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# On structural analysis of extension-based argumentation semantics

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**Abstract.** Dung’s abstract argumentation provides us with a general framework to deal with argumentation. For extension-based semantics, the central issue is how to determine the extensions wrt. various semantics. Motivated by the acceptability and reinstatement criterion, we propose the notions of J-acceptability and J-reinstatement. Correspondingly, we introduce the J-complete semantics which fills the gap between complete semantics and preferred semantics. It is shown that acceptability together with J-acceptability forms the foundation of extension-based semantics. For example, any admissible set can be built starting from a conflict-free collection of initial sets by iteratively applying some functions based on acceptability and J-acceptability. In fact, this novel idea has a powerful ability in picturing the structure of various extensions and can be expected to play an important role in the study of various extension-based semantics.

## 1 Introduction

In recent years, the area of argumentation begins to become increasingly central as a core study within Artificial Intelligence. Starting from the work of Dung [10], a number of papers investigated and compared the properties of different semantics which have been proposed for abstract argumentation frameworks [4, 5, 8, 11]. Recently, more excellent work has been done in extension-based semantics and dynamic argumentation [1–3, 6, 9, 12]. For further notations and techniques of argumentation, we refer the reader to [7, 13].

As is known, the concept of acceptability plays a fundamental role in the extension-based semantics. Each traditional semantics satisfies the acceptability principle, that is, each extension under the traditional semantics is an admissible set. The reinstatement principle and the characteristic function are developed from the acceptability. But, acceptability is not enough when we extend a known admissible set to a new admissible set which has more arguments. There exists the case when an admissible set is combined with some additional arguments to form a new admissible set, whereas each of the additional arguments is not accepted wrt. the given admissible set. This case motivated us to propose the notion of joint acceptability, J-acceptability for short. Based on this novel concept, we can define the J-characteristic function and the J-reinstatement criterion which play a similar role as the characteristic function and reinstatement criterion do in the theory of extension-based semantics. Furthermore, we define a new

semantics called J-complete semantics which exactly reveals the gap between complete semantics and preferred semantics.

The notion of initial set was first introduced by [15]. It is a generalization of the notion of initial argument and can be seen as the most basic germ of the building of various extensions. Based on this idea, our aim is to introduce a new fundamental criterion called J-acceptability and to combine it with the acceptability and initial sets to set up a procedure, by which any admissible set, complete extension and preferred extension can be built and described. Comparing with the known methods of finding extensions, we make it clear that initial sets should be seen as the starting points and discover that the J-acceptability is an essential supplement of acceptability. And so, our work provides a more workable method than the known approaches to construct all admissible sets.

The paper is organized as follows. Section 2 recalls the basic notions of argumentation frameworks. Section 3 introduces the J-acceptability criterion, J-complete semantics and studies their properties. Section 4 discusses our method for building and describing admissible sets, complete extensions and preferred extensions by the acceptability, J-acceptability and initial sets. Section 5 is devoted to concluding remarks and perspectives. The proofs can be found in [16].

## 2 The basic notions of argumentation frameworks

For each argumentation framework, the arguments are produced by agents and the attack relation between them is set up according to some specific rules. We do not consider the origin and structure of arguments and the practical interaction of them.

**Definition 1** *An argumentation framework is a pair  $AF = (A, R)$ , where  $A$  is a finite set of arguments and  $R \subseteq A \times A$  represents the attack relation.*

*Let  $AF = (A, R)$  be an argumentation framework,  $a, b \in A$  and  $S \subseteq A$ .  $a$  is attacked by  $b$  if  $(b, a) \in R$ , denoted by  $b \rightarrow a$ ;  $a$  is called initial if  $a$  is not attacked;  $a$  is attacked by  $S$  if there is some  $b \in S$  such that  $(b, a) \in R$ , denoted by  $S \rightarrow a$ ;  $R^+(S)$  denotes the set of arguments attacked by  $S$ ;  $a$  attacks  $S$  if there is some  $b \in S$  such that  $(a, b) \in R$ , denoted by  $a \rightarrow S$ .*

Usually, an argumentation framework  $AF = (A, R)$  can be represented by a directed graph. Nodes are used to stand for the arguments and edges represent the attack relation between arguments.

An extension is a set of arguments which can stand together. The basic requirement for any extension is conflict-freeness. That is, if an argument  $a$  attacks another argument  $b$ , then they can not stand together. Another requirement is known as admissibility and lies at the heart at all traditional extension-based semantics. It is based on the notions of acceptable argument and admissible set.

**Definition 2** *Let  $AF = (A, R)$  be an argumentation framework,  $S, T \subseteq A$ ,  $a \in A$ .*  
*-  $S$  is conflict-free if there are no  $a, b \in S$  such that  $(a, b) \in R$ . Furthermore,  $S$  is conflict-free with  $T$  if  $S \cup T$  is a conflict-free set.*  
*- By extension, a set  $\mathcal{B}$  of subsets of  $A$  is said to be conflict-free if the union of the*

elements of  $\mathcal{B}$ , denoted by  $\cup\mathcal{B}$ , is a conflict-free subset of  $A$ .

- $a$  is acceptable wrt.  $S$  (or  $a$  is defended by  $S$ ) if each attacker  $b$  of  $a$  is attacked by  $S$ .
- $S$  is an admissible set if  $S$  is conflict-free and each  $a \in S$  is defended by  $S$ . For convenience, we denote the collection of all admissible sets of  $AF$  by  $\mathcal{AS}(AF)$ .

In the literature, the reinstatement principle [3] is regarded as the converse of admissibility principle. Both principles lead to the following semantics.

**Definition 3** Let  $AF = (A, R)$  be an argumentation framework and  $S \subseteq A$ .

- $S$  is a complete extension if  $S \in \mathcal{AS}(AF)$  and for each  $a \in A$  defended by  $S$ ,  $a \in S$ . The collection of all complete extensions is denoted by  $\mathcal{CO}(AF)$ .
- $S$  is the grounded extension if it is the least element (wrt. set inclusion) of  $\mathcal{CO}(AF)$ . The grounded extension of  $AF$  is unique and denoted by  $GE(AF)$ .
- $S$  is a preferred extension of  $AF$  if it is a maximal element (wrt. set inclusion) of  $\mathcal{CO}(AF)$ . The collection of all preferred extensions is denoted by  $\mathcal{PR}(AF)$ .

The complete and grounded extensions can also be defined using the characteristic function. Let  $AF = (A, R)$ , the function  $\mathcal{F} : 2^A \rightarrow 2^A$  which, given a set  $S \subseteq A$ , returns the set of the acceptable arguments wrt.  $S$ , is called the characteristic function<sup>1</sup> of  $AF$ . Complete extensions are exactly conflict-free fixed points of  $\mathcal{F}$  and the grounded extension of  $AF$  is the least fixed point of  $\mathcal{F}$ .

In the following, we sometimes need to restrict to a subset of an argumentation framework.

**Definition 4** Let  $AF = (A, R)$  be an argumentation framework, and  $S \subseteq A$ . The restriction of  $AF$  to  $S$ , denoted by  $AF \upharpoonright_S$ , is the sub-argumentation framework  $(S, R \cap (S \times S))$ .

We also recall the I-maximality and directionality principles first introduced in [3]. The directionality principle is based on the sets of arguments which do not receive any attack from outside.

**Definition 5** Let  $\sigma$  be a semantics and  $AF$  be an argumentation framework.  $\mathcal{E}_\sigma(AF)$  denotes the set of extensions of  $AF$  under the semantics  $\sigma$ .

- A set  $\mathcal{E}$  of extensions is I-maximal if and only if  $\forall E_1, E_2 \in \mathcal{E}$ , if  $E_1 \subseteq E_2$  then  $E_1 = E_2$ . A semantics  $\sigma$  satisfies the I-maximality principle if and only if  $\forall AF$  such that  $\mathcal{E}_\sigma(AF)$  is non-empty,  $\mathcal{E}_\sigma(AF)$  is I-maximal.
- A non-empty set  $S \subseteq A$  is unattacked in  $AF$  if and only if there exists no  $a \in (A \setminus S)$  such that  $a \rightarrow S$ .
- A semantics  $\sigma$  satisfies the directionality principle if and only if  $\forall AF$  such that  $\mathcal{E}_\sigma(AF)$  is non-empty,  $\forall S$  unattacked in  $AF$ ,  $\mathcal{E}_\sigma(AF \upharpoonright_S) = \{(E \cap S) : E \in \mathcal{E}_\sigma(AF)\}$ .

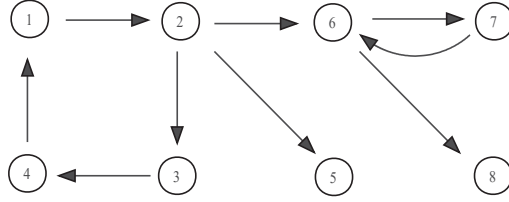
Now, let us turn to the notion of initial set first introduced in [15].

<sup>1</sup> Strictly speaking, this function should be denoted by  $\mathcal{F}_{AF}$ . The subscript will be omitted in the following.

**Definition 6** Let  $AF = (A, R)$  be an argumentation framework. A non-empty admissible set  $I$  is initial if it has no non-empty proper subset to be admissible. The collection of all initial sets of  $AF$  is denoted by  $\mathcal{IS}(AF)$ .

For any initial argument  $i$  of  $AF$ ,  $\{i\}$  is obviously an initial set. Two initial sets of  $AF$  may be conflicting. So, we usually consider conflict-free subsets of  $\mathcal{IS}(AF)$ .

**Example 1** Let  $AF = (A, R)$  with  $A = \{1, 2, 3, 4, 5, 6, 7, 8\}$  and  $R = \{(1, 2), (2, 3), (3, 4), (4, 1), (2, 5), (2, 6), (6, 7), (6, 8), (7, 6)\}$ . The directed graph is as follows.



There are three initial sets:  $I_1 = \{1, 3\}$ ,  $I_2 = \{2, 4\}$  and  $I_3 = \{7\}$ . Obviously,  $I_1$  and  $I_2$  are conflicting, whereas  $\{I_1, I_3\}$  is a conflict-free subset of  $\mathcal{IS}(AF)$ .

Due to Def.6 any non-empty admissible set contains at least one initial set. Certainly, any two initial sets contained in an admissible set are conflict-free. So, we have:

**Proposition 1** Let  $AF = (A, R)$  and  $E$  be an admissible set of  $AF$ . If  $\mathcal{B}$  is a collection of initial sets contained in  $E$ , then  $\cup \mathcal{B}$  is an admissible set. If  $\mathcal{B}$  is the collection of all initial sets contained in  $E$ , then  $E \setminus (\cup \mathcal{B})$  contains no initial set.

As is known, the grounded extension can be built starting from the set of all initial arguments by iteratively adding acceptable arguments. Namely, the initial arguments can be seen as starting points for building the grounded extension by acceptability. For an admissible extension  $E$ , the initial sets contained in  $E$  play the same role. That is, the initial sets can be regarded as the starting points for constructing an admissible set (certainly including complete and preferred extensions) by adding acceptable arguments and the so-called joint acceptable sets which we will introduce and discuss below.

### 3 The J-acceptability and related topics

Given an argumentation framework  $AF = (A, R)$  and an admissible set  $E$ , there are usually two ways to construct a new admissible set having more arguments. If  $S$  is an admissible set which is conflict-free with  $E$ , then  $E \cup S$  is an admissible set. If  $S \subseteq \mathcal{F}(E)$ , then  $E \cup S$  is an admissible set. In fact, there is another way to construct new admissible sets. There may be some set  $S$  of arguments, which is not admissible and has no argument contained in  $\mathcal{F}(E)$ , such that  $E \cup S$  is admissible.

**Example 1 (cont'd)** For the admissible set  $I_1 = \{1, 3\}$ , we have that  $I_3 = \{7\}$  is admissible and conflict-free with  $I_1$  and thus  $I_1 \cup I_3 = \{1, 3, 7\}$  is admissible. Since  $S_1 = \{5\} \subseteq \mathcal{F}(I_1)$ ,  $I_1 \cup S_1 = \{1, 3, 5\}$  is also admissible. Let  $S_2 = \{6\}$ . Although  $S_2$  is not admissible and  $S_2 \cap \mathcal{F}(I_1) = \emptyset$ , we also have that  $I_1 \cup S_2 = \{1, 3, 6\}$  is an admissible set.

In the above example,  $S_2$  is not admissible and its arguments are not acceptable with respect to  $I_1$ . But, the argument 6 can be acceptable with respect to  $I_1 \cup S_2$ . In words, all the arguments of  $S_2$  are acceptable with respect to the union of  $I_1$  and  $S_2$ . This situation leads us to propose the joint acceptability so as to distinguish from the acceptability.

**Definition 7** Given  $AF = (A, R)$ , a non-empty admissible set  $E \subset A$  and a non-empty subset  $S \subset A$ . If  $S$  is not admissible,  $\mathcal{F}(E) \cap S = \emptyset$  and  $E \cup S$  is admissible, then we say that  $S$  is joint acceptable wrt.  $E$  (J-acceptable wrt.  $E$  for short). The collection of all J-acceptable sets wrt.  $E$  is denoted by  $\mathcal{JA}(E)$ .

Although a J-acceptable set  $S$  wrt. an admissible set  $E$  is not admissible, it can be shown that  $S$  is an admissible set in the modified argumentation  $AF'$  obtained by deleting the arguments of  $E$  and the arguments attacked by  $E$ .

**Proposition 2** Let  $AF = (A, R)$ ,  $E$  be an admissible set. If  $S$  is J-acceptable wrt.  $E$ , then  $S$  is an admissible set in the framework  $AF' = AF \upharpoonright_{A \setminus B}$  where  $B = E \cup R^+(E)$ . Conversely, each admissible set  $S$  of  $AF'$ , which is conflict-free with  $E$  in  $AF$  but not admissible, is J-acceptable wrt.  $E$  in  $AF$ .

The notion of J-acceptability induces a new principle, namely the J-reinstatement principle.

**Definition 8** A semantics  $\sigma$  satisfies the J-reinstatement principle if  $\forall AF = (A, R)$  such that  $\mathcal{E}_\sigma(AF)$  is non-empty, for each  $\sigma$ -extension  $E$  of  $AF$ , the J-acceptable set wrt.  $E$  is contained in  $E$ . In words, there is no subset of  $A \setminus E$  to be J-accepted wrt.  $E$ .

Similar as the description of complete extensions by the reinstatement criterion, we can define a new class of extensions based on the J-reinstatement criterion. This class includes the preferred extensions.

**Definition 9** Given  $AF = (A, R)$  and an admissible set  $E$ .  $E$  is called a J-complete extension if there is no  $S \subseteq A \setminus E$  to be J-acceptable with respect to  $E$ . The set of all J-complete extensions of  $AF$  will be denoted by  $\mathcal{E}_{\mathcal{JCO}}(AF)$ .

**Example 1 (cont'd)**  $E_1 = \{1, 3, 5\}$  is complete but not J-complete. On the other hand, there is an admissible set  $E_2 = \{1, 3, 6\}$  which is J-complete but not complete. Note also that the admissible set  $E_3 = \{1, 3, 6, 5\}$  is both J-complete and complete. It is also a preferred extension.

The following proposition identifies the important role of J-reinstatement criterion in the theory of extension-based semantics. In words, J-complete semantics fills the gap between complete semantics and preferred semantics.

**Proposition 3** A complete extension  $E$  of  $AF = (A, R)$  is preferred if and only if it is J-complete and  $A \setminus E$  has no non-empty admissible subset to be conflict-free with  $E$ .

Similar as complete semantics, the J-complete semantics does not satisfy the I-maximality criterion. On the other hand, it can be proved that the J-complete semantics satisfies the directionality criterion.

**Proposition 4** *The J-complete semantics satisfies the directionality criterion.*

The notion of J-acceptability also enables to define the J-characteristic function for an argumentation framework  $AF$ .

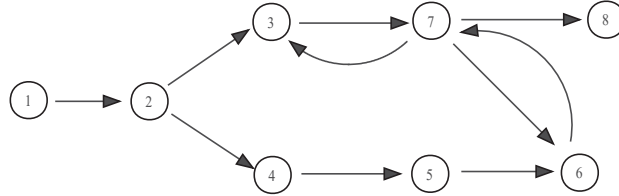
**Definition 10** *Let  $AF = (A, R)$ . The function  $\mathcal{F}_J : 2^A \rightarrow 2^{2^A}$  which, given an admissible set  $E \subseteq A$ , returns the collection of the J-acceptable sets wrt.  $E$ , is called the J-characteristic function of  $AF$ . In words,  $\mathcal{F}_J(E) = \mathcal{J}A(E)$ .*

Note that  $\mathcal{F}_J(E)$  is usually not conflict-free, so  $E \cup (\cup \mathcal{F}_J(E))$  may not be an admissible set, which in contrast, is always true for the characteristic function  $\mathcal{F}$ . If we select a conflict-free collection  $\mathcal{B}$  of J-acceptable sets wrt.  $E$ , then it is easy to check that  $E \cup (\cup(\mathcal{B}))$  is admissible. Based on these two facts, we define a selection J-function  $R_J$  on each argumentation framework as follows.

**Definition 11** *Let  $AF = (A, R)$ ,  $E$  be a non-empty admissible set. A selection function  $R_J$  assigns to  $E$  a set  $R_J(E)$ , which is the union of some random selected conflict-free J-acceptable sets wrt.  $E$ . That is,  $R_J(E) = \cup \mathcal{C}$  where  $\mathcal{C}$  is the random selected conflict-free subcollection  $\mathcal{C}$  of  $\mathcal{F}_J(E)$ .*

**Proposition 5** *Let  $AF = (A, R)$ ,  $E$  be a non-empty admissible set. Then,  $E \cup R_J(E)$  is admissible.*

**Example 2** *Let  $AF = (A, R)$  with  $A = \{1, 2, 3, 4, 5, 6, 7, 8\}$  and  $R = \{(1, 2), (2, 3), (2, 4), (3, 7), (4, 5), (5, 6), (6, 7), (7, 3), (7, 6), (7, 8)\}$ . The directed graph is as follows.*



Obviously,  $E_1 = \{1, 4\}$  is admissible and  $\mathcal{F}_J(E_1) = \{J_1, J_2\}$  with  $J_1 = \{3\}$  and  $J_2 = \{6\}$ . If  $R_J(E_1) = \cup\{J_1\}$ , then  $E_1 \cup R_J(E_1) = \{1, 4, 3\}$  is admissible. If  $R_J(E_1) = \cup\{J_2\}$ , then  $E_1 \cup R_J(E_1) = \{1, 4, 6\}$  is admissible. If  $R_J(E_1) = \cup\{J_1, J_2\}$ , then  $E_1 \cup R_J(E_1) = \{1, 4, 3, 6\}$  is admissible. In particular, if we let  $R_J(E_1) = \emptyset$ , then  $E_1 \cup R_J(E_1) = \{1, 4\} = E_1$  is obviously admissible.

## 4 The structure of traditional semantics

The study of extension-based semantics is a central topic in argumentation. Dung first introduced the admissible, complete, preferred and stable semantics in his outstanding

work. After that, new semantics have been introduced in order to meet some special requirements or make up the drawback of known traditional semantics for specific applications.

Here, we mainly focus on the structural analysis of various traditional semantics based on the initial sets, acceptability and J-acceptability.

#### 4.1 The structure of admissible semantics

Admissibility is a common feature for the traditional argumentation semantics. We first classify the admissible extensions into three types based on initial sets, acceptability and J-acceptability.

##### I-type admissible sets

For any admissible set  $E$ ,  $\mathcal{F}(E)$  is obviously admissible and can be expressed as  $E \cup (\mathcal{F}(E) \setminus E)$ . Note that, each argument of  $\mathcal{F}(E) \setminus E$  satisfies: being accepted by  $E$  and not belonging to  $E$ . This leads us to define a subclass of admissible sets.

**Definition 12** Given  $AF = (A, R)$  and  $S \subseteq A$ . An argument  $i$  is regularly accepted by  $S$  if  $i \notin S$  and  $i$  is defended by  $S$ .

If there exists an argument regularly accepted by the admissible set  $S$ , then  $S$  is a proper subset of  $\mathcal{F}(S)$ . And, any initial argument is regularly accepted by the empty set.

**Definition 13** Let  $E$  be an admissible set of  $AF = (A, R)$  and  $\mathcal{B}$  the collection of all initial sets contained in  $E$ . If each  $i \in E \setminus \cup \mathcal{B}$  is regularly accepted by some admissible set  $B \subseteq E$ , then we say that  $E$  is a I-type admissible set.

It is easy to check that the union of conflict-free initial sets is a I-type admissible set.

**Example 1 (cont'd)** For the admissible set  $I_1 = \{1, 3\}$ , as  $5 \in \mathcal{F}(I_1) \setminus I_1$  the argument 5 is regularly accepted by  $I_1$ . Let us consider the admissible set  $E_1 = \{1, 3, 5\}$  and the collection  $\mathcal{B} = \{I_1\}$  of initial sets contained in  $E_1$ . Obviously, the only argument 5 of  $E_1 \setminus \cup \mathcal{B}$  is regularly accepted by the admissible set  $I_1 \subseteq E_1$ . So,  $E_1$  is a I-type admissible set.

The grounded extension is also a I-type admissible set. More generally, we have:

**Proposition 6** Any admissible set  $\mathcal{F}^k(\emptyset)$  is a I-type admissible set.

Next, we will analyze the structure of I-type admissible sets from two different points of view. One is to construct a I-type admissible set starting from initial sets, another one is to describe a given I-type admissible set starting from initial sets contained in it.

From any admissible set the characteristic function  $\mathcal{F}$  can be iteratively applied to obtain a complete extension. We try to replace  $\mathcal{F}$  by some specific operator related to the acceptability so as to obtain a larger admissible set. This goal can be reached by defining a selection function as follows.



**Definition 14** Given an admissible set  $E$  of  $AF = (A, R)$ . A selection function  $R_A$  assigns to  $E$  a random selected subset  $R_A(E)$  of  $\mathcal{F}(E) \setminus E$ .

It is easy to check that  $E \cup R_A(E)$  is certainly a I-type admissible set whenever  $E$  is a I-type admissible set.

**Example 2 (cont'd)** It is easy to check that  $E_2 = \{1, 3\}$  is a I-type admissible set and  $\mathcal{F}(E_2) \setminus E_2 = \{4, 8\}$ . If  $R_A(E_2) = \{4\}$ , then  $E_2 \cup R_A(E_2) = \{1, 3, 4\}$  is a I-type admissible set. If  $R_A(E_2) = \{8\}$ , then  $E_2 \cup R_A(E_2) = \{1, 3, 8\}$  is a I-type admissible set. If  $R_A(E_2) = \{4, 8\}$ , then  $E_2 \cup R_A(E_2) = \{1, 3, 4, 8\}$  is a I-type admissible set.

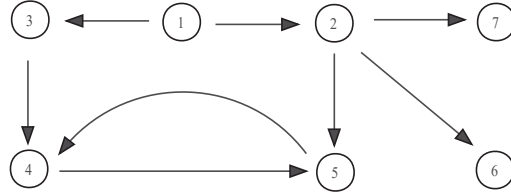
Now, let us start from initial sets to construct I-type admissible sets by using the selection function  $R_A$ .

**Constructing the I-type admissible sets:** Let  $\mathcal{B}$  be a conflict-free collection of initial sets, define  $E_0 = \cup \mathcal{B}$  and  $E_{k+1} = E_k \cup R_A(E_k)$  for each natural number  $k$ . Then,  $E_0$  is the union of some conflict-free initial sets,  $E_1$  is the set obtained by adding to  $E_0$  some arguments regularly accepted by  $E_0$ , and so on.

The following theorem indicates that starting from a conflict-free collection of initial sets we can construct many different I-type admissible sets by iteratively applying the selection function  $R_A$ .

**Theorem 1** Let  $\mathcal{B}$  be a conflict-free collection of initial sets and  $E_k$  as above, then  $E_k$  is a I-type admissible set for each natural number  $k$ .

**Example 3** Let  $AF = (A, R)$  with  $A = \{1, 2, 3, 4, 5, 6, 7\}$  and  $R = \{(1, 2), (1, 3), (2, 5), (2, 6), (2, 7), (3, 4), (4, 5), (5, 4)\}$ . The directed graph is as follows.



Obviously,  $E = \{1\}$  is the unique initial set of  $AF$  and  $\mathcal{F}(E) = \{1, 6, 7\}$ . If  $R_A(E) = \{6\}$ , then  $E \cup R_A(E) = \{1, 6\}$  is a I-type admissible set. If  $R_A(E) = \{7\}$ , then  $E \cup R_A(E) = \{1, 7\}$  is a I-type admissible set. If  $R_A(E) = \{6, 7\}$ , then  $E \cup R_A(E) = \{1, 6, 7\}$  is a I-type admissible set.

In order to describe a given I-type admissible set  $E$ , we need to define another operation also based on acceptability but restricted to  $E$ .

**Definition 15** Let  $S$  and  $E$  be two admissible sets of  $AF$  such that  $S \subseteq E$ . An operation  $P$  on  $S$  wrt.  $E$  assigns to  $S$  a subset of  $E$ :  $P(S, E) = E \cap (\mathcal{F}(S) \setminus S)$ .

**Example 2 (cont'd)** For the admissible set  $E_2 = \{1, 3\}$ , we have that  $\mathcal{F}(E_2) \setminus E_2 = \{4, 8\}$ . With the admissible set  $E_3 = \{1, 3, 8\}$ ,  $P(E_2, E_3) = \{8\}$ . With the admissible set  $E_4 = \{1, 3, 4\}$ ,  $P(E_2, E_4) = \{4\}$ . With the admissible set  $E_5 = \{1, 3, 4, 8\}$ ,  $P(E_2, E_5) = \{4, 8\}$ .

In the above definition, if  $S$  is a I-type admissible set, then  $S \cup P(S, E)$  is certainly a I-type admissible set. And thus, we can describe a given admissible set from the initial sets contained in it by using the operation  $P(\cdot, \cdot)$ .

**Describing a given I-type admissible set:** Let  $E$  be a I-type admissible set and  $\mathcal{B}$  the collection of all initial sets contained in  $E$ , define  $E_0 = \cup \mathcal{B}$  and  $E_{k+1} = E_k \cup P(E_k, E)$  for each natural number  $k$ . Then,  $E_0$  is the union of all initial sets contained in  $E$ ,  $E_1$  is the set obtained by adding to  $E_0$  all the arguments which are regularly accepted by  $E_0$  and contained in  $E$ , and so on.

The following theorem indicates that any I-type admissible set  $E$  can be described as starting from the collection  $\mathcal{B}$  of all initial sets contained in  $E$  and iteratively applying the function  $P(\cdot, E)$ .

**Theorem 2** Let  $E$  be a I-type admissible set and  $\mathcal{B}$  the collection of all initial sets contained in  $E$ , then  $E_k$  defined above is a I-type admissible set contained in  $E$  for each natural number  $k$ . Furthermore, there is some natural number  $m$  such that  $E = E_{m+1} = E_{m+2}$  and  $E_{m+1} = E_0 \cup P(E_0, E) \cup P(E_1, E) \dots \cup P(E_m, E)$ .

As a consequence of the above results, we can provide a way for building strongly admissible sets, first introduced in [3]. An argument  $i \in A$  is strongly defended by a set  $S \subseteq A$  iff each attacker  $j$  of  $i$  is attacked by some  $k \in S \setminus \{i\}$  such that  $k$  is strongly defended by  $S \setminus \{i\}$ . Then,  $S$  is said strongly admissible iff it strongly defends each of its arguments. An equivalent definition has been proposed by [8].  $S \subseteq A$  is strongly admissible iff  $S$  consists of some initial arguments, or every  $i \in S$  is defended by some subset  $T \subseteq (S \setminus \{i\})$  which in its turn is again strongly admissible. Following definitions, it is easy to see that every strongly admissible set is a I-type admissible set and thus can be constructed starting from some initial arguments by applying the function  $P$  iteratively.

## II-type admissible sets

Except for the I-type admissible sets, there is another kind of admissible sets called II-type admissible sets. They are the admissible sets which have no argument to be regularly accepted by admissible sets contained in them.

**Definition 16** Let  $E$  be an admissible set of  $AF = (A, R)$  and  $\mathcal{B}$  the collection of all initial sets contained in  $E$ . If each  $i \in E \setminus (\cup \mathcal{B})$  belongs to a  $J$ -acceptable set  $S \subseteq E$  w.r.t some admissible set  $D \subseteq E$ , then we say that  $E$  is a II-type admissible set.

Note that, the union of a conflict-free collection of initial sets is not only a I-type admissible set but also a II-type admissible set.

**Example 1 (cont'd)** Let us consider the admissible set  $E_2 = \{1, 3, 6\}$  and the collection  $\mathcal{B} = \{I_1\}$  of initial sets contained in  $E_2$ , where  $I_1 = \{1, 3\}$ .

It is easy to check that  $\{6\}$  is a J-acceptable set wrt.  $I_1$ , and thus  $E_2$  is a II-type admissible set.

In fact,  $6 \notin \mathcal{F}(I_1) \setminus I_1$  and is not regularly accepted by the admissible sets  $I_1$  and  $E_2$  which are the non-empty admissible sets contained in  $E_2$ .

Generally speaking, the membership of each argument of a II-type admissible set  $E$  does not only depend on other arguments of  $E$  but also on itself. This feature is exactly that the notion of J-acceptability states. Certainly, a II-type admissible set  $E$  may contain some regularly accepted arguments, whose membership depend completely on other arguments of  $E$ . The following proposition gives a description for a II-type admissible set having no regularly accepted arguments except initial arguments.

**Proposition 7** Let  $E$  be an admissible set of AF and  $\mathcal{B}$  the collection of all initial sets contained in  $E$ . Then  $E \setminus (\cup \mathcal{B})$  has no regularly accepted arguments if and only if for each admissible set  $D \subset E$  containing  $\cup \mathcal{B}$  as a subset,  $E \setminus D$  is J-acceptable wrt.  $D$ .

By the above proposition, an admissible set with no regularly accepted arguments except initial arguments must be a II-type admissible set. Next, we will analyze the structure of II-type admissible sets from two different points of view. One is to construct a II-type admissible set starting from initial sets, another is to describe a given II-type admissible set starting from the initial sets contained in it.

As for I-type admissible sets, in constructing II-type admissible sets we need to use a selection function related to the J-acceptability. Interestingly, the selection function  $R_J$  in Definition 11 is exactly the one we need. Furthermore, Prop.5 is also true if we substitute "admissible" by "II-type admissible". This result gives us the theoretical support for constructing II-type admissible sets by applying the selection function  $R_J$ .

**Constructing the II-type admissible sets:** Let  $\mathcal{B}$  be a conflict-free collection of initial sets, define  $E_0 = \cup \mathcal{B}$  and  $E_{k+1} = E_k \cup R_J(E_k)$  for each natural number  $k$ . Then,  $E_0$  is the union of some conflict-free initial sets,  $E_1$  is the set obtained by adding to  $E_0$  some conflict-free J-acceptable sets wrt.  $E_0$ , and so on.

The following theorem indicates that starting from a conflict-free collection of initial sets we can construct many different II-type admissible sets by iteratively applying the selection function  $R_J$ .

**Theorem 3** Let  $\mathcal{B}$  a conflict-free collection of initial sets and  $E_k$  as above, then  $E_k$  is a II-type admissible set for each natural number  $k$ .

**Example 3 (cont'd)** For the unique initial set  $E = \{1\}$  of AF, we have that  $\mathcal{F}_J(E) = \{J_1, J_2\}$  with  $J_1 = \{4\}$  and  $J_2 = \{5\}$ . If  $R_J(E) = J_1$ , then  $E \cup R_J(E) = \{1, 4\}$  is a II-type admissible set. If  $R_J(E) = J_2$ , then  $E \cup R_J(E) = \{1, 5\}$  is a II-type admissible set. Since  $J_1$  and  $J_2$  are in conflict,  $R_J(E) \neq J_1 \cup J_2$ .

In describing a given I-type admissible set, the main work is iteratively applying the function  $P(\cdot, \cdot)$ . This idea can be further extended to the case of J-acceptability so as to describe a given II-type admissible set.

**Definition 17** Let  $S$  and  $E$  be two admissible sets of  $AF$  such that  $S \subseteq E$ . An operation  $P_J$  on  $S$  wrt.  $E$  assigns to  $S$  a subset of  $E$ :  $P_J(S, E) = \cup\{T : T \text{ is } J\text{-acceptable wrt. } S \text{ and } T \subseteq E\}$ .

**Example 2 (cont'd)** For the admissible set  $E_1 = \{1, 4\}$ , we have that  $\mathcal{F}_J(E_1) = \{J_1, J_2\}$  where  $J_1 = \{3\}$  and  $J_2 = \{6\}$ . With the admissible set  $E_6 = \{1, 4, 3\}$ ,  $P_J(E_1, E_6) = \cup\{J_1\} = \{3\}$ . With the admissible set  $E_7 = \{1, 4, 6\}$ ,  $P_J(E_1, E_7) = \cup\{J_2\} = \{6\}$ . With the admissible set  $E_8 = \{1, 4, 3, 6\}$ ,  $P_J(E_1, E_8) = \cup\{J_1, J_2\} = \{3, 6\}$ .

Note that,  $S \cup P_J(S, E)$  is a II-type admissible set whenever  $S$  is a II-type admissible set. And so, we can describe any II-type admissible set  $E$  starting from the initial sets contained in it by iteratively applying the function  $P_J(\cdot, \cdot)$ .

**Describing a given II-type admissible set:** Let  $E$  be a II-type admissible set and  $\mathcal{B}$  the collection of all initial sets contained in  $E$ , define  $E_0 = \cup\mathcal{B}$  and  $E_{k+1} = E_k \cup P_J(E_k, E)$  for each natural number  $k$ . Then,  $E_0$  is the union of some conflict-free initial sets,  $E_1$  is the set obtained by adding to  $E_0$  all the J-acceptable sets wrt.  $E_0$  which are contained in  $E$ , and so on.

The following theorem indicates that any II-type admissible set  $E$  can be described as starting from the collection  $\mathcal{B}$  of all initial sets contained in  $E$  and iteratively applying the function  $P_J(\cdot, E)$ .

**Theorem 4** Let  $E$  be a II-type admissible set and  $\mathcal{B}$  the collection of all initial sets contained in  $E$ , then  $E_k$  defined above is a II-type admissible set contained in  $E$  for each natural number  $k$ . Furthermore, there is some natural number  $m$  such that  $E = E_{m+1} = E_{m+2}$  and  $E_{m+1} = E_0 \cup P_J(E_0, E) \cup P_J(E_1, E) \dots \cup P_J(E_m, E)$ .

### The mixed-type admissible sets

Roughly speaking, the I-type and II-type admissible extensions have onefold structure. So, we usually call them simple admissible extensions. The other admissible extensions may be given the name of mixed-type admissible sets as follows.

**Definition 18** Given  $AF = (A, R)$ , an admissible set  $E$  is mixed-type if it is neither I-type nor II-type.

**Example 1 (cont'd)** Let us consider the admissible set  $E_3 = \{1, 3, 5, 6\}$  and the collection  $\mathcal{B} = \{I_1\}$  of initial sets contained in  $E_3$ . Obviously, the argument 5 of  $E_3 \setminus \cup\mathcal{B}$  is regularly accepted by the admissible set  $I_1 \subseteq E_3$ . So,  $E_3$  is not a II-type admissible set.

We also note that the argument 6 is not regularly accepted by any admissible set  $S$  contained in  $E_3$ , where  $S = \{1, 3\}$  or  $\{1, 3, 5\}$ . It follows that  $E_3$  is not a I-type admissible set.

To sum up,  $E_3$  is a mixed-type admissible set.

Starting from a conflict-free collection  $\mathcal{B}$  of initial sets, many mixed-type admissible sets can be constructed by iteratively applying the functions  $R$  and  $R_J$ .

**Constructing an admissible extension of mixed-type:** Let  $\mathcal{B}$  be a conflict-free collection of initial sets, define  $S_0 = \cup \mathcal{B}$ ,  $T_0 = S_0 \cup R_J(S_0)$ . For each natural number  $k$ , let  $S_{k+1} = T_k \cup R(T_k)$  and  $T_{k+1} = S_{k+1} \cup R_J(S_{k+1})$ . Note that, both  $S_k$  and  $T_k$  are admissible. In order to obtain a mixed-type admissible set  $S_m$  or  $T_m$ , we require that  $S_{r+1} \neq T_r$  and  $T_{t+1} \neq S_{t+1}$  for some  $r, t < m$ .

**Example 3 (cont'd)** For the unique initial set  $E = \{1\}$  of  $AF$ , we have that  $S_0 = \{1\}$ . Note that,  $\mathcal{F}_J(S_0) = \{J_1, J_2\}$  with  $J_1 = \{4\}$  and  $J_2 = \{5\}$ . If we let  $R_J(S_0) = J_1$ , then  $T_0 = \{1, 4\}$  is a II-type admissible set. Furthermore,  $\mathcal{F}(T_0) = \{6, 7\}$ . If we let  $R(T_0) = \{6\}$ , then  $S_1 = \{1, 4, 6\}$  is a mixed-type admissible set. Again, we have  $\mathcal{F}(S_1) = \{J_2\}$ . If we let  $R_J(S_1) = J_2$ , then  $T_1 = \{1, 4, 6, 5\}$  is a mixed-type admissible set.

We can describe an admissible set of mixed-type starting from the initial sets contained in it by iteratively applying the functions  $P(\cdot, \cdot)$  and  $P_J(\cdot, \cdot)$ .

**Describing a given admissible extension of mixed-type:** Let  $E$  be a II-type admissible set and  $\mathcal{B}$  the collection of all initial sets contained in  $E$ , define  $S_0 = \cup \mathcal{B}$  and  $T_0 = S_0 \cup P_J(S_0, E)$ . For each natural number  $k$ , let  $S_{k+1} = T_k \cup P(T_k, E)$  and  $T_{k+1} = S_{k+1} \cup P_J(S_{k+1}, E)$  until  $E = S_m$  or  $T_m$  for some natural number  $m$ . That is, we have  $E = S_0 \cup P_J(S_0, E) \cup P(T_1, E) \dots \cup P_J(S_{m-1}, E) \cup P(T_{m-1}, E)$  or  $E = S_0 \cup P_J(S_0, E) \cup P(T_0, E) \dots \cup P(T_{m-1}, E) \cup P_J(S_m, E)$ .

## 4.2 The structure of complete and preferred semantics

Since both the complete extensions and the preferred extensions are all admissible sets, they also can be classified into different types just like we have done for admissible sets. Meanwhile, we have similar results for constructing them and describing them from conflict-free initial sets by iteratively applying the related functions  $R$ ,  $R_J$ ,  $P$  and  $P_J$ . Due to space limitation, we only list the main notions and results.

**Definition 19** Given a complete (or preferred) extension  $E$  of  $AF = (A, R)$ .  $E$  is said to be of I-type (resp. II-type, mixed-type) if it is a I-type (resp. II-type, mixed-type) admissible set.

**Constructing a I-type complete (or preferred) extension:** Let  $\mathcal{B}$  be a conflict-free collection of initial sets, define  $E_0 = \cup \mathcal{B}$  and  $E_{k+1} = \mathcal{F}(E_k)$  for each natural number  $k$ . Then,  $E_0$  is the union of conflict-free initial sets and thus a I-type admissible set.  $E_1$  is the set obtained by adding to  $E_0$  all arguments regularly accepted by  $E_0$  and thus a I-type admissible set, and so on.

The following result holds: There is some natural number  $m$  such that  $E_m = E_{m+1}$  which is exactly the I-type complete extension we want. Furthermore, if  $\mathcal{F}_J(E_m) = \emptyset$

and there is no initial set in  $A \setminus E_m$  conflicting with  $E_m$ , then  $E_m$  is a I-type preferred extension according to Prop.3.

**Example 1 (cont'd)** *Considering the conflict-free collection  $\mathcal{B} = \{I_1\}$  where  $I_1 = \{1, 3\}$  is an initial set. Let  $E_0 = \cup \mathcal{B} = \{1, 3\}$  and  $E_1 = \mathcal{F}(E_0) = \{1, 3, 5\}$ , then  $E_2 = \mathcal{F}(E_1) = E_1$  is a I-type complete extension.*

**Describing a I-type complete (or preferred) extension:** Let  $E$  be a I-type complete (preferred) extension and  $\mathcal{B}$  the collection of all initial sets contained in  $E$ , define  $E_0 = \cup \mathcal{B}$  and  $E_{k+1} = \mathcal{F}(E_k)$  for each natural number  $k$ . Then,  $E_0 \subseteq \mathcal{F}(E) = E$  is the union of initial sets contained in  $E$  and thus a I-type admissible set.  $E_1 = \mathcal{F}(E_0) \subseteq \mathcal{F}(E) = E$  is the set obtained by adding to  $E_0$  all arguments regularly accepted by  $E_0$  and thus a I-type admissible set, and so on.

**Remark:** Since  $\mathcal{F}(E_k) \subseteq \mathcal{F}(E) = E$ , we have that  $\mathcal{F}(E_k) \setminus E_k = P(E_k, E)$  and thus  $E_{k+1} = \mathcal{F}(E_k) = E_k \cup (\mathcal{F}(E_k) \setminus E_k) = E_k \cup P(E_k, E)$ . This coincides with the case in describing a given I-type admissible set.

The following result holds: There is some natural number  $m$  such that  $E = E_m = E_{m+1}$ .

Note that we can not always obtain a II-type complete (resp. preferred) extension starting from a conflict-free collection of initial sets. In fact, there are many argumentation frameworks which have no II-type complete (resp. preferred) extensions.

**Example 1 (cont'd)** *There are six II-type admissible sets:  $E_1 = \{1, 3\}$ ,  $E_2 = \{2, 4\}$ ,  $E_3 = \{7\}$ ,  $E_4 = \{1, 3, 6\}$ ,  $E_5 = \{1, 3, 7\}$ ,  $E_6 = \{2, 4, 7\}$ . But, they are all not complete extensions. In fact,  $\mathcal{F}(E_1) = \{1, 3, 5\}$ ,  $\mathcal{F}(E_2) = \{2, 4, 8\}$ ,  $\mathcal{F}(E_3) = \{7, 8\}$ ,  $\mathcal{F}(E_4) = \{1, 3, 6, 5\}$ ,  $\mathcal{F}(E_5) = \{1, 3, 7, 5, 8\}$ ,  $\mathcal{F}(E_6) = \{2, 4, 7, 8\}$ .*

*A further observation indicates that  $\mathcal{F}(E_4)$ ,  $\mathcal{F}(E_5)$  and  $\mathcal{F}(E_6)$  are the preferred extensions, but they are not II-type preferred.*

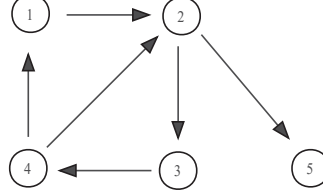
Next, we only talk about the description of II-type complete (resp. preferred) extensions here.

**Describing a II-type complete (or preferred) extension:** Let  $E$  be a II-type complete (preferred) extension and  $\mathcal{B}$  the collection of all initial sets contained in  $E$ , define  $E_0 = \cup \mathcal{B}$  and  $E_{k+1} = E_k \cup P_J(E_k, E)$  for each natural number  $k$ . Then,  $E_0 \subseteq E$  is the union of initial sets contained in  $E$  and thus a II-type admissible set.  $E_1 \subseteq E$  is the set obtained by adding to  $E_0$  all the J-acceptable sets wrt.  $E_0$  which are contained in  $E$  and thus a II-type admissible set, and so on.

The following result holds: There is some natural number  $m$  such that  $E = E_m = E_{m+1}$ .

As for II-type complete (resp. preferred) extensions, the mixed complete (resp. preferred) extensions may not exist. So, we only talk about the description of mixed-type complete (resp. preferred) extensions in the sequel.

**Example 4** Let  $AF = (A, R)$  with  $A = \{1, 2, 3, 4, 5\}$  and  $R = \{(1, 2), (2, 3), (3, 4), (4, 1), (4, 2), (2, 5)\}$ . The directed graph is as follows.



It is easy to check that  $I = \{1, 3\}$  is the only initial set and  $E = \{1, 3, 5\}$  is the unique preferred extension, but  $E$  is not mixed-type preferred.

**Describing a complete (or preferred) mixed-type extension:** Let  $E$  be a mixed-type complete (preferred) extension and  $\mathcal{B}$  the collection of all initial sets contained in  $E$ , define  $S_0 = \cup \mathcal{B}$  and  $T_0 = S_0 \cup P_J(S_0, E)$ . For each natural number  $k$ , let  $S_{k+1} = \mathcal{F}(T_k, E) = T_k \cup P(T_k, E)$  and  $T_{k+1} = S_{k+1} \cup P_J(S_{k+1}, E)$ . Then,  $S_0$  is the union of initial sets contained in  $E$ ,  $T_0$  is the union of  $S_0$  with all J-acceptable sets wrt.  $S_0$  which are contained in  $E$ .  $S_1$  is the union of  $T_0$  with the set of arguments which are regularly defended by  $T_0$  and contained in  $E$ ,  $T_1$  is the union of  $S_1$  with all J-acceptable sets wrt.  $S_1$  which are contained in  $E$ , and so on.

The following result holds: There is some natural number  $m$  such that  $E = S_m$  or  $T_m$ . That is, we have  $E = S_0 \cup P_J(S_0, E) \cup P(T_1, E) \dots \cup P_J(S_{m-1}, E) \cup P(T_{m-1}, E)$  or  $E = S_0 \cup P_J(S_0, E) \cup P(T_0, E) \dots \cup P(T_{m-1}, E) \cup P_J(S_m, E)$ .

## 5 Conclusion and future works

In this paper, the special type of acceptability called J-acceptability is studied. Meanwhile, the reinstatement criterion is extended to the J-reinstatement criterion and the characteristic function is extended to the J-characteristic function.

Based on the J-reinstatement criterion, we introduce the J-complete semantics which fills the gap between complete semantics and preferred semantics. It is claimed that an admissible set is preferred if and only if it is complete, J-complete and  $A \setminus E$  has no non-empty admissible subset to be conflict-free with  $E$ .

With acceptability and J-acceptability, we figure out the structure of admissible sets, complete extensions and preferred extensions. That is, any admissible (resp. complete, preferred) extension can be obtained starting from a conflict-free collection of initial sets by iteratively applying some operators related to the acceptability and J-acceptability. This work suggests that for any argumentation framework, the problem of determining extensions will be completely solved if we can find out all initial sets.

J-acceptability combined with acceptability has been proved useful for giving a clear description for the extensions of the standard semantics. We plan to study the role of J-acceptability in other non-standard semantics, and more particularly for the structure analysis of their extensions.

Another direction for further research concerns the use of J-acceptability in dynamic argumentation frameworks. In literature, several works have proposed efficient ways for handling dynamics, such as [12] which introduces the division-based method, and [14] where a matrix approach allows for a decomposition of standard extensions, using unattacked sets of arguments. We are going to investigate the role of initial sets and J-acceptability in the construction of the extensions of an updated argumentation framework.

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