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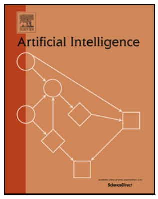

Complexity-sensitive decision procedures for abstract argumentation ☆

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ABSTRACT

Abstract argumentation frameworks (AFs) provide the basis for various reasoning problems in the area of Artificial Intelligence. Efficient evaluation of AFs has thus been identified as an important research challenge. So far, implemented systems for evaluating AFs have either followed a straight-forward reduction-based approach or been limited to certain tractable classes of AFs. In this work, we present a generic approach for reasoning over AFs, based on the novel concept of complexity-sensitivity. Establishing the theoretical foundations of this approach, we derive several new complexity results for preferred, semi-stable and stage semantics which complement the current complexity landscape for abstract argumentation, providing further understanding on the sources of intractability of AF reasoning problems. The introduced generic framework exploits decision procedures for problems of lower complexity whenever possible. This allows, in particular, instantiations of the generic framework via harnessing in an iterative way current sophisticated Boolean satisfiability (SAT) solver technology for solving the considered AF reasoning problems. First experimental results show that the SAT-based instantiation of our novel approach outperforms existing systems.

1. Introduction

Formal argumentation has evolved into an important field in Artificial Intelligence. Abstract argumentation frameworks (AFs for short), as introduced by Dung [1], are central in formal argumentation, providing a simple yet powerful formalism to reason about conflicts between arguments. The power of the formalism, however, comes at a price. In particular, many important reasoning problems for AFs are located on the second level of the polynomial hierarchy, including skeptical reasoning in the preferred semantics [2], and both skeptical and credulous reasoning in the semi-stable and the stage semantics [3]. This naturally raises the question about the origin of this high complexity and, in particular, calls for research on lower complexity fragments of the reasoning tasks. The focus of this article is both on the identification of such lower-complexity fragments of second-level reasoning problems arising from abstract argumentation, and on exploiting this knowledge in developing efficient *complexity-sensitive* decision procedures for the generic second-level problems.

Tractable (i.e., polynomial-time decidable) fragments have been quite thoroughly studied in the literature (see [4–8] for instance). However, there is only little work on identifying fragments which are located on the first level (NP/coNP layer), that is, *in-between* tractability and full second-level complexity.

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Identification of first-level fragments of second-level reasoning tasks is important due to several reasons. Firstly, from a theoretical point of view, such fragments show particular (but not all) sources of complexity of the considered problems, and pave the way towards "trichotomy"-style results (see [9] for an example in the context of answer-set programming). Secondly, NP fragments can be efficiently reduced to the problem of satisfiability in classical propositional logic (SAT). This allows for realizations of argumentation procedures by employing sophisticated SAT-solver technology [10,11] for reasoning over argumentation frameworks.

Going even further, in this work we aim at designing decision procedures for second-level argumentation problems by exploiting fragments extending such first-level fragments. To this end, we use the NP decision procedures as NP oracles in an iterative fashion. Such approaches fall under the general *counter-example guided abstraction refinement* (CEGAR) approach originating from the field of model checking [12,13]. For problems complete for the second level of the polynomial hierarchy, this leads to general procedures which, in the worst case, requires an exponential number of calls to the NP oracle, which is indeed unavoidable under the assumption that the polynomial hierarchy does not collapse. Nevertheless, we show in this work that such procedures can be designed to behave adequately on input instances that fall into the considered NP fragment and on instances for which a relatively low number of oracle calls is sufficient; as a generic notion, we say that such a procedure is *complexity-sensitive* w.r.t. the NP fragment at hand. For instance, for the second-level problem of answer-set existence for disjunctive logic programs [14], the successful loop-formula approach (see, e.g. [15]) yields a polynomial reduction to SAT for the fragment of tight programs, although in general the resulting SAT instance is of exponential size. This approach gives thus a practical decision procedure for (the second-level problems of) answer-set programming that is at the same time complexity-sensitive w.r.t. the NP fragment of tight disjunctive programs.

In this work we identify various lower-complexity fragments of second-level reasoning problems arising from abstract argumentation, and show how some of the fragments can be exploited in complexity-sensitive CEGAR-style decision procedures for the generic second-level problems. The fragments identified and exploited are based on notions of "*distance*" to particular NP fragments. This leads to the intuition that, the higher the distance, the more iterative calls to the NP oracle are needed. We also employ the concept of distance to *generalize* known classes of NP fragments.

In more detail, we focus on three important semantics for abstract argumentation: the preferred, semi-stable and stage semantics. Our complexity analysis is based on six different classes of argumentation frameworks which are known to yield milder complexity results for at least one of these semantics. Firstly, we present complexity results for these classes in cases where the exact complexity for a particular semantics has not been established yet. Moreover, we categorize the classes into *syntactical* and *semantical* families. For the former family, we consider the known concepts of acyclic and odd-cycle free AFs, as well as a new class (so-called weak cyclic AFs).

As semantical subclasses we consider the prominent class of coherent AFs [2]; the class of AFs which possess at least one stable extension (stable-consistent AFs); and the class of AFs which possess a unique preferred extension.

Secondly, we consider alternative notions of distance in order to capture AFs which are "close" to one of the aforementioned classes. We consider the following realizations of distance:

(i) *graph-based distance measures*, where the parameter is given by the number of arguments to be deleted from a given AF in order to fall into a specified class; and
(ii) *extension-based distance measures*, which apply to the semantical subclasses.

For instance (among others), starting from the class of coherent AFs (where the preferred and stable extensions coincide), we consider as parameter the number of additional preferred extensions.

The main contributions of this article are the following:

- We show new complexity results for acceptance problems in argumentation on certain fragments. In particular, for the class of frameworks which possess a unique preferred extension, semi-stable semantics yields milder complexity than stage semantics. To the best of our knowledge, this is the first result that indicates a difference between the complexities of these two semantics.
- We show that graph-based distance measures are in most cases tight: already a small distance from the subclass at hand leads to the full second-level complexity. This reveals that syntactic fragments based on such distance measures do not hint towards complexity-sensitive decision procedures.
- Towards the design of complexity-sensitive decision procedures, we also identify extension-based distance measures and show that certain problems can be solved by a bounded number (in terms of the distance) of NP-oracle calls.
- Exploiting the suitable extension-based distance measures, we develop a generic framework of complexity-sensitive decision procedures for the different second-level reasoning problems within abstract argumentation. We present our procedures in terms of (first-level) argumentation problems, i.e., we give novel characterizations of preferred, semi-stable, and stage semantics in terms of simpler semantics (such as stable and complete). The actual computation of the simpler semantics can be instantiated in various ways.
- We show in detail how the generic framework can be instantiated using an SAT-based CEGAR-style approach. For this, we develop novel SAT-encodings for the oracle calls, differing from previously suggested SAT-encodings of first-level AF reasoning problems [16]. Notably, we exploit possibilities of learning from counter-examples both on the level of the original argumentation framework as well as the SAT oracle during computation. Importantly, while monolithic SAT-encodings of second-level argumentation problems are deemed to be of exponential size, our procedures are truly