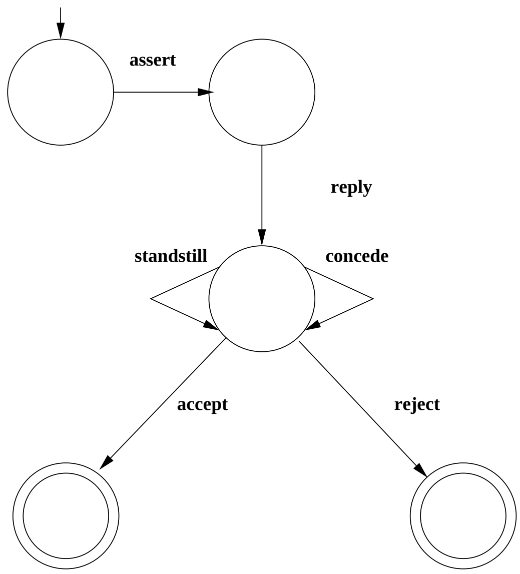

FIG. 1 – bilateral bargaining protocol

The strategy interfaces with the dialogue-game protocol through the condition mechanism of utterances for a move. For example, at a certain point in the dialogue the agent is able to send `standstill` or `concede`. The choice of which locution and which content to send depends on the agent's strategy.

5 Decision making

Taking into account the goals/preferences of the user, an agent needs to solve a decision-making problem where the decision amounts to a service it can agree on. This agent uses argumentation in order to assess their suitability and identify "optimal" services. It argues internally to link the deals and the benefits that these deals guarantee under possibly incomplete knowledge. This section presents our framework to perform decision making, illustrated by the agent ag_1.

Definition 6 (Decision framework) *A* ***decision framework*** *is a tuple DF $= \langle \mathcal{L}, \mathcal{G}, \mathcal{D}, \mathcal{B}, \mathcal{R}, \mathcal{A}sm, \mathcal{C}on, \mathcal{P} \rangle$ such that :*
- $\langle \mathcal{L}, \mathcal{R}, \mathcal{A}sm, \mathcal{C}on \rangle$ *is an ABA framework as defined in Def. 1 and $\mathcal{L} = \mathcal{G} \cup \mathcal{D} \cup \mathcal{B}$ where,*
  - $\mathcal{G}$ *is a set of literals in $\mathcal{L}$ called* ***goals****,*
  - $\mathcal{D}$ *is a set of assumptions in $\mathcal{A}sm$ called* ***decisions****,*
  - $\mathcal{B}$ *is a set of literals in $\mathcal{L}$ called* ***beliefs*** *;*
- $\mathcal{P} \subseteq \mathcal{G} \times \mathcal{G}$ *is a strict partial order over $\mathcal{G}$, called the* ***preference*** *relation.*

$\mathrm{o}([u,v,w],[x,y,z]) \leftarrow$	$\mathtt{d}([0,0,0],[0,0,0])$, $\mathtt{control}(\mathrm{ag}_1,[u,v,w])$, $\mathtt{control}(\mathrm{ag}_2,[x,y,z])$
$\mathrm{o}([u,v,1],[x,y,0]) \leftarrow$	$\mathtt{d}([0,0,0],[0,0,1])$, $\mathtt{control}(\mathrm{ag}_1,[u,v,0])$, $\mathtt{control}(\mathrm{ag}_2,[x,y,1])$
$\mathrm{o}([0,v,1],[1,y,0]) \leftarrow$	$\mathtt{d}([1,0,0],[0,0,1])$, $\mathtt{control}(\mathrm{ag}_1,[1,v,0])$, $\mathtt{control}(\mathrm{ag}_2,[0,y,1])$
$\mathrm{o}([u,0,1],[x,1,0]) \leftarrow$	$\mathtt{d}([0,1,0],[0,0,1])$, $\mathtt{control}(\mathrm{ag}_1,[u,1,0])$, $\mathtt{control}(\mathrm{ag}_2,[x,0,1])$
$\mathtt{control}(\mathrm{ag}_1,[1,1,0])$	
$\mathtt{control}(\mathrm{ag}_2,[0,0,1])$	

TAB. 2 – The inference rules of the agent ag_1

In the object language $\mathcal{L}$, we distinguish three disjoint components : a set of **goals** representing the objectives the agent wants to be fulfilled, i.e. the possible resource allocations (e.g. the situation where the agent ag_1 has the first resource and the third resource, $\mathrm{o}([1,0,1],[0,1,0])$) ; a set of **decisions** representing the possible deals (e.g. swapping the second resource with the third resource (denoted $\mathtt{d}([0,1,0],[0,0,1])$)) ; a set of **beliefs**, representing the initial resource allocation (e.g. the fact that the agent ag_1 initially has the first resource and the second resource $\mathtt{control}(\mathrm{ag}_1,[1,1,0])$). Decisions are **assumptions**. The multiple **contraries** capture the mutual exclusion of alternatives.

The inference rules of the agent ag_1 are depicted in Tab. 2. All variables occurring in an inference rule are implicitly universally quantified over the whole rule. A rule with variables is a scheme standing for all its ground instances. It is worth noticing that the agent only consider the **rational** deals (s.t the output is an allocation at least as preferred to the initial allocation). The inference rules of the agent ag_2 are similar.

We consider the **preference** relation $\mathcal{P}$ over the goals in $\mathcal{G}$, which is transitive, irreflexive and asymmetric. $g_1\mathcal{P}g_2$ can be read "g_1 is preferred to g_2". From the agent ag_1 viewpoint, $\mathrm{o}([1,1,1],[0,0,0])\mathcal{P}\mathrm{o}([1,0,1],[0,1,0])$, $\mathrm{o}([1,1,1],[0,0,0])\mathcal{P}\mathrm{o}([1,1,0],[0,0,1])$ and $\mathrm{o}([1,1,1],[0,0,0])\mathcal{P}\mathrm{o}([0,1,1],[1,0,0])$.

Formally, given an argument $\bar{\mathrm{a}}$, let

$$\mathtt{dec}(\bar{\mathrm{a}}) = \mathtt{asm}(\bar{\mathrm{a}}) \cap \mathcal{D}$$

be the set of decisions supported by the argument $\bar{\mathrm{a}}$.

Decisions are suggested to reach a goal if they are supported by arguments.

Definition 7 (Decisions) *Let $\mathsf{DF} = \langle \mathcal{L},\mathcal{G},\mathcal{D},\mathcal{B},\mathcal{R},\mathcal{A}sm,\mathcal{C}on,\mathcal{P}\rangle$ be a decision framework, $g \in \mathcal{G}$ be a goal and $\mathsf{D} \subseteq \mathcal{D}$ a set of decisions.*

- *The decisions D **argue for** g iff there exists an argument $\bar{a}$ such that $\mathtt{conc}(\bar{a}) = g$ and $\mathtt{dec}(\bar{a}) = \mathsf{D}$.*
- *The decisions D **credulously argue for** g iff there exists an argument $\bar{a}$ in an admissible set of arguments such that $\mathtt{conc}(\bar{a}) = g$ and $\mathtt{dec}(\bar{a}) = \mathsf{D}$.*
- *The decisions D **skeptically argue for** g iff for all admissible set of arguments $\underline{S}$ such that for some arguments $\bar{a}$ in $\underline{S}$ $\mathtt{conc}(\bar{a}) = g$, then $\mathtt{dec}(\bar{a}) = \mathsf{D}$.*

We denote $\mathtt{val}(\mathsf{D})$, $\mathtt{val}_c(\mathsf{D})$ and $\mathtt{val}_s(\mathsf{D})$ respectively the set of goals in $\mathcal{G}$ for which the set of decisions D argues, credulously argues and skeptically argues respectively.

Due to the uncertainties, some decisions satisfy goals for sure if they skeptically argue for them, or some decisions can possibly satisfy goals if they credulously argue for them. While the first case is required for convincing a risk-averse agent, the second case is enough to convince a risk-taking agent. We focus here on risk-taking agents.

Since agents can consider multiple objectives which may not be fulfilled all together by a set of non-conflicting decisions, high-ranked goals must be preferred to low-ranked goals.

Definition 8 (Preferences) *Let $\mathsf{DF} = \langle \mathcal{L},\mathcal{G},\mathcal{D},\mathcal{B},\mathcal{R},\mathcal{A}sm,\mathcal{C}on,\mathcal{P}\rangle$ be a decision framework. We consider G, G' two set of goals in $\mathcal{G}$ and D, D' two set of decisions in $\mathcal{D}$. G is **preferred** to G (denoted $\mathsf{G}\mathcal{P}\mathsf{G}'$) iff*

1. *$\mathsf{G} \supseteq \mathsf{G}'$, and*
2. *$\forall g \in \mathsf{G} \setminus \mathsf{G}'$ there is no $g' \in \mathsf{G}'$ such that $g'\mathcal{P}g$.*

*D is **preferred** to D' (denoted $\mathsf{D}\mathcal{P}\mathsf{D}'$) iff $\mathtt{val}_c(\mathsf{D})\mathcal{P}\mathtt{val}_c(\mathsf{D}')$.*

The reservation value (denoted RV) is the minimal set of goals which needs to be reached by a set of decisions to be acceptable. Formally, given a reservation value RV, let

$$\mathtt{ad} = \{\mathtt{d}(x,y) \mid \exists \mathsf{D} \in \mathcal{D} \text{ s.t. } \mathtt{d}(x,y) \in \mathsf{D} \text{ and } \mathtt{val}_c(\mathsf{D})\mathcal{P}\mathsf{RV}\}$$

be the deal which can be accepted by the agent.

The set of decisions $\{\mathsf{d}([0,0,0],[0,0,1])\}$ is the only one which skeptically argues for having all the resources while both $\{\mathsf{d}([0,0,0],[0,0,1])\}$ and $\{\mathsf{d}([0,0,0],[0,0,0])\}$ credulously argue for having the two first resources. Due to the preferences of the agent ag_1 over the goals, it prefers $\mathsf{d}([0,0,0],[0,0,1])$ to the other deals.

6 Minimal concession strategy

Taking into account the preferences/goals of the user and the dialogue state, an agent needs to solve some decision-making problems where the decision amounts to a move it can utter. This agent uses argumentation in order to assess the suitability of moves and identify "optimal" moves. It argues internally to link the current dialogue state, the legal moves (their speech acts and contents), and the resulting dialogue states of these moves under possibly incomplete knowledge. This section presents how our argumentation approach realizes the Minimal Concession (MC) strategy, illustrated by the agent ag_1.

A dialogue strategy is a plan that specifies the moves chosen by a player to achieve a particular goal. We consider here the MC strategy which specifies the move chosen by the player for every history when it is his turn to move. For this purpose, an agent adopts a decision framework $\mathsf{DF} = \langle \mathcal{L}, \mathcal{G}, \mathcal{D}, \mathcal{B}, \mathcal{R}, \mathcal{A}sm, \mathcal{C}on, \mathcal{P} \rangle$. The latter, as illustrated in the previous section, allows to perform decision making where the decision amounts to the deal it can agree on. This DF must be extended to perform the MC strategy. For this purpose, we incorporate in the object language $\mathcal{L}$:

- the goal $\mathtt{respond}$ (resp. $\mathtt{optimal}$) in $\mathcal{G}$ representing the objective of the agent which consists of responding (resp. uttering the "optimal" move) ;
- the decisions in $\mathcal{D}$ representing the possible locutions (e.g. $\mathtt{loc}(\mathtt{concede})$). Obviously, the multiple contraries capture the mutual exclusion of the corresponding alternatives (e.g. $\{\mathtt{loc}(\mathtt{concede}), \mathtt{loc}(\mathtt{accept}), \mathtt{loc}(\mathtt{reject})\} = \mathcal{C}on(\mathtt{loc}(\mathtt{standstill}))$) ;
- a set of beliefs in $\mathcal{B}$, related to the dialogue state,
  - the last locution of the interlocutor (e.g. $\mathtt{ll}(\mathtt{concede})$),
  - the last deals proposed by the players (denoted $\mathtt{lo}(p,d)$),
  - the previous deals proposed by the players (denoted $\mathtt{po}(p,d)$),
  - the deals which have been already (and implicitly) rejected by the interlocutor (denoted $\mathtt{rejected}(d)$) ;
- a set of assumptions in $\mathcal{A}sm$ representing that some deals have not been yet rejected (denoted $\mathtt{notrejected}(d)$), that some deals have not been proposed in the previous moves (denoted $\mathtt{notpo}(p,d)$) and that a number of standstills has not been reached (e.g. $\mathtt{notnbss}(3)$).

The **preference** relation $\mathcal{P}$ on the goals in $\mathcal{G}$ has been extended in order to take into the new goals $\mathtt{respond}$ and $\mathtt{optimal}$. By adopting the MC strategy, the agent tries to utter the "optimal" utterances, $\mathtt{optimal}$. If the agent cannot reach this goal, then the agents responds with a legal move, $\mathtt{optimal}\mathcal{P}\mathtt{respond}$ and $\mathtt{respond} \in \mathsf{RV}$. Since this decision framework (in particular the rules) depends on the dialogue state of the history h, we denote it by
$\mathsf{DF}_h = \langle \mathcal{L}, \mathcal{G}, \mathcal{D}, \mathcal{B}, \mathcal{R}_h, \mathcal{A}sm, \mathcal{C}on, \mathcal{P} \rangle$.

Some inference rules of the agent ag_1 (which plays the role of the initiator) are depicted in Tab. 2. The additional rules are depicted in Tab. 3. These rules are related to the dialogue state after the move mv_2 (1-6) or the negotiation strategy (7-18). While one of the players starts by asserting a first proposal (7), the other agent replies with a counter-proposal (8). An agent must adopt one of these attitudes : i) either it **stands still**, i.e. it repeats its previous proposal ; ii) or it **concedes**, i.e. it withdraws to put forward one of its previous proposal and it considers another one. In order to articulate these attitudes, the MC strategy consists of adhering the reciprocity principle during the negotiation. If the interlocutor stands still, then the agent will stand still (13). Whenever the interlocutor has made a concession, it will reciprocate by conceding as well (11). If the agent is not able to concede (e.g. there is no other deals which satisfy its constraints), the agent will standstill (12). It is worth noticing that the third step in the negotiation has a special status, in that the player has to concede (9). If the agent is not able to concede (e.g. there is no other deal which satisfies its constraints), the agent will standstill (10). If an acceptable offer has been put forward by the interlocutor, the player accepts it (16-18). When the player can no more concede, it stops the negotiation (15). It is worth noticing that, contrary to [7], our strategy does not stop the negotiation after 3 consecutive standstills but the strategy allows to concede after them (14). Moreover, any previous offer of the interlocutor can accepted. As we will see in the next section, this will allow a negotiation to succeed even if, contrary to [7], an agent does not know the preferences and the reservation value of the other agent. The inference rules of the `part` are similar.

Differently from [7], we do not assume that the agents know the preferences of their interlocutors. Therefore, we say that a decision is a **minimal** concession for a speaker since there is no other deal which has not been already (and implicitly) rejected by the interlocutor and which is preferred by the speaker.

Definition 9 (Minimal concession) *Let $DF = \langle \mathcal{L}, \mathcal{G}, \mathcal{D}, \mathcal{B}, \mathcal{R}, \mathcal{A}sm, \mathcal{C}on, \mathcal{P} \rangle$ be a decision framework as defined in Section 5. The decision d is a **concession** wrt d' iff there exists a set of decisions D such that $d \in D$ and for all $D' \subseteq \mathcal{D}$ with $d' \in D'$, it is not the case that $D \mathcal{P} D'$.*
*The decision d is a **minimal concession** wrt d' iff it is a concession wrt d' and there is no $d'' \in \mathcal{D}$ such that*
– d'' is a concession wrt d', and
– there is $D'' \subseteq \mathcal{D}$ with $d'' \in D''$ with $D'' \mathcal{P} D$.

The minimal concessions are computed by the decision framework proposed in this section. In our example, the agent ag_1 concedes not to grab the third resource after the move mv_1, since its first proposal has been rejected.

The MC strategy has been implemented by means of MARGO[2] [16] (Multiattribute ARGumentation framework for Opinion explanation), an argumentation-based engine for decision-making adopting the assumption-based approach of argumentation [3]. It is written in Prolog and its distributed under the GNU GPL. MARGO is built on top of CaSAPI[3] [8] (Credulous and Sceptical Argumentation : Prolog Implementation), a general-purpose tool for (several types of) assumption-based argumentation which is also written in Prolog.

7 Properties

The negotiation protocol, as well as the MC strategy, has useful properties. The negotiations always terminate. Moreover, if both players adopt the MC strategy, the negotiation is successful, when it is possible. Finally, the outcome is optimal.

Due to the finiteness assumption of the language, and hence the finiteness of possible decisions, the set of histories is also finite. Hence it is immediate that the negotiations always terminate.

Theorem 1 (Termination) *The dialogues are finite.*

Due to the finiteness assumption and the definition of the MC strategy over the potential agreements, it is not difficult to see that such negotiations are successful, if a potential agreement exists. The final agreement of the negotiation is said to be a Pareto optimal if it is not possible to strictly improve the individual welfare of an agent without making the other worse off. This is the case of our realisation of the MC strategy in a bilateral bargaining.

Claim 1 (Outcome) *If both players adopt a MC strategy and a potential agreement exists, then the dialogue is a success and the outcome is Pareto optimal.*

Differently from [7], a player will concede at a certain point even if its interlocutor stands still since it can no more concede. Therefore, the negotiation between two players adopting the MC strategy go throw the whole sets of acceptable deals. In our example, $d([0, 1, 0], [0, 0, 1])$, which is Pareto optimal, is the outcome of the successful dialogue.

Differently from [7], our realisation of the MC strategy allows to reach an agreement even if the agents do not know the preferences and the reservation value of the other agents. However, this realisation of the MC strategy is not in a pure symmetric Nash equilibrium.

8 Related works

Rahwan et al. [21] propose an analysis grid of strategies for agents engaged in negotiations. According to this grid, the factors which influence our strategy are : the goals (an optimal outcome here), the domain (represented in terms of multi-attribute choice here), the negotiation protocol, the abilities of agents (their resources

[2] http ://margo.sourceforge.net
[3] http ://casapi.sourceforge.net

$$
\begin{array}{rcll}
\texttt{ll}(\texttt{reply}) & \leftarrow & & (1)\\
\texttt{nbss}(0) & \leftarrow & & (2)\\
\texttt{po}(p,d) & \leftarrow & \texttt{lo}(p,d) & (3)\\
\texttt{lo}(\texttt{init},\texttt{d}([0,0,0],[0,0,1])) & \leftarrow & & (4)\\
\texttt{lo}(\texttt{part},\texttt{d}([1,1,0],[0,0,0])) & \leftarrow & & (5)\\
\texttt{rejected}(d) & \leftarrow & \texttt{po}(\texttt{init},d) & (6)\\
\texttt{optimal} & \leftarrow & \texttt{loc}(\texttt{assert}),\texttt{ll}(\texttt{none}) & (7)\\
\texttt{optimal} & \leftarrow & \texttt{loc}(\texttt{reply}),\texttt{ll}(\texttt{assert}) & (8)\\
\texttt{optimal} & \leftarrow & \texttt{loc}(\texttt{concede}),\texttt{d}(x,y),\texttt{ll}(\texttt{reply}), & \\
 & & \texttt{notrejected}(\texttt{d}(x,y)),\texttt{notpo}(\texttt{part},\texttt{d}(x,y)) & (9)\\
\texttt{respond} & \leftarrow & \texttt{loc}(\texttt{standstill}),\texttt{d}(x,y),\texttt{ll}(\texttt{reply}), & \\
 & & \texttt{po}(\texttt{init},\texttt{d}(x,y)) & (10)\\
\texttt{optimal} & \leftarrow & \texttt{loc}(\texttt{concede}),\texttt{d}(x,y),\texttt{ll}(\texttt{concede}), & \\
 & & \texttt{notrejected}(\texttt{d}(x,y)),\texttt{notpo}(\texttt{part},\texttt{d}(x,y)) & (11)\\
\texttt{respond} & \leftarrow & \texttt{loc}(\texttt{standstill}),\texttt{d}(x,y),\texttt{ll}(\texttt{concede}), & \\
 & & \texttt{lo}(\texttt{init},\texttt{d}(x,y)) & (12)\\
\texttt{optimal} & \leftarrow & \texttt{loc}(\texttt{standstill}),\texttt{ll}(\texttt{standstill}), & \\
 & & \texttt{notnbss}(3) & (13)\\
\texttt{optimal} & \leftarrow & \texttt{loc}(\texttt{concede}),\texttt{d}(x,y),\texttt{ll}(\texttt{standstill}), & \\
 & & \texttt{notrejected}(\texttt{d}(x,y)), & \\
 & & \texttt{notpo}(\texttt{part},\texttt{d}(x,y)),\texttt{nbss}(3) & (14)\\
\texttt{respond} & \leftarrow & \texttt{loc}(\texttt{reject}),\texttt{d}(x,y),\texttt{ll}(\texttt{standstill}), & \\
 & & \texttt{lo}(\texttt{part},\texttt{d}(x,y)), & \\
 & & \texttt{nbss}(3) & (15)\\
\texttt{optimal} & \leftarrow & \texttt{loc}(\texttt{accept}),\texttt{d}(x,y),\texttt{ll}(\texttt{reply}), & \\
 & & \texttt{po}(\texttt{part},d(x,y)) & (16)\\
\texttt{optimal} & \leftarrow & \texttt{loc}(\texttt{accept}),\texttt{d}(x,y),\texttt{ll}(\texttt{concede}), & \\
 & & \texttt{notrejected}(\texttt{d}(x,y)), & \\
 & & \texttt{po}(\texttt{part},\texttt{d}(x,y)) & (17)\\
\texttt{optimal} & \leftarrow & \texttt{loc}(\texttt{accept}),\texttt{d}(x,y),\texttt{ll}(\texttt{standstill}), & \\
 & & \texttt{notrejected}(\texttt{d}(x,y)), & \\
 & & \texttt{po}(\texttt{part},\texttt{d}(x,y)),\texttt{nbss}(3) & (18)
\end{array}
$$

TAB. 3 – The additional inference rules of the agent ag_1 (which plays the role of the initiator) after the move $\texttt{mv}_2$

here), the values (promoted by the reciprocity principle here). While the strategy of our agents is directly influenced by the behaviour of its interlocutor, it is not clear how to situate this factor in the analysis grid of [21].

Few concrete strategies of agents engaged in negotiations have been proposed. More works are concerned by dialogues with theoretical issues rather than practical issues. In particular, some works aim at formalizing and implementing communication strategies for argumentative agents, specifying how an agent selects a move according to the dialogue state and the arguments it has. For instance, Amgoud and Parsons [2] define different attitudes : an agent can be agreeable/disagreeable, open-minded/argumentative or an elephant's child, depending on the the legal moves and their rational conditions of utterance. Differently from [2], our strategy takes into account also the overt behaviour of the interlocutor, since this strategy is based on the reciprocity principle. More attitudes have been proposed in [19] (credulous, skeptical, cautious) based on the various degrees of justification captured by these different semantics of abstract argumentation. In this paper, we claim that, in negotiations, the different semantics allow us to distinguish risk-taking agents and risk-averse agents. In [2, 19], some properties of these strategies have been studied, such as the existence/determinism of the responds of these strategies, as well as the impact of these attitudes on the result and the termination and the complexity of the dialogue. In this paper, we have similar results expected for the complexity. The main difference between the work in [2, 19] and our work is the type of dialogues which are considered. While [19] focus on theoretical dialogues, i.e. with discursive purposes, we are interested on bilateral bargaining dialogues between parties which aim at reaching a practical agreement.

Alternatively, Kakas et al. [13, 14] consider the argumentation-based mechanism for decision-making [10] implemented in GORGIAS [4] to perform the communication strategy of agents which depends on the agent knowledge, roles, context and possibly on dynamic preferences. The work of Kakas, Maudet and Moraitis is guided by the requirements for communication strategies of an expressive and declarative language which is directly implementable. The Agent Argumentation Architecture model we have proposed in [18] shares with [11] (a) the vision of argumentative deliberation for internal agent modules and (b) the assumption that an agent can prioritize its needs. This paper focus on a simple strategy and the study of its properties in game-theoretical terms.

9 Conclusions

In this paper we have presented a realisation of the minimal concession strategy which applies argumentation for generating and evaluating proposals during negotiations. According to this strategy, agents start the negotiation with their best proposals. During the negotiation, an agent may concede or stand still. It concedes minimally if the other agent has conceded in the previous step, or after the optimal offers for the participants have been put forward. It stands still if the other agent has stood still in the previous step. A concession is minimal for a speaker since there is no other alternative which has not been already (and implicitly) rejected by the interlocutor, and which is preferred by the speaker. Our realisation of the minimal concession strategy has useful properties : the outcome of the negotiation, which is guaranteed to terminate, is optimal when it is possible, even if the agents ignore the preferences and the reservation values of the other agents.

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Références

[1] Leila Amgoud, Yannis Dimopoulos, and Pavlos Moraitis. A unified and general framework for argumentation-based negotiation. In *Proc. of AAMAS*, pages 963–970, 2007.

[2] Leila Amgoud and Simon Parsons. Agent dialogues with conflicting preferences. In *Proc. of ATAL*, volume 2333 of *LNCS*, pages 190–205. Springer, 2002.

[3] Andrei Bondarenko, Francesca Toni, and Robert Kowalski. An assumption-based framework for non-monotonic reasoning. In *Proc. of LPNMR*, pages 171–189. MIT Press, 1993.

[4] Neophytos Demetriou and Antonis C. Kakas. Argumentation with abduction. In *Proc. of the 4th Panhellenic Symposium on Logic*, 2003.

[5] Yannis Dimopoulos, Pavolis Moraitis, and Leila Amgoud. Characterizing the outcomes of argumentation-based integrative negotiation. In *Proc. of IAT*, pages 456–460, 2008.

[6] Phan Minh Dung. On the acceptability of arguments and its fundamental role in nonmonotonic reasoning, logic programming and n-person games. *Artif. Intell.*, 77(2) :321–357, 1995.

[7] Phan Minh Dung, Phan Minh Thang, and Francesca Toni. Towards argumentation-based contract negotiation. In *Proc. of COMMA*, pages 134–146. IOS Press, 2008.

[8] Dorian Gartner and Francesca Toni. CaSAPI : a system for credulous and sceptical argumentation. In *Proc. of ArgNMR*, pages 80–95, 2007.

[9] Nick R. Jennings, Peyman Faratin, Alession R. Lomuscio, Simon Parsons, Carles Sierra, and Michael Wooldridge. Automated negotiation : prospects, methods and challenges. *Int. Journal of Group Decision and Negotiation*, 10(2) :199–215, 2001.

[10] Antonis Kakas and Pavlos Moraitis. Argumentative-based decision-making for autonomous agents. In *Proc. of the 2nd International Joint Conference on Autonomous Agents and Multi-Agent Systems (AAMAS)*, pages 883–890. ACM Press, 2003.

[11] Antonis Kakas and Pavlos Moraitis. Argumentative-based decision-making for autonomous agents. In *Proc. of AAMAS*, pages 883–890. ACM Press, 2003.

[12] Antonis Kakas and Pavlos Moraitis. Adaptive agent negotiation via argumentation. In *Proc. of AAMAS*, pages 384–391, 2006.

[13] Antonis C. Kakas, Nicolas Maudet, and Pavlos Moraitis. Flexible agent dialogue strategies and societal communication protocols. In *Proc. of AAMAS*, pages 1434–1435, 2004.

[14] Antonis C. Kakas, Nicolas Maudet, and Pavlos Moraitis. Layered strategies and protocols for argumentation-based agent interaction. In *Proc. of ArgMAS*, volume 3366 of *LNCS*, pages 64–77. Springer, 2004.

[15] Michael Luck and Peter McBurney. Computing as interaction : agent and agreement technologies. In *Proc. of the 2008 IEEE International Conference on Distributed Human-Machine Systems*, 2008.

[16] Maxime Morge and Paolo Mancarella. The hedgehog and the fox. An argumentation-based decision support system. In *Proc. of ArgMAS*, pages 55–68, 2007.

[17] Maxime Morge and Paolo Mancarella. Assumption-based argumentation for the minimal concession strategy. In *Proc. of ArgMAS*, page 18 pages, 2009.

[18] Maxime Morge and Kostas Stathis. The agent argumentation architecture revisited. In *Proc. of EUMAS*, 2007.

[19] Simon Parsons, Michael Wooldridge, and Leila Amgoud. Properties and complexity of some formal inter-agent dialogues. *Journal of Logic and Computation*, 13(3) :347–376, 2003.

[20] Henry Prakken. Formal systems for persuasion dialogue. *The Knowledge Engineering Review*, 21 :163–188, 2006.

[21] Iyad Rahwan, Peter McBurney, and Liz Sonenberg. Towards a theory of negotiation strategy (a preliminary report). In *Proc. of the AAMAS Workshop on Game Theoretic and Decision Theoretic Agents*, 2003.