Chapter 4
Advances in Argumentation-based Negotiation

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Abstract. Argumentation-based negotiation (ABN) is a prevailing approach for automated negotiation. It is based on the exchange of arguments that allow an agent to aquire additional information about the other agents and the particular circumstances of the negotiation, and can be used for attacking or justifying offers. This is an important element in resolving conflicts that very often are due to the assumptions agents have made when making decisions and which may be found to be false in the course of the negotiating. Argumentation-based negotiation can be characterized in terms of three main topics, namely a) the *reasoning mechanisms* the agents use for negotiating and which are based on argumentation, b) the *protocols* the agents use for conveying arguments and offers and, c) the *strategies* that determine their choices at each step of the negotiation. This chapter presents argumentation-based negotiation by discussing representative works dealing with these three topics.

4.1 Introduction

During the last years argumentation based techniques have been acknowledged as powerful tools for automated negotiation and several interesting works have appeared in the literature (see e.g. [1], [2], [3], [4] [5], [6], [7], [8]), [9],[10],

F. Lopes and H. Coelho (Eds.), *Negotiation and Argumentation in MAS*

[11], [12]). A first survey has also been published in [13]. The reasons of this increasing interest for argumentation based techniques have been analyzed repeatedly in the literature. Thus, it is commonly accepted now (see e.g. [14]), that the added value of an argumentation-based negotiation (ABN) compared to a game theoretic or heuristic based one is essentially related to the possibility of the negotiating agents to exchange arguments. These arguments may concern the reasons for which an offer is proposed and could be related to the beliefs of the proposing agent. They may also concern the reasons for which an offer cannot be accepted and could also be related to the beliefs of the receiving agent. In these cases the arguments support the proposal of an offer or explain its rejection. Moreover, arguments can be also used for attacking the arguments supporting an offer or the arguments that justify the rejection of an offer. This confrontation of arguments may allow for conflict resolution in certain situations where a deadlock appears as an unavoidable outcome of the negotiation. We can therefore have some situations where a deadlock could be overcomed. This is the result of the fact that negotiating agents may find out that decisions and choices they have made based on some particular assumptions, become obsolete in the light of the new information conveyed though the exchanged arguments. Such a situation may be the case of a proposing agent who realizes, after receiving an argument, that his offer is not anymore the best option for him or that his offer cannot be accepted by his opponent due to objective reasons that he ignored at the time that he made the offer.

Negotiation among different agents is usually based on incomplete information that each agent has about the others and about the negotiation context. That means that agents propose and evaluate received offers based on assumptions made either on the profile of the other agents or on the circumstances of the negotiation. The problem is that these assumptions may be false and, thus, a deadlock could occur, due to a false piece of information, which could be avoided if the agents had the accurate information. Therefore, the exchange of arguments gives to the agents the possibility to verify the veracity of their assumptions, to clarify situations, to avoid misunderstandings and, through that, to resolve conflicts due to the lack of information. The power of ABN lies in this phenomenon, which allows agents to revise their beliefs on the basis of the accumulated extra information about the external environment in the course of the negotiation. This provides its added value compared to other type of approaches (i.e. game theoretic and heuristic based), where the only exchange among agents concerns different values of the negotiation object (e.g. price) without any further information on the reasons those values have been chosen.

Thus, ABN seems to be a powerful mechanism for situations where deadlocks are due to assumptions that are revealed as false further on. Argumentation in negotiation could also be useful in situations where a deal might become possible if one of the agents could persuade another to change his beliefs. However, this presupposes an argumentation based persuasion dialogue embedded in a negotiation dialogue, as proposed in [15] and presented later in this chapter, although the case of embedded dialogues (see e.g. [16]) is not discussed in this chapter. It is, however, obvious that if the deadlock is due to the lack of common ground, even if a belief can change, the negotiation will fail independently of the approach used.

Similarly to any other negotiation approach (i.e. game theoretic or heuristic based), *argumentation-based negotiation* deals with three main topics. The first is the *reasoning mechanisms* that agents use for making decisions and choices (e.g. best offer to propose, the acceptance or the rejection of an offer) at each step of the negotiation. However, the particularity of ABN lies in the possibility of argument exchange among the agents. Thus, decisions may refer to selecting the best (evaluated by using different methods and semantics) arguments to use for defending or attacking an offer based on different parameters (e.g. the profile of the opponent, the negotiation context). These reasoning mechanisms are based on *argumentation* and several works have been or could be used for this purpose (see e.g. [17], [18], [19], [20], [21], [22], [23], [24], [25], [26]). The second topic is the *protocols*, which define the rules of encounter (see [27]) among the negotiating agents. They specify the possible actions an agent is allowed to execute during a negotiation as a function of the action previously executed by his opponent. Several protocols have been proposed in the literature such as [5], [7], [4], [8], [6], [15], [28], [29]. Finally, the third topic is about the *strategies* that determine the choices of an agent. These choices may depend on different parameters (e.g. the agent's profile, the profile of the agent's opponent, the context of the negotiation, the time left for negotiating). Several works (e.g. [8], [30], [31], [32], [33]) have proposed different strategies although we could argue that this issue is less studied in the literature than the previous two.

The aim of this chapter is to present some of the advances that have been made over the last years in ABN concerning the three topics introduced above. We first discuss the basic characteristics of an ABN framework, followed by the presentation of some representative works on argumentation-based reasoning mechanisms that have been (or may be) used in the context of negotiation, and some representative works on protocols and strategies. We close by presenting different properties that ABN frameworks should exhibit and discuss possible research directions for future works.

4.2 Structure of Argumentation-based Negotiation Frameworks

To explain the structure of an *argumentation-based negotiation framework*, we use the work of HADIDI, DIMOPOULOS and MORAITIS [8] which is based on the work proposed by AMGOUD, DIMOPOULOS and MORAITIS [4] on a *general and unified argumentation-based negotiation framework* and the *abstract preference-based argumentation framework* proposed by AMGOUD, DIMOPOULOS and MORAITIS [19].

We assume a logical language $\mathcal{L}$ from which a set of arguments $Args(\mathcal{L})$ can be constructed. Moreover, $Args(\mathcal{L})$=$A_e \cup A_p$ with $A_e \cap A_p = \emptyset$, i.e. $Args(\mathcal{L})$ is divided into two disjoint sets of arguments A_e and A_p. The elements of A_p are the *practical arguments*, and are used to justify offers (or, more generally, decisions), whereas A_e contains the *epistemic arguments* that represent what the agent believes about the world.

Three binary preference relations are defined on arguments [19]:

- $\succeq_e$: Partial pre-order on the set A_e,
- $\succeq_p$: Partial pre-order on the set A_p,
- $\succeq_m$: defined on the sets A_e and A_p, such that $\forall\alpha \in A_e$, $\forall\delta \in A_p$, (α,δ) $\in \succeq_m$ and (δ,α) $\notin \succeq_m$. That means that any epistemic argument is stronger (preferred) than any practical argument (m stands for mixed relation).

We note that $\succ_x$, with $x \in \{e, p, m\}$, denotes the strict relation associated with $\succeq_x$. It is defined as $(a, b) \in \succ_x$ iff $(a, b) \in \succeq_x$ and $(b, a) \notin \succeq_x$. Moreover when $(a, b) \in \succeq_x$ and $(b, a) \in \succeq_x$ we will say that the arguments a and b are *indifferent*, denoted by $a \sim b$.

Conflicts between arguments in $\mathcal{A} = A_p \cup A_e$ are captured by the binary relation R [19].

- R_e: Represents the conflicts between arguments in A_e.
- R_p: Represents the conflict between practical arguments, such that R_p =$\{(\delta, \delta') \mid \delta, \delta' \in A_p, \delta \neq \delta'$ and $Conc(\delta) \neq Conc(\delta')\}$. This relation is symmetric.

- R_m: Represents the conflicts between epistemic and practical arguments s.t. $(\alpha, \delta) \in R_m$, $\alpha \in A_e$ and $\delta \in A_p$.

Thus we have $R = R_e \cup R_p \cup R_m$.

Each preference relation $\succeq_x$ ($x \in \{e, p, m\}$) is combined with the conflict relation R_x to give a *defeat relation* between arguments, noted Def_x ($x \in \{e, p, m\}$).

Therefore, (see [19]) given a set of arguments $\mathcal{A} \subseteq Args(\mathcal{L})$ and $a, b \in \mathcal{A}$ we have that $(a, b) \in Def_x$ iff $(a, b) \in R_x$, and $(b, a) \notin \succ_x$. It also holds that $Def_{global} = Def_e \cup Def_p \cup Def_m$.

From $\mathcal{L}$, a set $\mathcal{O} = \{o_1, ..., o_n\}$ of n *offers* is also identified, such that $\nexists o_i, o_j \in \mathcal{O}$ such that $o_i \equiv o_j$ where $\equiv$ is an equivalence relation associated with it. This means that the offers are different. Offers correspond to the different alternatives that can be exchanged during a negotiation dialogue.

Arguments are linked to offers through a function $\mathcal{F}$ that maps each offer to the practical arguments that support it, i.e., $\forall o \in \mathcal{O}$, $\mathcal{F}(o) \subseteq A_p$. Each argument can support only one offer, thus $\forall o_y, o_z \in \mathcal{O}, o_y \neq o_z, \mathcal{F}(o_y) \cap \mathcal{F}(o_z) = \emptyset$. When $\delta \in \mathcal{F}(o)$, we say that o is the conclusion of δ, noted Conc(δ)=o.
We assume that practical arguments supporting different offers are in conflict. Thus for any two offers o_y, o_z, $\forall a \in \mathcal{F}(o_y)$ and $\forall a' \in \mathcal{F}(o_z)$, it holds that $(a, a') \in R_p$ and $(a', a) \in R_p$.

In order to explain the relationship between practical and epistemic arguments in the context of negotiation we will need two particular notions of defeat namely *rebuttal* and *undercutting*. To explain these notions, here we consider a particular structure of arguments based on a propositional language $\mathcal{L}'$, although this negotiation framework is independent of the structure of the arguments. $\vdash$ stands for classical inference and $\equiv$ for logical equivalence.

Definition 4.1 (Argument Structure) An argument is a pair $a = (S, q)$, where q is a formula in $\mathcal{L}'$ and S a set of formulae in $\mathcal{L}'$ s.t.

- S is consistent
- $S \vdash q$
- S is a minimal set of propositions that satisfies the two previous conditions

Here S is called the support of the argument a and it is written $S = Support(a)$ and q its conclusion and it is written $q = Conclusion(a)$.

Definition 4.2 (Undercutting) Let a and b be two arguments. Argument a *undercuts* b iff $\exists\, p \in Support(b)$ s.t. $p \equiv \neg Conclusion(a)$.

Definition 4.3 (Rebuttal) Let a and b be two arguments. Argument a *rebuts* b iff $Conclusion(a) \equiv \neg Conclusion(b)$.

In the context of a negotiation, *practical* arguments *rebut* practical arguments, *epistemic* arguments *undercut* practical arguments, whereas *epistemic* arguments can both *undercut* and *rebut* other epistemic arguments. Recall that practical arguments *cannot attack* epistemic arguments.

Based on all the above elements, we assume that each agent involved in an *argumentation-based negotiation* has a *negotiation theory* which can formally be defined as follows:

Definition 4.4 (Negotiation theory [8], [4]) Let $\mathcal{O}$ be a set of options, $ag \in Ag$ an agent and Ag the set of negotiating agents. The negotiation theory $\mathcal{T}^{ag}$ of agent ag is a tuple $\mathcal{T}^{ag} =< \mathcal{A}^{ag}, \mathcal{F}^{ag}, Def^{ag}_{global} >$ where $Def^{ag}_{global} = Def_e \cup Def_p \cup Def_m$ and $\mathcal{A}^{ag} = A^{ag}_e \cup A^{ag}_p$ such that:

- $\mathcal{A}^{ag} \subseteq Args(\mathcal{L})$. This set represents all the arguments that the agent can built from his beliefs and all the arguments that support each option in $\mathcal{O}$.
- $\mathcal{F}^{ag} : \mathcal{O} \rightarrow 2^{A^{ag}_p}$ associates practical arguments to offers. It holds that $\bigcup\limits_{1 \leq y \leq n} \mathcal{F}^{ag}(o_y) = A^{ag}_p$.
- $Def^{ag}_{global} \subseteq \mathcal{A}^{ag} \times \mathcal{A}^{ag}$

In this section we presented a generic setting where a clear distinction between *practical* (supporting offers) and *epistemic* (representing beliefs) arguments is made in the ABN theory of the agents. This distinction makes explicit the influence that the beliefs of the the agents about the world may have on the decisions they make in a negotiation context. Thus, agents can use practical arguments to support their offers and epistemic arguments for defending or rejecting an offer by attacking practical or epistemic arguments of their opponents. This allows agents to influence the decisions of their opponents by ”attacking” their beliefs. However, this distinction is not made in the other works, some of which are presented in the following sections. Nevertheless, we do believe that this distinction can be integrated in any existing ABN framework. Indeed, when agents exchange arguments according to an existing (i.e. of one of these frameworks) protocol, they could make use of both types, namely practical and epistemic, without any (or minor) modification in the overall framework.

4.3 Argumentation-based Agent Reasoning

As it has been explained in the previous section, agents use *argumentation* in order to take the appropriate decisions about the offers they want to negotiate with other agents. Thus, the *reasoning mechanisms*, used by the agents for negotiating are based on argumentation frameworks. Argumentation frameworks can be divided in two categories. *Abstract* frameworks where no assumption is made on the structure of the arguments and *specific* frameworks where a specific underlying logic is assumed for representing arguments. In this section we present some representative abstract as well as specific argumentation frameworks that, as it will become apparent later, have already been or could be used in the context of negotiation.

4.3.1 Abstract Frameworks

AMGOUD, DIMOPOULOS and MORAITIS study in [19] the abstract *preference-based argumentation* framework that has been presented in section 4.2. This framework is an extension of the abstract preference-based argumentation framework presented by the same authors in [4], where given a set of *arguments* $\mathcal{A} \subseteq Args(\mathcal{L})$ and a *defeat relation* as defined above, an argumentation system $\mathcal{T} =< A, Def >$ is obtained. However, in this latter work no distinction is made between practical and epistemic arguments (i.e. as in [19]). The semantics used is Dung's *acceptability semantics* [34].

AMGOUD and PRADE [18] propose another abstract framework which is used in the context of negotiation in [6] (see section 4.4). In this abstract framework each of the negotiating agents has three knowledge bases that model his beliefs and goals in a logical language that accommodates uncertainty for knowledge and preference (encoding priority or importance) for goals. The first knowledge base $\mathcal{K}$ contains pairs of the form (k, p), where k is a proposition of the underlying logical language and $p \in [0, 1]$ is its associated certainty level. Knowledge base $\mathcal{G}$ contains similar pairs where the first element is a proposition representing a goals and the second element is the priority of that goal. Finally, $\mathcal{GO}$ is (a set of) knowledge base(s) that contains the goals of the other agent, as perceived by the agent, and their corresponding priority level.

An argument is a triple of the form $A =< S, C, d >$, where d is a decision, in the case of negotiation of an offer, S and C are subsets of $\mathcal{K}$ and $\mathcal{G}$ respectively, where the weights are ignored. An argument $< S, C, d >$ is *in favor of decision* d if $S \cup \{d\}$ is consistent, entails d, and S and C are minimal and maximal sets respectively satisfying these conditions. By taking into account the weights associated with the propositions of an argument A its strength is defined by the pair $(Level(A), Weight(A))$, where $Level(A)$ captures the certainty of the knowledge used in A and $Weight(A)$ the importance of the goals attained when the decision supported by A is realized. One criterion for choosing among different decisions (offers), called the *pessimistic criterion*, is to select the one that satisfies the most important goals of the agent, taking into account the most certain part of the knowledge. Formally, this is defined as follows.

Definition 4.5 Argument A is *preferred* to argument B, denoted $A \succeq B$, iff $min(Level(A), Weight(A)) \geq min(Level(B), Weight(B))$. A decision d is *preferred* to a decision d', denoted $d \rhd d'$, iff there is an argument A in favor of d such that for any argument B in favor of d' it holds that $A \succeq B$.

In a way similar to the pessimistic criterion described above, an *optimistic criterion* for selecting a decision (offer) is also defined. The basic idea here is to choose the decision that has the weakest possible arguments against it.

BENCH-CAPON [23], extends Dung's argumentation with two new elements, values and audiences. More specifically, a *value-based argumentation framework* is a $5 - tuple$ of the form $< A, R, V, val, R >$, where A and R are the arguments and attacking relation as in Dung's original framewrok, V is a set of values, $val : A \rightarrow V$, and P is a set of audiences. Each audience defines a different preference relation on the set of values, and via the $value$ function this preference relation is reflected on the set of arguments A. Then, argument a defeats argument b for audience d iff a attacks b and $val(b) \not\succeq_d val(a)$, where $\succeq_d$ is the preference relation for audience d. Note that if each argument maps to a different value, we obtain a preference-based argumentation system in the sense of [35], and similar to the way preferences on arguments are defined in [8]. The semantics of a value-based argumentation framework are similar to Dung's acceptability semantics. [23] discusses the merits of the framework as a means of studying persuasion in abstract argumentation.

MODGIL [22] presents an *extended argumentation framework (EAF)* where arguments express preferences between other arguments and so determine whether *attacks* succeed. This framework is based on an attack relation as it is defined by Dung, namely $\mathcal{R} \subseteq Args \times Args$, where $Args$ is a set of arguments and extends Dung's argumentation framework by including a *second attack* relation $\mathcal{D}$ that ranges from arguments X to attacks $(Y, Z) \in \mathcal{R}$. If X attacks (Y, Z) then X expresses that Z is preferred to Y. If now X' attacks (Z, Y), then X' expresses that Y is preferred to Z. In $EAFs$ it is assumed that such arguments expressing contradictory preferences must attack each other, i.e. $(X, X'), (X'X) \in \mathcal{R}$.

Definition 4.6 ([22]) An Extended Argumentation framework (EAF) is a tuple $(Args, \mathcal{R}, \mathcal{D})$ s.t. $Args$ is a set of arguments and:

- $\mathcal{R} \subseteq Args \times Args$
- $\mathcal{D} \subseteq Args \times \mathcal{R}$
- If $(X, (Y, Z)), (X', (Z, Y)) \in \mathcal{D}$ then $(X, X'), (X', X) \in \mathcal{R}$

In $EAFs$ preferences are claimed by arguments. Thus, given that an argument A attacks B it may be assumed that A defeats B only if the arguments S that one is committed to, contain no arguments considering that B is preferred to A. Therefore the success of an attack as a defeat is parameterized w.r.t. the preference arguments available in some such set S of arguments.

Definition 4.7 ([22]) Let $(Args, \mathcal{R}, \mathcal{D})$ be an EAF and $S \subseteq Args$. Then A $defeats_S$ B iff $(A, B) \in \mathcal{R}$ and $\nexists C \in S$ s.t. $(C, (A, B)) \in \mathcal{D}$. If A $defeats_S$ B and B does not $defeats_S$ A then A *strictly* $defeats_S$ B.

The author proposes extensional semantics for an EAF that is defined in the same way as in Dung's framework. However the definition of acceptability for $EAFs$ extends Dung's definition. Thus, this framework allows arguments to express preferences between other arguments by incorporating meta-level argumentation based reasoning about preferences in the object-level, the extended theory preserving the abstract nature of Dung's approach though. This work can be seen as a generalization of the frameworks proposed by PRAKKEN-SARTOR [21] and KAKAS-MORAITIS [36, 20].

4.3.2 Specific Frameworks

KAKAS and MORAITIS [36, 20] propose a framework based on *logic programming without negation as failure (LPwNF)* [37] where argumentation theories are represented at three levels. The *object level arguments* representing the decisions or the actions an agent can undertake in a specific domain of application and *priority arguments* expressing preferences on the object level arguments in order to resolve possible conflicts. Subsequently, additional priority arguments can be used in order to resolve potential conflicts between priority arguments of the previous level. This framework allows for the representation of dynamic preferences under the form of dynamic priorities over arguments.

An argumentation theory is a pair $(\mathcal{T}, \mathcal{P})$ whose sentences are formulae in the background monotonic logic $(\mathcal{L}, \vdash)$ of the form $L \leftarrow L_1, \ldots, L_n$, where $L, L_1, \ldots, L_n$ are positive or negative ground literals. Rules in $\mathcal{T}$ represent the object level arguments. For rules in $\mathcal{P}$ (priority arguments) the head L refers to an (irreflexive) *higher priority* relation, i.e. L has the general form L = $h\_p(rule1, rule2)$ (h_p stands for higher priority). The derivability relation, $\vdash$, of the background logic is given by the simple inference rule of modus ponens.

An argument for a literal L in a theory $(\mathcal{T}, \mathcal{P})$ is any subset, T, of this theory that derives L, $T \vdash L$, under the background logic. A part of the theory $\mathcal{T}_0 \subseteq \mathcal{T}$, is the background theory that is considered as a *non defeasible part* (the indisputable facts).

The framework applies Dung's acceptability semantics. A composite argument (T, P) is a counter-argument to another such argument (T', P') when they derive contrary conclusions (i.e. L and $\neg L$) and (T', P') makes the rules of its counter proof at least "as strong" as the rules of the proof of the argument (T, P) that is under attack. An attack can also occur on a contrary conclusion L that refers to the priority between rules. Therefore, for an argument (from $\mathcal{T}$) to be *admissible* it needs to take along with it priority arguments (from $\mathcal{P}$) to make itself at least "as strong" as the opposing counter-arguments. This need for priority rules can repeat itself when the initially chosen ones can themselves be attacked by opposing priority rules and again we would need to make the priority rules themselves at least as strong as their opposing ones.

We therefore have three levels in an agent's theory. In the first level we have the rules $\mathcal{T}$ that refer directly to the subject domain of the agent (the *object-level decision rules*). In the other two levels we have rules that relate to the policy under which the agent uses his object-level decision rules according to roles and context. We call the rules in $\mathcal{P}_R$ and $\mathcal{P}_C$, *role (or default context) priorities* and *(specific) context priorities respectively*.

The priorities defined by the rules in $\mathcal{P}_R$ are related to the roles agents may have in a *(default) context* (e.g. company, army). These roles define shared social relations of different forms (e.g. authority, friendship, relationship, etc.) and specify the behaviour of agents between each others. However, in a more general setting, these priorities could also be associated with *normal situations* in which an agent acts.

The default context that determines the basic roles filled by the agents is not the only environment where they could find themselves. Thus the priorities defined by the rules in $\mathcal{P}_C$ are related to the *specific contexts* the agents can find themselves. For example, two friends can also be colleagues or an officer and a soldier can be family friends in civil life. Therefore we consider a second level of context, called *specific context*, which can overturn the pre-imposed, by the default context, ordering between roles and establish a different social relation between them. For instance, the authority relationship between an officer and a soldier would change under the specific context of a social meeting at home or the specific context of treason by the officer. However, in a more general setting, these priorities could also be associated with *specific situations* in which an agent acts. Thus, more formally we have.

Definition 4.8 An agent's **argumentative policy theory or theory,** T, is a triple $T = (\mathcal{T}, \mathcal{P}_R, \mathcal{P}_C)$ where the rules in $\mathcal{T}$ do not refer to h_p, all the rules in $\mathcal{P}_R$ are priority rules with head $h\_p(r_1, r_2)$ s.t. $r_1, r_2 \in \mathcal{T}$ and all rules in $\mathcal{P}_C$ are priority rules with head $h\_p(R_1, R_2)$ s.t. $R_1, R_2 \in \mathcal{P}_R \cup \mathcal{P}_C$.

This framework is used in negotiation context [7] as it presented in the sections 4.4 and 4.5. A concrete example of argumentation theories representation is given in section 4.5.

DUNG, KOWALSKI and TONI in [24] present *assumption-based argumentation* (ABA) which has been used in negotiation in [30]. An ABA framework is a $4-tuple$ $(\mathcal{L}, \mathcal{R}, \mathcal{A}, ^{-})$, where $\mathcal{L}$ is an underlying language, $\mathcal{R}$ a set of inference rules, $\mathcal{A} \subseteq \mathcal{L}$ a set of *assumptions*, and $^{-}$ a mapping that returns the contrary $\overline{a}$ of an argument a. An argument is a deduction using the rules of $\mathcal{R}$, whose premises are all assumptions, whereas an attack is defined as follows.

Definition 4.9 (Attacks between arguments [24]) An argument a attacks an assumption s iff the conclusion of a is the contrary $\overline{s}$ of s. An argument a attacks an argument b iff a attacks an assumption in the set of assumptions on which b is based.

Definition 4.10 (Attacks between assumptions [24]) A set of assumptions A attacks a set of assumptions B iff there is an argument a based on a set of assumptions $A' \subseteq A$ which attacks an assumption in B

Based on these notions of attack, the *admissibility semantics* is defined as follows.

Definition 4.11 (Admissibility [24]) A *set of assumptions* A is *admissible* iff A does not attack itself and attacks every set of assumptions that attacks A. A *sentence* a is *admissible* iff there exists an argument for a based on a set of assumptions A_0, and A_0 is a subset of an admissible set A.

GARCIA and SIMARI proposed a framework combining logic programming and argumentation called *Defeasible Logic Programming* ($DeLP$). This framework was introduced in [25] and has been then used in *deliberation* dialogues [38]. In $DeLP$, knowledge is represented by using *facts*, *strict rules* and *weak rules* in a declarative manner. The weak rules are necessary for introducing defeasibility and they are used for representing a *defeasible* relation between pieces of the knowledge. $DeLP$ uses a defeasible argumentation inference mechanism for warranting the entailed conclusions.

A *defeasible logic program* is defined as follows:

- *Facts* that are ground literals representing atomic information or the negation of atomic information using strong negation represented by the symbol " $\sim$ " (or by "$\neg$" in other frameworks).
- *Strict rules* denoted by $L_0 \leftarrow L_1, ..., L_n$, representing non-defeasible information. The *head* of the rule, L_0 is a ground literal and the body $\{L_1, ..., L_n\}$ is a non-empty set of ground literals (e.g. $bird \leftarrow chicken$ and $\sim innocent \leftarrow guilty$).
- *Defeasible rules* denoted by $L_0 \prec\!\!\!- L_1, ..., L_n$ representing tentative information. The head L_0 is a grounded literal and the body $\{L_1, ..., L_n\}$ is a non empty set of ground literals (e.g. $\sim flies \prec\!\!\!- chicken$ or $flies \prec\!\!\!- chicken, scared$)

Based on the previous elements an argumentation structure is defined as follows:

Definition 4.12 (Argument Structure [39]) Let H be a ground literal, (Π, Δ) a $DeLP$-program and $\mathcal{A} \subseteq \Delta$. The pair $\langle \mathcal{A}, H \rangle$ is an argument structure if:

1. there exists a defeasible derivation for H from $(\Pi, \mathcal{A})$,
2. there is no defeasible derivation from $(\Pi, \mathcal{A})$ of contradictory literals,
3. and there is no proper subset $\mathcal{A}'$ of $\mathcal{A}$ s.t. $\mathcal{A}'$ satisfies (1) and (2).

A *counter-argument* is defined as follows:

Definition 4.13 (Counter-Argument [39]) An argument $\langle\ \mathcal{B}\ , S\rangle$ is a *counter-argument* for $\langle\ \mathcal{A},\ H\rangle$ at literal P, is there exists a sub-argument $\langle\ \mathcal{C},\ P\rangle$ of $\langle\mathcal{A},\ H\rangle$ s.t. P and S disagree, that, is there exist two contradictory literals that have a strict derivation from $\Pi \cup \{S, P\}$. The literal P is referred to as the counter-argument point and $\langle\ \mathcal{C}\ , P\rangle$ as the disagreement sub-argument.

To compare arguments and sub-arguments a *preference relation* among arguments is used. In $DeLP$ the *argument comparison criterion* is modular. In the literature of $DeLP$ different criteria have been defined such as a criterion based on *rule priorities*, a criterion based on *priorities among selected literals* of the program or a *syntactic criterion* called *generalized specificity*. This last criterion gives a preference to a *more precise* argument or a *more concise* argument.

The KAKAS-MORAITIS and GARCIA-SIMARI frameworks are both based on logic programming. However, they are different in many ways. For example, one difference is that the KAKAS-MORAITIS framework uses only strict rules while the GARCIA-SIMARI framework uses strict and defeasible rules. Another difference concerns the way *defeasibility* is captured/modeled. The framework of KAKAS-MORAITIS, is based on LPwNF where the *Negation as Failure* operator (i.e. "not") is removed (allowing only *strong negation* i.e. "$\neg$"), and *defeasibility* is captured through the use of priorities among rules. These priorities give the priority to the rules representing exceptional situations against the rules representing default situations. The extension that has been made in KAKAS-MORAITIS has given the possibility to integrate dynamic priorities among rules allowing the expression of dynamic preferences among arguments and thus to make context dependent decisions. In GARCIA-SIMARI the defeasibility is generated through the defeasible rules. On the other hand the priorities among arguments can be defined in this work in a modular way by using different comparison criteria. Finally, the framework KAKAS-MORAITIS has integrated abduction which reinforces the reasoning under incomplete information.

BESNARD and HUNTER in [40] present a framework where arguments are represented by using *classical logic*. Thus an argument is a set of appropriate formulae that can be used to classically prove some claim together with that claim. More formally:

Definition 4.14 (Argument [40]) An argument is a pair $\langle\Phi, \alpha\rangle$ such that

1. $\Phi \nvdash \bot$

2. $\Phi \vdash \alpha$
3. Φ is a minimal subset of Δ satisfying 2

We say that $\langle \Phi, \alpha \rangle$ is an argument for α. So α is called the *consequent (or claim)* of the argument while Φ is called the *support* of the argument. The above definition is similar to the definition 4.1 used in section 4.2.

The notion of *undercut* is also defined in order to represent how some arguments oppose the support of others. More formally:

Definition 4.15 (Undercut [40]) An undercut for an argument $\langle \Phi, \alpha \rangle$ is an argument $\langle \Psi, \neg(\Phi_1 \wedge ... \wedge \Phi_n) \rangle$ where $\{\Phi_1, ..., \Phi_n\} \subseteq \Phi$ and $\Phi \cup \Psi \subseteq \Delta$ by definition of an argument.

The notions of *maximally conservative undercuts* and *canonical undercuts* are also defined. The authors propose then the notion of *argument tree* in order to describe the various ways an argument can be challenged, as well as how the counter-arguments to the initial one can themselves be challenged, and so on recursively.

Definition 4.16 (Argument Tree [40]) An argument tree for α is a tree where the nodes are arguments such that

1. The root is an argument for α
2. For no node $\langle \Phi, \beta \rangle$ with ancestor nodes $\langle \Phi_1, \beta_1 \rangle, ..., \langle \Phi_n, \beta_n \rangle$ is Φ a subset of $\Phi_1 \cup ... \cup \Phi_n$
3. The children nodes of a node N consist of all canonical undercuts for N that obey 2.

Based on the above definition the authors define the so called *argument structure* which considers how arguments trees for and against a point (or claim) can be gathered.

Definition 4.17 (Argument Structure [40]) An argument structure for a formula α is a pair of sets $\langle \mathcal{P}, \mathcal{C} \rangle$ where $\mathcal{P}$ is the set of argument trees for α and $\mathcal{C}$ is the set of argument trees for $\neg\alpha$.

Other argumentation frameworks used in negotiation are those of PRAKKEN-SARTOR [21] (see sections 4.4 and 4.5) and FOX and colleagues ([41], [17]) (see section 4.4).

We note that there are of course other important argumentation frameworks that are not presented in this section.

4.4 Argumentation based Negotiation Protocols

Protocols define the rules of encounter [27] among the negotiating agents. Simply put, a protocol specifies the possible actions an agent is allowed to take during a negotiation as a function of the action previously taken by his opponent. In ABN, such actions are usually an agent proposing an offer, accepting an offer, rejecting an offer, arguing for supporting an offer, justifying the rejection of an offer, attacking an argument that supports or rejects an offer. Over the last years, several interesting protocols have been proposed in the literature. In all these protocols, arguments and offers are conveyed through exchanged messages usually characterized as *dialogue moves* or simply *moves*. In this section we will present a few among the most representative protocols, where moves are defined in slightly different ways.

PARSONS, SIERRA and JENNINGS [5] present a negotiation protocol where the reasoning mechanism used by the agents is based on the argumentation framework proposed by Fox and colleagues (see e.g. [41], [17]). The protocol is presented in Figure 4.1. in the form of a state transition diagram depicting the different legal states that an agent may be in during a negotiation, and therefore the legal transitions between states which an agent is allowed to take. Agents have *beliefs*, *desires* and *intentions*. The process starts (state 0) when an agent makes a proposal to another agent. Agents generate proposals by constructing arguments for their intentions and they use the move $proposal(a, b, \phi)$ in order to send them to their opponents. The protocol makes no distinction between proposals and counter-proposals, and agents can make proposals without waiting for a response to a previous proposal. Any of the proposals (except for the initial that starts the negotiation) may be a counter-proposal. The construction process also generates explanations in the form of the grounds of these arguments which can be sent to the opponent agent if desired. ϕ denotes both the proposal being made and any explanation the agent desires to give (he can of course give none). After receiving a proposal the receiver agent evaluates it and attempts to build arguments against it. If the attempt is successful, the generates arguments are used as critiques and can be sent via a $critique(a, b, \phi)$ move, but also as a means for generating counter-proposals. Thus upon the receipt of a proposal an agent can reply by making a $counter - proposal$, by making a $critique$, by accepting (with $accept(a, b, \phi)$) the proposal or withdrawing (i.e. with $withdraw$) from the process. An agent may give an explanation even in the case he accepts the proposal. A critique can also be supported by a reason. If a critique (state 2) or a counter proposal (state 3) is made, either agent may keep the process moving

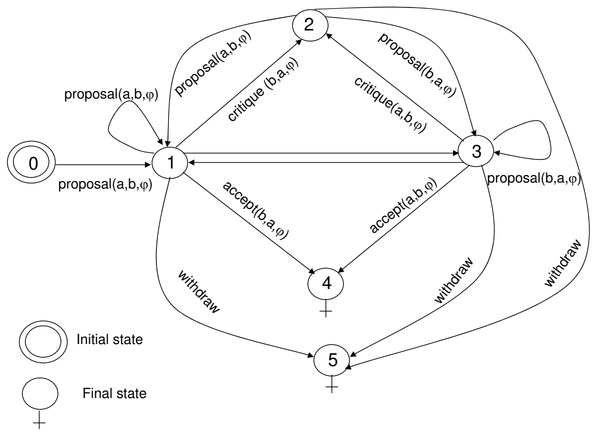

Fig. 4.1 The negotiation protocol for two agents

by making another proposal which could be evaluated and responded to in the same way as the initial one. The process iterates until one of the negotiating agents sends an $accept$ or $withdraw$.

AMGOUD, BELABBES and PRADE [6] study a negotiation protocol where the reasoning mechanism used by agents is based on the abstract argumentation framework of [18], presented in section 4.3.1. This protocol is general in the sense it can be instantiated in different ways and produce different dialogues that respect the proposed properties. It allows handling negotiation between multiple agents ($n \geq 2$), which is an interesting feature. It is run as long as there are non-discussed offers and a common agreement is still not found. The agents take turns to start new runs of the protocol and only one offer is discussed at each run.

A negotiation interaction protocol is a tuple $\langle$ Objective, Agents, Object, Acts, Replies, Wff-Moves, Dialogue, Results $\rangle$ such that:

Objective is the aim of the dialogue which is to find an acceptable offer
Agents is the set of agents participating in the dialogue, $Ag = \{a_0, ..., a_{n-1}\}$
Object is the multi-issue subject of the dialogue, denoted by the tuple $\langle O_1, ..., O_m \rangle$, $m \geq 1$. Each O_i is a variable taking its values in a set T_i. The

elements of the set of all possible offers X are x=$\langle x_1, ..., x_m \rangle$ with $x_i \in T_i$.
Acts is the set of possible negotiation acts: $Acts = \{Offer$, $Challenge$, $Argue$, $Accept$, $Refuse$, $Withdraw$, $Saynothing\}$.
Replies: $Acts \rightarrow 2^{Acts}$ is a mapping that associates each speak act to its possible replies.

- Replies($Offer$)=$\{Accept, Refuse, Challenge\}$
- Replies($Challenge$)=$\{Argue\}$
- Replies($Argue$)=$\{Accept, Challenge, Argue\}$
- Replies($Accept$)=$\{Accept, Challenge, Argue, Withdraw\}$
- Replies($Refuse$)=$\{Accept, Challenge, Argue, Withdraw\}$
- Replies($Withdraw$)=$\emptyset$

Well-founded moves=$\{M_0, ..., M_p\}$ is a set of tuples M_k=$\langle S_k, H_k, Move_k \rangle$ such that:

- $S_k \in$ Agents, the agent who plays the move is given by the function $Speaker(M_k)$=S_k
- $H_k \subseteq$ Agents $\setminus \{S_k\}$, the set of agents to whom the move is addressed to is given by the function $Hearer(M_k)$=H_k
- $Move_k$=$Act_k(c_k)$ is the uttered move where Act_k is a speech act applied to a content c_k.

Dialogue is a finite non-empty sequence of well-formed moves $\mathcal{D}$=$\{M_0, ..., M_p\}$ such that:

- M_0=$\langle S_0, H_0, offer(x) \rangle$: each dialogue starts with an offer $x \in X$
- $Move_k \neq offer(x)$, $\forall k \neq 0$ and $\forall x \in X$: only one offer is proposed during the dialogue at the first move
- $Speaker(M_k)$=$a_{kmodulon}$: the agents take turns during the dialogue
- $Speaker(M_k) \notin Hearer(M_k)$. This condition forbids an agent to address a move to himself
- $Hearer(M_0)$=a_j, $\forall j \neq i$: the agent a_i, which utters the first move addresses it to all the agents
- For each pair of tuples $M_k, M_h, k \neq h$, if $S_k = S_h$ then $Move_k \neq Move_h$. This condition forbids an agent to repeat a move that it has already played.

Result: $\mathcal{D} \rightarrow \{sucess, faillure\}$, is a mapping which returns the result of the dialogue

- Result($\mathcal{D}$)=$success$ if the preferences of the agents are satisfied by the current offer
- Result($\mathcal{D}$)=$failure$ if the most important preferences of at least one agent are violated by the current offer

The negotiation protocol is therefore based on alternating runs, each run consisting of an exchange of legal moves. The legality of moves is determined by the function Replies. This protocol is based on dialogue games. Each agent is equipped with a *commitment store* [42] containing the set of facts he is committed to during the dialogue.

AMGOUD, DIMOPOULOS and MORAITIS [4] propose a negotiation protocol where the reasoning mechanism used by the agents is based on the abstract preference-based argumentation framework of [4], discussed in section 4.3.1. It is a generic protocol for bilateral negotiations in the sense that no assumption is made about the structure of the arguments and the offers conveyed through. It can be instantiated in different ways for producing different dialogues. An interesting feature of this protocol, as opposed to other protocols, is that it considers the *evolution* of the agents' theories during the dialogue. Another novelty is the introduction of the notion of *concession* for the first time in an argumentative negotiation context. Before analyzing the protocol we define the notion of *dialogue move*.

Definition 4.18 (Move [4]) A *move* is a tuple $m_i = \langle p_i, a_i, o_i, t_i \rangle$ such that:

- $p_i \in \{P, R\}$
- $a_i \in \mathtt{Args}(\mathcal{L}) \cup \theta$[1]
- $o_i \in \mathcal{O} \cup \theta$
- $t_i \in \mathcal{N}^*$ is the target of the move, such that $t_i < i$

The function `Player` (resp. `Argument`, `Offer`, `Target`) returns the player of the move (i.e. p_i) (resp. the argument of a move a_i, the offer o_i, and the target of the move, t_i). The players are designed as P and R and are respectively the proposer and the recipient of the offer.

The two agents P and R negotiate about an object whose possible values belong to a set of offers $\mathcal{O}$. This set $\mathcal{O}$ is supposed to be known and common to both agents. Furthermore, for simplicity it is assumed that it does not change during the dialogue. The agents are equipped with theories denoted respectively $\langle \mathcal{A}^P, \mathcal{F}^P, \succeq^P, \mathcal{R}^P, \mathtt{Def}^P \rangle$, and $\langle \mathcal{A}^C, \mathcal{F}^C, \succeq^C, \mathcal{R}^C, \mathtt{Def}^C \rangle$ as it is presented in section 4.3.1. The two theories may be different in the sense that the agents may have different sets of arguments and different preference relations. Worst yet, they may have different arguments in favor of the same offers. Moreover, these theories may *evolve* during the dialogue.

Before defining a negotiation dialogue it is necessary to define the notion of a legal continuation of moves.

[1] In what follows θ denotes the fact that no argument, or no offer is given

Definition 4.19 (Legal move [4]) A move m is a *legal continuation* of a sequence of moves $m_1, \ldots, m_l$ iff $\nexists j, k < l$, such that:

- $\texttt{Offer}(m_j) = \texttt{Offer}(m_k)$, and
- $\texttt{Player}(m_j) \neq \texttt{Player}(m_k)$

The idea here is that if the two agents present the same offer, then the dialogue should terminate, and there is no longer possible continuation of the dialogue.

An ABN dialogue is therefore formally defined as follows:

Definition 4.20 (Argumentation-based negotiation [4]) An *argumentation-based negotiation dialogue* d between two agents P and R is a non-empty sequence of moves $m_1, \ldots, m_l$ such that:

- $p_i = P$ iff i is even and $p_i = R$ iff i is odd
- $\texttt{Player}(m_1) = P$, $\texttt{Argument}(m_1) = \theta$, $\texttt{Offer}(m_1) \neq \theta$, and $\texttt{Target}(m_1) = \text{nil}$[2]
- $\forall\, m_i$, if $\texttt{Offer}(m_i) \neq \theta$, then $\texttt{Offer}(m_i) \rhd o_j, \forall\, o_j \in \mathcal{O} \backslash (\mathcal{O}_{i,r}^{\texttt{Player}(m_i)} \cup ND_i^{\texttt{Player}(m_i)})$
- $\forall i = 1, \ldots, l$, m_i is a legal continuation of $m_1, \ldots, m_{i-1}$
- $\texttt{Target}(m_i) = m_j$ such that $j < i$ and $\texttt{Player}(m_i) \neq \texttt{Player}(m_j)$
- If $\texttt{Argument}(m_i) \neq \theta$, then:
  - if $\texttt{Offer}(m_i) \neq \theta$ then $\texttt{Argument}(m_i) \in \mathcal{F}(\texttt{Offer}(m_i))$
  - if $\texttt{Offer}(m_i) = \theta$ then $\texttt{Argument}(m_i)$ $\texttt{Def}_i^{\texttt{Player}(m_i)}$ $\texttt{Argument}(\texttt{Target}(m_i))$
- $\nexists\, i, j \leq l$ such that $m_i = m_j$
- $\nexists\, m \in \mathcal{M}$ such that m is a legal continuation of $m_1, \ldots, m_l$

The symbol $\rhd$ represents a preference relation which can be defined in different ways, whereas ND denotes the non-defendable offers (i.e. the agent makes a *concession*). These are offers for which the agent has no other supporting (and not defeated) arguments.

KAKAS and MORAITIS [7] study a negotiation protocol where the reasoning mechanism used by the agents is based on the argumentation framework of [20], presented in 4.3.2. The agents negotiate by proposing offers and counter offers. The negotiation consists of two phases: a first phase where agents make proposals and counter-proposals and a second phase, which

[2]The first move has no target.

is called *conciliation phase*. A proposal is accompanied by an *evaluation* of the previously received proposal which can be considered as a *critique* (see [5]). The negotiation object(s) (e.g. the price of a product) decided by the agents is associated to a class of goals for each agent (e.g. sell at high prices for a seller and buy at low prices for a buyer). During the negotiation the agents accumulate extra information about the external environment via *supporting information* conditions that each agent generates to support, in his own theory, the argument for his offer. This supporting information is then associated with the offer and in some cases it can be seen as means for extending the negotiation object. The various items of supporting information are collected together and built gradually during the negotiation, thus allowing a form of incremental deliberation of the agents as they acquire more information. This accumulated supporting information agreed by both agents and taken into account by the deliberation mechanism during the dialogue can be seen as an evolution of the theories in the spirit of the definition in [4].

The advantage of this protocol is the possibility for an agent to enter to a *conciliation phase* when he cannot produce a new offer with supporting information for his goal. So before leading the negotiation to a failure this phase gives the possibility to this agent to make a concession with respect to the goal of his opponent by proposing to accept this goal, provided that the latter will accept some conditions. This corresponds to an extension of the negotiation object and may allow to reach a compromise when a failure seems unavoidable in the first phase. Another important feature of this protocol is the possibility for the agents to use meaningful supporting information due to the integration of *abduction* in the argumentation framework used for agent reasoning.

In this protocol three *dialogue moves* are used, namely $propose$ for sending the three possible types of proposals (see Algorithm 1), $reject$ in the case of failure and $accept$ in the case of agreement. This negotiation protocol operates via the alternate application of the Algorithm 1 by each of the two negotiating agents. This defines formally the steps of the negotiation process. Note that in the presentation of this algorithm, it is assumed that agent X is applying it. Agent Y applies exactly the same algorithm, and, therefore, the reader has only to replace X with Y in order to see how a negotiation process between two agents would evolve.

Below we will denote by G^X the argumentation goal corresponding to an offer O^X and by $e_n^{X \rightarrow Y}$ the evaluation by agent X of the supporting information sent by agent Y. Also we will denote by $s^{I,J}$ the supporting

Algorithm 1 Negotiation protocol [7]

S={}; n=0
agent X receives a proposal O from an agent Y
if O is of the form $propose(O^Y, e_{n-1}^{Y \to X}, s_n^{Y,Y})$ **then**
  $e_n^{X \to Y} \leftarrow evaluate(X, s_n^{Y,Y})$;
  $S \leftarrow update(S, e_{n-1}^{Y \to X} \cup e_n^{X \to Y})$
  if $e_n^{X \to Y}$ = $s_n^{Y,Y}$ and $accept(X, G^Y, S)$ **then**
    $END(agreement, O^Y)$
  else
    $n \leftarrow n + 1$
    find $s_n^{X,X}$ s.t. deliberate($X, G^X, S; s_n^{X,X}$)
    and $s_n^{X,X} \neq s_i^{X,X}, \forall i < n$
    if s_n^X exists **then**
      $propose(O^X, e_{n-1}^{X \to Y}, s_n^{X,X})$ to Y
    else
      (ENTER CONCILIATION PHASE) $m = 0$
      $S \leftarrow update(S, e_n^{Y \to X})$
      $m \leftarrow m + 1$
      find $s_m^{X,Y}$ s.t. deliberate($X, G^Y, S; s_m^{X,Y}$)
      and $s_m^{X,Y} \neq s_j^{X,Y}, \forall j < m$
      if $s_m^{X,Y}$ exists **then**
        $propose(O^Y, \otimes, s_m^{X,Y})$ to Y
      else
        $END(Failure)$
      end if
    end if
  end if
end if
if O is of the form $propose(O_Y, e_m^{Y \to X}, \otimes)$ **then**
  $goto 16$
end if
if O is of the form $propose(O^X, \otimes, s_k^{Y,X})$ **then**
  $e_k^{X \to Y} \leftarrow evaluate(X, s_k^{Y,X})$
  $S \leftarrow update(S, e_k^{X,Y})$
  if $e_k^{X \to Y}$ = $s_k^{Y,X}$ and $accept(X, G^X, S)$ **then**
    $END(agreement, O^X)$
  else
    $propose(O^X, e_k^{X \to Y}, \otimes)$
  end if
end if

information generated by agent I, for the goal of agent J, (I,J can take the values X or Y).

Each agent (agent X here) can receive three types of proposals. In the first one, denoted by $propose(O^Y, e^{Y\to X}, s_n^{Y,Y})$, another agent, Y, sends to X an offer, O^Y, with a new alternative supporting information, $s_n^{Y,Y}$. This proposal also includes, $e_{Y\to X}$, which is the evaluation by Y of the supporting information sent to him in the previous step by X for its offer O^X. In the second type of proposal, denoted by$propose(O^Y, e_m^{Y\to X}, \otimes)$, the other agent, Y, sends to X (via step 37 for agent Y) his answer to an offer made previously by X to consider the offer O^Y of Y, i.e. X has entered the conciliation phase and Y is responding to this. This answer contains the evaluation, $e_n^{Y\to X}$, by Y of the terms (or conditions) proposed by X in order to accept an offer O^Y satisfying the goal of Y. Finally, in the third type of proposal, denoted by $propose(O^X, \otimes, s_n^{Y,X})$ another agent, Y, sends to X an answer where he proposes the conditions, $s_n^{Y,X}$, under which he could accept the offer O^X of X, i.e. Y has previously entered the *conciliation phase*.

HADIDI, DIMOPOULOS and MORAITIS [8] present an argumentative version of the well known *alternating offers negotiation protocol* [43]. The reasoning mechanism used by the agents is based on the abstract preference-based argumentation framework of [19], presented in section 4.2. This protocol is generic in the sense that no assumption is made about the structure of the arguments and the offers conveyed through. It can be also instantiated to produce different specific dialogues. Moreover, it takes into account the evolution of the negotiation theories like in [4]. A main difference with the other protocols that appear in the literature is that for the first time agents can use both *epistemic* and *practical* arguments for defending and attacking offers during the negotiation (as it is shown in section 4.2).

In this work the classical alternating offers protocol has been adapted to the case of ABN. To achieve this, the notion of a *round* is extended to include, besides the classic *propose*, *accept* or *reject* messages, the possibility to *argue* in order to defend or attack an offer. In addition, *propose* and *argue* are accompanied by *supporting (practical or epistemic) arguments*.

Arguments and offers are conveyed through *dialogue moves* (or simply *moves*). A move is denoted by $m_{r,g}$, whereas $r \geq 1$ is the round (and therefore the offer which is currently discussed), and $g \geq 1$ the number (order) of the move in that round. In the *argumentative alternating offers protocol* the following moves are used. In all moves ag_i and ag_j are the participating agents and $o_y \in O$ is an offer belonging to the set of offers O. The semantics of used moves is as follows.

- $Propose(ag_i, ag_j, o_y, \delta)$ where $\delta \in \mathcal{F}^{ag_i}(o_y)$ (see definition 4.4). This move allows agent ag_i to propose an offer o_y to agent ag_j, along with a practical argument δ that supports it.
- $Argue(ag_i, ag_j, a, Target)$, where $a \in A^{ag_i}$ and $Target$ is the move the argument of which is attacked by a or nil. This move allows agent ag_i to argue by defending his own offer o_y or to counter-attack an offer sent by ag_j. The arguments used in this move satisfy the following conditions
  - If $Target$ =nil then $a \in \mathcal{F}^{ag_i}(o_y)$, i.e., a is a practical argument that support the offer o_y.
  - If $Target$ ≠nil then $a \in A_e^{ag_i}$ is an epistemic argument presented against the argument of $Target$. Thus, an agent can't present an argument against his own arguments.
- $Reject(ag_i, ag_j, o_y)$. This move is sent by ag_i to inform ag_j that he has no arguments to present and he does not accept ag_j's offer.
- $Nothing(ag_i, ag_j)$. This move notifies ag_j that ag_i has no arguments to present and he either still considers his offer as a most preferred one for him (when he is the proposer), or believes that he has better options that the current offer (when he is the recipient of an offer sent by the other agent).
- $Accept(ag_i, ag_j, o_y)$. This move is used by agent ag_i to notify that he accepts the offer o_y made by ag_j.
- $Agree(ag_i, ag_j)$. This move means that ag_i now believes that his current offer is not optimal for himself and therefore accepts the arguments sent by ag_j. Agent ag_j starts a new round.
- $Withdraw(ag_i, ag_j)$. This move indicates that agent ag_i withdraws from negotiation.
- $final(ag_i, ag_j)$. This is a shorthand for $Propose(ag_i, ag_j, o_y, \emptyset)$ and is used during a final round of the negotiation.

The following functions retrieve the parameters of the moves.

- $Performative(m_{r,g})$ returns one of $Propose, Argue,$ $Nothing, Reject, Accept, Withdraw, Agree.$
- $Agent(m_{r,g})$ returns the agent who sent the move.
- $Offer(m_{r,g})$ returns the offer sent in the round r.
- $Argument(m_{r,g})$ returns the argument sent to the other agent.
- $Targ(m_{r,g})$ returns the target of the move.

Finally, the following hold.

- If $Performative(m_{r,g})$=$Propose$ then $Argument(m_{r,g}) \in A_p^{ag_i}$ where $A_p^{ag_i}$ is the set of practical arguments
- If $Performative(m_{r,g})$=$Argue$ then $Argument(m_{r,g}) \in A_e^{ag_i} \cup A_p^{ag_i}$ where $A_e^{ag_i}$ is the set of epistemic arguments

A round takes place in alternating way between two agents, the proposer of the offer and the recipient of the offer. A round is defined formally as follows.

Definition 4.21 (Round [8])[3] A round r between two agents is a non empty sequence of moves $m_{r,1}, ..., m_{r,n}$, such that for $1 \leq g < n$ or $1 \leq g \leq n$:

- $Agent(m_{r,g}) \neq Agent(m_{r,g+1})$
- If $Odd(g)$ then $Performative(m_{r,g}) \in \{Propose, Argue, Agree, Nothing, Withdraw\}$.
- If $Even(g)$ then $Performative(m_{r,g}) \in \{Argue, Reject, Accept, Nothing, Withdraw\}$.
- $Performative(m_{r,1}) \in \{Propose, Withdraw\}$.
- If $Performative(m_{r,g}) = Performative(m_{r,g+1}) = Withdraw$ then the dialogue ends with a disagreement.
- If $Performative(m_{r,g})$=$Argue$ then:
  - If $Targ(m_{r,g}) \neq$ nil then $Targ(m_{r,g})$=$m_{r,g'}$ with $g' < g$, $Argument(m_{r,g})$ $Def_{global}^{Agent(m_{r,g})}$ $Argument(m_{r,g'})$ and $Agent(m_{r,g}) \neq Agent(m_{r,g'})$. Here the agent sends an argument which attacks one presented previously by the other agent in the same round.
  - Else $Agent(m_{r,g})$=$Agent(m_{r,1})$ and $Argument(m_{r,g}) \neq Argument(m_{r,g'})$ for all $1 \leq g' < g$ and $\{Argument(m_{r,g}), Argument(m_{r,g'})\} \subseteq \mathcal{F}^{Agent(m_{r,1})}(Offer(m_{r,1}))$. Here the agent sends a new argument to support his offer. In this protocol, unlike [4], an agent can use more than one practical argument for supporting the same offer during a round.
- If $Performative(m_{r,n}) = Accept$ then $Offer(m_{r,1})$ is the outcome of the dialogue which terminates with agreement.
- If $Performative(m_{r,n}) \in \{Agree, Reject\}$ then a new round $r+1$ starts with $Agent(m_{r+1,1}) \neq Agent(m_{r,1})$, i.e. with the other agent as proposer.

[3]This version fixes two minor problems of the original version

- If $Performative(m_{r,g})$=$Nothing$ then $Performative(m_{r,g+1}) \in \{Nothing, Reject\}$.

So in this work an argumentative alternating offers negotiation dialogue can be defined as follows:

Definition 4.22 (Argumentative alternating offers dialogue) An argumentative alternating offers dialogue d between two agents α, β is a non-empty sequence of rounds d=$\{r_1...r_\lambda\}$ between α and β.

VAN VEENEN and PRAKKEN [15] present a negotiation protocol based on that of Wooldridge and Parsons [29] which embeds the persuasion dialogue of Prakken [44]. The argumentation based reasoning is based on the framework of Prakken and Sartor [21]. In this protocol the agents can ask the reasons of a rejection, and then, once these reasons are given, they attempt to persuade each other that a reason is or is not acceptable. The protocol has social semantics (see chapter 5) as it does not refer to the internal state of the agents. Table 4.1 presents the speech acts and the possible replies in the combined communication language $\mathcal{L}_c$ used by the agents. These speech acts characterize the *dialogue moves* used in the protocol by the agents. The definition of the moves is a combination of the definitions presented previously.

A $reject(\phi)$ move is used to signify the existence of a conflict between the preferences of an agent and the offer that he receives. A reply to this move with the move $why{-}reject(\phi)$ may generate a reply (other than a withdrawal) with the persuasion move $claim(\neg\phi)$ inducing a shift from the negotiation dialogue to a persuasion dialogue. Statements made during the persuasion involve commitments that reflect the preferences of the agents. These commitments are used for restricting other negotiations.

The definition of the combined protocol P^c is based on the definition of the persuasion protocol P^p and the speech acts of the combined language presented in Table 4.1.

Definition 4.23 (Protocol P^p for language $\mathcal{L}_c^p$ [15]) For all moves m it holds that $m \in P^p(d)$ iff m satisfies all of the following rules:

- R_1 : $pl(m)$=$T(d)$
- R_2 : If $d \neq d_0$ and $m \neq m_1$, then $s(m)$ is a reply to $s(t(m))$ according to $\mathcal{L}_c^p$
- R_3 : If m replies to m', then $pl(m) \neq pl(m')$
- R_4 : If there is an m' in d such that $t(m)$=$t(m')$ then $s(m) \neq s(m')$
- R_5 : If d=d_0, then $s(m)$ is of the form $claim(\phi)$
- R_6 : If $s(m)$=$retract(\phi)$ then $C_s(d, m) \nvdash \phi$

Acts	Attacks	Surrenders
Negotiation		
request(ϕ)	offer(ϕ') withdraw	
offer(ϕ)	offer(ϕ') ($\phi \neq \phi'$) reject(ϕ) withdraw	accept(ϕ)
reject(ϕ)	offer(ϕ') ($\phi \neq \phi'$) why-reject(ϕ) withdraw	
accept(ϕ)		
why-reject(ϕ)	claim($\neg\phi$) withdraw	
withdraw		
Persuasion		
claim(ϕ)	why(ϕ)	concede(ϕ)
why(ϕ)	argue(A) (conc(A)=ϕ)	retract(ϕ)
argue(A)	why(ϕ) ($\phi \in$ prem(A)) argue(B) (B defeats A)	concede(ϕ) ($\phi \in$ prem(A) or ϕ=conc(A))
concede(ϕ)		
retract(ϕ)		

Table 4.1 Speech Acts of the negotiation protocol of [15]

- R_7 : $C_s(d, m)$ is consistent
- R_8 : if m is a replying move, then m is relevant in d

where $pl(m)$ is the player of m, d is a legal dialogue, $s(m)$ the speech act performed in the move, $t(m)$ the target of the move, $T(d)$ denotes the player whose turn it is to move in d, $C_s(d, m)$ denotes the commitments and $\mathcal{L}_c^p$ is the language that defines the speech acts of the persuasion dialogue (see the second part of Table 4.1).

The combined protocol is thus defined as follows:

Definition 4.24 (Protocol P for $\mathcal{L}_c$ [15])
For all dialogues d and moves m it holds that $m \in P(d)$ iff m satisfies all the following rules:

- R_1 : m satisfies $R_1 - R_8$ of definition 4.23 but where in R_2, L_c^P is replaced by L_c and in R_5, $claim(\phi)$ is replaced by $request(\phi)$
- R_2 : If $s(m)$=$offer(\phi)$ and $s(m_1)$=$request(\phi')$ then $\{\phi, \phi'\}$ is consistent and ϕ contains at least the same issues as ϕ'
- R_3 : If $s(m)$=$offer(\phi)$ then of no $m' \in d$, $s(m')$=$offer(\phi)$
- R_4 : If $s(m)$=$accept(\phi)$ then ϕ contains no variables
- R_5 : If m is a negotiation locution, then m replies to the most recent target to which a reply is legal
- R_6 : If m is a negotiation locution, then there is no move $m' \in P(d)$ s.t. $s(m')$ is a persuasion locution
- R_7 : If $s(m)$=$offer(\phi)$ then $C_s(d) \cup \{\phi\}$ and $C_{\overline{s}}(d) \cup \{\phi\}$ are consistent

Rule R_1 generalizes the general structure of the persuasion protocol to the combined protocol and says that each combined dialogue starts with a request for an offer. Rules $R_2 - R_4$ formalize the negotiation protocol rules of [29] that are not implied by R_1. Rule R_5 prevents unnecessary negotiation backtrack moves while rules R_6 and R_7 concern the embedding of persuasion in negotiation.

4.5 Argumentation based Negotiation Strategies

Strategies determine the different choices an agent makes at each step of the negotiation. These choices may concern for example the acceptance or the rejection of an offer (e.g. considering the time left for negotiating), the possibility to make a concession (i.e. propose a less preferred offer for him and better for his opponent) or to withdraw from the negotiation. They may depend on different parameters such as the agents' profiles, the loss of profit due to a negotiation failure compared to the gain earned by the acceptance of an offer belonging to the less preferred ones, etc.

Moreover, negotiating agents must be able to adapt their negotiation strategies to the changing environment as well as the new information that is exchanged in the course of the negotiation. The agents must be able to deliberate on alternative choices and take decisions which are conditional on assumptions about the environment of the negotiation (e.g. assumptions on the preferences of other agents, the specific conditions in the current negotiation context). Thus the agents must be able to express, in a simple and direct way, policies that can vary according to the particular circumstances in which they are applied.

Argumentation is a powerful means for satisfying all these requirements. As it has been shown in section 4.2, offers are linked to supporting arguments and preferences on the offers are computed on the basis of the preferences the agents have among the supporting arguments. These preferences may depend on the different parameters discussed above. We need, therefore, argumentation frameworks capable of capturing those situations where arguments and their strength depend on the particular context the agents find themselves in, thus allowing to adapt their decisions in a changing environment.

In this section we will present a typology of representative strategies including strategies conditional on different agent *attitudes (or profiles)* and/or *the negotiation context*, strategies based on the *notion of concession* as in game theoretic approaches, and strategies based on *normative* and *teleological* issues.

4.5.1 Typology of negotiation strategies

The argumentation framework proposed by KAKAS and MORAITIS [20] (and presented in section 4.3.2) is giving the possibility to take into account the profiles (or the roles) of the negotiating agents as well as the negotiation context. It is therefore very suitable for representing *adaptive negotiation strategies* for dynamic environments (see [7], [45]). In addition, aiming to provide agents with a level of robustness in the face of incomplete information from the negotiation environment, *abduction* is integrated within the argumentation framework. For illustrating the representation powerfulness of this framework we propose the following example:

Let's consider the goal of a seller agent X is $G^X = sell(prd, buyer, high\_price)$. There are two ways or methods to get this "$high\_price$", either through a *normal payment method* or through *payment via installments*. The *object-level theory* T^X (see section 4.3.2) may contains the rules:

$r_1 : sell(Prd, Ag, high\_price, method1) \leftarrow pay\_normal(Ag, Prd)$
$r_2 : sell(Prd, Ag, high\_price, method2) \leftarrow pay\_install(Ag, Prd)$
$r_3 : sell(Prd, Ag, low\_price) \leftarrow pay\_cash(Ag, Prd)$
$r_4 : sell(Prd, Ag, Price) \leftarrow sell(Prd, Ag, Price, Method)$
$r_5 : \neg sell(Prd, Ag, P_2) \leftarrow sell(Prd, Ag, P_1), P_2 \neq P_1$
$r_6 : \neg sell(Prd, Ag, P, M_2) \leftarrow sell(Prd, Ag, P, M_1), M_2 \neq M_1$

The *roles (or profiles)* P_R^X and *context* P_C^X *priority theories* (see section 4.3.2) are given below. They contain the policy of the seller under which he should negotiate with the various types of customers. For example, he should prefer to sell with normal paying conditions (e.g. cash or visa) over payment by installments when the buyer is a normal customer (see R_1). Also that there is always a preference to sell at high price (see R_2, R_3) but for regular customer there are conditions under which the seller would sell at low price (see R_4, R_5). This low price offer to a regular customer applies during a sales season (see C_3, C_4) and not during a high season (see C_1, C_2) where the preference of a high price is stronger.

$R_1 : h\_p(r_1, r_2) \leftarrow normal(A)$
$R_2 : h\_p(r_1, r_3)$
$R_3 : h\_p(r_2, r_3)$
$R_4 : h\_p(r_3, r_1) \leftarrow regular(A), buy\_2(A, Prd)$
$R_5 : h\_p(r_3, r_1) \leftarrow regular(A), late\_del(A, Prd)$

$C_1 : h\_p(R_2, R_4) \leftarrow high\_season$
$C_2 : h\_p(R_2, R_5) \leftarrow high\_season$
$C_3 : h\_p(R_4, R_2) \leftarrow sales\_season$
$C_4 : h\_p(R_5, R_2) \leftarrow sales\_season$
$C_5 : h\_p(R_4, R_5)$

AMGOUD and KACI [31] present an interesting study of the influence of agents' profiles on the negotiation strategies. They define the strategy on the basis of the mental states of the agents, namely 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 word, goals are *motivational* attitudes and intrinsic to agents and represent what the agents wants to achieve (or to get) and rejections are also *motivational* attitudes intrinsic to the agent and represent what the agent rejects .

Offers selection is done by following a three steps process:

- defining a relation $\succeq$ between $\mathcal{B}$, $\mathcal{R}$ and $\mathcal{G}$. The ordering on $\mathcal{B}$, $\mathcal{R}$ and $\mathcal{G}$ determines the selection of offers and we may not have the same set of candidate offers according to $\mathcal{G} \succeq \mathcal{R}$ or $\mathcal{R} \succeq \mathcal{G}$. Beliefs should also have a priority over rejections. The feasibility of an offer is more important than its acceptability. Thus we have the ordering $\mathcal{B} \succ \mathcal{R}$ and $\mathcal{B} \succ \mathcal{G}$. However, the ordering between $\mathcal{G}$ and $\mathcal{R}$ is not easy to guess, and depends on agents'profile. Different profiles can be defined according to the ordering between $\mathcal{G}$ and $\mathcal{R}$.

- defining *criteria* (i.e. $\Vdash_{c_a}$) for selecting *acceptable* offers
- defining *criteria* (i.e. $\Vdash_{c_s}$) for selecting *satisfactory* offers

The definition of sets of acceptable and satisfactory offers is based on $\mathcal{B}$, $\mathcal{R}$ and $\mathcal{G}$ and the criteria $\Vdash_{c_a}$ and $\Vdash_{c_s}$. In the following definition the term *candidates* is used as it may happen that several offers are equally preferred by the agents. A strategy is formally defined as follows.

Definition 4.25 (Strategy [31]) 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 $\underline{S} \subseteq X$ of candidate offers.

On the basis of the relation between $\mathcal{R}$ and $\mathcal{G}$ three profiles of agents are defined, namely *consensual* agent ($\mathcal{R} \approx \mathcal{G}$ both sets have the same preference), *cautious agent* ($\mathcal{R} \succ \mathcal{G}$), *adventurous agent* ($\mathcal{G} \succ \mathcal{R}$).

An offer x can be characterized in terms of different notions such as *acceptability level*, $Level_A(x)$ (satisfaction of the greater number of integrity constraints induced by rejections), *acceptability criterion* (acceptable offers are those satisfying the more important integrity constraints), *cardinality-based* criterion (x is satisfactory when it satisfies a maximum of prioritized goals), *disjunctive satisfaction level*, $Level_{DS}(x)$ (satisfactory offers are those that satisfy at least one prioritized goal), *disjunctive-based criterion* (x is satisfactory when satisfies at least one prioritized goal), *conjunctive satisfaction level*, $Level_{CS}(x)$ (satisfactory offers are the ones having a small satisfaction level).

Based on these notions several strategies are proposed. For their formal definitions the reader is referred to the original paper.

- *Drastic strategy*: candidate offers are those that are both acceptable (i.e. falsify all rejections) and satisfactory (i.e. satisfy all the goals)
- *Optimistic strategy*: this strategy looks for the offers that falsify as many prioritized rejections as possible, and satisfy at least one prioritized goal
- *Pessimistic strategy*: this strategy selects offers that satisfy as many prioritized integrity constraints and goals as possible
- *Requiring strategy*: among feasible offers this strategy selects first acceptable offers that falsify as many prioritized rejections as possible, and among acceptable offers it selects those that satisfy as many goals as possible
- *Relaxed strategy*: among feasible offers this strategy selects first those that falsify as many prioritized rejections as possible, and among

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

Table 4.2 Relation between agent profiles and strategies in [31].

acceptable offers it selects those which satisfy at least one prioritized goal

Table 4.2 summarizes the relation between the possible agents profiles and the different negotiation strategies.

In *game theoretic negotiation* approaches the notion of strategy is usually linked to the notion of *concession*. However, this notion has been introduced and formally defined in an ABN approach only recently by AMGOUD, DIMOPOULOS and MORAITIS [4]. Basically the idea is that agents make *concessions* by proposing or accepting less preferred offers with respect to a preference relation which can be defined in different ways.

Following this idea, HADIDI, DIMOPOULOS and MORAITIS [8] study a specific way of implementing a *concession*. This work presents algorithms that implement a bilateral negotiation strategy based on the theory of the agents T, their preference $\trianglerighteq$ on the set of offers and the alternating offers protocol (presented in section 4.4), where a concession is possible for an agent after the rejection of his offer. The authors propose a specific definition for the preference relation $\trianglerighteq$, but other alternative definitions are possible.

The main procedure of the strategy is $negotiate(T, O, outcome)$, depicted in Algorithm 2. The reader is pointed to the original paper for a description of the procedures invoked in the algorithm. Procedure $negotiate(T, O, outcome)$ accepts as parameters the agent theory T, and the set of possible offers O, and returns an $outcome$ that can be either an offer, when an agreement is reached, or nil when the negotiation fails. Set O contains an option o_D representing the possibility that the agent leaves the negotiation without an agreement, and therefore remains in the same state that he was initially.

Algorithm 2 Negotiation strategy [8]

$r = 1$; $g = 1$; $own = false$; $T_{1,1} = T$
$Received = \emptyset$; $Offered = \emptyset$; $UsedAtt = \emptyset$
if Agent proposes first **then**
  Call $proposal(T_{1,1}, O, o^{cur}, a^{curr})$
  Send $Propose(o^{cur}, a^{cur})$; $own = true$
end if
while true **do**
  $g = g + 1$; Get $m_{r,g}$
  Incorporate $argument(m_{r,g})$ into $T_{r,g}$
  switch $Performative(m_{r,g})$ **do**
  case $Argue$
  Add $argument(m_{r,g})$ to $Received$
  if own **then**
    Call $defend(T_{r,g}, O, o^{cur}, Received, UsedAtt)$
  else
    Call $check(T_{r,g}, O, o^{cur}, Received, UsedAtt)$
  end if
  case $Propose$
  Add $argument(m_{r,g})$ to $Received$
  $o^{cur} = Offer(m_{r,g})$
  Add o^{cur} to $Offered$; $r = r + 1$; $g = 1$;
  Call $check(T_{r,g}, O, o^{cur}, Received, UsedAtt)$
  case $Agree$
  $Call\ proposal(T_{r,g}, O, o^{cur}, a^{curr})$
  if $o^{cur} = nil$ **then**
    Send $withdraw$; $g = g + 1$
  else
    Send $Propose(o^{cur}, a^{cur})$
    $Received = \emptyset$; $UsedAtt = \emptyset$
    $r = r + 1$; $g = 1$; $o = o^{cur}$; $own = true$
  end if
  case $Nothing$
  Call $nothing - reply(T_{r,g}, O, own, o^{cur}, Received, UsedAtt)$
  case $Reject$
  $O = O - \{o^{cur}\}$; $own = false$
  Remove from $T_{r,g}$ all arguments of $\mathcal{F}(o^{cur})$
  case $Withdraw$
  Call $withdrawal(T_{r,g}, O, Offered, outcome)$
  return $outcome$ and $exit$
  case $Accept$
  $outcome = o^{cur}$
  return $outcome$ and $exit$
  case $Final$
  $outcome = Offer(m_{r,g})$
  return $outcome$ and $exit$
  end
end while

Therefore, offers that lead to situations that are less desirable than his current state are less preferred by the agent. This option o_D corresponds to what in classical negotiation theory is referred to as *reservation value*. The semantics of the dialogue moves has been presented in section 4.4.

This negotiation strategy allows an agent to support his offers by using different arguments during a round. He only concedes by abandoning this offer when all these arguments are defeated by arguments of his opponent. Agents are using *practical arguments* for supporting their offers and *practical or epistemic arguments* for attacking the arguments that attack their offers.

Concession is triggered after the receipt of a $reject$ move, and it is implemented by removing the rejected offer from the available offers, the supporting arguments of this offer from the set of arguments of the current theory $T_{r,g}$ (this allows the argumentation based reasoning mechanism to compute the next best offer) and by giving the turn to the other agent. The agents theories evolve during the negotiation through the integration of the arguments received by the other agents and the removal of the arguments supporting the rejected offers. Integration of the received arguments is done as in [4].

It is worth noting that although the above algorithm implements a specific negotiation strategy, the overall process it describes, is generic in the sense that it can easily adapted to accommodate other strategies. For instance, a different concession procedure can be easily integrated without altering in any way the working of the overall algorithm.

Concession is also considered by DUNG, THANG and TONI in [30]. The reasoning mechanism of the agents is based on the assumption-based argumentation framework of [24], presented in section 4.3.2. More specifically, the notion of *minimal concession* is defined in a two-phases negotiation protocol grounded upon a concrete ”home-buying” scenario, whereby the buyer agent is looking for a property to buy while the seller agent has a number of properties to sell. An interesting aspect of this work is that minimal concession strategy is a symmetric Nash equilibrium (see section 4.6).

The notion of minimal concession it based on that of *contractual state*.

Definition 4.26 (Contractual state [30]) A *contractual(goal) state* is a maximal consistent set of goals literal from G^{contr}.

The set G^{contr} of contractual goals concerns features that can be subject to negotiation leading to the agreement of a contract. A contractual state in a home-buying example consists of a price, a deposit, time for completion and several add-on items such as washing-machines, curtains, etc. The preference of an agent a between contractual states can be represented as a total pre-order $\sqsupseteq_a$, where given contractual states t and t', $t \sqsupseteq_a t'$ states that t is preferred to t' (for a). It is assumed that both buyers and sellers agents know each other's preferences between contractual states.

Definition 4.27 ([30]) Let t,t' be contractual states. We say that:

- t is strictly preferred to t' for agent a if $t \sqsupseteq_a t'$ and $t' \not\sqsupseteq_a t$
- t dominates t' if t is preferred to t' for both seller and buyer (i.e. $t \sqsupseteq_b t'$ and $t \sqsupseteq_a t'$) and, for at least one of these agents, t is strictly referred to t'
- t is *Pareto-optimal* if it is not dominated by any other contractual state.

We can present now the definition of the *minimal concession strategy*.

Definition 4.28 ([30]) A contractual state t' is said to be a minimal concession of agent a wrt t if t' is strictly preferred to t for $\overline{a}$ and for each contractual state r, if r is strictly preferred to t for $\overline{a}$ then r is preferred to t' for $\overline{a}$.

An agent *concedes minimally* at step i if he offers at step i a contractual state t that is a minimal concession wrt the offer the agent made at step $i-2$. The *minimal concession strategy* calls for agents

- to start the bargain with their best state and
- to concede minimally if the opponent has conceded in the previous step or it is making a move in the third step of the negotiation and
- to stand still if the opponent stands still in previous step

Note that the third step in the negotiation has a special status, in that if no concession is made at that step the negotiation stops.

It is obvious that the minimal concession strategy adheres to the reciprocity principle. Hence, the minimal concession strategy is permissible for fair agents.

Another strategy is proposed by DIJKSTRA, PRAKKEN and VEY MESTDAGH in [32]. The agents negotiate through the protocol presented in [15] and discussed in 4.4. This *negotiation policy* considers two issues: the *normative issue* of whether accepting an offer is obligatory or forbidden, and the *teleological issue* whether accepting an offer violates the agent's own interests. These policies can be different for the proposer and the recipient agent. Different agents can also have different policies. The advantage of this work is the use of persuasion within negotiation, an option that could provide additional help to avoid conflicts in situations where the persuasion dialogue terminates successfully (i.e. one of the agents is convinced to change his beliefs which lay on the basis of the conflict).

The agents have a modular architecture containing a *negotiation policy module*, a *persuasion policy module*, a *communication module* and an *argumentation system*. Agents communicate through a language that consists of speech acts $l(content)$ where l is a locution (e.g. offer) and the $content$ is divided into two parts $q \wedge conditions$. $Conditions$ is a (possibly empty) conjunction of conditions and q has the elements $sender$, $receiver$ and $action$ the first two denoting respectively the sender and the receiver of the speech act, the last denoting the requested action. The conjunction defines the conditions for acceptance.

Upon receiving a message, the *negotiation policy* module of the agent prepares a response by triggering the argumentation system which seeks to find a justifiable or defensible (status-type) conclusion given the union of the argumentative knowledge base, the action and the conjunction of conditions. The authors use $[A] \vdash B$, originally proposed in [46], to denote that a reasoner is called to infer that the set of rules A implies conclusions B.

The first step of the negotiation policy for an offer is to check whether it is possible to create a justified or defensible argument for the conclusion that the *requested content is obliged*. If that is possible the negotiation policy returns the answer to accept the offer.

$$IF\ offer(q \wedge conditions) \wedge [KB_{argumentation-engine} \cup conditions] \vdash_{status-type} obliged(q)\ THEN\ accept(q \wedge conditions)$$

The second step is to check whether it is possible to create a justified or defensible argument for the conclusion that the *requested content is forbidden*. If that is possible the negotiation policy returns the answer to reject the offer. Since only the $obliged$ operator is used, $forbidden(q)$ is rewritten as $obliged(not(q))$ in the negotiation policies.

$$ELSE\ IF\ offer(q \wedge conditions) \wedge [KB_{argumentation-engine} \cup conditions] \vdash_{status-type} obliged(not(q))\ THEN\ reject(q \wedge conditions)$$

The third step is to check whether it is possible to create a justified or defensible argument for the conclusion that the requested content is a *violation* of the agent's (denoted by $'a'$) own *interests*. If that is impossible the negotiation policy returns the answer to *accept the offer*.

$ELSE\ IF\ offer(q \wedge conditions) \wedge [KB_{argumentation-engine} \cup holds(q) \cup conditions] \not\vdash_{status-type} violation - of - own - interests(\text{a})\ THEN\ accept(q \wedge conditions)$

In the fourth step the argumentation system looks for a minimal set of conditions for the conclusion such that the responding agent's own interests are not violated and the conclusion that the *requested content* is not *forbidden*. If this is possible, the negotiation policy returns the answer to *make a counteroffer* with the extra conditions. Otherwise, the negotiation policy returns the answer to *reject the offer*.

$ELSE\ IF\ offer(q \wedge conditions) \wedge [KB_{argumentation-engine} \cup holds(q) \cup (subset - minimal\ set\ c)] \not\vdash_{status-type} violation - of - own - interests(\text{a}) \wedge [KB_{argumentation-engine} \cup (subset - minimal\ set\ c)] \not\vdash_{status-type} obliged(not(q))$
$THEN\ offer(q \wedge c)$
$ELSE\ reject(q \wedge conditions)$

In the negotiation policy for a $reject$, the policy returns a $why - reject$ move which triggers an embedded persuasion dialogue.

4.6 Properties of Argumentation-based Negotiation Frameworks

The properties characterizing ABN frameworks may concern the *argumentation-based reasoning mechanisms*, *the protocols*, *the strategies* or a combination of some of them.

Properties characterizing the **argumentation-based reasoning mechanisms** are related to the basic ingredients of argumentation frameworks, such as the *structure of the argumentation theories*, the *preference relations* (in the case of preference-based argumentation frameworks), the *attacking* or *defeat relations*, etc. and depend on the particular argumentation framework used.

Properties that characterize exclusively the **protocols** include a) *termination* that refers to the capability of the protocol P_{arg} to terminate a negotiation dialogue d independently of the outcome (i.e. successfully or with failure) and, b) *legality* of dialogue based on the *legality of moves* m_i, assuming that a negotiation dialogue is a consequence of moves $d = \{m_1, ..., m_n\}$, This property means that the protocol guaranties by construction that the agents will only use legal moves i.e. $m_i \in \mathcal{M}_L$ during the dialogue. The legality of moves can be defined by using different semantics. This property seems important especially in open environments as it guarantees that an agent cannot use moves that are illegal in the particular context of the negotiation (i.e. threats or rewards) for convincing his opponent.

Termination and legality can be defined formally as follows.

Proposition 4.1 (Termination) $\forall d \in \mathcal{D}$ where $\mathcal{D}$ is the set of all possible dialogues built from the protocol P_{arg}, d terminates.

Proposition 4.2 (Legality) Let $d = \{m_1, ..., m_n\}$ be a dialogue s.t. $d \in \mathcal{D}$ where $\mathcal{D}$ is the set of all possible dialogues built from the protocol P_{arg} and $\{m_1, ..., m_n\}$ is the set of moves used during this dialogue. Then $\forall m_i \in d$ it holds that $m_i \in \mathcal{M}_L$, where $\mathcal{M}_L$ is the set of legal moves defined by using a particular semantics.

Moreover, there are properties that refer to the whole negotiation process involving *argumentation-based reasoning mechanisms*, *protocols* and *strategies*. They provide guarantees that the outcomes of an ABN dialogue are *sound solutions* and that, if such solutions exist (according to the beliefs, the preferences and the goals of agents), they will be found by the agents. We call the first property *soundness* and the second *completeness*.

Before giving a formal and general definition of these properties, we need to define the notion of the *outcome* of an argumentative negotiation. The *outcome* of a ABN dialogue is either failure (disagreement) or an offer $offer(o) \in \mathcal{O}$ on which both agents agree, and is essentially the result returned by the negotiation algorithm. Note that this notion can be defined formally only for specific negotiation algorithms.

We associate the outcome of a negotiation with two notions of *agreement*, namely *weak* and *strong agreement*. A *disagreement* corresponds to a value for $offer(o)$ that is below the *reservation value* (i.e. the worse acceptable value for an outcome), denoted by o_D, for both agents.

Weak and strong agreements are defined as follows.

Definition 4.29 (Weak agreement) Let a, $\overline{a}$ be two agents, $\mathcal{O}$ a set of offers common to both agents and $\mathcal{O}^{\overline{a}}_{acc}$, $\mathcal{O}^{a}_{acc}$ the sets of *acceptable* offers (under different semantics and computed by different methods). An $offer(o) \in \mathcal{O}$ is called *weak agreement* if $offer(o) \in \mathcal{O}^{\overline{a}}_{acc} \cap \mathcal{O}^{a}_{acc}$ and it holds that $offer(o)$ $\trianglerighteq_a offer(o^a_D)$ and $offer(o) \trianglerighteq_{\overline{a}} offer(o^{\overline{a}}_D)$ where o_D corresponds to the *reservation value* for each agent, and $\trianglerighteq$ to a preference relation defined according to different criteria.

Definition 4.30 (Strong agreement) Let a, $\overline{a}$ be two agents, $\mathcal{O}$ a set of offers common to both agents, and $\mathcal{O}^{\overline{a}}_{acc}$, $\mathcal{O}^{a}_{acc}$ the sets of *acceptable* offers (under different semantics and computed by different methods). An agreement $offer(o) \in \mathcal{O}$ is called *strong agreement* if it is a weak agreement and in addition it holds that $\nexists\ offer(o') \in \mathcal{O}^{\overline{a}}_{acc} \cap \mathcal{O}^{a}_{acc}$ s.t. $offer(o') \trianglerighteq_a offer(o)$ and $offer(o') \trianglerighteq_{\overline{a}} offer(o)$ where $\trianglerighteq$ is a preference relation defined according to different criteria.

Obviously, the set of strong agreements is a subset of the set of weak agreements. The notion of *weak agreement* provides a sufficient characterization of an ABN dialogue wrt properties of *soundness* and *completeness* and this is because some circumstances (e.g. time constraints) could not allow the search for a *strong agreement*. However, one could use alternatively the notion of *strong agreement* for defining the above properties.

It is highly desirable that the negotiation algorithms satisfy the properties of *soundness* and *completeness*. Thus, *soundness* and *completeness* can be stated formally as follows.

Proposition 4.3 (Soundness) A bilateral ABN algorithm N is *sound* if for any pair of agents a and b with a set of weak agreements G_w and each possible dialogue d generated by N when a and b are its input agents, it is the case that if offer o is the outcome of d then $o \in G_w$.

Proposition 4.4 (Completeness) A bilateral ABN algorithm N is *complete* if for any pair of agents a and b with a set of weak agreements G_w such that $G_w \neq \emptyset$, and each possible dialogue d generated by N when a and b are its input agents, it is the case that the outcome of dialogue d is not failure.

Such properties (i.e. completeness, soundness, termination) are proposed in different works (see e.g. [4], [30], [8], [6]).

Another property concerns the *quality* of a dialogue, and refers to the ability of a dialogue to find an *optimal outcome*.

Definition 4.31 (Optimal outcome) Let $d = \{m_1, ..., m_n\}$ be a dialogue and $\mathcal{O}$ a set of offers. We call optimal outcome of the dialogue d any $offer(o) \in \mathcal{O}$ that is a strong agreement.

Now, the property of *optimal negotiation dialogue* can be defined as follows.

Proposition 4.5 (Optimal negotiation dialogue) Let $d = \{m_1, ..., m_n\}$ be a dialogue and $\mathcal{O}$ a set of offers. Any outcome $offer(o) \in \mathcal{O}$ of dialogue d is an optimal outcome.

The following proposition of KAKAS and MORAITIS [7] can be seen as a concrete example of a property that refers to the quality of the result of a negotiation under the protocol discussed in section 4.4.

Proposition 4.6 ([7]) Let X and Y be two agents and T_X, T_Y their respective argumentation policy theories which contain a finite number of sentences. Then if a negotiation process terminates with agreement on an offer O and S is the final set of supporting information accumulated during the negotiation then the corresponding goal, $G(O)$, is a skeptical conclusion of both $T_X \cup S$ and $T_Y \cup S$.

Skeptical decisions are the best that an agent can take based on his argumentation theory, and thus any goal supported by skeptical arguments can be considered as an optimal goal.

Properties characterizing **strategies** may be of different types depending on the typology of the strategies. Essentially properties that characterize strategies relate to the *quality of the outcomes* obtained. This is the case of the following property of [30] that refers to the *minimal concession strategy* discussed in section 4.5.1.

Proposition 4.7 ([30]) The minimal concession strategy is in symmetric Nash equilibrium.

A strategy is said to be in *symmetric Nash equilibrium* if under the assumption that one agent is using this strategy the other agent cannot do better by not using this strategy. That means that the outcome is an efficient and stable outcome in the sense of a Nash equilibrium.

Other properties related to strategies could characterize the *quality of the outcome* or the *length* and the *termination* of the dialogue by considering possible *combinations of strategies* applied by the agents (i.e. each agent applies a different strategy or both agents apply the same strategy) and related to the possible different *profiles* they may have. However to the best of our knowledge, in ABN literature, there is no a deep study of such properties. Some first results related to that issue can be found in [47], though stated in a more general setting than negotiation.

Moreover, strategies could also characterize other parameters of the negotiation such as the number of *possible offers* that can be proposed. For example AMGOUD and KACI [31] prove the following property that refers to the strategies discussed in section 4.5.1.

Proposition 4.8 ([31]) Let $\underline{S}_1, \underline{S}_2, \underline{S}_3$ 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 the requiring strategy is a weakening of drastic strategy and it is weakened by relaxed strategy. This means that a weakening of the strategy increases the number of possible offers.

Other interesting properties characterizing *protocols* and *strategies* and related to outcomes could be the following that are very often used in the game theoretic negotiation approaches (see e.g. [48], [49]):

- *Uniqueness*: If the solution is unique then it can be identified unequivocally
- *Symmetry*: an ABN dialogue could be considered to be symmetric if it does not treat players differently on the basis of inappropriate criteria (that must be defined). For instance, such a property is one that requires that the outcome does not depend on the player that starts the negotiation
- *Efficiency*: characterization of the outcome regarding notions as Pareto optimality, etc.

4.7 Conclusions and Future Research

This chapter presented recent advances in ABN considering three topics it is dealing with, namely the argumentation-based mechanisms that agents use for reasoning and making decisions during the negotiation, the protocols they use for exchanging offers and arguments and the strategies that guide their choices at each step of the negotiation. For this reason we have presented and discussed a significant number of representative works dealing with these three topics. The aim of this chapter was to provide sufficient material to the reader so that the latter firstly understands what an automated negotiation approach based on argumentation is, which the main ingredients of ABN frameworks are and then, if desired, how to become able to build specific ABN frameworks for particular applications. This could be done by instantiating abstract argumentation-based frameworks such as those proposed in [18], [19], [22] (i.e. by defining a specific structure for arguments and offers) or by applying specific argumentation frameworks such as those proposed in [20], [21], [24], [40], by instantiating protocols for developing specific dialogues and by implementing strategies among those presented (or cited) herein. The chapter can also be used as supporting material for an advanced course on computational argumentation and ABN.

This section is devoted to some thoughts about possible directions for future research in ABN. We believe that one possible direction might concern devising efficient protocols that guarantee that strong agreements will be found (when such agreements exist). That means protocols that would allow agents (according to their strategies) to explore efficiently all the possible situations that could lead to an optimal deal. Therefore, an important research direction is the study of different operators for aggregating argumentative negotiation theories (i.e. making the assumption of the "ideal" situation where agents have complete knowledge or negotiate though a mediator). Such aggregation operators have been proposed for abstract Dung's argumentation frameworks in [50] and for preference-based argumentation frameworks but with particular characteristics in [51]. This work would allow firstly to characterize the outcomes of the aggregated theory and, thus, to find whether strong agreements are possible (or not) according to the specific structures of the initial theories and then to put in evidence the characteristics that a protocol should have in order to allow agents to find these optimal outcomes in a distributed context. This analysis could help the design of such protocols and the conception of appropriate specific strategies. These results would be useful in the case of integrative negotiations (the agents are benevolent and cooperative) and in some cases in negotiations between self-interest agents (situations where failure is the worst solution and should be avoided if possible). Another interesting direction concerns strategies with time (or other) constraints. To the best of our knowledge, such issues are until now ignored in the ABN context. An adaptation of tactics and strategies used in several game theoretic negotiation approaches, which take into account time constraints (see e.g. [52]) would be a possible way to deal with this problem and to devise heuristics that could be integrated in the argumentation-based reasoning of the agents. A third interesting direction is the study of how the knowledge (and how it could be acquired) about the other agents could improve the negotiation process and more particularly the quality of the outcomes, the time of negotiation for finding a weak or strong agreement (or for finding whether it is impossible to reach an agreement, thus having no reason to continue the negotiation), the length of the dialogue, etc. Finally, other interesting directions are related to new concession policies (with or without time constraints) and preference relations based on different (and probably multiple) criteria used in the reasoning mechanisms for comparing and choosing offers.

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