# Assumption-Based Argumentation for the Minimal Concession Strategy[*]

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**Abstract.** Several recent works in the area of Artificial Intelligence focus on computational models of argumentation-based negotiation. However, even if computational models 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 propose a realisation of the Minimal Concession (MC) strategy which has been theoretically validated. The main contribution of this paper is the integration of this intelligent strategy in a practical application by means of assumption-based argumentation. 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.

## 1 Introduction

Negotiations occur in electronic procurement, commerce, health and government, amongst individuals, companies and organisations. 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 are time consuming, emotionally demanding and emotions may affect the quality of the outcomes of negotiations. These issues can be addressed by delegating (at least partially) negotiations to a multiagent system responsible for (or helping with) reaching agreements (semi-)automatically [1]. Within this approach, software agents are associated with stakeholders in negotiations. As pointed out by [2] (resp. [3]), there is a need for a solid theoretical foundation for negotiation (resp. argumentation-based 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 [4,5,6,7]. In these works, argumentation serves as a unifying medium to provide a model for agent-based

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negotiation systems, in that it can support: the reasoning and decision-making process of agents [4], the inter-agent negotiation process to reach an agreement [5], the definition of contracts emerging from the negotiation [6,7,8] and, finally, the resolution of disputes and disagreements with respect to agreed contracts [9]. However, even if computational models 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 with respect to our real-world scenario, e.g. the fact the agents know the preferences and the reservation values of the other agents. In this paper we propose a realisation of the MC strategy which has been practically validated. Actually, our strategy has been tested within industrial scenarios [10,11] from which we extract an intuitive and illustrative example. Moreover, we show here that negotiations are guaranteed to terminate. The negotiation outcome emerges from the interleaved decision-making processes of agents specified by the MC strategy. We claim that this outcome is an optimal agreement when it is possible. 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 assumptions-based argumentation, agents select the "optimal" utterances to fulfil the preferences/constraints of users and the requirements imposed by the other agents. The main contribution of this paper is the integration of our intelligent strategy in a practical application by means of assumptions-based argumentation.

The paper is organised as follows. Section 2 introduces the basic notions of assumption-based argumentation in the background of our work. Section 3 introduces the walk-through example. Section 3 outlines 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 our strategy. Section 8 briefly describes the deployment of the multiagent system responsible for the negotiation. Section 9 discusses some related works. Section 10 concludes with some directions for future work.

## 2 Assumption-Based Argumentation

Assumption-based argumentation [12] (ABA) is a general-purpose computational framework which allows to reason with incomplete information, whereby 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 [13] (AA). Actually, all the semantics used in AA, which capture various degrees of collective justifications for a set of arguments, can be applied to ABA.

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 [14].

**Definition 1 (ABA).** *An **assumption-based argumentation framework** is a tuple* $\mathtt{ABF} = \langle \mathcal{L}, \mathcal{R}, \mathcal{A}sm, \mathcal{C}on \rangle$ *where:*

- $(\mathcal{L}, \mathcal{R})$ *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* $\alpha \in \mathcal{L}$ *is called the **head** of the rule, and the conjunction* $\alpha_1, \ldots, \alpha_n$ *is called the **body** of the rule, with* $n \geq 0$ *and* $\alpha_i \in \mathcal{L}$ *for each* $i \in [1, n]$*;*
- $\mathcal{A}sm \subseteq \mathcal{L}$ *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;*
- $\mathcal{C}on$*:* $\mathcal{A}sm \rightarrow 2^{\mathcal{L}}$ *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 also restrict ourselves to flat frameworks [12], in which assumptions do not occur as conclusions of inference rules.

We adopt here the tree-like structure for arguments proposed in [15] and we adapt it for ABA.

**Definition 2 (Argument).** *Let* $\mathtt{ABF} = \langle \mathcal{L}, \mathcal{R}, \mathcal{A}sm, \mathcal{C}on \rangle$ *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*** $\mathtt{A}$ *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 in* $\mathtt{A}$ *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* $\bar{a} : \mathtt{A} \vdash \alpha$ *to denote an argument* $\bar{a}$ *such that* $\mathtt{conc}(\bar{a}) = \alpha$ *and* $\mathtt{asm}(\bar{a}) = \mathtt{A}$*. The set of arguments built upon* $\mathtt{ABF}$ *is denoted by* $\mathcal{A}(\mathtt{ABF})$*.*

Our definition corresponds to the definition of tight argument in [16]. Arguments can be built by reasoning backwards as in the dialectical proof procedure proposed in [16] and extended in [14]. It is worth noticing that all the rules and assumptions of our arguments are useful to deduce their conclusion even if we do not explicitly enforce the minimality of the premises as in [17]. Moreover, we do not enforce the

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

consistency of the premises but this property will arise in the arguments computed by the dialectical proof procedure due to the attack relation.

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

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. Therefore, we can adopt Dung's calculus of opposition [13].

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

We consider e-procurement scenarios where buyers seek to purchase earth observation services from sellers [10]. Each agent represents a user, i.e. a service requester or a service provider. The negotiation of the fittest image is a complex task due to the number of possible choices, their characteristics and the preferences of the users. It makes this usecase interesting enough for the evaluation of our strategy [11]. For simplicity, we abstract away from the real world data of these features and we present here an intuitive scenario illustrating our strategy.

In our scenario, we consider a `buyer` that seeks to purchase a service $\mathtt{s}(x)$ from a `seller`. The latter is responsible for the four following concrete instances of services: `s(a)`, `s(b)`, `s(c)` and `s(d)`. These four concrete services reflect the combinations of their features (cf Fig. 1). For instance, the price of `s(a)` is high (`Price(a, high)`), its resolution is low (`Resolution(a, low)`) and its delivery time

**Table 1.** Negotiation dialogue

| Move | Speaker | Locution | Offer |
|---|---|---|---|
| $\mathtt{mv}_0$ | seller | assert | s(a) |
| $\mathtt{mv}_1$ | buyer | reply | s(d) |
| $\mathtt{mv}_2$ | seller | concede | s(b) |
| $\mathtt{mv}_3$ | buyer | concede | s(c) |
| $\mathtt{mv}_4$ | seller | accept | s(c) |

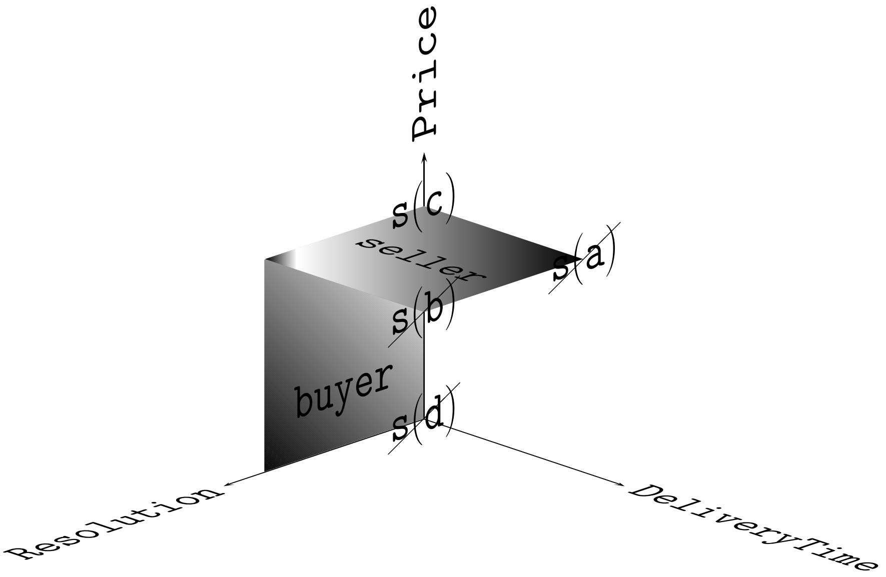

**Fig. 1.** Acceptability space of participants and proposals after the move $\texttt{mv}_3$

is high (`DeliveryTime(a, high)`). According to the preferences and the constraints of the user represented by the `buyer`: the cost must be low (`cheap`); the resolution of the service must be high (`good`); and the delivery time must be low (`fast`). Additionally, the `buyer` is not empowered to concede about the delivery time but it can concede indifferently about the resolution or the cost. According to the preferences and constraints of the user represented by the `seller`: the cost of the service must be high; the resolution of the service must be low; and the delivery time must be high (`slow`). The `seller` is not empowered to concede about the cost but it can concede indifferently about the resolution and the delivery time. The agents attempt to come to an agreement on the contract for the provision of a service $\texttt{s}(x)$. Taking into account some goals, preferences and constraints, the `buyer` (resp. the `seller`) needs to interactively solve a decision-making problem where the decision amounts to a service it can buy (resp. provide). 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, $\texttt{mv}_t$; it is uttered by a speaker, and the speech act is composed of a locution and a content, which consists of an offer. With the first moves, the `seller` and the `buyer` start with the proposals which are "optimal" for themselves, which are `s(a)` and `s(d)` respectively. In the third step of the negotiation, the `seller` can concede minimally either with `s(b)` or with `s(c)`. Arbitrarily, it suggests `s(b)` rather than `s(c)`, and so implicitly it rejects `s(d)`. The `buyer` rejects `s(b)` since its delivery time is high, and so the `buyer` concedes minimally with `s(c)`. Finally, the `seller` accepts `s(c)`.

The evaluation of the services during the negotiation are represented at the three axis of the three dimension plot represented in Fig. 1. The acceptability space of the two participants is represented by shaded areas and depends on the delivery time (x-axis), on the resolution (y-axis) and the price (z-axis). As said previously, the four points of intersection reflect the combinations of their values. The services `s(a)`, `s(b)` and `s(c)` respect the constraints of the `seller`. According to the latter, `s(a)` is preferred to `s(b)` and `s(c)`, which are equally preferred. The services `s(d)` and `s(c)` respect the constraints of the `buyer`. According to the latter, `s(d)` is preferred to `s(c)`.

## 4 Bilateral Bargaining Protocol

A negotiation is a social interaction amongst self-interested parties intended to resolve a dispute by verbal means and to produce an agreement upon a course of action. For instance, the aim for all parties is to "make a deal" while bargaining over their interests, typically seeking to maximise their individual welfare, and prepared to concede some aspects while insisting on others. 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, 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 $\mathtt{DG}=\langle \mathtt{P}, \Omega_M, \mathtt{H}, \mathtt{T}, \mathtt{proto}, \mathtt{Z}\rangle$ where:*

- *$\mathtt{P}$ is a set of agents called players;*
- *$\Omega_M \subseteq \mathcal{ACL}$ is a set of well-formed moves;*
- *$\mathtt{H}$ 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 $\mathtt{T}$ and the moves agree with the protocol $\mathtt{proto}$;*
- *$\mathtt{T}$: $\mathtt{H} \rightarrow \mathtt{P}$ is the turn-taking function;*
- *$\mathtt{proto}$: $\mathtt{H} \rightarrow 2^{\Omega_M}$ is the function determining the legal moves which are allowed to expand an history;*
- *$\mathtt{Z}$ 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 `DG` for bilateral bargainings.

In bilateral bargainings, there are two players, the initiator `init` and the responder `resp`, which utter moves each in turn. In our scenario, the initiator is the `buyer` and the responder is the seller. 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 ($\mathtt{sp}_t \in \mathtt{P}$) 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, $\mathcal{L}$.

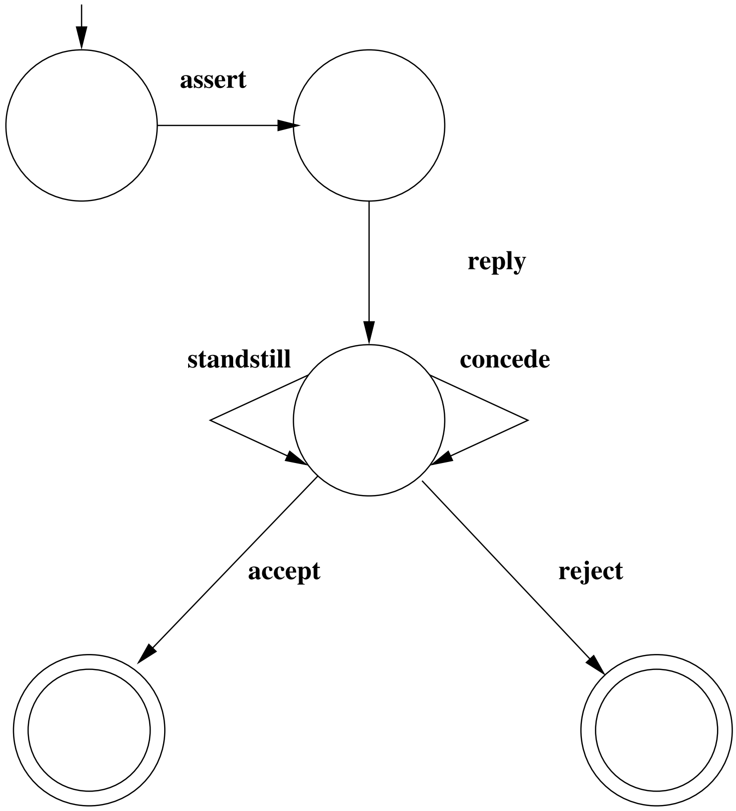

**Fig. 2.** Bilateral bargaining protocol

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 $\mathtt{DS}_t = \langle \mathtt{lloc}_t, \mathtt{loffer}_t(\mathtt{init}), \mathtt{loffer}_t(\mathtt{resp}), \mathtt{nbss}_t \rangle$ where:

- $\mathtt{lloc}_t$ is the last locution which has been uttered, possibly `none`;
- $\mathtt{loffer}_t(\mathtt{init})$ (resp. $\mathtt{loffer}_t(\mathtt{resp})$) represents the last offer of the initiator (resp. responder), i.e. the content of its last move;
- $\mathtt{nbss}_t$ is the number of consecutive `standstill` in the last moves.

Fig. 2 represents our dialogue-game protocol with the help of a deterministic finite-state automaton. A dialogue begins with a first offer when a player (the initiator or the responder) 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`. 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 and preferences of the user, an agent needs to solve a decision-making problem where the decision amounts to an alternatives it can select. This agent uses argumentation in order to assess the suitability of alternatives and to identify "optimal" services. It argues internally to link the alternatives, their features and the benefits that these features guarantee under possibly incomplete knowledge. This section presents our framework to perform decision making, illustrated by our scenario.

**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.*

In the object language $\mathcal{L}$, we distinguish three disjoint components: a set of **goals** representing the objectives the agent wants to be fulfilled (e.g. `cheap`, `good` or `fast`); a set of **decisions** representing the possible services (e.g. `s(d)` or `s(c)`); a set of **beliefs**, representing the characteristics of the services (e.g. `Price(c, high)` or `Resolution(c, low)`). Decisions are **assumptions**. The multiple **contraries** capture the mutual exclusion of alternatives. For instance, we have $\mathcal{C}on(\mathtt{s(d)}) = \{\mathtt{s(a)}, \mathtt{s(b)}, \mathtt{s(c)}\}$.

The inference rules of the players 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. The players are aware of the characteristics of the available services and the benefits that these features guarantee.

**Table 2.** The inference rules of the players

$\mathtt{expensive} \leftarrow \mathtt{s}(x), \mathtt{Price}(x, \mathtt{high})$
$\mathtt{cheap} \leftarrow \mathtt{s}(x), \mathtt{Price}(x, \mathtt{low})$
$\mathtt{good} \leftarrow \mathtt{s}(x), \mathtt{Resolution}(x, \mathtt{high})$
$\mathtt{bad} \leftarrow \mathtt{s}(x), \mathtt{Resolution}(x, \mathtt{low})$
$\mathtt{fast} \leftarrow \mathtt{s}(x), \mathtt{DeliveryTime}(x, \mathtt{low})$
$\mathtt{slow} \leftarrow \mathtt{s}(x), \mathtt{DeliveryTime}(x, \mathtt{high})$
$\mathtt{Price}(\mathtt{a}, \mathtt{high}) \leftarrow$
$\mathtt{Resolution}(\mathtt{a}, \mathtt{low}) \leftarrow$
$\mathtt{DeliveryTime}(\mathtt{a}, \mathtt{high}) \leftarrow$
$\mathtt{Price}(\mathtt{b}, \mathtt{high}) \leftarrow$
$\mathtt{Resolution}(\mathtt{b}, \mathtt{high}) \leftarrow$
$\mathtt{DeliveryTime}(\mathtt{b}, \mathtt{high}) \leftarrow$
$\mathtt{Price}(\mathtt{c}, \mathtt{high}) \leftarrow$
$\mathtt{Resolution}(\mathtt{c}, \mathtt{low}) \leftarrow$
$\mathtt{DeliveryTime}(\mathtt{c}, \mathtt{low}) \leftarrow$
$\mathtt{Price}(\mathtt{d}, \mathtt{low}) \leftarrow$
$\mathtt{Resolution}(\mathtt{d}, \mathtt{low}) \leftarrow$
$\mathtt{DeliveryTime}(\mathtt{d}, \mathtt{low}) \leftarrow$

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 `buyer`'s viewpoint, $\texttt{fast}\mathcal{P}\texttt{cheap}$, $\texttt{fast}\mathcal{P}\texttt{good}$, it is not the case that $\texttt{cheap}\mathcal{P}\texttt{good}$ and it is not the case that $\texttt{good}\mathcal{P}\texttt{cheap}$. From the `seller`'s viewpoint, $\texttt{expensive}\mathcal{P}\texttt{slow}$, $\texttt{expensive}\mathcal{P}\texttt{bad}$, it is not the case that $\texttt{bad}\mathcal{P}\texttt{slow}$ and it is not the case that $\texttt{slow}\mathcal{P}\texttt{bad}$.

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

$$\texttt{dec}(\bar{\text{a}}) = \texttt{asm}(\bar{\text{a}}) \cap \mathcal{D}$$

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

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

**Definition 7 (Decisions).** *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, $g \in \mathcal{G}$ be a goal and $D \subseteq \mathcal{D}$ be a set of decisions.*

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

*We denote $\texttt{val}(D)$, $\texttt{val}_c(D)$ and $\texttt{val}_s(D)$ 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 $DF = \langle \mathcal{L}, \mathcal{G}, \mathcal{D}, \mathcal{B}, \mathcal{R}, \mathcal{A}sm, \mathcal{C}on, \mathcal{P} \rangle$ 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 $G\mathcal{P}G'$) iff*

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

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

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
$\texttt{ad} = \{\texttt{D}(x) \mid \exists \texttt{D} \in \mathcal{D} \text{ such that } \texttt{D}(x) \in \mathcal{D} \text{ and it is not the case that } \texttt{RV}\mathcal{P}\texttt{val}_c(\texttt{D})\}$
be the decisions which can be accepted by the agent.

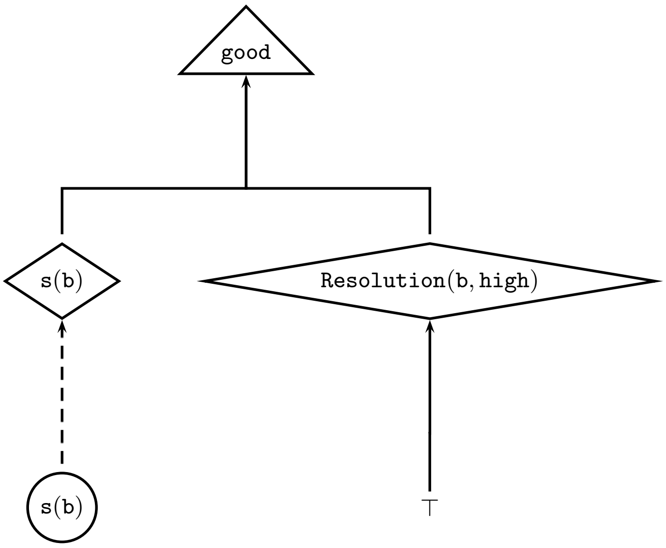

**Fig. 3.** Arguments concluding `good`

In our example, the argument $\bar{b}$ supports the service `s(b)` due to its resolution. This argument is depicted in Fig. 3. While te resolution of `b` is a fact, the decision is an assumption. Some of the arguments are: $\bar{c}$ supporting the service `s(c)` due to its delivery time; $\bar{d}_1$ supporting the service `s(d)` due to its price and $\bar{d}_2$ supporting the service `s(d)` due to its delivery time. The set of decisions {`s(d)`} (resp. {`s(b)`}) is the only one which skeptically argues for `cheap` (resp. `good`) while both {`s(c)`} and {`s(d)`} credulously argue for `fast`. Since the `buyer` is not empowered to concede about the delivery time but it can concede about the other goals, its reservation value is {`fast`}. Therefore, both {`s(c)`} and {`s(d)`} are acceptable for the `buyer`. Since {`s(d)`} credulously argue for `good` and this is not the case for {`s(c)`}, the `buyer` prefers {`s(d)`} rather than {`s(c)`}. Since the `seller` is not empowered to concede about the cost but it can concede about the other goals, its reservation value is {`expensive`}. Therefore, {`s(a)`}, {`s(b)`} and {`s(c)`} are acceptable for the `seller`. Since {`s(a)`} credulously argue for `slow` and `bad` while this is not the case for {`s(b)`} and {`s(c)`}, the `seller` prefers {`s(a)`} rather than {`s(b)`} or {`s(c)`} which are equally preferred.

## 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 their 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 our scenario.

A dialogue strategy is a plan that specifies the moves chosen by a player to achieve a particular goal. As defined in the classical game theory, this is the strategy of a player in a particular extensive game, a dialogue-game.

**Definition 9 (Strategy).** *Let* $\mathtt{DG}=\langle \mathtt{P}, \Omega_M, \mathtt{H}, \mathtt{T}, \mathtt{proto}, \mathtt{Z}\rangle$ *be a dialogue-game. A* ***strategy*** *of the player* $\mathtt{p} \in \mathtt{P}$ *is a function that assigns a move* $s_{\mathtt{p}}(h)$ *to each nonterminal history* $h \in \mathtt{H} \setminus \mathtt{Z}$ *for which* $\mathtt{T}(h) = \mathtt{p}$*. For each strategy profile* $\boldsymbol{S} = (s_{\mathtt{p}})_{\mathtt{p}\in \mathtt{P}}$*, we define the* ***outcome*** $O(\boldsymbol{S})$ *of* $\boldsymbol{S}$ *to be: either the content of the last move if the terminal history (that results when each player* $\mathtt{p} \in \mathtt{P}$ *follows the precepts of* $s_{\mathtt{p}}$*) is successful, or nothing (denoted* $\theta$*) if the terminal history is a failure.*

We consider here the MC strategy which specifies the move chosen by the player for every history when it is his turn to move.

In order to perform the MC strategy, an agent adopts a decision framework $\mathtt{DF} = \langle \mathcal{L}, \mathcal{G}, \mathcal{D}, \mathcal{B}, \mathcal{R}, \mathcal{A}sm, \mathcal{C}on, \mathcal{P}\rangle$. The latter, as illustrated in the previous section, allows to perform decision making where the decision amounts to the service it can agree on. This $\mathtt{DF}$ must be extended to perform the MC strategy. For this purpose, we incorporate in the object language $\mathcal{L}$:

- the goal `respond` (resp. `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. `loc(standstill)` or `loc(concede)`). Obviously, the multiple contraries capture the mutual exclusion of the corresponding alternatives (e.g. $\{\mathtt{loc(concede)}, \mathtt{loc(accept)}, \mathtt{loc(reject)}\} = \mathcal{C}on(\mathtt{loc(standstill)})$);
- a set of beliefs in $\mathcal{B}$, related to the dialogue state,
  - the last locution of the interlocutor (e.g. `lloc(concede)`),
  - the last offers of the players (e.g. `loffer(seller, b)` or `loffer(buyer, d)`),
  - the previous offers of the players (e.g. `poffer(seller, a)`),
  - the offers which have been already (and implicitly) rejected by the interlocutor (e.g. `rejected(d)`);

**Table 3.** The additional inference rules of the `buyer` related to the dialogue state after the move $\mathtt{mv}_2$

$$\mathtt{lloc(concede)} \leftarrow \qquad (1)$$

$$\mathtt{nbss}(0) \leftarrow \qquad (2)$$

$$\mathtt{poffer(seller,a)} \leftarrow \qquad (3)$$

$$\mathtt{loffer}(p, x) \leftarrow \mathtt{poffer}(p, x) \qquad (4)$$

$$\mathtt{loffer(seller,b)} \leftarrow \qquad (5)$$

$$\mathtt{loffer(buyer,d)} \leftarrow \qquad (6)$$

$$\mathtt{rejected}(x) \leftarrow \mathtt{poffer}(\mathtt{buyer}, x) \qquad (7)$$

- a set of assumptions in $\mathcal{A}sm$ representing that some alternatives have not been yet rejected (e.g. $\texttt{notrejected}(\texttt{c})$), that some alternatives have not been proposed in the last move (e.g. $\texttt{notloffer}(\texttt{seller}, \texttt{c})$) and that a number of standstills has not been reached (e.g. $\texttt{notnbss}(3)$).

The **preference** relation $\mathcal{P}$ on the goals in $\mathcal{G}$ is extended in order to take into account the new goals `respond` and `optimal`. Actually, these goals are incomparable with the other ones (e.g. $\texttt{cheap}, \texttt{good}, \texttt{fast}$). By adopting the MC strategy, the agent tries to utter the "optimal" utterances, `optimal`. If the agent cannot reach this goal, then the agents responds with a legal move, $\texttt{optimal}\mathcal{P}\texttt{respond}$

**Table 4.** The additional inference rules of the players related to the negotiation strategy

$$\texttt{optimal} \leftarrow \texttt{loc}(\texttt{assert}), \texttt{lloc}(\texttt{none}) \tag{8}$$

$$\texttt{optimal} \leftarrow \texttt{loc}(\texttt{reply}), \texttt{lloc}(\texttt{assert}) \tag{9}$$

$$\begin{aligned}\texttt{optimal} \leftarrow {} & \texttt{loc}(\texttt{concede}), \texttt{s}(x),\\ & \texttt{lloc}(\texttt{reply}), \texttt{notrejected}(x), \texttt{notloffer}(\texttt{seller}, x)\end{aligned} \tag{10}$$

$$\begin{aligned}\texttt{respond} \leftarrow {} & \texttt{loc}(\texttt{standstill}), \texttt{s}(x),\\ & \texttt{lloc}(\texttt{reply}), \texttt{loffer}(\texttt{buyer}, x)\end{aligned} \tag{11}$$

$$\begin{aligned}\texttt{optimal} \leftarrow {} & \texttt{loc}(\texttt{concede}), \texttt{s}(x),\\ & \texttt{lloc}(\texttt{concede}), \texttt{notrejected}(x), \texttt{notloffer}(\texttt{seller}, x)\end{aligned} \tag{12}$$

$$\begin{aligned}\texttt{respond} \leftarrow {} & \texttt{loc}(\texttt{standstill}), \texttt{s}(x)\\ & \texttt{lloc}(\texttt{concede}), \texttt{loffer}(\texttt{buyer}, x)\end{aligned} \tag{13}$$

$$\begin{aligned}\texttt{optimal} \leftarrow {} & \texttt{loc}(\texttt{standstill}),\\ & \texttt{lloc}(\texttt{standstill}), \texttt{notnbss}(3)\end{aligned} \tag{14}$$

$$\begin{aligned}\texttt{optimal} \leftarrow {} & \texttt{loc}(\texttt{concede}), \texttt{s}(x),\\ & \texttt{lloc}(\texttt{standstill}), \texttt{notrejected}(x),\\ & \texttt{notloffer}(\texttt{seller}, x), \texttt{nbss}(3)\end{aligned} \tag{15}$$

$$\begin{aligned}\texttt{respond} \leftarrow {} & \texttt{loc}(\texttt{reject}), \texttt{s}(x),\\ & \texttt{lloc}(\texttt{standstill}), \texttt{loffer}(\texttt{seller}, x),\\ & \texttt{nbss}(3)\end{aligned} \tag{16}$$

$$\begin{aligned}\texttt{optimal} \leftarrow {} & \texttt{loc}(\texttt{accept}), \texttt{s}(x),\\ & \texttt{lloc}(\texttt{reply}),\\ & \texttt{loffer}(\texttt{seller}, x)\end{aligned} \tag{17}$$

$$\begin{aligned}\texttt{optimal} \leftarrow {} & \texttt{loc}(\texttt{accept}), \texttt{s}(x),\\ & \texttt{lloc}(\texttt{concede}), \texttt{notrejected}(x),\\ & \texttt{loffer}(\texttt{seller}, x)\end{aligned} \tag{18}$$

$$\begin{aligned}\texttt{optimal} \leftarrow {} & \texttt{loc}(\texttt{accept}), \texttt{s}(x),\\ & \texttt{lloc}(\texttt{standstill}), \texttt{notrejected}(x),\\ & \texttt{loffer}(\texttt{seller}, x), \texttt{nbss}(3)\end{aligned} \tag{19}$$

and `respond` $\in$ `RV`. Since this decision framework (in particular the rules) depends on the dialogue state of the history $h$, we denote it by $\mathtt{DF}_h = \langle \mathcal{L}, \mathcal{G}, \mathcal{D}, \mathcal{B}, \mathcal{R}_h, \mathcal{A}sm, \mathcal{C}on, \mathcal{P} \rangle$.

Some inference rules of the `buyer` are depicted in Tab. 2. While the additional rules related to the dialogue state after the move $\mathtt{mv}_2$ are depicted in Tab. 3, the additional rules related to the negotiation strategy are depicted in Tab. 4. Let us consider these latter rules (8-19). While one of the players starts by asserting a first proposal (8), the other agent replies with a counter-proposal (9). 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 (14). Whenever the interlocutor has made a concession, it will reciprocate by conceding as well (12). If the agent is not able to concede (e.g. there is no other services which satisfy its constraints), the agent will standstill (13). It is worth noticing that the third step in the negotiation has a special status, in that the player has to concede (10). If the agent is not able to concede (e.g. there is no other service which satisfies its constraints), the agent will standstill (11). If an acceptable offer has been put forward by the interlocutor, the player accepts it (17-19). When the player can no more concede, it stops the negotiation (16). 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 (15). 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.

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 decisons which are preferred.

**Definition 10 (Minimal concession).** *Let* $\mathtt{DF} = \langle \mathcal{L}, \mathcal{G}, \mathcal{D}, \mathcal{B}, \mathcal{R}, \mathcal{A}sm, \mathcal{C}on, \mathcal{P} \rangle$ *be a decision framework as defined in Section 5. The decision* $\mathtt{dec} \in \mathcal{D}$ *is a* ***concession*** *wrt* $\mathtt{dec}' \in \mathcal{D}$ *iff there exists a set of decisions* $\mathtt{D}$ *such that* $\mathtt{dec} \in \mathtt{D}$ *and for all* $\mathtt{D}' \subseteq \mathcal{D}$ *with* $\mathtt{dec}' \in \mathtt{D}'$*, it is not the case that* $\mathtt{D}\mathcal{P}\mathtt{D}'$*. The decision* $\mathtt{dec}$ *is a* ***minimal concession*** *wrt* $\mathtt{dec}'$ *iff it is a concession wrt* $\mathtt{dec}'$ *and there is no* $\mathtt{dec}'' \in \mathcal{D}$ *such that*

- $\mathtt{dec}''$ *is a concession wrt* $\mathtt{dec}'$*, and*
- *there is* $\mathtt{D}'' \subseteq \mathcal{D}$ *with* $\mathtt{dec}'' \in \mathtt{D}''$ *with* $\mathtt{D}''\mathcal{P}\mathtt{D}$.

The minimal concessions are computed by our decision framework. Concerning the negotiation, we say that an offer is a minimal concession for a speaker since there is no other offer which has not been already (and implicitly) rejected by the interlocutor and which is preferred by the speaker. The minimal concessions are computed by the decision framework proposed in this section. In our example, `s(c)` is a minimal concession wrt $\mathtt{s}(d)$. Actually, the `buyer` concedes the service `s(c)` after the move $\mathtt{mv}_2$ since `s(d)` has been rejected.

## 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 (Terminaison).** *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.

**Theorem 2 (Success).** *If both players adopt a MC strategy and a potential agreement exists, then the dialogue is a success.*

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 services. In our example, `s(c)`, which fulfills the constraints of both of the participants, 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.

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 (Social welfare).** *If both players adopt a MC strategy and a potential agreement exists, then the outcome of the dialogue is Pareto optimal.*

The outcome is Pareto optimal since the concessions are minimal.

## 8 Deployment

In this paper we have proposed a realisation of the MC strategy which has been practically validated. Actually, our strategy has been tested within industrial scenarios [10] from which we have extracted an intuitive and illustrative example.

We demonstrate in [11] the use of a fully decentralised multi-agent system supporting agent-automated service discovery, agent-automated service selection, and agent-automated negotiation of Service Level Agreements (SLAs) for the selected services. The system integrates

- GOLEM[2] (Generalized OntoLogical Environments for Multi-agent systems), an agent environment middleware [18]
- MARGO[3] (A Multiattribute ARGumentation frame- work for Opinion explanation), an argumentation-based mechanism for decision-making [19]. MARGO is written in Prolog and it is distributed under the GNU GPL. MARGO is built on top of CaSAPI[4] [14] (Credulous and Sceptical Argumentation: Prolog Implementation), a general-purpose tool for (several types of) assumption-based argumentation which is also written in Prolog
- PLATON[5] (Peer-to-Peer Load Adjusting Tree Over- lay Networks), a Peer-to-Peer platform supporting multi-attribute and range queries [20]

This system is used for service composition and orchestration within the ARGUGRID[6] project. As discussed in [21], the PlATEM system (GOLEM + MARGO + PLATON) is interfaced with a semantic composition environment, allowing users to interact with their agents, and the GRIA grid middleware for the actual deployment of services.

Our system uses the MARGO tool for multi-attribute qualitative decision-making to support the decision on suitable services. Moreover, the MC strategy has been implemented by means of MARGO.

## 9 Related Works

Rahwan et al. [22] 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 (buy/sell services 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 [22].

Few concrete strategies of agents engaged in negotiations have been proposed. For instance, Sierra et al. [23] propose different strategies based on arguments such as threats, rewards or appeals (e.g. to authority). 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 [24] 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 [24], our strategy takes into account also the overt behaviour of the interlocutor, since

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[2] http://www.golem.cs.rhul.ac.uk

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

[4] http://casapi.sourceforge.net

[5] http://platonp2p.sourceforge.net

[6] http://www.argugrid.eu

this strategy is based on the reciprocity principle. More attitudes have been proposed in [25] (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 [24,25], 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 [24,25] and our work is the type of dialogues which are considered. While [25] focus on theoretical dialogues, i.e. with discursive purposes, only concerned by beliefs, we are interested on bilateral bargaining dialogues between parties which aim at reaching a practical agreement, i.e a course of action.

Alternatively, Kakas et al. [26,27] consider the argumentation-based mechanism for decision-making [28] implemented in GORGIAS [29] 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 [30,31] shares with [32] (a) the vision of argumentative deliberation for internal agent modules and (b) the assumption that an agent can prioritize its needs. However, this paper focus on a simple strategy and the study of its properties in game-theoretical terms.

Adopting a game-theory perspective as well, Riveret et al. [33] model an argumentation dialogue [34] as an extensive game with perfect and complete information. While they focus on argumentation games in adjudication debates, we have considered here negotiation games where arguments are not push forward, but instead they are used to evaluate proposals. Moreover, they abstract away for the underlying logical language, whereas we concretise the structure of arguments. Rahwan and Larson [35] consider abstract argumentation as a game-theoretic mechanism design problem. In this perspective, Rahwan and Larson [36] analyse and design intuitive rational criteria for self-interested agents involved in adjudication games. These rational criteria extend the attitudes based on the different semantics of abstract argumentation (credulous, skeptical, cautious). An agent may aim at maximising (resp. minimising) the number of its own arguments which will be accepted (resp. rejected or considered as undecided) by a judge. An aggressive agent aims at maximising the number of arguments from other agents which will be rejected by a judge. Differently from [36], we have defined the underlying logical language, and so the agents' preferences are on the goals. Therefore, our agents try to maximise the number of goals which will be promoted by their agreements, and high-ranked goals are preferred to low-ranked goals.

## 10 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: it guarantees that 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.

Our negotiation model only allows the exchange of proposals and counter-proposals. Our plan for future work is to extend it and to extend the current strategy for exchanging, generating and evaluating arguments during negotiations. The extra information carried out by these arguments will allow agents to influence each other, and so it may allow to decrease the number messages required to reach an agreement. Our negotiation model can only handle negotiation about fixed item/service. In future works, we want to apply our argumentation-based mechanism for integrative negotiations rather than distributive negotiations. Contrary to distributive negotiations, all aspects are considered in [8] for a solution that maximizes the social welfare, such as new services to accommodate each other's needs for a better deal. We aim at adopting this negotiation model and extend the strategy to generate and evaluate additional sub-items.

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