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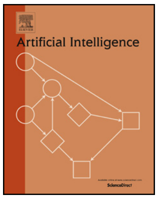

Argument graphs and assumption-based argumentation [☆]

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ABSTRACT

Arguments in structured argumentation are usually defined as trees, and extensions as sets of such tree-based arguments with various properties depending on the particular argumentation semantics. However, these arguments and extensions may have redundancies as well as circularities, which are conceptually and computationally undesirable. Focusing on the specific case of Assumption-Based Argumentation (ABA), we propose novel notions of arguments and admissible/grounded extensions, both defined in terms of graphs. We show that this avoids the redundancies and circularities of standard accounts, and set out the relationship to standard tree-based arguments and admissible/grounded extensions (as sets of arguments). We also define new notions of graph-based admissible/grounded dispute derivations for ABA, for determining whether specific sentences hold under the admissible/grounded semantics. We show that these new derivations are superior with respect to standard dispute derivations in that they are complete in general, rather than solely for restricted classes of ABA frameworks. Finally, we present several experiments comparing the implementation of graph-based admissible/grounded dispute derivations with implementations of standard dispute derivations, suggesting that the graph-based approach is computationally advantageous.

1. Introduction

Argumentation theory is a powerful reasoning abstraction in which conflicting arguments are represented and evaluated against one another in order to resolve conflicts and find those sets of arguments which are together dialectically superior. It has been extensively studied in AI over the past two decades—see [2,4,24] for an overview—and used as the formal basis of a number of applications. Several forms of argumentation have been proposed. The simplest form is the seminal *abstract argumentation* defined by Dung [11], where the basic structure is a graph whose vertices represent *arguments* and whose edges, called *attacks*, represent a relation of conflict between arguments. By contrast, in *structured argumentation*—see [3] for an overview—arguments and attacks are not primitive but are derived from more basic structures. It is common in structured argumentation to define arguments as trees, whose edges represent a relation of dependency holding between sentences labelling the nodes.

Assumption-Based Argumentation (ABA) [6,12,14,13,27,28] is a well-known form of structured argumentation. In ABA, arguments are obtained from the *rules* of a given deductive system and *assumptions* (special sentences in the language

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underlying the deductive system). More specifically, arguments are finite trees whose leaves must either be labelled by assumptions or must represent the empty body of a rule in the deductive system. Such an argument is attacked by another argument when an assumption on which the first argument is built has as *contrary* a sentence labelling the root of the second argument. In ABA, the internal structure of arguments is explicit, as is also the reason why there is an attack between two arguments.

The semantics of argumentation frameworks typically determine different dialectically superior or winning sets of arguments, known as *acceptable extensions*. Both abstract argumentation and ABA define various alternative semantics and corresponding kinds of acceptable extensions. In the case of ABA, extensions can be equivalently understood in terms of sets of assumptions (in the support of arguments in acceptable extensions)—see [6,14,28].

ABA has been applied in several settings, e.g., to support medical decision-making [8,19] and e-procurement [22]. ABA's applicability relies on the existence of computational mechanisms, based on various kinds of *dispute derivation* [12,14,27] that are formally proven to be correct procedures under various semantics. Whereas the semantics are non-constructive specifications of what can be deemed acceptable extensions, dispute derivations are fully constructive algorithms. One kind of dispute derivation for computation under the semantics of admissible extensions was presented by Dung et al. [12]; this was extended to the semantics of grounded and ideal extensions by Dung et al. [14], and, in a parametric version with a richer output (encompassing both views of extensions as sets of arguments and as sets of assumptions) by Toni [27].

ABA is not alone among forms of structured argumentation in representing arguments as tree structures; [23] and others do the same. This has several consequences. Positively, it means that the relation of support is depicted explicitly in the formalism, with an edge of such a tree-based argument representing the relation of dependence of one sentence on others. Yet, negatively, it can lead to several problems, both conceptual and computational. First, defining arguments as trees whose nodes are labelled by sentences means that there can be circular dependencies amongst those sentences, even if these trees are required to be finite. The potential for circular dependency also causes problems computationally: it means that, in the course of a dispute derivation, loops may be encountered which prevent standard procedures from terminating, leading to incompleteness. Secondly, even if there is no circular dependency, the use of trees to represent arguments allows a sentence to be proved in several different ways (which we call *flabbiness*). Flabbiness is conceptually undesirable and involves redundancy, with the same sentence being reproved needlessly; it is also therefore inefficient.

Thirdly, some of these issues arise not only with the definition and computation of individual arguments, but also with the definition and computation of extension-based semantics, i.e., with sets of arguments. These sets are intended to represent a coherent dialectical position, but, as we discuss in the paper, if the same sentence is proved in multiple different ways in different arguments belonging to the set (which we call *bloatedness*), it can rightly be questioned whether an appropriate notion of coherence applies. Indeed, one may have already computed that there is an argument for some sentence, but not use this where it could serve as a subargument elsewhere. Again, as with the case of the flabbiness of individual arguments, there is also a question of efficiency in the computation of extensions.

In the current paper we provide a solution, which answers the conceptual problems, as well as the computational issues of incompleteness and inefficiency. The solution relies upon altering the underlying conception of an argument to an approach which is graph-based rather than tree-based, and which also reconceives the nature of the set of arguments sanctioned by the semantics and computed in a dispute derivation, removing redundancy across arguments. Using graphs rather than sets of trees, circularity, flabbiness and bloatedness are removed at a stroke. Our work focuses on the case of ABA in particular, but we think that the approach of using graphs would also generalize to other forms of structured argumentation which are currently based on trees, such as [23].

We provide a link between our argument-graph approach and *rule-minimal* arguments, which makes the connection to standard, tree-based accounts of arguments in ABA explicit. We define novel *admissible* and *grounded* graph-based semantics for our argument graphs, and show the correspondence with the standard semantics using trees. We then define dispute derivations for the new structures, which we prove are sound and complete with respect to the novel semantics. Completeness in the dispute derivations for grounded semantics is an important further advantage of our approach, for previous dispute derivations for ABA—those of Dung et al. [12], Dung et al. [14] and Toni [27]—are complete solely for a special form of (p-acyclic) ABA frameworks. Indeed, our dispute derivations are complete for any form of ABA framework.

In addition to the gains in conceptual justification and completeness, there are improvements in the speed with which computation is performed in the new approach. We implemented our algorithms in Prolog,[1] and conducted a preliminary experimental evaluation of the new algorithms in comparison with an implementation of the previous dispute derivations of Toni [27]. The results, as can be seen in §6, favour the graph-based approach.[2]

The work here substantially extends the preliminary research in [9]. First, the previous work was restricted to the grounded semantics, still defined in terms of sets of tree-based arguments rather than graphs. Secondly, the main results of that paper were given as proof sketches; full proofs are now provided. Thirdly, the previous paper focused on soundness; full completeness results are now also provided. Fourthly, we conduct a more thorough experimental comparison with standard dispute derivations. Fifthly, many more examples are provided. Sixthly, in previous work argument graphs were conceived more as a data structure to aid computation; in the present paper they are justified on more conceptual grounds,

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[1] Implementations and several ABA frameworks freely available at http://robertcraven.org/proarg/.

[2] Experimental data and results available from http://robertcraven.org/proarg/experiments.html.