On the General Epistemic Abstract Argumentation Framework

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Abstract

The Epistemic Abstract Argumentation Framework (EAAF) has been recently proposed to extend Dung's framework (AAF) by allowing the representation of epistemic attacks [1]. In this paper, we discuss an intuitive semantics for (general) EAAF, that is a class of frameworks where epistemic attacks may occur in cycles. The EAAF semantics naturally extends that for AAF as well as that for acyclic EAAF.

Keywords

Formal Argumentation, Epistemic Argumentation

1. Introduction

Recent developments in Artificial Intelligence (AI) have shown the necessity to provide new approaches concerning transparency and explanations on how AI systems make decisions. To address this issue, researchers have investigated several directions, including how formal argumentation and ontology techniques can be used together for reasoning about intentions to build complex natural language dialogues to support human decision-making [2]. In this paper, we focus on Dung's Abstract Argumentation Framework (AAF), a simple yet powerful formalism for modeling disputes between two or more agents [3], whcih is applicable in modeling dialogues, negotiation [4], persuasion [5], process mining [6], and all that contexts where controversials occur and reasonable solutions should be found. An AAF consists of a set of *arguments* and a binary *attack* relation over the set of arguments that specifies the interactions between arguments: intuitively, if argument a attacks argument b, then b is acceptable only if a is not. Hence, arguments are abstract entities whose status is entirely determined by the attack relation. An AAF can be seen as a directed graph, whose nodes represent arguments and edges represent attacks. Several argumentation semantics—e.g. *grounded* (gr), *complete* (co), *preferred* (pr), and *stable* (st) [3]—have been defined for AAF, leading to the characterization of σ*-extensions*, that intuitively consist of the sets of arguments that can be collectively accepted under semantics σ.

Example 1. Consider the AAF Λ_1 shown in Figure 1 describing the following planning scenario. A party planner invites Alice (a) and Bob (b) to join a party. Alice replies that she will not join the party if Bob does, whereas Bob replies that he will not join the party if Alice does. An argument x states that "*(the person whose initial is)* x *joins the party*". There are two pr-extensions $E_1 = \{\mathtt{a}, \neg\mathtt{b}\}$ and $E_2 = \{\neg\mathtt{a}, \mathtt{b}\}$ stating that only Alice or only Bob will attend the party, respectively. Herein, an extension represents a solution and is a set of argument literals, where the occurrence of a positive/negative literal x/$\neg$x means that argument x is accepted/rejected—the remaining arguments, if any, are said to be undecided. Thus,

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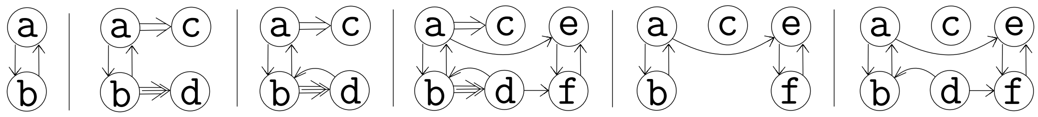

Figure 1: (From left to right) AAF Λ_1, acyclic EAAF Δ_1, general EAAFs Δ_2 and Δ_3, reducts $\Delta_3^{\mathcal{T}}$ and $\Delta_3^{\mathcal{T}'}$. An arrow of the form $\Rightarrow$ (resp. $\Rrightarrow$) represents a weak (resp. strong) epistemic attack.

the presence of two alternative extensions, namely E_1 and E_2, suggest that the participation of Alice and Bob to the party is uncertain. □

To deal with uncertain information represented by the presence of multiple extensions, credulous and skeptical reasoning has been introduced. Specifically, an argument is credulously/skeptically true (or accepted) if it is contained in any/all extensions. However, uncertain information in AAF under multiple-status semantics proposed so far cannot be exploited to determine the status of arguments by taking into account the information given by the whole set of extensions, as in the case of credulous and skeptical acceptance. To overcome such a situation, and thus provide a natural and compact way for expressing such kind of conditions, the Epistemic AAF (EAAF) has been recently proposed in [1], where the concept of epistemic arguments and attacks is introduced. Informally, epistemic attacks allow considering all extensions and not only the current one. Therefore, a *strong* (resp. *weak*) *epistemic attack* from a to b is such that a defeats b if a occurs in any/all extensions.

Example 2. To illustrate the importance of epistemic attacks in knowledge representation, consider the AAF Λ_1 and assume there are two more people: Carol ($\mathtt{c}$) and David ($\mathtt{d}$). Carol's answer is that she will not attend the party if *it is sure (i.e. it is skeptically true)* that Alice will, whereas David answers that he will not attend the party if *the participation of Bob is possible (i.e. it is credulously true)*. Intuitively, the party planner should conclude that, as the participation of both Alice and Bob is uncertain, Carol will attend the party, whereas David will not. This situation can be modeled by means of the EAAF Δ_1 of Figure 1 where $\mathtt{a}$ attacks $\mathtt{c}$ with a weak epistemic attack, whereas $\mathtt{b}$ attacks $\mathtt{d}$ with a strong epistemic attack. Under the preferred semantics, there are two extensions: $E_1 = \{\mathtt{a}, \neg\mathtt{b}, \mathtt{c}, \neg\mathtt{d}\}$ modeling the fact that Alice and Carol will attend the party, whereas Bob and David will not; and $E_2 = \{\neg\mathtt{a}, \mathtt{b}, \mathtt{c}, \neg\mathtt{d}\}$ modeling the fact that Bob and Carol will attend the party, whereas Alice and David will not. □

The semantics of EAAF has been defined only for *acyclic* EAAF (called well-formed in [1, 7]), where (weak and strong) epistemic attacks cannot be involved in any cycle (as e.g. Δ_1). This is a quite strong limitation as cycles involving epistemic attacks are as natural as those involving standard attacks, which are common in real-life argumentation frameworks—the role and effect of cycles in argumentation have been deeply investigated [8, 9, 10, 11, 12, 13]. In this paper we illustrate a *general framework*, recently introduced in [14, 15], where the presence of cycles is allowed. An example of cyclic EAAF is Δ_2, shown in Figure 1. Intuitively, continuing with our example, Δ_2 represents a scenario where Bob changes his mind: he will not join the party if Alice or David do. The addition of the standard attack ($\mathtt{d}$,$\mathtt{b}$) leads to the cycle $(\mathtt{b}, \mathtt{d}, \mathtt{b})$ involving the strong epistemic attack $(\mathtt{b}, \mathtt{d})$.

2. General Epistemic AAF

Syntax. An Epistemic AAF is a quadruple $\Delta = \langle A, \Omega, \Psi, \Phi\rangle$ where A is a set of arguments, $\Omega \subseteq A\times A$ is a set of (standard) attacks, $\Psi \subseteq A \times A$ is a set of weak (epistemic) attacks, and $\Phi \subseteq A \times A$ is a set of strong (epistemic) attacks such that $\Omega \cap \Psi = \Omega \cap \Phi = \Psi \cap \Phi = \emptyset$ and $\Omega[2] \cap (\Psi[2] \cup \Phi[2]) = \emptyset$, where $P[i]$ denotes the projection of relation P on the i-th element (with $i \in [1, 2]$). Hence, the set of attacks are pairwise disjoint, and arguments cannot be jointly attacked through standard and epistemic attacks. The latter ensures that epistemic arguments, i.e. arguments attacked through epistemic attacks, are *deterministic* [16]. We represent attacks $(a, b) \in \Omega$ by $a \to b$, $(a, b) \in \Psi$ by $a \Rightarrow b$, $(a, b) \in \Phi$ by $a \Rrightarrow b$. An EAAF $\langle A, \Omega, \Psi, \Phi\rangle$ can be seen as a directed graph, where A denotes the set of nodes and Ω, Ψ, and

Φ denotes three different kinds of edges. In the following, we consider the acceptability of (argument) literals, that is either an argument a or its negation $\neg a$. We use $\neg S$ to denote the set $\{\neg a \mid a \in S\}$, and S^* to denote $S \cup \neg S$. Moreover, for any set of literals S, we use $S^+ = \{a \mid a \in S\}$, $S^- = \{a \mid \neg a \in S\}$, and $S^u = \{a \mid a \in \text{A} \setminus (S^+ \cup S^-)\}$ to denote the set of arguments that occur as positive, negative, and neither positive nor negative literals in S, respectively. For any EAAF $\Delta = \langle A, \Omega, \Psi, \Phi \rangle$, a set W of (consistent) sets of literals in A^* such that all $S \in W$ assign the same status (either true, false, or undefined) to every epistemic argument is called *world view* of Δ. Intuitively, we can think of a world view as a set of candidate extensions where we take a decision on the status of epistemic arguments.

Defeated and Acceptable arguments. The definitions of defeated and acceptable arguments for EAAF extends that of AAF [3], by taking into account the additional concept of world view that is used to decide if an argument is epistemically defeated/acceptable. Given an EAAF Δ, a world view W of Δ, and a (consistent) set $S \in W$, the sets of arguments defeated/accepted w.r.t. S and W are:

- $Def(W,S) = \{b \in A \mid (\exists a \in S \,.\, a \rightarrow b) \vee$
  $(\exists T \in W \,.\, \exists a \in T \,.\, a \Rrightarrow b) \vee$
  $(\forall T \in W \,.\, \exists a \in T \,.\, a \Rightarrow b)\}$;
- $Acc(W,S) = \{b \in A \mid \forall a \in A \,.\, ((a \rightarrow b) \text{ implies } a \in Def(W,S)) \wedge$
  $((a \Rrightarrow b) \text{ implies } \forall\, T \in W \,.\, a \in Def(W,T)) \wedge$
  $((a \Rightarrow b) \text{ implies } \exists T \in W \,.\, a \in Def(W,T))$.

Given an EAAF $\Delta = \langle A, \Omega, \Psi, \Phi \rangle$ and a world view W of Δ, a set $S \in W$ is said to be *W-conflict-free* if $S^+ \cap Def(W,S) = \emptyset$; *W-admissible* if it is W-conflict-free, $S^+ \subseteq Acc(W,S)$ and $S^- \subseteq Def(W,S)$; and *W-complete* if it is W-conflict-free, $S^+ = Acc(W,S)$ and $S^- = Def(W,S)$. Moreover, a W-complete set S is said to be *W-preferred* (resp. *W-stable*, *W-grounded*) if S^+ is $\subseteq$-maximal (resp. if $S^+ \cup S^- = A$, if S^+ is $\subseteq$-minimal). Given a world view W for EAAF Δ, we use τ_W (or simply τ if W is understood) to denote an assignment of truth values to the epistemic arguments $\epsilon(\Delta)$ of Δ w.r.t. W, that is, $\tau_W = S \cap \epsilon(\Delta)^*$ where S is any element of W.

Reduct. Intuitively, the reduct of an EAAF is an AAF which is determined by a choice of the truth values (i.e. acceptance statuses) of the epistemic arguments. Given an EAAF Δ and a truth value assignment τ for the epistemic arguments $\epsilon(\Delta)$ of Δ, the reduct of Δ w.r.t. τ (denoted by Δ^τ) is the AAF obtained from Δ by *i)* deleting all epistemic attacks and every argument in τ^-, and *ii)* adding a self-attack to every argument in τ^u.

Semantics. Given an EAAF Δ, a semantics σ, and a truth assignment τ for the epistemic arguments $\epsilon(\Delta)$ of Δ, we denote by $\sigma(\Delta,\tau) = \{S \cup \tau \mid S \in \sigma(\Delta^\tau)\}$ the set of σ-extensions of Δ under assignment τ, where $\sigma(\Delta^\tau)$ is the set of σ-extensions of AAF Δ^τ. That is, $\sigma(\Delta,\tau)$ extends the σ-extensions of the reduct Δ^τ with the acceptance status τ of epistemic arguments. Then, a world view W for a given EAAF Δ is a σ-world view for Δ if for every $S \in W$ there exists a unique set $T \in \sigma(\Delta, \tau_W)$ such that $Def(W,S) = T^-$ and $Acc(W,S) = T^+$, and vice versa. Moreover, for $\sigma = \texttt{st}$, $\tau_W^u = \emptyset$. Thus, a σ-world view W can be obtained by *i)* fixing a truth value assignment τ_W for the epistemic arguments, *ii)* determining the set of σ-extensions entailed by the reduct $W = \sigma(\Delta, \tau_W)$, and *iii)* checking that for every $S \in W$, the conditions $Def(W,S) = S^-$ and $Acc(W,S) = S^+$ hold, that is each extension in W is confirmed by the defeated and accepted sets.

Example 3. Consider the EAAF Δ_3 (Figure 1) and the assignment $\tau = \{\texttt{c}, \neg\texttt{d}\}$. The reduct Δ_3^τ is shown in Figure 1. Its preferred extensions are $\{\texttt{a}, \neg\texttt{b}, \texttt{c}, \neg\texttt{e}, \texttt{f}\}$, $\{\neg\texttt{a}, \texttt{b}, \texttt{c}, \texttt{e}, \neg\texttt{f}\}$, and $\{\neg\texttt{a}, \texttt{b}, \texttt{c}, \neg\texttt{e}, \texttt{f}\}\}$. Thus, $\texttt{pr}(\Delta_3, \tau) = W = \{S_1 = \{\texttt{a}, \neg\texttt{b}, \texttt{c}, \neg\texttt{d}, \neg\texttt{e}, \texttt{f}\}, S_2 = \{\neg\texttt{a}, \texttt{b}, \texttt{c}, \neg\texttt{d}, \texttt{e}, \neg\texttt{f}\}, S_3 = \{\neg\texttt{a}, \texttt{b}, \texttt{c}, \neg\texttt{d}, \neg\texttt{e}, \texttt{f}\}\}$. As $Def(W, S_i) = {S_i}^-$ and $Acc(W, S_i) = {S_i}^+$, for $i \in [1..3]$, then W is a $\texttt{pr}$-world view. For $\tau' = \{\texttt{c}, \texttt{d}\}$, we have that $\texttt{pr}(\Delta_3, \tau') = W' = \{S_1' = \{\texttt{a}, \neg\texttt{b}, \texttt{c}, \texttt{d}, \neg\texttt{e}, \neg\texttt{f}\}\}$. Since $\texttt{c}$ is epistemically attacked by $\texttt{a}$, we have that $\texttt{c} \notin Acc(W', S_1')$ (i.e. $S_1' \neq Acc(W', S_1)$), entailing that W' is not a $\texttt{pr}$-world view. $\square$

	AAF [17]			acyclic EAAF [1, 14]		(general) EAAF [14]			
σ	Ver_σ	CA_σ	SA_σ	Ver_σ	EA_σ	$PVer_\sigma$	$NVer_\sigma$	PEA_σ	NEA_σ
gr	P	P	P	P	P	P	coNP-c	NP-c	coNP-c
co	P	NP-c	P	Θ_2^p-c	Θ_2^p-h, Δ_2^p	Θ_2^p-c	Θ_2^p-h, Π_2^P	Θ_2^p-h, Σ_2^P	Θ_2^p-h, Π_2^P
st	P	NP-c	coNP-c	Θ_2^p-c	Θ_2^p-h, Δ_2^p	Θ_2^p-c	Π_2^P-c	Θ_2^p-h, Σ_2^P	Π_2^P-c
pr	coNP-c	NP-c	Π_2^P-c	Θ_2^p-h, Θ_3^p	Π_2^P-h, Δ_3^p	Θ_2^p-h, Θ_3^p	Σ_2^P-h, Π_3^P	Π_2^P-h, Σ_3^P	Π_2^P-h, Π_3^P

Table 1
Complexity of *i*) verification (Ver_σ), credulous acceptance (CA_σ), and skeptical acceptance (SA_σ) problems for AAF; *ii*) verification (Ver_σ) and epistemic acceptance (EA_σ) problems for acyclic EAAF; and *iii*) possible and necessary verification ($PVer_\sigma$ and $NVer_\sigma$) as well as possible and necessary epistemic acceptance (PEA_σ and NEA_σ) problems for (general) EAAF. For a class C, C-c (resp. C-h) means C-complete (resp. C-hard); an interval C-h, C' means C-hard and in C'.

Complexity. We discuss the recent complexity analysis for two fundamental reasoning problems for EAAF [1, 14, 15]: the *verification* and *credulous/skeptical acceptance* problems, that are usually considered for analyzing the computational complexity of argumentation frameworks [18, 19, 20, 17, 21]. To deal with multiple world views, the possible and necessary variants of those problems are recalled in what follows—this is somehow analogous to the approach adopted for instance in incomplete AAF [19] where multiple *completions* may exist, each corresponding to a possible materialization of uncertain arguments and attacks. Given an EAAF $\Delta = \langle A, \Omega, \Psi, \Phi \rangle$ and a semantics $\sigma \in \{\mathtt{gr}, \mathtt{co}, \mathtt{pr}, \mathtt{st}\}$:

- the *possible* (resp. *necessary*) *verification* problem for EAAF, denoted as $PVer_\sigma$ (resp. $NVer_\sigma$), consists in deciding whether a given set of literals $S \subseteq A^*$ is in *any* (resp. *every*) σ-world view of Δ;
- the *possible* (resp. *necessary*) *credulous acceptance* problem, denoted as PCA_σ (resp. NCA_σ), consists in deciding whether a given goal argument $g \in A$ belongs to *any* σ-extension of *any* (resp. *every*) world view of Δ.
- the *possible* (resp. *necessary*) *skeptical acceptance* problem, denoted as PSA_σ (resp. NSA_σ), consists in deciding whether a given goal argument $g \in A$ belongs to *every* σ-extension of *any* (resp. *every*) world view of Δ.

Observe that if argument g is epistemic, then credulous and skeptical reasoning coincide. In fact, since epistemic arguments are deterministic, their acceptance status does not change in different extensions of a world view (though may change in different world views). Thus, possible (resp. necessary) credulous and skeptical acceptance problems coincide, and we this problem can be simply called *possible* (resp. *necessary*) *epistemic acceptance*, denoted as PEA_σ (resp. NEA_σ).

The complexity results are summarized in Table 1. While the complexity lower- and upper-bounds provided for $PVer_\sigma$ are the same of those for Ver_σ (i.e. for acyclic EAAF), the complexity bounds for $NVer_\sigma$ suggest that necessary verification turns out to be computationally more expensive. This is evident for the grounded and stable semantics, where $NVer_{\mathtt{gr}}$ and $NVer_{\mathtt{st}}$ become coNP-complete and Π_2^P-complete, respectively. Moreover, considering the results for the grounded and stable semantics, it turns out that the acceptance problem is harder than in case of acyclic EAAF. Overall, the complexity results confirms the intuition that general EAAF is more expressive than acyclic EAAF.

3. Conclusion

We have discussed a natural, declarative semantics for general (possibly cyclic) EAAFs that extends that of AAF as well as that of acyclic EAAF. Differently from the case of acyclic EAAF, whose semantics prescribes a single world view, an EAAF may have multiple world views. In general, we may have cyclic EAAFs with multiple or single world views. Interesting future work could include the investigation of the computational complexity of canonical argumentation problems in general EAAF, as done for other frameworks extending AAF e.g. [1, 22, 16, 23, 24, 25, 20, 18, 21, 19, 26, 27, 28].

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Declaration on Generative AI

The author(s) have not employed any Generative AI tools.

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