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A Principle-based Framework for Analyzing Dialogue Game-based Semantics

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Abstract

The dialogue game-based approach to argumentation semantics proposes to determine the acceptance status of arguments through two-party zero-sum dialogue games. Furthermore, by selecting different sets of rules to govern the moves of arguments in the game, it allows for the characterization of distinct argumentation semantics. This approach has proven significant for theoretical and practical reasons. Accordingly, the ability to identify the most suitable semantics for a given domain is a key element in promoting the adoption of dialogue game-based semantics in real-world systems. This paper introduces a set of principles for systematically analyzing dialogue game-based semantics. We aim to contribute to existing frameworks by enabling a deeper understanding of the theoretical foundations of such argumentation semantics. In doing so, our framework may also guide the development of new dialogue game-based semantics.

1 Introduction

Argumentation has become an effective paradigm for knowledge representation and reasoning in Artificial Intelligence, due to its ability to capture commonsense reasoning (Bench-Capon and Dunne 2007; Rahwan and Simari 2009). The different ways in which the arguments under consideration and their relations can be evaluated offer a wide range of possibilities and applications, such as legal reasoning (Prakken and Sartor 2015; Atkinson and Bench-Capon 2021), decision-support systems (Amgoud and Prade 2009) and e-democracy (Bench-Capon, Atkinson, and Wyner 2015), among others. Such alternative behaviors can be encoded under the notion of argumentation semantics (Baroni, Caminada, and Giacomin 2011), which are the subject of continuous and ongoing studies in the literature.

The dialogue game-based approach to argumentation semantics (see for instance (Modgil and Caminada 2009)) proposes determining the acceptance status of arguments through two-party zero-sum dialogue games where the first move corresponds to the *proponent*, who moves an initial argument that they wish to put to the test. Then, the *opponent*, the counterpart of the proponent, and the proponent take turns in moving arguments defeating their counterpart's last move while satisfying the set of rules imposed by the game. Different sets of rules governing the move of arguments in the game allow for characterizing distinct argumentation semantics. Then, an argument is accepted if its proponent can successfully defend it against all its defeaters.

Dialogue game-based semantics for abstract argumentation have proven significant for several reasons. From a theoretical perspective, they offer a complementary viewpoint to other approaches for analyzing the foundations of argumentation semantics—such as extension-based or labeling-based. From a practical perspective, they focus on individual argument evaluation without requiring the computation of complete sets of extensions or labelings, thereby serving as a basis for algorithmic development. Furthermore, several techniques can be applied to dialogue games, allowing for the development of efficient algorithms for argument evaluation (Rotstein et al. 2011; Gottifredi et al. 2013; Alfano et al. 2018; Cohen, Gottifredi, and García 2019). The latter is particularly significant for developing argumentation-based knowledge representation and reasoning tools for real-world applications (Briguez et al. 2012; Deagustini et al. 2013; Briguez et al. 2014; Deagustini et al. 2017).

A key element in promoting the adoption of dialogue game-based semantics in real-world systems is the capability to identify the most suitable semantics for a given domain. To achieve this, it is essential to formally analyze the foundations of existing dialogue game-based semantics, compare them, and develop new ones when current alternatives do not meet the requirements of a particular domain.

A principle-based framework for evaluating extension-based argumentation semantics has been proposed in (Baroni and Giacomin 2007). In that framework, several principles embedded in different extension-based semantics were presented, while others were introduced in subsequent works (*e.g.*, (van der Torre and Vesic 2017; Rienstra et al. 2020; Yu et al. 2021)). Our work introduces a set of principles that aim at contributing to existing frameworks to improve the study of the theoretical foundations of argumentation semantics. By deepening the understanding of the principles underlying argumentation semantics, our framework may also serve as a guide for developing new dialogue game-based semantics. Each principle we propose mainly emerges from the consideration of the dialogue game-based approach to defining semantics.

The set of principles we introduce is then used to analyze the dialogue game characterization of the *grounded* and (credulous) *preferred semantics* (Dung 1995), the special purpose semantics from (García and Simari 2004)—here referred to as *default semantics*—and the *pairwise cogency semantics* (Bodanza, Tohmé, and Simari 2016). The rationale for focusing on these semantics is given in Section 4.

The rest of the paper is organized as follows. In Section 2 we present the basis of abstract argumentation. Section 3 introduces the bundle set-based approach for characterizing dialogue games. The argumentation semantics we focus on are given in Section 4. Section 5 proposes a set of principles for analyzing dialogue game-based semantics. Finally, conclusions and future work are discussed in Section 6.

2 Background on Abstract Argumentation

Briefly, an *argumentation framework* (AF) (Dung 1995) is a directed graph where the nodes represent arguments and the edges represent a defeat relation between those arguments.

Definition 2.1. An *argumentation framework* is a pair $\mathfrak{F} = (Ar, Def)$, where Ar is a non-empty finite set of arguments and $Def \subseteq Ar \times Ar$ is a defeat relation.

We say that $\mathcal{A}$ *defeats* $\mathcal{B}$ iff $(\mathcal{A}, \mathcal{B}) \in Def$. $\mathcal{A}$ is a *self-defeating* argument iff $\mathcal{A}$ defeats $\mathcal{A}$. If $(\mathcal{A}, \mathcal{B}) \in Def$ and $(\mathcal{B}, \mathcal{A}) \notin Def$, $\mathcal{A}$ *strictly defeats* $\mathcal{B}$. If $(\mathcal{A}, \mathcal{B}) \in Def$ and $(\mathcal{B}, \mathcal{A}) \in Def$, $\mathcal{A}$ and $\mathcal{B}$ *mutually defeat* each other.

Argumentation semantics are functions that embed some reasonable behavior and determine, given an AF, which arguments should be accepted and which should be rejected. Next, some mainstream semantics from the literature are presented following the extension-based approach.

Definition 2.2. Let $\mathfrak{F} = (Ar, Def)$ be an AF, $E \subseteq Ar$, and $\mathcal{A} \in Ar$. E *defends* $\mathcal{A}$ iff for all $\mathcal{B}$ that defeats $\mathcal{A}$ there exists $\mathcal{C} \in E$ such that $\mathcal{C}$ defeats $\mathcal{B}$. The function $Ch : 2^{Ar} \to 2^{Ar}$ such that $Ch(E) = \{\mathcal{A} \mid E \text{ defends } \mathcal{A}\}$ is the *characteristic function* of $\mathfrak{F}$.

Definition 2.3. Let $\mathfrak{F} = (Ar, Def)$ be an AF and $E \subseteq Ar$.

- E is *conflict-free* iff $\nexists \mathcal{A}, \mathcal{B} \in E$ such that $\mathcal{A}$ defeats $\mathcal{B}$.
- E is *naive* iff it is a maximal (*w.r.t.* $\subseteq$) conflict-free set.
- E is *admissible* iff it is conflict-free and $E \subseteq Ch(E)$.
- E is a *complete extension* iff it is conflict-free and $E = Ch(E)$.
- E is the *grounded extension* of $\mathfrak{F}$ iff it is the least fixed point of the characteristic function Ch.
- E is a *preferred extension* of $\mathfrak{F}$ iff it is a maximal (*w.r.t.* $\subseteq$) admissible set.

3 The Bundle Set-based Approach

Here, we build on the bundle set-based approach for dialogue game-based argumentation semantics (Chesñevar and Simari 2007; Soto et al. 2024). This approach relies on the notions of argumentation line and bundle set.

Definition 3.1. Let $\mathfrak{F} = (Ar, Def)$ be an AF and $\mathcal{A} \in Ar$. An *argumentation line* for $\mathcal{A}$ from $\mathfrak{F}$ is a finite sequence of arguments of the form $\lambda = [\mathcal{A}_1, \ldots, \mathcal{A}_n]$ where $\mathcal{A} = \mathcal{A}_1$ and each $\mathcal{A}_i$, with $1 < i \leqslant n$, is a defeater of $\mathcal{A}_{i-1}$.

Throughout the rest of the paper we adopt the following conventions: $\mathcal{A}, \mathcal{B}, \mathcal{C}, \ldots$ represent different arguments, while $\mathcal{A}_i$ denotes the argument appearing in the i-th position of some argumentation line λ. We use $\mathcal{A}_i \in \lambda$ to denote that $\mathcal{A}_i$ appears in λ. Sometimes we will refer to an argumentation line simply as a line. If λ is an argumentation line for $\mathcal{A} \in Ar$, we say that λ is *rooted* in $\mathcal{A}$. Moreover, when the root argument of λ is not explicitly stated, we denote it as $root(\lambda)$. Lastly, when referring to multiple argumentation lines, we will denote them using lowercase subscripts $h, i, j, k, \ldots$. These subscripts serve solely to differentiate lines and do not express any type of relation between them.

Next we formalize the notion of *segment* as a (sub) sequence of arguments from an argumentation line.

Definition 3.2. Let $\mathfrak{F}$ be an AF and $\lambda = [\mathcal{A}_1, \ldots, \mathcal{A}_n]$ an argumentation line from $\mathfrak{F}$. A *segment* of λ is a sequence $\lambda' = [\mathcal{A}_i, \ldots, \mathcal{A}_j]$, where $1 \leqslant i \leqslant j \leqslant n$. We say λ' is *initial* if $i = 1$, *proper* if it is initial and $j < n$, and *upper* if $j = n$.

Note that, given an argumentation line λ, every segment λ' of λ is also a line. Furthermore, every argumentation line is an initial and upper segment of itself.

Next, we give the concept of *bundle set*, which is the structure representing dialogue games in our setting. Intuitively, a bundle set is a set of argumentation lines such that no line in the set is a proper segment of another.

Definition 3.3. Let $\mathfrak{F} = (Ar, Def)$ be an AF and $\mathcal{A} \in Ar$. A finite set of argumentation lines for $\mathcal{A}$ is a *bundle set* for $\mathcal{A}$, denoted $\Lambda(\mathcal{A})$, iff there exist no $\lambda_i, \lambda_j \in \Lambda(\mathcal{A})$ such that λ_i is a proper segment of λ_j.

Unless otherwise stated, in the following we focus on non-empty bundle sets. We denote $\Lambda(\mathcal{A})$ simply as Λ whenever $\mathcal{A}$ is irrelevant for the current discussion. Bundle sets will be graphically represented as trees. This representation aligns with common practices in the literature, where dialogue games are frequently depicted in this way. Given a bundle set Λ, $root(\Lambda)$ is the label of the root node of a tree $\mathcal{T}$, and for each node N of $\mathcal{T}$ labeled with an argument $\mathcal{B}$, N has a child N' labeled with $\mathcal{C}$ for each argument $\mathcal{C}$ defeating $\mathcal{B}$ and belonging to the same line (*i.e.*, if there exists $\lambda \in \Lambda$ such that $\lambda = [\ldots, \mathcal{B}, \mathcal{C}, \ldots]$). For a formal definition, see (Rotstein, Moguillansky, and Simari 2009).

The following concepts are part of the developments and contributions of this paper. Bundle sets can be used to represent dialogue games that have been explored to their fullest extent; that is, dialogue games where no line can be extended by adding arguments, and no further lines can be considered. This idea is formalized below.

Definition 3.4. Let $\mathfrak{F} = (Ar, Def)$ be an AF, and Λ a bundle set for $\mathcal{A} \in Ar$. Λ is *exhaustive*, denoted Λ^{Ex}, iff there exists no bundle set Λ' for $\mathcal{A}$ such that $\Lambda' \neq \Lambda$ and every line $\lambda_j \in \Lambda$ is an initial segment of $\lambda_k \in \Lambda'$. Otherwise, Λ is *partial*.

Note that the presence of a line involving a cycle (*w.r.t.*the defeat relation) is sufficient to prevent the existence of an exhaustive bundle set. Intuitively, this represents a never-ending dialogue game in which no conclusion about the root argument's acceptance can be reached. To guarantee the existence of an exhaustive bundle set, we rely on the notion of *acceptability*[1], which characterizes a set of restrictions on bundle sets. Hence, when referring to bundle sets satisfying a given set of constraints, we will refer to them as *acceptable*. Moreover, alternative definitions of *acceptability* allow us to characterize the specific behavior of different semantics. Thus, we will add a prefix to the term acceptability in order to identify the intended semantics. Since the concepts presented below are general and apply to several definitions of acceptability, we use the prefix σ to denote a generic notion of acceptability for the remainder of this section. Concrete definitions will be introduced in Section 4.

Definition 3.5. Let $\mathfrak{F} = (Ar, Def)$ be an AF, σ a definition of acceptability, and Λ a bundle set of $\mathfrak{F}$. Λ is *σ-acceptable*, denoted Λ_σ, iff it satisfies all the constraints imposed by σ.

An argumentation line is σ-acceptable if it belongs to a σ-acceptable bundle set. We will occasionally refer to a σ-acceptable line without explicitly mentioning its bundle set.

In what follows, we focus exclusively on σ-acceptable bundle sets, denoting the corresponding semantics as a subscript of the bundle set. This choice does not limit our approach since even the total absence of restrictions can yield a possible version of acceptability. An exhaustive and σ-acceptable bundle set is a bundle set such that no line in the set can be further extended while satisfying σ-acceptability.

Definition 3.6. Let $\mathfrak{F} = (Ar, Def)$ be an AF, σ a definition of acceptability, and Λ a bundle set of $\mathfrak{F}$. Λ is *exhaustive and σ-acceptable*, denoted Λ^{Ex}_σ, iff Λ is σ-acceptable and there exists no σ-acceptable bundle set $\Lambda' \neq \Lambda$ such that every line $\lambda_j \in \Lambda$ is an initial segment of $\lambda_k \in \Lambda'$.

Example 1. *Let $\mathfrak{F}$ be the AF depicted in Figure 1 (a). Let us focus on argument $\mathcal{A}$ (a similar analysis holds for $\mathcal{B}$) and assume a definition of acceptability σ that does not impose restrictions on bundle sets. Due to the cycle between $\mathcal{A}$ and $\mathcal{B}$, for any bundle set $\Lambda_\sigma(\mathcal{A})$, there always exists another bundle set $\Lambda'_\sigma(\mathcal{A})$ such that $\lambda_j \in \Lambda_\sigma(\mathcal{A})$ is an initial segment of $\lambda_k \in \Lambda'_\sigma(\mathcal{A})$. Thus, there exists no exhaustive and σ-acceptable bundle set for $\mathcal{A}$. Let us now assume another definition of acceptability σ' that prevents the repetition of arguments in a line in a bundle set. In this case, the exhaustive and σ'-acceptable bundle set for $\mathcal{A}$ is $\Lambda^{Ex}_{\sigma'}(\mathcal{A}) = \{[\mathcal{A}, \mathcal{B}]\}$.*

Next, we introduce the *marking procedure* for bundle sets, whereby a label or mark D (*defeated*) or U (*undefeated*) is assigned to each occurrence of an argument in an argumentation line in a bundle set. The interpretation of these labels is as follows. A label U indicates that all defeaters of the argument are defeated, while the label D represents that at least one defeater of the argument remains undefeated.

Before formalizing the marking procedure, let us introduce the following notation. Let $\mathfrak{F} = (Ar, Def)$ be an AF, Λ_σ a bundle set for some argument in Ar, and λ'_j an initial segment of $\lambda_j \in \Lambda_\sigma$. The set of lines in Λ_σ extending λ'_j is $Ex(\lambda'_j) = \{\lambda_h \in \Lambda_\sigma \mid \lambda'_j$ is a proper segment of $\lambda_h\}$. The marking of the last argument $\mathcal{A}_i$ of λ'_j is denoted $mark(\mathcal{A}_i, \lambda'_j, \Lambda_\sigma)$. We adopt this notation since $\mathcal{A}_i$ may appear in different lines, positions, bundle sets, and with differing markings. Then, this notation allows us to identify the argument $\mathcal{A}_i$ (note that λ'_j is shared by all lines where $\mathcal{A}_i$ appears in the same position i) and the context in which the marking of $\mathcal{A}_i$ is being analyzed, unambiguously.

[1]It should not be mistaken for the notion of *acceptability* used in (Dung 1995). Rather, it aligns more closely with the notion of *acceptability* adopted in approaches like (García and Simari 2004).

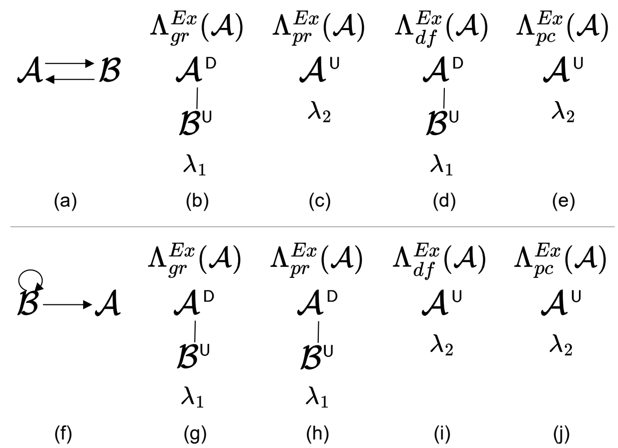

Figure 1: (b)–(e) and (g)–(j) illustrate the exhaustive bundle sets for argument $\mathcal{A}$ from the AFs depicted in (a) and (f), respectively. Each bundle set corresponds to one of the following semantics (in order): grounded, preferred, default, and pairwise cogency.

Definition 3.7. Let $\mathfrak{F}$ be an AF, Λ_σ a bundle set, and $\lambda'_j = [\mathcal{A}_1, \ldots, \mathcal{A}_i]$ an initial segment of $\lambda_j \in \Lambda_\sigma$. The *marking* of Λ_σ is the result of marking the last argument $\mathcal{A}_i$ of each initial segment λ'_j of every $\lambda_j \in \Lambda_\sigma$ as follows:

1. If $Ex(\lambda'_j) = \emptyset$, then $mark(\mathcal{A}_i, \lambda'_j, \Lambda_\sigma) = \mathsf{U}$.
2. If $Ex(\lambda'_j) \neq \emptyset$, then $mark(\mathcal{A}_i, \lambda'_j, \Lambda_\sigma) = \mathsf{U}$ iff for every line $\lambda_k \in Ex(\lambda'_j)$ it holds that the defeater $\mathcal{A}_{i+1}$ of $\mathcal{A}_i$ is such that $mark(\mathcal{A}_{i+1}, \lambda'_k, \Lambda_\sigma) = \mathsf{D}$, where $\lambda'_k = [\mathcal{A}_1, \ldots, \mathcal{A}_i, \mathcal{A}_{i+1}]$. Otherwise, $mark(\mathcal{A}_i, \lambda'_j, \Lambda_\sigma) = \mathsf{D}$.

Intuitively, condition 1 refers to the situation in which no argument can be put against $\mathcal{A}_i$; it is the last argument of the line, accordingly marked as U. Condition 2 represents the situation in which $\mathcal{A}_i$ has at least one defeater, hence $Ex(\lambda'_j) \neq \emptyset$. In this case, the marking of all defeaters $\mathcal{A}_{i+1}$ of $\mathcal{A}_i$ must be considered. Only if $\mathcal{A}_i$ is defended from all its defeaters (*i.e.*, every $\mathcal{A}_{i+1}$ is marked as D), will it be marked as U (in all $\lambda_k \in Ex(\lambda'_j)$).

Building on the concepts defined thus far, we can formally define the conditions under which an argument is ultimately undefeated and is therefore considered *accepted*.

Definition 3.8. Let $\mathfrak{F} = (Ar, Def)$ be an AF. An argument $\mathcal{A} \in Ar$ is *σ-accepted* in $\mathfrak{F}$ iff there exists an exhaustive bundle set $\Lambda^{Ex}_\sigma(\mathcal{A})$ such that $mark(\mathcal{A}, [\mathcal{A}], \Lambda^{Ex}_\sigma(\mathcal{A})) = \mathsf{U}$. Otherwise, $\mathcal{A}$ is *σ-rejected*.

With these tools, we are able to characterize some of the semantics we want to address in this work. However, others require additional elements, which we introduce next.

Relevance and Parsimony for Bundle Sets

This section aims at characterizing a minimal bundle set including the argumentation lines required to unambiguously establish the marking of the bundle set root. This idea of minimality is represented through the notions of *relevance* and *parsimony*. Relevance has been defined in various ways in the literature. In (Caminada 2006), an argument $\mathcal{A}$ is relevant *w.r.t.* another argument $\mathcal{B}$ if there exists an undirected path from $\mathcal{A}$ to $\mathcal{B}$. In (Prakken 2005), an argument is relevant for a dialogue game if its incorporation changes the acceptance status of the root argument. Here, we align with (Soto et al. 2024) and consider that an argumentation line λ is relevant for the marking of the root of a bundle set Λ if such marking depends on the presence of λ in Λ. However, we provide an alternative definition that better fits with our requirement of representing several semantics. In what follows, we introduce the necessary concepts to characterize our intended notion of relevance.

The first concept that we introduce is the one of *marking sequence* for argumentation lines (Rotstein, Moguillansky, and Simari 2009; Moguillansky et al. 2013), originally introduced in the context of dialectical trees (García and Simari 2004). Below we adapt this notion to our general setting. Given an AF $\mathfrak{F}$, $S_{\mathfrak{F}}$, $L_{\mathfrak{F}}$, and $B_{\mathfrak{F}}$ represent the domain of all segments, lines, and bundle sets from $\mathfrak{F}$, respectively.

Definition 3.9. Let $\mathfrak{F}$ be an AF, Λ_σ a bundle set from $\mathfrak{F}$, $\lambda \in \Lambda_\sigma$, λ' an initial segment of λ, and $\lambda''=[\mathcal{A}_i,\ldots,\mathcal{A}_j]$ an upper segment of λ'. The function $mseq : S_{\mathfrak{F}} \times L_{\mathfrak{F}} \times B_{\mathfrak{F}} \to \{\mathsf{U},\mathsf{D}\}^*$ defines a *marking sequence* $mseq(\lambda'',\lambda',\Lambda_\sigma) = [\mathsf{m}_i,\ldots,\mathsf{m}_j]$, with $\mathsf{m}_k = mark(\mathcal{A}_k,\lambda''',\Lambda_\sigma)$, where $\lambda''' = [\mathcal{A}_1,\ldots,\mathcal{A}_k]$ is an initial segment of λ', and $i \leqslant k \leqslant j$.

In the following, we will use regular expressions to characterize the marking sequence of argumentation lines (Moguillansky et al. 2013). Intuitively, only argumentation lines with a marking sequence conforming to either $\mathsf{U}(\mathsf{DU})^*$ or $(\mathsf{DU})^*$ are relevant. The first expression, $\mathsf{U}(\mathsf{DU})^*$, describes the marking sequence of an odd-length line, where the U mark is propagated from the last element of the line to the root. The second, $(\mathsf{DU})^*$, represents an even-length line that results in the root argument being marked as D. An argumentation line whose marking sequence contains two consecutive identical marks (*i.e.*, $[\ldots,\mathsf{D},\mathsf{D},\ldots]$ or $[\ldots,\mathsf{U},\mathsf{U},\ldots]$) is not considered relevant, since the latter mark in such a sequence does not produce the former—this follows directly from Definition 3.7.

Definition 3.10. Let $\mathfrak{F} = (Ar, Def)$ be an AF and $\Lambda_\sigma(\mathcal{A})$ a bundle set for $\mathcal{A} \in Ar$. An argumentation line $\lambda \in \Lambda_\sigma(\mathcal{A})$ is *relevant* for $\Lambda_\sigma(\mathcal{A})$ iff it holds that: if $mark(\mathcal{A},[\mathcal{A}],\Lambda_\sigma(\mathcal{A})) = \mathsf{U}$, then $mseq(\lambda,\lambda,\Lambda_\sigma(\mathcal{A})) = \mathsf{U}(\mathsf{DU})^*$; otherwise, $mseq(\lambda,\lambda,\Lambda_\sigma(\mathcal{A})) = (\mathsf{DU})^*$.

Next, we extend the notion of relevance to bundle sets.

Definition 3.11. Let $\mathfrak{F}$ be an AF and Λ_σ a bundle set from $\mathfrak{F}$. The *relevant bundle set* for Λ_σ, denoted Λ_σ^{Re}, is defined as $\Lambda_\sigma^{Re} = \{\lambda \in \Lambda_\sigma \mid \lambda \text{ is relevant for } \Lambda_\sigma\}$.

Example 2. *Consider an AF $\mathfrak{F} = (Ar, Def)$, with $Ar = \{\mathcal{A},\mathcal{B},\mathcal{C},\mathcal{D}\}$ and $Def = \{(\mathcal{B},\mathcal{A}),(\mathcal{C},\mathcal{B}),(\mathcal{B},\mathcal{C}),(\mathcal{D},\mathcal{A})\}$. To keep the example short, let us focus on argument $\mathcal{A}$ and assume a definition of acceptability σ prohibiting the repetition of arguments in lines within a bundle set. We have that $\Lambda_\sigma^{Ex}(\mathcal{A}) = \{\lambda_1,\lambda_2\}$, where $\lambda_1 = [\mathcal{A},\mathcal{B},\mathcal{C}]$ and $\lambda_2 = [\mathcal{A},\mathcal{D}]$. Furthermore, $mseq(\lambda_1,\lambda_1,\Lambda_\sigma^{Ex}(\mathcal{A})) = [\mathsf{D},\mathsf{D},\mathsf{U}]$ and $mseq(\lambda_2,\lambda_2,\Lambda_\sigma^{Ex}(\mathcal{A})) = [\mathsf{D},\mathsf{U}]$. Then, the only relevant argumentation line for $\Lambda_\sigma^{Ex}(\mathcal{A})$ is λ_2. Thus, $\Lambda_\sigma^{Re}(\mathcal{A}) = \{\lambda_2\}$ is the relevant bundle set for $\Lambda_\sigma^{Ex}(\mathcal{A})$.*

As another example, if we consider the AFs and the exhaustive and σ-acceptable bundle sets illustrated in Figure 1, every $\Lambda_\sigma^{Ex}(\mathcal{A})$ is also a relevant bundle set for itself.

Next, we show that the marking of a root argument is preserved when considering its relevant bundle set.

Proposition 1. *Let $\mathfrak{F} = (Ar, Def)$ be an AF, $\Lambda_\sigma(\mathcal{A})$ a bundle set for $\mathcal{A} \in Ar$, and $\Lambda_\sigma^{Re}(\mathcal{A})$ the relevant bundle set for $\Lambda_\sigma(\mathcal{A})$. It holds that $mark(\mathcal{A},[\mathcal{A}],\Lambda_\sigma(\mathcal{A})) = mark(\mathcal{A},[\mathcal{A}],\Lambda_\sigma^{Re}(\mathcal{A}))$.*

Proof. We focus on bundle sets of odd-length lines. A similar analysis can be done for bundle sets of even-length lines.

($\Rightarrow$) Let us assume that $mark(\mathcal{A},[\mathcal{A}],\Lambda_\sigma(\mathcal{A})) = \mathsf{U}$. From Definition 3.11, every $\lambda \in \Lambda_\sigma^{Re}(\mathcal{A})$ is such that $mseq(\lambda,\lambda,\Lambda_\sigma(\mathcal{A})) = \mathsf{U}(\mathsf{DU})^*$. Now we need to show that the previous marking remains unchanged in $\Lambda_\sigma^{Re}(\mathcal{A})$. Note that all $\lambda \in \Lambda_\sigma^{Re}(\mathcal{A})$ are odd-length. Then, from Definition 3.7, for every $\lambda \in \Lambda_\sigma^{Re}(\mathcal{A})$, $mseq(\lambda,\lambda,\Lambda_\sigma^{Re}(\mathcal{A})) = \mathsf{U}(\mathsf{DU})^*$. Therefore, $mark(\mathcal{A},[\mathcal{A}],\Lambda_\sigma^{Re}(\mathcal{A})) = \mathsf{U}$.

($\Leftarrow$) Let us assume that $mark(\mathcal{A},[\mathcal{A}],\Lambda_\sigma^{Re}(\mathcal{A})) = \mathsf{U}$. From Definitions 3.10 and 3.11, all $\lambda \in \Lambda_\sigma^{Re}(\mathcal{A})$ are odd-length. Then, from Definition 3.7, for all $\lambda \in \Lambda_\sigma^{Re}(\mathcal{A})$, $mseq(\lambda,\lambda,\Lambda_\sigma^{Re}(\mathcal{A})) = \mathsf{U}(\mathsf{DU})^*$. Suppose there exists $\lambda \in \Lambda_\sigma^{Re}(\mathcal{A})$ such that $mseq(\lambda,\lambda,\Lambda_\sigma^{Re}(\mathcal{A})) \neq mseq(\lambda,\lambda,\Lambda_\sigma(\mathcal{A}))$. Then, $mseq(\lambda,\lambda,\Lambda_\sigma(\mathcal{A}))$ must be of the form $[\ldots,\mathsf{D},\mathsf{D},\ldots]$ or $[\ldots,\mathsf{U},\mathsf{U},\ldots]$. Accordingly, λ is not relevant and $\lambda \notin \Lambda_\sigma^{Re}(\mathcal{A})$, which is absurd. Then, for all $\lambda \in \Lambda_\sigma^{Re}(\mathcal{A})$, $mseq(\lambda,\lambda,\Lambda_\sigma^{Re}(\mathcal{A})) = mseq(\lambda,\lambda,\Lambda_\sigma(\mathcal{A}))$. Therefore, $mark(\mathcal{A},[\mathcal{A}],\Lambda_\sigma(\mathcal{A})) = \mathsf{U}$. $\square$

Below we introduce the notion of *parsimonious* bundle set. Intuitively, a bundle set is parsimonious if it is a subset of a relevant bundle set such that, for each argument in an even position of a line within the set, there is a unique defeater placed at the following odd position.

Definition 3.12. Let $\mathfrak{F}$ be an AF, Λ_σ a bundle set from $\mathfrak{F}$, and Λ_σ^{Re} the relevant bundle set for Λ_σ. The *parsimonious* bundle set for Λ_σ, denoted Λ_σ^{Pa}, is defined as $\Lambda_\sigma^{Pa} = \{\lambda_j \in \Lambda_\sigma^{Re} \mid$ for every even-length proper segment $\lambda'_j = [\mathcal{A}_1,\ldots,\mathcal{A}_i]$ of λ_j, $\lambda'_k = [\mathcal{A}_1,\ldots,\mathcal{A}_i,\mathcal{A}_{i+1}]$ is an initial segment of every $\lambda_k \in (Ex(\lambda'_j) \cap \Lambda_\sigma^{Pa})\}$.

Note that, if $\Lambda_\sigma^{Pa}(\mathcal{A})$ is the parsimonious bundle set for $\Lambda_\sigma^{Ex}(\mathcal{A})$ such that $\mathcal{A}$ is marked as U, then the notion of parsimonious bundle set is equivalent to the notion of winning strategy in (Modgil and Caminada 2009).

Proposition 2. *Let $\mathfrak{F} = (Ar, Def)$ be an AF, $\Lambda_\sigma(\mathcal{A})$ a bundle set for $\mathcal{A} \in Ar$, and $\Lambda_\sigma^{Pa}(\mathcal{A})$ a parsimonious bundle set for $\Lambda_\sigma(\mathcal{A})$. It holds that $mark(\mathcal{A},[\mathcal{A}],\Lambda_\sigma(\mathcal{A})) = mark(\mathcal{A},[\mathcal{A}],\Lambda_\sigma^{Pa}(\mathcal{A}))$.*

Proof. The proof is similar to that of Proposition 1. We focus on bundle sets of odd-length lines. A similar analysis can be done for bundle sets of even-length lines.

($\Rightarrow$) Let us assume that $mark(\mathcal{A}, [\mathcal{A}], \Lambda_\sigma(\mathcal{A})) = \mathsf{U}$. From Definition 3.12, $\Lambda_\sigma^{Pa}(\mathcal{A})$ is a subset of $\Lambda_\sigma^{Re}(\mathcal{A})$ for $\Lambda_\sigma(\mathcal{A})$. From Definition 3.11, every $\lambda \in \Lambda_\sigma^{Pa}(\mathcal{A})$ is such that $mseq(\lambda, \lambda, \Lambda_\sigma(\mathcal{A})) = \mathsf{U}(\mathsf{DU})^*$. Thus, all $\lambda \in \Lambda_\sigma^{Pa}(\mathcal{A})$ are odd-length. Then, from Definition 3.7, for all $\lambda \in \Lambda_\sigma^{Pa}(\mathcal{A})$, $mseq(\lambda, \lambda, \Lambda_\sigma^{Pa}(\mathcal{A})) = \mathsf{U}(\mathsf{DU})^*$. Therefore, $mark(\mathcal{A}, [\mathcal{A}], \Lambda_\sigma^{Pa}(\mathcal{A})) = \mathsf{U}$.

($\Leftarrow$) Let us assume that $mark(\mathcal{A}, [\mathcal{A}], \Lambda_\sigma^{Pa}(\mathcal{A})) = \mathsf{U}$. From Definition 3.12, $\Lambda_\sigma^{Pa}(\mathcal{A})$ is a subset of $\Lambda_\sigma^{Re}(\mathcal{A})$ for $\Lambda_\sigma(\mathcal{A})$. From Definitions 3.10 and 3.11, all $\lambda \in \Lambda_\sigma^{Pa}(\mathcal{A})$ are odd-length. Then, from Definition 3.7, for all $\lambda \in \Lambda_\sigma^{Pa}(\mathcal{A})$, $mseq(\lambda, \lambda, \Lambda_\sigma^{Pa}(\mathcal{A})) = \mathsf{U}(\mathsf{DU})^*$. Suppose there exists $\lambda \in \Lambda_\sigma^{Pa}(\mathcal{A})$ such that $mseq(\lambda, \lambda, \Lambda_\sigma^{Pa}(\mathcal{A})) \neq mseq(\lambda, \lambda, \Lambda_\sigma(\mathcal{A}))$. Then, $mseq(\lambda, \lambda, \Lambda_\sigma(\mathcal{A}))$ must be $[\ldots, \mathsf{D}, \mathsf{D}, \ldots]$ or $[\ldots, \mathsf{U}, \mathsf{U}, \ldots]$. Accordingly, λ is not relevant and $\lambda \notin \Lambda_\sigma^{Pa}(\mathcal{A})$, which is absurd. Then, for all $\lambda \in \Lambda_\sigma^{Pa}(\mathcal{A})$, $mseq(\lambda, \lambda, \Lambda_\sigma^{Pa}(\mathcal{A})) = mseq(\lambda, \lambda, \Lambda_\sigma(\mathcal{A}))$. Therefore, $mark(\mathcal{A}, [\mathcal{A}], \Lambda_\sigma(\mathcal{A})) = \mathsf{U}$. □

4 Acceptability for Bundle Sets

In this section, we provide the definitions of the semantics we address. We restrict our attention to semantics with a dialogue game characterization and adapt them to the bundle set-based approach. As stated in Section 1, we focus on the grounded (*gr*), (credulous) preferred (*pr*), default (*df*), and (credulous) pairwise cogency (*pc*) semantics. Our selection is motivated by the following reasons:

(1) The grounded and preferred semantics are two of the most well-known semantics in the literature.

(2) The default and pairwise cogency semantics are both non-naive and non-admissible, offering a contrast to the grounded and preferred semantics, which are admissibility-based. Also, the grounded and default semantics are skeptical, while the preferred and pairwise cogency semantics are credulous. Thus, the semantics we selected cover all combinations of the aforementioned characteristics.

(3) We acknowledge the existence of semantics defined through meta-games rather than standard argument games. For instance, in the *skeptical preferred game* (Vreeswijk and Prakken 2000; Modgil and Caminada 2009), parties exchange extensions instead of individual arguments. Similarly, in *weak cogency* and *cyclic cogency* games (Bodanza, Tohmé, and Simari 2016), parties exchange games. These approaches differ significantly in structure, making a direct comparison with our selected semantics difficult. For this reason, we leave them outside the scope of this work.

(4) Most dialogue-based semantics involve two types of moves—argue (proposing an argument as topic of discussion) and counter-argue (attacking a previous argument)—though these are not always made explicit. The semantics we consider follow this approach. We acknowledge that some semantics include additional types of moves; for example, the game for *stable semantics* (Caminada and Wu 2008) introduces the *question* move. While such additional locutions are certainly of interest, they introduce an extra layer of complexity when comparing semantics. For this reason, we exclude semantics that incorporate additional speech acts from our analysis.

Before we delve into the different definitions of acceptability, we introduce some additional concepts and notation that will be of use throughout the rest of the paper. We refer to the semantics resulting from using σ-acceptability in the bundle set-based approach as "σ-semantics". In our setting, the *support* and the *opposition* will be the two parties involved in a dialogue. Intuitively, the support represents the reasons in favor of the root argument, whereas the opposition represents the reasons against it.

Definition 4.1. Let $\mathfrak{F}$ be an AF, Λ_σ a bundle set from $\mathfrak{F}$, and $\lambda \in \Lambda_\sigma$. $Supp(\lambda) = \{\mathcal{A}_i \in \lambda \mid i = 2k+1\}$, with $k \in \mathbb{N}$, is the *support* of λ. Similarly, $Opp(\lambda) = \{\mathcal{A}_j \in \lambda \mid j = 2k\}$, with $k \in \mathbb{N}$, is the *opposition* of λ. The *Support* of Λ_σ is defined as $Supp(\Lambda_\sigma) = \bigcup\{Supp(\lambda) \mid \lambda \in \Lambda_\sigma\}$.

In the following, we use $\mathcal{A}_i \equiv_2 \mathcal{A}_j$ as shorthand for $\mathcal{A}_i \equiv \mathcal{A}_j \pmod 2$. Each argument $\mathcal{A}_i$ in a line λ is a *move* carried out by the support or the opposition. $\mathcal{A}_i$ supports (resp., opposes) $\mathcal{A}_h$ in a line, with $h < i$, if $\mathcal{A}_i \equiv_2 \mathcal{A}_j$ (resp., if $\mathcal{A}_i \not\equiv_2 \mathcal{A}_j$). Similarly, λ supports (resp., opposes) *root*(λ) if λ is an odd-length (resp., even-length) line.

As mentioned in Section 3, acceptability allows us to characterize different semantics by imposing restrictions on bundle sets. These constraints can be seen as rules that the support and the opposition must satisfy. Depending on the semantics, such rules may or may not be the same for both parties. To distinguish them, we denote the rules governing the support and the opposition according to a given semantics σ as SR_σ and OR_σ, respectively.

Except for the *df* semantics, multiple dialogue games exist for each of the semantics we address. Although these dialogue games are equivalent in terms of the set of accepted arguments, they differ essentially in the number of moves required to conclude the root argument's acceptance. We focus on the most restrictive dialogue games—those constraining the moves of each party the most. This choice is motivated by the fact that such dialogue games tend to be the most brief and concise, a feature we consider desirable. However, we acknowledge that in certain scenarios, less restrictive variants of the dialogue games may be preferable.

gr-semantics. The first acceptability definition we consider is equivalent to the grounded game (Prakken and Sartor 1997; Modgil and Caminada 2009). Hence, we refer to it as *grounded acceptability* (*gr*-acceptability for short).

Definition 4.2. Let $\mathfrak{F}$ be an AF. A bundle set Λ_σ from $\mathfrak{F}$ is *gr-acceptable*, denoted Λ_{gr}, iff for all $\lambda \in \Lambda_\sigma$, every $\mathcal{A}_i \in Supp(\lambda)$ satisfies SR_{gr}, which is characterized by the following rules

1. There is no $\mathcal{A}_j \in \lambda$ such that $i \equiv_2 j$ and $\mathcal{A}_i$ defeats $\mathcal{A}_j$.
2. For all $\mathcal{A}_j \in \lambda$ such that $j < i$ and $i \equiv_2 j$, $\mathcal{A}_i \neq \mathcal{A}_j$.
3. $\mathcal{A}_i$ is a strict defeater of $\mathcal{A}_{i-1}$.

Intuitively, rule 1 establishes that the support of each line must be conflict-free. Rule 2 states that the support cannot repeat arguments to defend the root argument. Finally, rule 3 says the support must strictly defeat each argument moved by the opposition. Note that *gr*-acceptability only imposes restrictions on the support, *i.e.*, the set of rules OR_{gr} is empty and that is why it is not given. The opposition is only restricted by the concept of argumentation line, *i.e.*, for all $\mathcal{A}_i$ (with i even) in some $\lambda \in \Lambda_{gr}$, $\mathcal{A}_i$ is a defeater of $\mathcal{A}_{i-1}$.

Credulous pr-semantics. The second version of acceptability we address is equivalent to the credulous preferred game (Vreeswijk and Prakken 2000; Cayrol, Doutre, and Mengin 2001; Modgil and Caminada 2009). Accordingly, we call it *preferred acceptability* (*pr*-acceptability for short).

Definition 4.3. Let $\mathfrak{F}$ be an AF. A bundle set Λ_σ from $\mathfrak{F}$ is *pr*-acceptable, denoted Λ_{pr}, iff for all $\lambda \in \Lambda_\sigma$, every $\mathcal{A}_i \in Supp(\lambda)$ satisfies SR_{pr} and every $\mathcal{A}_j \in Opp(\lambda)$ satisfies OR_{pr}, where:

- SR_{pr}:
  1. There is no $\mathcal{A}_h \in \lambda$ such that $i \equiv_2 h$ and $\mathcal{A}_i$ defeats $\mathcal{A}_h$.
  2. Let Λ_σ^{Pa} be a parsimonious bundle set for Λ_σ. If $\mathcal{A}_i \in \lambda_j$, with $\lambda_j \in \Lambda_\sigma^{Pa}$, then there is no $\mathcal{A}_h \in \lambda_k$, with $\lambda_k \in \Lambda_\sigma^{Pa}$, such that $i \equiv_2 h$ and $\mathcal{A}_i$ defeats $\mathcal{A}_h$.
- OR_{pr}:
  1. For all $\mathcal{A}_k \in \lambda$ such that $k < j$ and $j \equiv_2 k$, $\mathcal{A}_j \neq \mathcal{A}_k$.
  2. There is no $\mathcal{A}_k \in \lambda$ such that $j \not\equiv_2 k$, $k < j$, and $\mathcal{A}_k$ defeats $\mathcal{A}_j$.

Rule 1 for the support is the same as in *gr*-acceptability. Rule 2 extends the requirement of conflict-freeness to the support of Λ_σ^{Pa} for Λ_σ. In the case of OR_{pr}, rule 1 specifies that the opposition cannot repeat arguments. Then, rule 2 prohibits the opposition from advancing any argument that is defeated by a prior argument in the support.

df-semantics. The following acceptability definition is *default acceptability*, *df*-acceptability for short. It was proposed in (García and Simari 2004) for DeLP, a structured formalism for defeasible argumentation. DeLP was a pioneer in the use of the notion of acceptability for argumentation lines, firstly introduced in (Simari and García 1994). Although the notion of acceptability is modular in DeLP and several variations exist (*e.g.*, (García and Simari 2014; Cohen et al. 2021; Brarda, Tamargo, and García 2023)), the definition provided in (García and Simari 2004) has become the default one, hence the name and why we focus on it. Here, we introduce a slightly modified version of *df*-acceptability adapted to abstract argumentation.

Definition 4.4. Let $\mathfrak{F}$ be an AF. A bundle set Λ_σ from $\mathfrak{F}$ is *df-acceptable*, denoted Λ_{df}, iff for all $\lambda \in \Lambda_\sigma$, every $\mathcal{A}_i \in \lambda$ satisfies R_{df}, with $R_{df} = SR_{df} = OR_{df}$, and is characterized by the following rules:

1. There is no $\mathcal{A}_j \in \lambda$ such that $i \equiv_2 j$ and $\mathcal{A}_i$ defeats $\mathcal{A}_j$.
2. For all $\mathcal{A}_j \in \lambda$ such that $i \neq j$, $\mathcal{A}_i \neq \mathcal{A}_j$.
3. If $\mathcal{A}_{i-1}$ is a mutual defeater of $\mathcal{A}_{i-2}$, then $\mathcal{A}_i$ is a strict defeater of $\mathcal{A}_{i-1}$.

Note that the support and the opposition must satisfy the same set of rules. Rules 1 and 2 define restrictions imposed by *gr* and *pr*-acceptability, but in a broader sense. According to rule 1, the support (resp., the opposition) of each line must be conflict-free. Rule 2 goes beyond by establishing that no argument (neither from the support nor the opposition) can be repeated in a line. Finally, by rule 3, a strict defeat is the only available move after a mutual defeat.

Credulous pc-semantics. The last acceptability version we consider corresponds to the pairwise cogency game (Bodanza, Tohmé, and Simari 2016); hence, we refer to it as *pairwise cogency acceptability*, or *pc*-acceptability for short. To clarify the underlying ideas of this dialogue game, we offer an intuitive overview of the concepts of cogency and pairwise cogency (for a formal and detailed discussion see (Bodanza, Tohmé, and Simari 2016)). The *cogency principle* is a relation among arguments. It is based on admissibility but relaxed to offer alternative solutions to cycles of arguments. Given an AF $\mathfrak{F} = (Ar, Def)$ and $S, S' \subseteq Ar$, S is at least as cogent as S' if S is admissible in $\mathfrak{F}_{\downarrow S \cup S'}$—the restriction of $\mathfrak{F}$ to $S \cup S'$. The set S is *pairwise cogent* iff S is maximal *w.r.t.* cogency, *i.e.*, if there exists no set S' such that S' is at least as cogent as S and S is not as cogent as S'.

Definition 4.5. Let $\mathfrak{F}$ be an AF. A bundle set Λ_σ from $\mathfrak{F}$ is *pc*-acceptable, denoted Λ_{pc}, iff for all $\lambda \in \Lambda_\sigma$, every $\mathcal{A}_i \in Supp(\lambda)$ satisfies SR_{pc}, and every $\mathcal{A}_j \in Opp(\lambda)$ satisfies OR_{pc}, where:

- $SR_{pc} = SR_{pr}$.
- $OR_{pc} = OR_{pr} \cup \{\mathcal{A}_j \text{ is not a self-defeating argument}\}$.

It is easy to see that *pc*-acceptability is based on *pr*-acceptability. The additional restriction is that the opposition is prohibited from moving self-defeating arguments.

5 A Set of Principles for Studying Dialogue Game-based Semantics

In this section we propose a set of formal principles to analyze dialogue game-based semantics. These principles emerge from addressing argumentation semantics as dialogue games, and are not meant to be exhaustive. This is a first step towards a deeper discussion on the foundations of dialogue game-based semantics.

Before introducing our proposed set of principles, it is worth mentioning that all the semantics we address share some characteristics. On the one hand, all of them correspond to two-party zero-sum argument games. Moreover, each argument moved in the dialogue might receive multiple arguments in response, and each party must respond with each available argument. This last point is a direct consequence of adopting the bundle set-based approach and might differ in other approaches. However, this difference in the characterization of a dialogue game-based semantics does not affect the outcome—the set of arguments accepted/rejected by it.

We emphasize that some results in this section depend both on the chosen semantics and on the specific set of restrictions used to characterize it. That is, different sets of rules characterizing the same semantics may yield distinct results regarding some principles.

The first principle we consider is *finiteness*, which intuitively refers to the fact that each dialogue game must end. This is a crucial characteristic of any semantics; otherwise, one would not be able to make a decision about an argument's acceptance status. Here, this is captured by the existence of an exhaustive bundle set.

Proposition 3. *Let $\mathfrak{F} = (Ar, Def)$ be an AF and $\sigma \in \{gr, pr, df, pc\}$ an acceptability-based semantics. For every non-self-defeating argument $\mathcal{A} \in Ar$, there exists an exhaustive bundle set $\Lambda_\sigma^{Ex}(\mathcal{A})$.*

Proof. By Definition 2.1, every AF $\mathfrak{F} = (Ar, Def)$ is finite. Also, from Definitions 4.2–4.5, all considered semantics avoid the repetition of arguments for at least one of the parties. Then, $L_\mathcal{A}^\sigma$ is finite for every $\mathcal{A} \in Ar$. Furthermore, there exists at least one bundle set $\Lambda_\sigma(\mathcal{A})$ such that all $\lambda_j \in L_\mathcal{A}^\sigma$ are initial segments of $\lambda_k \in \Lambda_\sigma(\mathcal{A})$. Thus, by Definition 3.4, $\Lambda_\sigma(\mathcal{A})$ is an exhaustive bundle set for $\mathcal{A}$. □

Self-defeating arguments represent an interesting case because, no exhaustive bundle set exists for them under the considered semantics.

Proposition 4. *Let $\mathfrak{F} = (Ar, Def)$ be an AF, $\mathcal{A} \in Ar$ a self-defeating argument and $\sigma \in \{gr, pr, df, pc\}$ an acceptability-based semantics. There exists no $\Lambda_\sigma^{Ex}(\mathcal{A})$.*

Proof. From Definitions 4.2–4.5, all considered semantics require $Supp(\lambda)$ to be conflict-free, for every line λ in any bundle set. Since $\mathcal{A}$ is self-defeating, there exists no σ-acceptable bundle set for $\mathcal{A}$. Therefore, there exists no exhaustive and σ-acceptable bundle set for $\mathcal{A}$. □

By Proposition 4 and Definition 3.8, all self-defeating arguments are σ-rejected in $\mathfrak{F}$ under all considered semantics.

We refer to the next principle as *impartiality*. The underlying intuition is that, in certain contexts, a dialogue game should be fair or impartial for both parties. To characterize this, we adopt an approach based on determining the set of available moves for each party according to each set of rules provided by a given semantics. We formalize this below.

Definition 5.1. Let $\mathfrak{F}$ be an AF and $\lambda = [\mathcal{A}_1, \ldots, \mathcal{A}_i]$ a σ-acceptable argumentation line for some argument from $\mathfrak{F}$.

- If λ is even-length, the *set of available moves for λ w.r.t. SR_σ* is $MSR_\sigma(\lambda) = \{\mathcal{A}_{i+1} \mid \lambda' = [\mathcal{A}_1, \ldots, \mathcal{A}_i, \mathcal{A}_{i+1}]$ and all $\mathcal{A}_j \in Supp(\lambda')$ satisfy $SR_\sigma\}$. The *set of available moves for λ w.r.t. OR_σ* is $MOR_\sigma(\lambda) = \{\mathcal{A}_{i+1} \mid \lambda' = [\mathcal{A}_1, \ldots, \mathcal{A}_i, \mathcal{A}_{i+1}]$ and all $\mathcal{A}_j \in Supp(\lambda')$ satisfy $OR_\sigma\}$.
- If λ is odd-length, the *set of available moves for λ w.r.t. SR_σ* is $MSR_\sigma(\lambda) = \{\mathcal{A}_{i+1} \mid \lambda' = [\mathcal{A}_1, \ldots, \mathcal{A}_i, \mathcal{A}_{i+1}]$, and all $\mathcal{A}_j \in Opp(\lambda')$ satisfy $SR_\sigma\}$. The *set of available moves for λ w.r.t. OR_σ* is $MOR_\sigma(\lambda) = \{\mathcal{A}_{i+1} \mid \lambda' = [\mathcal{A}_1, \ldots, \mathcal{A}_i, \mathcal{A}_{i+1}]$ and all $\mathcal{A}_j \in Opp(\lambda')$ satisfy $OR_\sigma\}$.

We use common abbreviations for set inclusion. Let $X, Y \in \{MSR_\sigma(\lambda), MOR_\sigma(\lambda)\}$. We write $X = Y$ if $X \subseteq Y$ and $Y \subseteq X$. Moreover, if $X \subseteq Y$ and $Y \nsubseteq X$, we write $X \subset Y$.

Definition 5.2. Let σ be an acceptability-based semantics. σ is *impartial* iff for every AF $\mathfrak{F}$ and for every σ-acceptable argumentation line λ, $MSR_\sigma(\lambda) = MOR_\sigma(\lambda)$. σ is *incomparable w.r.t.* impartiality iff there exist σ-acceptable argumentation lines λ, λ', possibly from different AFs, such that $MSR_\sigma(\lambda) \nsubseteq MOR_\sigma(\lambda)$ and $MOR_\sigma(\lambda') \nsubseteq MSR_\sigma(\lambda')$. Otherwise, σ is *partial*, *i.e.*, σ is not incomparable *w.r.t.* impartiality, and there exists some σ-acceptable argumentation line λ from some $\mathfrak{F}$ such that $MSR_\sigma(\lambda) \subset MOR_\sigma(\lambda)$ or $MOR_\sigma(\lambda) \subset MSR_\sigma(\lambda)$.

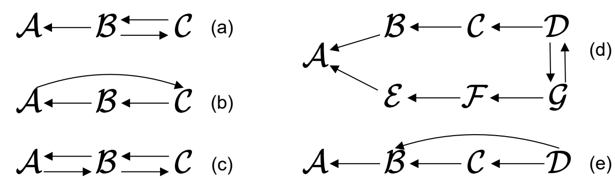

Figure 2: AFs used to illustrate results in Section 5.

Proposition 5. *The df-semantics (1) is impartial; the gr-semantics (2) is partial; and both the pr-semantics (3) and pc-semantics (4) are incomparable w.r.t. impartiality.*

Proof. (1) From Definition 4.4, $SR_{df} = OR_{df}$. Then, $MSR_{df}(\lambda) = MOR_{df}(\lambda)$ for all *df*-acceptable line λ for any AF $\mathfrak{F}$. Thus, from Definition 5.2, *df*-semantics is impartial.

(2) Note that $MOR_{gr}(\lambda) = \{\mathcal{A}_{i+1} \mid \mathcal{A}_{i+1}$ defeats $\mathcal{A}_i\}$ for all gr-acceptable line $\lambda = [\mathcal{A}_1, \ldots, \mathcal{A}_i]$ for any AF $\mathfrak{F}$. Then, it is always the case that $MSR_{gr}(\lambda) \subseteq MOR_{gr}(\lambda)$. Let us consider the AF depicted in Figure 1 (a), and the line $\lambda_2 = [\mathcal{A}]$. Then, $MSR_{gr}(\lambda) = \emptyset$ and $MOR_{gr}(\lambda) = \{\mathcal{B}\}$. Thus, $MSR_{gr}(\lambda) \subset MOR_{gr}(\lambda)$. Accordingly, from Definition 5.2, the *gr*-semantics is partial.

(3) We prove this through counterexamples. Let us consider the AF from Figure 2 (a) and the *pr*-acceptable line $\lambda_j = [\mathcal{A}, \mathcal{B}, \mathcal{C}]$. We have $MSR_{pr}(\lambda_j) = \{\mathcal{B}\}$ and $MOR_{pr}(\lambda_j) = \emptyset$. Then, $MOR_{pr}(\lambda_j) \subset MSR_{pr}(\lambda_j)$. Let us also consider the AF from Figure 2 (b) and the *pr*-acceptable line $\lambda_k = [\mathcal{A}, \mathcal{B}]$. $MSR_{pr}(\lambda_k) = \emptyset$ and $MOR_{pr}(\lambda_k) = \{\mathcal{C}\}$; thus, $MSR_{pr}(\lambda_k) \subset MOR_{pr}(\lambda_k)$. As a result, from Definition 5.2, the *pr*-semantics is incomparable *w.r.t.* impartiality.

(4) From Definition 4.5, the *pc*-semantics adds to the *pr*-semantics a rule prohibiting the opposition from moving self-defeating arguments. Since the above counterexamples for the *pr*-semantics do not include self-defeating arguments, we obtain the same results as for the *pr*-semantics. Then, *pc*-semantics is incomparable *w.r.t.* impartiality. □

Whether impartiality is desirable in a given semantics depends on the context of its application. For instance, in multi-agent decision-making, an agent may refuse to engage in a dialogue game it perceives as unfair. Conversely, a partial semantics benefiting the opposition may be sensible whenever cautious conclusions are required.

Impartiality appears to be related to how difficult it is to accept an argument under a given semantics and whether that semantics is skeptical or credulous. Intuitively, a more skeptical semantics makes less committed decisions regarding the acceptance status of arguments. This can be seen as a more skeptical semantics requiring stricter conditions for accepting an argument: only those arguments that do not require committed decisions will be accepted. This corresponds with a partial semantics that imposes stricter rules on the support, such as the *gr*-semantics. Conversely, an impartial semantics, such as *df*-semantics, represents a dialogue in which it is easier to accept an argument—in contrast to a partial semantics in favor of the opposition—since it is committed to the acceptance status of some arguments. On the other hand, a hypothetical partial semantics favoring the support would make acceptance even easier, since the burden lies in rejecting arguments. While this analysis offers useful insights—which we explore in the following principles—we acknowledge that it has limitations. For instance, both the *pr*- and *pc*-semantics are credulous, yet they are incomparable *w.r.t.* impartiality.

To characterize how impartial a semantics is, we compared $MSR_\sigma(\lambda)$ and $MOR_\sigma(\lambda)$ (*i.e.*, the sets of available moves according to the support and the opposition rules, respectively). Now, we will compare $MSR_\sigma(\lambda)$ and $MSR_{\sigma'}(\lambda)$ (resp., $MOR_\sigma(\lambda)$ and $MOR_{\sigma'}(\lambda)$) to analyze how restricted each party is at each stage of a dialogue game under two acceptability-based semantics σ and σ'.

Definition 5.3. Let σ, σ' be acceptability-based semantics. σ' is *at least as support-permissive* as σ, denoted $\sigma \preceq_s \sigma'$, iff for all σ-acceptable and σ'-acceptable argumentation line λ from any AF $\mathfrak{F}$ it holds that $MSR_\sigma(\lambda) \subseteq MSR_{\sigma'}(\lambda)$.

Definition 5.4. Let σ, σ' be acceptability-based semantics. σ' is *at least as opposition-permissive* as σ, denoted $\sigma \preceq_o \sigma'$, iff for all σ-acceptable and σ'-acceptable argumentation line λ from any AF $\mathfrak{F}$ it holds that $MOR_\sigma(\lambda) \subseteq MOR_{\sigma'}(\lambda)$.

Let $\preceq_x$ be such that $x \in \{s, o\}$. Given two acceptability-based semantics σ and σ', we write $\sigma \prec_x \sigma'$ if $\sigma \preceq_x \sigma'$ and $\sigma' \not\preceq_x \sigma$. If $\sigma \preceq_x \sigma'$ and $\sigma' \preceq_x \sigma$, we write $\sigma \equiv_x \sigma'$. Moreover, we use $\sigma \not\equiv_x \sigma'$ if $\sigma \not\preceq_x \sigma'$ and $\sigma' \not\preceq_x \sigma$.

We first study the support-permissiveness among the semantics presented in Section 4.

Proposition 6. *gr-semantics $\prec_s$ df-semantics.*

Proof. Let $\lambda = [\mathcal{A}_1, \ldots, \mathcal{A}_i]$ be a *gr*-acceptable and *df*-acceptable argumentation line from some AF $\mathfrak{F}$. From Definitions 4.2 and 4.4, we know that SR_{gr} and SR_{df} only differ in that the former prevents the support from moving a mutual defeater $\mathcal{A}_{i+1}$ while SR_{df} allows it as long as $\mathcal{A}_i$ is not a mutual defeater of $\mathcal{A}_{i-1}$. Then, it is always the case that $MSR_{gr}(\lambda) \subseteq MSR_{df}(\lambda)$ and, by Definition 5.3, it holds that *gr*-semantics $\preceq_s$ *df*-semantics.

To prove that *df*-semantics $\not\preceq_s$ *gr*-semantics, it suffices to show that there might exist a *gr*-acceptable and *df*-acceptable line λ such that $MSR_{gr}(\lambda) \subset MSR_{df}(\lambda)$. Consider the AF from Figure 2 (a), and $\lambda = [\mathcal{A}, \mathcal{B}]$. Then, $MSR_{df}(\lambda) = \{\mathcal{C}\}$ and $MSR_{gr}(\lambda) = \emptyset$. Thus, $MSR_{gr}(\lambda) \subset MSR_{df}(\lambda)$ and *gr*-semantics $\prec_s$ *df*-semantics. □

Proposition 7. *pr-semantics $\equiv_s$ pc-semantics.*

Proof. By Definition 4.5, $SR_{pr} = SR_{pc}$. Then, for every *pr*-acceptable and *pc*-acceptable line λ from any AF $\mathfrak{F}$, $MSR_{pc}(\lambda) = MSR_{pr}(\lambda)$. Therefore, it holds that *pr*-semantics $\equiv_s$ *pc*-semantics. □

Observation 1. *pr-semantics $\not\equiv_s$ df-semantics.*

The above observation follows straightforwardly from the following two examples. Let us consider the AF from Figure 2 (d) and the *pr*-acceptable and *df*-acceptable bundle set $\Lambda = \{\lambda_1, \lambda_2\}$, where $\lambda_1 = [\mathcal{A}, \mathcal{B}, \mathcal{C}, \mathcal{D}, \mathcal{G}]$ and $\lambda_2 = [\mathcal{A}, \mathcal{E}]$. Then, $MSR_{df}(\lambda_2) = \{\mathcal{F}\}$ and $MSR_{pr}(\lambda_2) = \emptyset$, because $\mathcal{F}$ is defeated by $\mathcal{G}$, an argument belonging to $Supp(\lambda_1)$. Therefore, $MSR_{pr}(\lambda_2) \subset MSR_{df}(\lambda_2)$. Let us now consider the AF from Figure 2 (c) and $\lambda = [\mathcal{A}, \mathcal{B}]$. Then, $MSR_{df}(\lambda) = \emptyset$ and $MSR_{pr}(\lambda) = \{\mathcal{A}, \mathcal{C}\}$. Therefore, $MSR_{df}(\lambda) \subset MSR_{pr}(\lambda)$ and *pr*-semantics $\not\equiv_s$ *df*-semantics.

Proposition 8. *gr-semantics $\prec_s$ pr-semantics.*

Proof. From the results proved in (Modgil and Caminada 2009) it follows that if there exists a parsimonious bundle set Λ_{gr}^{Pa} for some Λ_{gr}^{Ex} such that $root(\Lambda_{\sigma}^{Ex})$ is U-marked, then $Supp(\Lambda_{gr}^{Pa})$ is conflict-free. From the above and Definitions 4.2 and 4.3, it follows that SR_{gr} implies a superset of SR_{pr}. Then, $MSR_{gr}(\lambda) \subseteq MSR_{pr}(\lambda)$ for all *gr*-acceptable and *pr*-acceptable line λ from any AF $\mathfrak{F}$. Hence, by Definition 5.3, *gr*-semantics $\preceq_s$ *pr*-semantics. To prove that *pr*-semantics $\not\preceq_s$ *gr*-semantics, it is sufficient to show that there might exist a *gr*-acceptable and *df*-acceptable line λ such that $MSR_{gr}(\lambda) \subset MSR_{pr}(\lambda)$. Consider the AF from Figure 2 (a), and $\lambda = [\mathcal{A}, \mathcal{B}]$. Then, $MSR_{pr}(\lambda) = \{\mathcal{C}\}$, $MSR_{gr}(\lambda) = \emptyset$, and $MSR_{gr}(\lambda) \subset MSR_{df}(\lambda)$. Thus, *gr*-semantics $\prec_s$ *pr*-semantics. □

Corollary 1. *The set of semantics $\{gr, pr, df, pc\}$ is a partially ordered set w.r.t. $\preceq_s$.*

Proof. It follows from Props. 6–8 and Observation 1. □

The following results address opponent-permissiveness.

Proposition 9. *df-semantics $\prec_o$ gr-semantics.*

Proof. From Definitions 4.2 and 4.4, we know that OR_{df} is a superset of OR_{gr}. Then, $MOR_{df}(\lambda) \subseteq MOR_{gr}(\lambda)$ for all *gr*-acceptable and *df*-acceptable line λ from any AF $\mathfrak{F}$. Let us consider the AF from Figure 1 (f), and $\lambda_2 = [\mathcal{A}]$. Then, $MOR_{gr}(\lambda_2) = \{\mathcal{B}\}$ and $MOR_{df}(\lambda_2) = \emptyset$. Therefore, $MOR_{df}(\lambda_2) \subset MOR_{gr}(\lambda_2)$ and *df*-semantics $\prec_o$ *gr*-semantics. □

Proposition 10. *pc-semantics $\prec_o$ pr-semantics.*

Proof. From Definition 4.5, OR_{pc} is a superset of OR_{pr} which incorporates a restriction to avoid moving self-defeating arguments. Then, $MOR_{pc}(\lambda) \subseteq MOR_{pr}(\lambda)$ for all *pr*-acceptable and *pc*-acceptable line λ from any AF $\mathfrak{F}$. Let us consider the AF depicted in Figure 1 (f), and the line $\lambda_2 = [\mathcal{A}]$. Then, $MOR_{pr}(\lambda_2) = \{\mathcal{B}\}$ and $MOR_{pc}(\lambda_2) = \emptyset$. Therefore, $MOR_{pc}(\lambda_2) \subset MOR_{pr}(\lambda_2)$ and *pc*-semantics $\prec_o$ *pr*-semantics. □

Observation 2. *pr-semantics $\not\equiv_o$ df-semantics.*

The above observation follows straightforwardly from the following two examples. Let us consider the AF depicted in Figure 1 (a) and the line $\lambda_2 = [\mathcal{A}]$. Then, $MOR_{df}(\lambda_2) = \{\mathcal{B}\}$ and $MOR_{pr}(\lambda_2) = \emptyset$. Let us also consider the AF depicted in Figure 1 (f) and the line $\lambda_2 = [\mathcal{A}]$. Then, $MOR_{df}(\lambda_2) = \emptyset$ and $MOR_{pr}(\lambda_2) = \{\mathcal{B}\}$. Consequently, *df*-semantics $\not\equiv_o$ *pr*-semantics.

Proposition 11. *pr-semantics $\prec_o$ gr-semantics.*

Proof. From Definitions 4.2 and 4.3, it is easy to see that OR_{pr} is a superset of OR_{gr}. Then, $MOR_{pr}(\lambda) \subseteq MOR_{gr}(\lambda)$ for all *gr*-acceptable and *pr*-acceptable line λ from any AF $\mathfrak{F}$. By Definition 5.4, it holds that *pr*-semantics $\preceq_o$ *gr*-semantics. Let us consider the AF depicted in Figure 1 (a), and the line $\lambda_2 = [\mathcal{A}]$. Then, $MOR_{gr}(\lambda) = \{\mathcal{B}\}$ and $MOR_{pr}(\lambda) = \emptyset$. Therefore, $MOR_{pr}(\lambda) \subset MOR_{gr}(\lambda)$ and *pr*-semantics $\prec_o$ *gr*-semantics. □

Observation 3. *df-semantics $\not\equiv_o$ pc-semantics.*

The above observation follows straightforwardly from the following two examples. Let us consider the AF depicted in Figure 1 (a), and the line $\lambda_2 = [\mathcal{A}]$. Then, $MOR_{df}(\lambda_2) = \{\mathcal{B}\}$ and $MOR_{pc}(\lambda_2) = \emptyset$. Let us also consider the AF from Figure 2 (e) and $\lambda = [\mathcal{A}, \mathcal{B}, \mathcal{C}]$. Then, $MOR_{df}(\lambda) = \emptyset$ and $MOR_{pc}(\lambda) = \{\mathcal{D}\}$. Thus, *df*-semantics $\not\equiv_o$ *pc*-semantics.

Corollary 2. *The set of semantics $\{gr, pr, df, pc\}$ is a partially ordered set w.r.t. $\preceq_o$.*

Proof. It follows from Props. 9–11 and Obs. 2–3. □

The following intuition inspired our last proposed principle. The acceptance of an argument $\mathcal{A}$ is always grounded[2] in a set of arguments. This set might be the empty set (if the argument has no defeaters), the argument itself, or a set of arguments S such that $\mathcal{A} \notin S$. It seems reasonable to require that the groundings of $\mathcal{A}$ also be σ-accepted, since otherwise we are accepting an argument without basis. This is formalized below.

Definition 5.5. Let $\mathfrak{F} = (Ar, Def)$ be an AF and $\mathcal{A}$ a σ-accepted argument in $\mathfrak{F}$. $Supp(\Lambda^{Pa}_{\sigma}(\mathcal{A}))$ is a *grounding* for $\mathcal{A}$, where $\Lambda^{Pa}_{\sigma}(\mathcal{A})$ is a parsimonious bundle set for $\Lambda^{Ex}_{\sigma}(\mathcal{A})$. The set of groundings for $\mathcal{A}$ is denoted $Gr_{\sigma}(\mathcal{A})$.

Definition 5.6. Let $\mathfrak{F}$ be an AF, $\mathcal{A}$ a σ-accepted argument in $\mathfrak{F}$, and $Gr_{\sigma}(\mathcal{A})$ the set of groundings of $\mathcal{A}$. The semantics σ satisfies the *grounding soundness* property iff for every $S \in Gr_{\sigma}(\mathcal{A})$ and $\mathcal{B} \in S$ it holds that $\mathcal{B}$ is σ-accepted in $\mathfrak{F}$.

Proposition 12. *The gr-semantics (1), pr-semantics (2), and pc-semantics (3) satisfy the grounding soundness property.*

Proof. (1) Let $\mathfrak{F}$ be an AF and $\mathcal{A}$ a *gr*-accepted argument in $\mathfrak{F}$. By Definition 3.8, there exists $\Lambda^{Ex}_{gr}(\mathcal{A})$ such that $mark(\mathcal{A}, [\mathcal{A}], \Lambda^{Ex}_{gr}(\mathcal{A})) = \mathsf{U}$. From Proposition 2, $mark(\mathcal{A}, [\mathcal{A}], \Lambda^{Pa}_{gr}(\mathcal{A})) = \mathsf{U}$ for any parsimonious bundle set $\Lambda^{Pa}_{gr}(\mathcal{A})$ for $\Lambda^{Ex}_{gr}(\mathcal{A})$. From Definition 3.11, for all $\lambda \in \Lambda^{Pa}_{gr}(\mathcal{A})$, $mseq(\lambda, \lambda, \Lambda^{Pa}_{gr}(\mathcal{A})) = \mathsf{U}(\mathsf{DU})^*$. Let $\mathcal{A}_n$ be the last argument of $\lambda \in \Lambda^{Pa}_{gr}(\mathcal{A})$. By Definition 4.2, $\mathcal{A}_n$ has no defeaters and, by Definition 2.3, $\mathcal{A}_n$ is in the grounded extension E. Let $\mathcal{A}_{2k-1}$, with $1 \leqslant 2k-1 < n$, be the last argument of a proper segment λ'_h of $\lambda_h \in \Lambda^{Pa}_{gr}(\mathcal{A})$ such that for all $\lambda_k \in Ex(\lambda'_h)$, $\mathcal{A}_{2k+1} \in \lambda_k$ and $\mathcal{A}_{2k+1} \in E$. Then, $\mathcal{A}_{2k-1} \in E$ since E defends $\mathcal{A}_{2k-1}$ from all $\mathcal{A}_{2k} \in \lambda_k$. Thus, $Supp(\Lambda^{Pa}_{gr}(\mathcal{A})) \subseteq E$. Then, for every $\mathcal{B} \in Supp(\Lambda^{Pa}_{gr}(\mathcal{A}))$, $\mathcal{B}$ is *gr*-accepted and, by Definition 5.6, the *gr*-semantics satisfies grounding soundness.

(2) Let $\mathfrak{F}$ be an AF and $\mathcal{A}$ a *pr*-accepted argument in $\mathfrak{F}$. By Definition 3.8, there exists $\Lambda^{Ex}_{pr}(\mathcal{A})$ such that $mark(\mathcal{A}, [\mathcal{A}], \Lambda^{Ex}_{pr}(\mathcal{A})) = \mathsf{U}$. From Proposition 2, it follows that $mark(\mathcal{A}, [\mathcal{A}], \Lambda^{Pa}_{pr}(\mathcal{A})) = \mathsf{U}$ for any parsimonious bundle set $\Lambda^{Pa}_{pr}(\mathcal{A})$ for $\Lambda^{Ex}_{pr}(\mathcal{A})$. From Definition 4.3, $Supp(\Lambda^{Pa}_{pr}(\mathcal{A}))$ is conflict-free. Furthermore, for every $\mathcal{B}$ defeating $\mathcal{C} \in Supp(\Lambda^{Pa}_{pr}(\mathcal{A}))$, there exists $\mathcal{D} \in Supp(\Lambda^{Pa}_{pr}(\mathcal{A}))$ defeating $\mathcal{B}$. Then, by Definition 2.3, $Supp(\Lambda^{Pa}_{pr}(\mathcal{A}))$ is an admissible set and, accordingly, a subset of a preferred extension of $\mathfrak{F}$. Therefore, for all $\mathcal{C} \in Supp(\Lambda^{Pa}_{gr}(\mathcal{A}))$, $\mathcal{C}$ is *pr*-accepted and, by Definition 5.6, *pr*-semantics satisfies grounding soundness.

(3) From Definition 4.5, the *pc*-semantics is based on the *pr*-semantics while also preventing the opposition from moving self-defeating arguments. Then, the proof for the *pr*-semantics also applies to the *pc*-semantics. □

In the case of *df*-semantics, a counterexample is sufficient to show that it does not satisfy the grounding soundness property. Let us consider the AF from Figure 2 (a). We have $\Lambda^{Ex}_{df}(\mathcal{A}) = \{[\mathcal{A}, \mathcal{B}, \mathcal{C}]\}$ and $mark(\mathcal{A}, [\mathcal{A}], \Lambda^{Ex}_{df}(\mathcal{A})) = \mathsf{U}$. Then, by Definition 3.8, $\mathcal{A}$ is *df*-accepted. From Definition 3.12, it holds that $\Lambda^{Pa}_{df}(\mathcal{A}) = \Lambda^{Ex}_{df}(\mathcal{A})$. Here, $Supp(\Lambda^{Pa}_{df}(\mathcal{A})) = \{\mathcal{A}, \mathcal{C}\}$. Moreover, $\Lambda^{Ex}_{df}(\mathcal{C}) = \{[\mathcal{C}, \mathcal{B}]\}$ and $mark(\mathcal{C}, [\mathcal{C}], \Lambda^{Ex}_{df}(\mathcal{C})) = \mathsf{D}$. Thus, by Definition 3.8, $\mathcal{C}$ is *df*-rejected. As a result, by Definition 5.6, *df*-semantics does not satisfy the grounding soundness property.

6 Conclusions and Future Work

In this work, we introduced a set of principles to extend existing principle-based frameworks for analyzing the theoretical foundations of argumentation semantics. Each proposed principle arises from adopting a dialogue game-based approach to defining semantics. By deepening the understanding of the principles underlying argumentation semantics, we offer a basis for both critical analysis and the development of new dialogue game-based semantics.

Several future lines of research remain open. We aim to extend the present work by considering a broader range of dialogue-game based semantics and principles. In addition, we plan to explore different variants of each semantics to examine how distinct protocol versions affect the principle-based analysis. We also intend to investigate in detail the relationship between existing principles for extension-based (or labeling-based) semantics and those introduced in this paper. Finally, to evaluate the broader applicability of the proposed principles, we plan to apply them to the analysis of dialogue-game-based semantics for formalisms that extend AFs by incorporating additional relations—such as the sub-argument relation—and elements such as hashtags or multiple agents.

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[2]The term *grounded* as used here should not be confused with the name of the *grounded* semantics.

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