A reasoning model based on the production of acceptable arguments

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Abstract

Argumentation is a reasoning model based on the construction of arguments and counter-arguments (defeaters) then the selection of the most acceptable of them. In this paper, we propose to take into account preference relations between arguments in order to integrate two complementary points of view on the concept of acceptability : acceptability based on the existence of direct counter-arguments and acceptability based on the existence of defenders. An argument is thus acceptable if it is preferred to its direct defeaters or if it is defended against its defeaters. We propose a proof theory verifing if a given argument is acceptable.

Introduction

Various argument-based approaches to defeasible reasoning have been developed ((Lin and Shoham 1989), (Vreeswijk 1991), (Pollock 1992), (Pinkas and Loui 1992), (Simari and Loui 1992), (Dung 1993&1995), (Prakken and Sartor 1996)). Particularly, argumentation is a promising model for reasoning with inconsistent knowledge, based on the construction and the comparison of arguments. It may also be considered as a different method for handling uncertainty. The basic idea behind argumentation is that it should be possible to say more about the certainty of a particular fact than the certainty quantified with a degree in [0, 1]. In particular, it should be possible to assess the reason why a fact holds, in the form of arguments, and combine these arguments to evaluate the certainty. Indeed, the process of combination may be viewed as a kind of reasoning about the arguments in order to determine the most acceptable of them. For that purpose, we can take into account the existence of arguments in favour of, or against, a given fact as well as preference orderings for comparing arguments. The main approaches, which have been developed for reasoning within an argumentation system, rely on the idea of differentiating arguments with a notion of acceptability. Two kinds of acceptability have been proposed:

Individual acceptability: an acceptability level is assigned to a given argument on the existence of direct defeaters. That leads to the concept of acceptability class introduced by (Elvang, Fox and Krause 1993) and (Elvang and Hunter 95).

Joint acceptability (Dung 1993&1995): the set of all the arguments that a rational agent accepts must defend itself against any defeater.

In a previous work (Amgoud, Cayrol and Le Berre 1996), we have studied different preference relations between arguments. In ((Amgoud and Cayrol 1997), (Amgoud and

Cayrol 1998)), we have presented the principles of preference-based argumentation and how preference relations can be integrated into argumentation systems. In this paper, we propose a general preference-based argumentation framework where the notion of acceptability is defined by both points of view (individual and joint acceptability). We will show that the two points of view are complementary. The basic idea is to accept an argument if it is not defeated, if it defends itself against its defeaters (because it is preferred to its defeaters), or if it is defended by other arguments. The two notions of defense (individual defense and joint defense) are modelled via preference relations between arguments. We propose then a proof theory. All the proofs can be found in (Amgoud 1999).

The argumentation framework

Definition 1. A *preference-based argumentation framework* (PAF) is a triplet $<\mathcal{A}, \mathcal{R}, \text{Pref}>$ where $\mathcal{A}$ is a set of arguments, $\mathcal{R}$ is a binary relation representing a defeat relationship between arguments, $\mathcal{R} \subseteq \mathcal{A} \times \mathcal{A}$, and Pref is a (partial or complete) preordering on $\mathcal{A} \times \mathcal{A}$.
$>>^{\text{Pref}}$ denotes the strict ordering associated with Pref.

Different definitions for the preference relation Pref lead to different preference-based argumentation frameworks.

Definition 2. Let A, B be two arguments of $\mathcal{A}$. B *attacks* A iff B $\mathcal{R}$ A and not (A $>>^{\text{Pref}}$ B).

To illustrate the concepts of argument, defeat relation ($\mathcal{R}$) and preference relation (Pref), let's consider particular argumentation frameworks proposed for handling inconsistency in knowledge bases. The arguments are built from a propositional knowledge base Σ, which may be inconsistent.

An *argument* of Σ is a pair (H, h) where $H \subseteq \Sigma$ s.t: i) H is consistent, ii) $H \vdash h$, iii) H is minimal (for set inclusion). ($\vdash$ denotes classical entailment). H is called the *support* and h the *conclusion* of the argument. $A(\Sigma)$ denotes the set of all the arguments which are constructed from Σ.

As examples of defeat relations, let's consider "Rebut" and "Undercut" relations defined in (Elvang, Fox and Krause 1993) as follows: Let (H_1, h_1), (H_2, h_2) be two arguments of $\mathcal{A}(\Sigma)$.

- (H_1, h_1) *rebuts* (H_2, h_2) iff $h_1 \equiv \neg h_2$.
- (H_1, h_1) *undercuts* (H_2, h_2) iff $\exists h \in H_2$ such that $h \equiv \neg h_1$. ($\equiv$ denotes logical equivalence).

Note that a similar methodology for defining the concept of defeat is used in (Prakken and Sartor 1995&1996) with the same terminology but with a different structure of arguments. In (Prakken and Sartor 1995&1996), an argument is a sequence of chained implicative rules. Each rule has a consequent part (consisting of one literal) and an antecedent part (consisting of a conjunction of literals). The consequent of each rule in a given argument is considered as a conclusion of that argument.

In (Amgoud, Cayrol and Le Berre 1996), we have presented several preference relations between arguments of $A(\Sigma)$. The preference relations are induced by a preference relation defined on the supports of arguments. The preference relation on the supports is itself defined from a (total or partial) preordering on the knowledge base Σ.

An example of such preference relations is the one based on the elitism principle (ELI-preference (Cayrol, Royer and Saurel 1993)). Let $\geq$ be a total preordering on Σ and $>$ be the associated strict ordering. In that case, the knowledge base Σ is supposed to be stratified into $(\Sigma_1, \ldots, \Sigma_n)$ such that Σ_1 is the set of $\geq$-maximal elements in Σ and Σ_{i+1} the set of $\geq$-maximal elements in $\Sigma \backslash (\Sigma_1 \cup \ldots \cup \Sigma_n)$.

Let H and H' be two subbases of Σ. H is *preferred* to H' according to ELI-preference iff $\forall k \in H \setminus H', \exists k' \in H' \setminus H$ such that $k > k'$.

Let (H_1, h_1), (H_2, h_2) be two arguments of $\mathcal{A}(\Sigma)$. $(H_1, h_1) >>^{\text{ELI}} (H_2, h_2)$ iff H_1 is preferred to H_2 according to ELI-preference.

Example 1. *$\Sigma = \Sigma_1 \cup \Sigma_2 \cup \Sigma_3$ such that $\Sigma_1 = \{a, \neg a\}$, $\Sigma_2 = \{a \rightarrow b\}$ and $\Sigma_3 = \{\neg b\}$. $(\{a, a \rightarrow b\}, b) >>^{ELI} (\{\neg b\}, \neg b)$.*

Other definitions of argument, defeat relations and preference relations between arguments can be found in (Amgoud 1999).

From a preference-based argumentation framework $<\mathcal{A}, \mathcal{R}, Pref>$, we define three categories of arguments:

- S_a is the set of *acceptable arguments* of the argumentation framework.
- $S_r = \{A \in \mathcal{A} \mid \exists B \in S_a$ such that $B \mathcal{R} A$ and not$(A >>^{Pref} B)\}$ is the set of *rejected arguments*. In other terms, S_r gathers the arguments which are attacked by acceptable arguments.
- $S_s = \mathcal{A} \setminus (S_a \cup S_r)$ is the set of arguments which are in *abeyance*.

The two sets S_r and S_s are modelled via the set of acceptable arguments. So next, we focus on the construction of S_a. To do that, we have defined two notions of defense (individual defense and joint defense) using preference relations.

Definition 3. Let $<\mathcal{A}, \mathcal{R}, Pref>$ be a PAF. Let A, B be two arguments of $\mathcal{A}$ such that $B \mathcal{R} A$. A *defends itself against* B iff $A >>^{Pref} B$. An argument *defends itself* iff it is preferred w.r.t Pref to each counter-argument.
$\mathcal{C}_{\mathcal{R}, Pref}$ denotes the set of arguments defending themselves against their defeaters.

This set contains also the arguments which are not defeated (in the sense of the relation $\mathcal{R}$). Obviously, the arguments of $\mathcal{C}_{\mathcal{R}, Pref}$ must be considered as acceptable. This corresponds to the individual point of view. However, $\mathcal{C}_{\mathcal{R}, Pref}$ is too restricted since it discards arguments which appear acceptable. Intuitively, if an argument A is less preferred than its defeater B then it is weakened. But the defeater B itself may be weakened by another argument C which defeats B and is preferred to B. In this later case we would like to accept A because it is defended by C. This notion of defense has been introduced by Dung (Dung 1993) in the case without preference relations. We define below the notion of defense in preference-based argumentation frameworks.

Definition 4. Let $<\mathcal{A}, \mathcal{R}, Pref>$ be a PAF and $S \subseteq \mathcal{A}$. An argument A is *defended* by S iff $\forall B \in \mathcal{A}$, if $B \mathcal{R} A$ and not$(A >>^{Pref} B)$ then $\exists C \in S$ such that $C \mathcal{R} B$ and not$(B >>^{Pref} C)$. In other terms: A is *defended* by S iff $\forall B \in \mathcal{A}$, if B attacks A then $\exists C \in S$ such that C attacks B.

In (Dung 1995), several sets of arguments, called extensions, have been introduced with different semantics. All of them are obtained as fixpoints of different functions. For our purpose, the function which permits us to find the arguments of $\mathcal{C}_{\mathcal{R}, Pref}$ and the arguments which are defended by other arguments is the function $\mathcal{F}$ defined as follows:

$$\mathcal{F} : 2^{\mathcal{A}} \to 2^{\mathcal{A}}$$
$$S \to \mathcal{F}(S) = \{A \in \mathcal{A} \mid A \text{ is defended by } S\}.$$

The set of acceptable arguments S_a of the PAF $<\mathcal{A}, \mathcal{R}, Pref>$ is obtained as the least fixpoint of the function $\mathcal{F}$. It corresponds to the least complete extension in Dung's work.

Formally:

Definition 5. A PAF is *finite* iff each argument is defeated (in the sense of the relation $\mathcal{R}$) by a finite number of arguments.

Proposition 1. Let $<\mathcal{A}, \mathcal{R}, Pref>$ be a finite PAF. $\mathcal{F}$ is monotonic and continuous.

The monotonicity of $\mathcal{F}$ gives it a constructive flavour: its least fixpoint can be approached and under the finiteness condition even obtained by iterative applications of $\mathcal{F}$ to the empty set ($\emptyset$).

Proposition 2. Let $<\mathcal{A}, \mathcal{R}, Pref>$ be a finite PAF.

- The least fixpoint of $\mathcal{F}$ is:
  $\cup\mathcal{F}^{i\geq 0}(\emptyset) = \mathcal{C}_{\mathcal{R}, Pref} \cup [\cup\mathcal{F}^{i\geq 1}(\mathcal{C}_{\mathcal{R}, Pref})]$.
- The least fixpoint of $\mathcal{F}$ is the set S_a of acceptable arguments of the framework $<\mathcal{A}, \mathcal{R}, Pref>$.

The above result shows that the acceptable arguments are the ones which defend themselves against their defeaters ($\mathcal{C}_{\mathcal{R}, Pref}$) and also the arguments which are defended (directly or indirectly) by the arguments of $\mathcal{C}_{\mathcal{R}, Pref}$.

Example 2. *Let* $<\mathcal{A}, \mathcal{R}, Pref>$ *be a PAF such that* $\mathcal{A} = \{A, B, C, D, E\}$, $\mathcal{R} = \{(C, D), (D, C), (A, E)\}$ *and* $C >>^{Pref} D$, *then* $\mathcal{C}_{\mathcal{R}, Pref} = \{A, B, C\}$.

Due to the use of propositional langage and finite knowledge bases, in the particular case of handling inconsistency in knowledge bases, the two frameworks $<\mathcal{A}(\Sigma)$, Rebut, Pref> and $<\mathcal{A}(\Sigma)$, Undercut, Pref> are finite. So, the associated sets of acceptable arguments are respectively: $\mathcal{C}_{Rebut, Pref} \cup [\cup\mathcal{F}^{i\geq 1}(\mathcal{C}_{Rebut, Pref})]$, $\mathcal{C}_{Undercut, Pref} \cup [\cup\mathcal{F}^{i\geq 1}(\mathcal{C}_{Undercut, Pref})]$.

Proof theory

So far, we have only provided a semantics for our system by defining a set of acceptable arguments, a set of rejected arguments and a set of arguments which are in abeyance. However, in practice we don't need to calculate all the sets of arguments in order to know the status of a given argument. In this section we will define a test for membership of these sets for an individual argument A, i.e. we will define a proof theory for our semantics. For that purpose, we are inspired by the work of Prakken and Sartor (Prakken and Sartor 1997), developed in the legal domain.

Definitions

Let's start by defining some new concepts : disqualification, strict defense, indirect defeat and indirect defense. These new concepts will be used to prove important properties for the definition of the proof theory.

Definition 6. An argument A *disqualifies* another argument B iff A attacks B and B does not attack A.
Disqualification represents strict attack.

Example 3. *Let <$\mathcal{A}$, $\mathcal{R}$, Pref> be a PAF such that $\mathcal{A}$ = {A, B, C} and $\mathcal{R}$ = {(A, B), (B, A), (B, C)}. Let's suppose that B $>>^{Pref}$ C. The argument A attacks the argument B and B attacks A. So A does not disqualify B and B does not disqualify A. But B attacks and disqualifies C.*

From the notion of disqualification, we define a new notion of strict defense as follows:

Definition 7. Let <$\mathcal{A}$, $\mathcal{R}$, Pref> be a PAF, A an argument and S $\subseteq$ $\mathcal{A}$. A is *strictly defended* by S iff $\forall$ B $\in$ $\mathcal{A}$ such that B attacks A then $\exists$ C $\in$ S such that C disqualifies B. We say also that S strictly defends A.

Proposition 3. $\forall$ A $\in$ S_a, S_a defends strictly A.
In other terms, the set of acceptable arguments strictly defends all its elements.

This proposition is of great importance. It shows that to verify if an argument is acceptable, we only have to take into account its strict defenders rather than all the defenders.

Definition 8. Let <$\mathcal{A}$, $\mathcal{R}$, Pref> be a PAF and A, B two arguments.
B *indirectly attacks* A iff there exists a finite sequence of arguments $A_0 \ldots A_{2n+1}$ such that:

- A = A_0 and B = A_{2n+1}
- $\forall$i, 0 ≤ i ≤ 2n, A_{i+1} attacks A_i.

Definition 9. Let <$\mathcal{A}$, $\mathcal{R}$, Pref> be a PAF and A, B two arguments.
B *indirectly defends* A iff there exists a finite sequence of arguments $A_0 \ldots A_{2n}$ such that:

- A = A_0 and B = A_{2n}
- $\forall$i, 0 ≤ i < 2n, A_{i+1} attacks A_i.

We say that the argument B indirectly defends A against the argument A_1.

Proposition 4. Let <$\mathcal{A}$, $\mathcal{R}$, Pref> be a PAF.
$\forall$ x $\in$ S_a, x is indirectly defended by arguments of $\mathcal{C}_{\mathcal{R}, Pref}$ against all its defeaters.

Remark: An argument indirectly defended against all its defeaters by arguments of $\mathcal{C}_{\mathcal{R}, Pref}$ is not necessarily acceptable (i.e. it does not necessarily belong to the set S_a). Let's consider the following example:

Example 4. *Let <$\mathcal{A}$, $\mathcal{R}$, Pref> be a PAF such that $\mathcal{A}$ = {a0, a1, a2, a3, a4, a5, a6, a7}, $\mathcal{R}$ = {(a1, a0), (a2, a0), (a4, a2), (a3, a1), (a5, a3), (a6, a3), (a7, a6)}.*

Let's suppose that: a4 $>>^{Pref}$ a2 $>>^{Pref}$ a0, a5 $>>^{Pref}$ a3 $>>^{Pref}$ a1 $>>^{Pref}$ a0, a7 $>>^{Pref}$ a6 $>>^{Pref}$ a3. The argument a0 is defeated by two arguments a1 and a2 and it does not defend itself. The argument a0 is indirectly defended by a7 , which is in $\mathcal{C}_{R, Pref}$, against a1. a0 is also defended against a2 by the argument a4 which belongs to $\mathcal{C}_{R, Pref}$. However, a0 is not in the set S_a because it is indirectly attacked by the argument a5 of $\mathcal{C}_{R, Pref}$.

Proposition 5. Let <$\mathcal{A}$, $\mathcal{R}$, Pref> be a PAF. If x $\in$ S_r then $\exists$ y $\in$ $\mathcal{C}_{\mathcal{R}, Pref}$ such that y indirectly attacks x.
In other terms, if an argument is rejected then it is indirectly attacked by an argument of $\mathcal{C}_{\mathcal{R}, Pref}$.

The argument proof

According to proposition 2, an argument A is acceptable in a finite PAF if and only if it is in the result of finitely iterative applications of the function $\mathcal{F}$ to the set $\mathcal{C}_{\mathcal{R}, Pref}$. Basically, the idea is to traverse the resulting sequence $\mathcal{F}^1$, …, $\mathcal{F}^n$ where A occurs for the first time in $\mathcal{F}^n$, in the reverse direction. We start with A, and then for any argument B_i attacking A we find an argument C in $\mathcal{F}^{n-1}$ which defends A. According to proposition 3, it is useless to find all the defenders, we just consider the strict defenders. Thus, the defenders of A disqualify the arguments B_i. The same process is repeated for each strict defender until there is no strict defender or defeater.

Inspired by the work of (Prakken and Sartor 1997), who were themselves inspired by (Vreeswijk 1993), (Dung 1994), (Brewka 1994), we present the proof theory in a dialectical style. A proof that an argument A is acceptable will take the form of a dialogue tree, where each branch of the tree is a dialogue, and the root of the tree is the argument A. Each move in a dialogue consists of an argument of <A, R, Pref> which attacks or disqualifies the last move. Formally, a dialogue is defined as follows:

Definition 10. A *dialogue* is a nonempty sequence of moves: $move_i = (Player_i, Arg_i)$ $(i \geq 0)$ such that:

1. $Player_i = P$ iff i is even, $Player_i = C$ iff i is odd
2. $Player_0 = P$ and $Arg_0 = A$.
3. If $player_i = player_j = P$ and $i \neq j$ then $Arg_i \neq Arg_j$.
4. If $player_i = P$ $(i>1)$ then Arg_i disqualifies Arg_{i-1}.
5. If $player_i = C$ then Arg_i attacks Arg_{i-1}.

The first condition says that the players take turns. The second condition says that P begins the dialogue with the argument we are interested in. The third condition prevents the proponent from repeating its attacks. The conditions 4 and 5 show that the two players have different roles. The role of P is to justify its initial argument A, hence his moves have to be strictly defeating ; C wants to prevent A from being justified, hence his moves may be just defeating.

Definition 11. A *dialogue tree* is a finite tree with each branch is a dialogue.

To illustrate the notion of dialogue tree, let's consider the following example:

Example 5. *Let <A, R, Pref> be a PAF such that A =* $\{a_0, a_{01}, a_{02}, a_{03}, a_{10}, a_{11}, a_{12}, a_{13}, a_{14}\}$*, R =* $\{(a_{10}, a_0), (a_{01}, a_{10}), (a_{12}, a_{02}), (a_{02}, a_{10}), (a_{03}, a_{11}), (a_{11}, a_0), (a_{13}, a_{14}), (a_{14}, a_{13})\}$*. Let's suppose:* $a_{03} >>^{Pref} a_{11} >>^{Pref} a_0$, $a_{01} >>^{Pref} a_{10} >>^{Pref} a_0$, $a_{12} >>^{Pref} a_{02} >>^{Pref} a_{10}$, $a_{13} >>^{Pref} a_{14}$*. We are interested in the status of the argument* a_0*. The corresponding dialogue tree is presented in figure 1.*

According to definition 10, the player P presents the arguments a_0*,* a_{01}*,* a_{02} *and* a_{03}*; the player C presents the arguments* a_{10}*,* a_{11} *and* a_{12}*.*

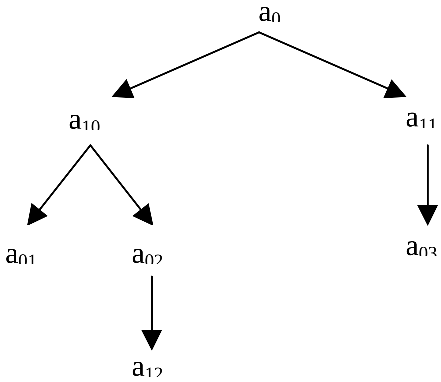


Fig. 1.

The dialogue tree can be considered as an AND/OR tree. A node corresponding to the player P is an AND node, and a node corresponding to the player C is an OR node. That distinction between nodes is due to the fact that an argument is acceptable if it is defended against all its defeaters. The edges of a node containing an argument of P represent defeaters so they all must be defeated. In contrast, the edges of a node containing an argument of C represent defenders of P so it's enough that one of them defeats the argument of C.

Example 5. (continued) *In the dialogue tree given in figure 1,* a_0 *is an AND node, contrastedly* a_{10} *is an OR node.*

Definition 12. A player *wins a dialogue* iff he ends the dialogue (he makes the last argument).

A player who wins a dialogue does not necessarily win in all the sub-trees of the dialogue tree. And if a player wins a dialogue, the last argument he makes is not necessarily acceptable. Let's consider the following example:

Example 6. *Let <A, R, Pref> be a PAF such that A =* $\{a_0, a_1, a_2, a_3, a_4\}$*, R =* $\{(a_1, a_0), (a_2, a_0), (a_1, a_3), (a_3, a_1), (a_2, a_4), (a_4, a_2)\}$*. Let's suppose that:* $a_1 >>^{Pref} a_0$*,* $a_2 >>^{Pref} a_0$*. Let's consider the argument* a_0*. The corresponding dialogue tree is presented in figure 2 below:*

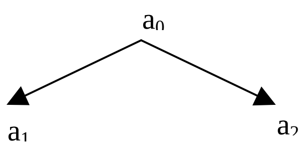


Fig. 2.

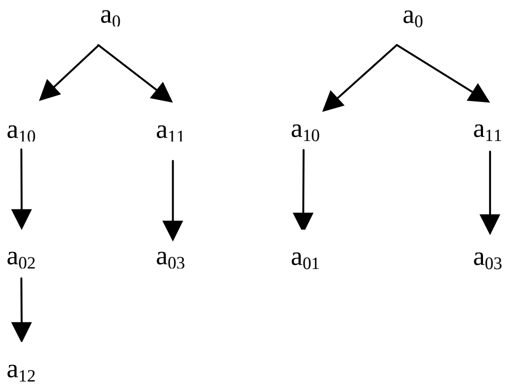
The player P presents the argument a_0 whereas player C presents the two arguments a_1 and a_2. C wins the two dialogues and yet the arguments a_1 and a_2 are not acceptable.

Proposition 6. If a player P wins a dialogue then its last move is an argument of $\mathcal{C}_{\mathcal{R}, \mathrm{Pref}}$.

To formalize the winning of a dialogue tree, we define the concept of solution sub-tree.

Definition 13. A *candidate sub-tree* is a sub-tree of the dialogue tree containing all the edges of each AND node and exactly one edge of each OR node. A *solution sub-tree* is a candidate sub-tree whose branches are all won by P.

Example 5. (continued) *The dialogue tree presented in example 5 has exactly two candidate sub-trees S_1 and S_2.*



S_1 **S_2**

Fig. 3.

Example 6. (continued) *The dialogue tree presented in example 6 possesses only one candidate sub-tree which is the dialogue tree itself.*

Definition 14. P *wins a dialogue tree* iff the dialogue tree has a solution sub-tree.

Example 5. (continued) *The player P wins the dialogue tree presented in figure 1 because S_2 is a solution sub-tree.*

Proposition 7. If the player P wins the dialogue tree then:

- All the leaves of the solution sub-tree are arguments of $\mathcal{C}_{\mathcal{R}, \mathrm{Pref}}$.
- Each leaf of a solution sub-tree indirectly defends the arguments given by P in the dialogue leading to that leaf.

Definition 15. An argument A is *justified* iff there exists a dialogue tree whose root is A, won by the player P.

Example 4. (continued) *The argument a_0 is not justified because the dialogue tree whose root is a_0 is not won by P.*

Example 5. (continued) *The argument a_0 is justified because the player P won the dialogue tree.*

Example 6. (continued) *The argument a_0 is not justified because the player P didn't win the dialogue tree.*

We show next that justified arguments exactly correspond to acceptable arguments.

Proposition 8. Let <$\mathcal{A}$, $\mathcal{R}$, Pref> be a finite PAF.

- $\forall x \in \mathcal{A}$, if x is justified then each argument of P belonging to the solution sub-tree is in S_a, in particular x.
- $\forall x \in S_a$, x is justified.

Conclusion

The work presented here concerns the acceptability of arguments in preference-based argumentation frameworks. Our first contribution is to identify two complementary notions of acceptability (individual acceptability and joint acceptability) and to present a unified framework where both notions are used. Our second contribution is to take into account preference relations between arguments in order to select the most acceptable of them. The use of those preferences allows us to define a notion of individual defense and a notion of joint defense. We have proposed an argumentation framework in which an argument is acceptable if it is not defeated or if it defends itself against its defeaters or if it is defended by other arguments. We have also proposed a proof theory for that preference-based argumentation framework. The proof theory verifies whether a given argument A is acceptable or not. The proof theory is presented as a dialogue tree between two players P and C. P gives the initial argument A and its defenders (direct and indirect), the player C gives the defeaters (direct and indirect) of A.

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