On Combining Abstract Argumentation Frameworks with Knowledge Bases

(Extended Abstract)

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Abstract

Dung's abstract Argumentation Framework (AF) has been extended in several directions to make knowledge representation and reasoning more intuitive and expressive. In this paper, we discuss the *Knowledge-based Argumentation Framework* (KAF), an extension of AF with a Knowledge Base (KB) expressed in *DL-Lite*, which includes concept and role instances describing the topology of an AF, besides additional knowledge on the domain [1]. The KAF semantics is given by a set of KAF *extensions*, each consisting of an extension of the underlying AF together with a "pertinent" subset of the original KB, which is obtained by discarding assertions referring to arguments that have been ruled out in the AF extension. Then, the framework is further expanded into the *Constrained* KAF (CKAF), where a set of restricted relational calculus formulae is used for reasoning over 'feasible' subframeworks that satisfy the formulae and *minimally* differ from the original framework.

Introduction

Formal argumentation has become a prominent research field in the area of knowledge representation and reasoning [2]. Dung's *abstract Argumentation Framework (AF)* is a foundational yet expressive formalism for representing disputes among agents [3]. An AF consists of a set of abstract arguments and a binary attack relation that defines how arguments interact: intuitively, if argument a attacks argument b, then b is considered acceptable only if a is not. Arguments themselves are treated as abstract entities whose acceptability essentially depends on the attack relation. This framework can be naturally represented as a directed graph, where nodes represent arguments and edges denote attacks. The formal meaning of an AF is given in terms of *argumentation semantics*, which intuitively tell us the sets of arguments (called *extensions*) that can collectively be accepted. Several (argumentation) semantics have been introduced, such as *grounded* ($\mathtt{gr}$), *complete* ($\mathtt{co}$), *preferred* ($\mathtt{pr}$), and *stable* ($\mathtt{st}$) [3], each defining a set of σ-extensions, with $\sigma \in \{\mathtt{gr}, \mathtt{co}, \mathtt{pr}, \mathtt{st}\}$. To enhance the expressive power of Dung's framework, various extensions of the original framework have been proposed [4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25]. Although significant advancements have been made in extending AF, there still remain situations where supplementary but potentially valuable information is neglected.

Example 1. Assume that there is a debate with several participants expressing opinions about climate change. Opinions and their relationships are represented by means of AF $\Lambda_1 = \langle\{\mathtt{a}, \mathtt{b}, \mathtt{c}, \mathtt{d}, \mathtt{e}\}, \{(\mathtt{a}, \mathtt{b}), (\mathtt{b}, \mathtt{a}), (\mathtt{c}, \mathtt{b}), (\mathtt{c}, \mathtt{d}), (\mathtt{d}, \mathtt{c}), (\mathtt{e}, \mathtt{c})\}\rangle$ shown in Figure 1. We also know that the opinions synthesized by arguments $\mathtt{a}, \mathtt{b}, \mathtt{c}$, and $\mathtt{d}$ are expressed by `john`, `mary`, `frank`, and `anne`, respectively; we do not know who expressed opinion $\mathtt{e}$. AF Λ_1 has three complete extensions: $E_1 = \{\mathtt{d}, \mathtt{e}\}$ (which is also grounded), and $E_2 = \{\mathtt{a}, \mathtt{d}, \mathtt{e}\}$ and $E_3 = \{\mathtt{b}, \mathtt{d}, \mathtt{e}\}$ (which are also stable and preferred). □

By modeling a problem through a plain AF, we may neglect important information that can be very useful. In our example, AF Λ_1 disregards useful information about the text associated with each argument, the author (and her gender and age), etc. Generally, a concrete argument is associated with a sentence

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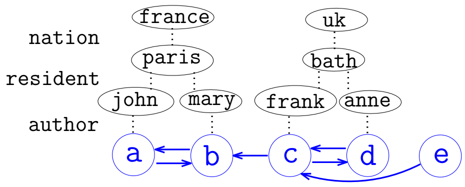

Figure 1: AF Λ of Example 1 (highlighted in blue), and (representation of the) assertions of the (C)KAF of our running example.

with a proper meaning and with several additional information that could be very important in answering queries and making informed decisions. This means that, in adopting the abstraction of AF, a large amount of relevant information may be lost, such as the argument's text, the author's id and gender, the date it has been introduced, the topic (e.g., what the argument is about), the polarity (e.g., whether the sentence conveys a positive, negative or neutral sentiment), the polarity rating, the sentence style (e.g., veracity, sarcasm, irony), the city and nationality of the author, and much more. An argumentation system should also carry auxiliary yet important information that could be very useful for users. That is, an argumentation framework should be coupled with a Knowledge Base (KB) containing information related to arguments. Prominent (families of) languages for such kind of KBs are those in Description Logics (DLs) [26], where a KB is a pair consisting of the ABox component, containing the data, and the TBox component, containing axioms (enabling further information to be derived).

Example 2 (Cont'd)**.** Assume now that we have a KB containing in the ABox information on the topology of the AF (i.e., $\mathtt{arg}(\mathtt{a})$, $\mathtt{att}(\mathtt{a},\mathtt{b})$, and so on) as well as additional information such as authorship (i.e., $\mathtt{author}(\mathtt{a},\mathtt{john})$, $\mathtt{author}(\mathtt{b},\mathtt{mary})$, $\mathtt{author}(\mathtt{c},\mathtt{frank})$, and $\mathtt{author}(\mathtt{d},\mathtt{anne})$), the city of authors (i.e., $\mathtt{resident}(\mathtt{john},\mathtt{paris})$, $\mathtt{resident}(\mathtt{mary},\mathtt{paris})$, $\mathtt{resident}(\mathtt{frank},\mathtt{bath})$, and $\mathtt{resident}(\mathtt{anne},\mathtt{bath})$), and the nation cities are in (e.g., $\mathtt{nation}(\mathtt{paris},\mathtt{france})$ and $\mathtt{nation}(\mathtt{bath},\mathtt{uk})$).

Assume that the TBox contains two axioms (expressed according to the *DL-Lite* syntax) of the form: *i*) $\mathtt{arg} \sqsubseteq \exists\,\mathtt{author}$ (equivalent to the first-order logic formula $\forall\,\mathtt{x}\,.\,\mathtt{arg}(\mathtt{x}) \Rightarrow \exists\,\mathtt{y}\,.\,\mathtt{author}(\mathtt{x},\mathtt{y})$), stating that every argument must have an author, and *ii*) $\exists\,\mathtt{author}^- \sqsubseteq \exists\,\mathtt{resident}$ (equivalent to the first-order logic formula $\forall\,\mathtt{x},\mathtt{y}\,.\,\mathtt{author}(\mathtt{x},\mathtt{y}) \Rightarrow \exists\mathtt{z}\,.\mathtt{resident}(\mathtt{y},\mathtt{z})$), stating that every author must be resident in some place. Using such a *DL-Lite* KB, the (certain) answer of the query $\mathtt{author}(\mathtt{x},\mathtt{john})$, asking for the arguments authored by $\mathtt{john}$, returns $\mathtt{a}$. Because of the axioms in the TBox, the answer to the query $\exists\,\mathtt{y},\mathtt{z}\,.\,\mathtt{author}(\mathtt{e},\mathtt{y}),\mathtt{resident}(\mathtt{y},\mathtt{z})$ is true, even if the ABox does not contain the author of $\mathtt{e}$. □

The Knowledge-based Argumentation Framework

Example 2 shows a possible integration of AF and KBs. However, as argumentation semantics are not leveraged during the reasoning process, the information on the AF's topology is not adequately exploited, although it is encoded into the ABox component. Thus, the classical reasoning loses the potential of AF in managing conflicts and uncertainty. To this end, we recently proposed a novel framework called *Knowledge-based Argumentation Framework* (KAF), augmenting AF with a *DL-Lite* KB [27], whose semantics is given by a set of KAF *σ-extensions*, each consisting of a σ-extension of the underlying AF together with a "pertinent" subset of the original KB. The latter is obtained by discarding assertions referring to arguments that have been ruled out in the AF extension. Notably, a KAF σ-extension (with $\sigma \in \{\mathtt{gr},\mathtt{co},\mathtt{pr},\mathtt{st}\}$) can be represented as a *DL-Lite* KB.

Example 3 (Cont'd)**.** The (grounded) KAF extension yielded by $E_1 = \{\mathtt{d},\mathtt{e}\}$ consists of the ABox containing $\mathtt{arg}(\mathtt{d})$, $\mathtt{arg}(\mathtt{e})$, $\mathtt{author}(\mathtt{d},\mathtt{anne})$, $\mathtt{resident}(\mathtt{john},\ \mathtt{paris})$, $\mathtt{resident}(\mathtt{mary},\ \mathtt{paris})$, $\mathtt{resident}(\mathtt{frank},\ \mathtt{bath})$, $\mathtt{resident}(\mathtt{anne},\ \mathtt{bath})$, $\mathtt{nation}(\mathtt{paris},\mathtt{france})$, and $\mathtt{nation}(\mathtt{bath},\mathtt{uk})$, that is the original ABox except assertions referring to arguments which are not in the extension E_1, while the TBox is that of the original KB. □

Similarly to classical reasoning in AF, credulous and skeptical acceptance in KAF are defined over the set of KAF σ-extensions, consisting of *DL-Lite* KBs, each of them queried according to the usual notion of certain answer [27]. For instance, the query $\exists\, \mathtt{x}, \mathtt{y}\, .\, \mathtt{author}(\mathtt{x}, \mathtt{y}) \wedge \mathtt{resident}(\mathtt{y}, \mathtt{bath})$, asking whether there exists an author of an argument resident in bath, is true under both credulous and skeptical reasoning, w.r.t. all the aforementioned argumentation semantics (as argument d, whose author is anne who is from bath, is a certain answer in every KAF σ-extension, with $\sigma \in \{\mathtt{gr}, \mathtt{co}, \mathtt{pr}, \mathtt{st}\}$, and the set of σ-extensions is non-empty). On the other hand, under complete semantics, the query $\exists \mathtt{x}\, .\, \mathtt{author}(\mathtt{x}, \mathtt{john})$, asking whether john authored some argument, is true under credulous reasoning and false under skeptical reasoning (as john's argument a belongs to E_2 only).

Consider now the case where there are two people from France and UK and they are interested in opinions expressed by people resident in their respective countries. That is, the subframeworks of interest are those where only opinions of French and UK people, respectively, are considered. This can be achieved by extending KAF with constraints expressed by means of restricted relational calculus formulae [28]. The safe, range-restricted relational calculus provides adequate power for many applications and at the same time can be implemented efficiently. Continuing our example, the KAF subframework containing only opinions from UK people can be selected by using the following constraint: $\forall \mathtt{x}.\mathtt{arg}(\mathtt{x}) \Rightarrow \exists \mathtt{y}, \mathtt{z}.\mathtt{author}(\mathtt{x}, \mathtt{y}) \wedge \mathtt{resident}(\mathtt{y}, \mathtt{z}) \wedge \mathtt{nation}(\mathtt{z}, \mathtt{uk})$.

Constraints and Complexity. The *Constrained* KAF (CKAF) is a KAF where a set of restricted relational calculus formulae is used for reasoning over the subframeworks that satisfy the formulae and *minimally* differ from the original framework. Two minimality criteria are considered, *set* and *card* minimality. Hence, a subframework is obtained by deleting a minimal set or a minimal number of arguments and attacks, as well as the related information in the KB, so that the set of constraints is satisfied w.r.t. the resulting KAF. Intuitively, a CKAF concisely represents a set of KAFs that could be obtained by extracting 'feasible' subframeworks. Then, its semantics can be defined in terms of the semantics of its subframeworks: similarly to other frameworks previously introduced in the literature such as incomplete AF (iAF) [29], and Probabilistic AF [30, 31, 32], the subframeworks can be seen as possible worlds. Thus, classical verification and credulous/skeptical acceptance problems need to be reconsidered in light of the presence of possible worlds, leading to the concepts of *possible* and *necessary verification*, as well as *possible* and *necessary* credulous/skeptical acceptance. The complexity of acceptance problems in KAF coincides with that of standard AFs. Moving to CKAF entails a significant complexity jump: i) for *verification* problems, both possible and necessary, the cardinality-based subframework semantics yields Θ_2^p-complete results, while the set-based semantics leads to Σ_2^p (resp., Π_2^p) for possible (resp., necessary) verification. For *acceptance* problems, the complexity ranges from Θ_2^p to Σ_3^p. Overall, compared to iAF and constrained iAF [33], CKAF is strictly harder. Overall, the cardinality-based semantics is systematically no harder than the set-based one. Finally, it has also been proven that CKAF strictly generalizes iAF and ciAF: for any ciAF, there exists an extensions-equivalent CKAF. However, the converse does not hold, as CKAF is provably harder than ciAF (and thus than iAF).

Conclusions and Future Work

Integrating AF with DLs addresses a crucial need in knowledge representation, leveraging the strengths of both: DLs handle structured domain knowledge (e.g. medical ontologies), while AFs manage conflicts and justifications among inferences derived from this knowledge. We have briefly discussed CKAF, a new framework combining abstract argumentation with Description Logics [1].

Future work should be devoted to the investigation of integrating AF with more general DL KBs by considering both more powerful query languages [34, 35] and more powerful DL languages for axioms' definition [36, 37]. Though the primary focus was on formal foundations, a possible solution for bridging this theoretical framework with practical implementations would be to adopt hybrid solving approaches that combine existing DL reasoners for KB reasoning (e.g., Pellet [38], HermiT [39]) and AF solvers (e.g., those of the ICCMA competition) for extensions computation, a direction left for future work.

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Declaration on Generative AI

The authors have not employed any Generative AI tools.

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