Introducing Probabilistic Reasoning in Defeasible Argumentation Using Labeled Deductive Systems

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Abstract

Labeled Deductive Systems (LDS) were developed as a rigorous but flexible methodology to formalize complex logical systems, such as temporal logics, database query languages and defeasible reasoning systems.

LDS_{AR} is a LDS-based framework for *defeasible argumentation* which subsumes different existing argumentation frameworks, providing a testbed for studying different relevant features (such as emerging logical properties, ontological aspects, semantic characterization, etc.)

This paper discusses some relevant issues concerning the introduction of *probabilistic reasoning* into defeasible argumentation. In particular, we consider a first approach for recasting the existing LDS_{AR} framework in order to incorporate numeric attributes (certainty factors) as part of the argumentation process.

1 Introduction and motivations

Labeled Deductive Systems (LDS) [Gab96] were developed as a rigorous but flexible methodology to formalize complex logical systems, such as temporal logics, database query languages and defeasible reasoning systems. In labeled deduction, the usual notion of formula is replaced by the notion of *labeled formula*, expressed as *Label*:*f*, where *Label* represents a label associated with the wff *f*. A labeling language $\mathcal{L}_{Label}$ and knowledge-representation language $\mathcal{L}_{kr}$ can be combined to provide a new, labeled language, in which labels convey additional information also encoded at object-language level. Formulas are labeled according to a family of *deduction rules*, and with agreed ways of propagating labels via the application of these rules.

The study of logical properties of *defeasible argumentation* [PV99, CML00] motivated the development of LDS_{AR} [Che01], an LDS-based argumentation formalism. In LDS_{AR}, labels provide information about the *epistemic status* of wffs (defeasible vs. non-defeasible) and the *name* of the wff involved. LDS_{AR} provides a useful formal framework for studying logical properties of defeasible argumentation in general, and of DeLP [Gar00] in particular. Equivalence results with other argumentative frameworks were also studied.

Labeled deduction has a number of features which make it suitable for characterizing new ontologies. Thus, different *variants* of defeasible argumentation can be explored from the original LDS_{AR} formulation by introducing changes in the object language. These changes can be introduced in a modular way, without affecting the whole framework.

This paper is motivated by extending the original notion of label in order to incorporate *probabilistic reasoning* in the LDS_{AR} framework. The success of argumentation-based approaches is partly due to the sound setting it provides *qualitative reasoning*. Numeric attributes, on the other hand, offer an useful source of information for *quantitative reasoning* in several knowledge domains. We think that combining both kinds of reasoning into an single argumentation framework would be highly desirable.

2 The $\boldsymbol{LDS_{AR}}$ framework: a brief sketch[1]

In LDS_{ar}, the language $\mathcal{L}_{kr}$ is the one of *extended logic programming*. Labels extend this language by distinguishing *defeasible* and *non-defeasible* information. A consequence relation $\mid\!\sim_{Arg}$ propagates labels, implementing the SLD resolution procedure along with a consistency check every time new defeasible information is introduced in a proof. This information is collected into a *set of support*, containing all defeasible information needed to conclude a given formula. Thus, arguments are modeled as labeled formulas $\mathcal{A}$:h, where $\mathcal{A}$ stands for a set of (ground) clauses, and h for an extended literal.

Given a knowledge base Γ the consequence relation $\mid\!\sim_{Arg}$ allows to infer labeled formulas of the form *argument*:*literal*. Since arguments may be in conflict, a new, extended consequence relationship $\mid\!\sim_{\mathcal{T}}$ is defined. Those wffs derivable from Γ via $\mid\!\sim_{\mathcal{T}}$ will correspond to *dialectical trees*. These new labeled wffs will therefore have the form *dialectical tree*:*conclusion*.

3 Approaches to uncertainty based on probabilistic reasoning

As Judea Pearl points out [Pea88], commonsense reasoning involves *summarizing exceptions* at a given stage. In defeasible argumentation this is done by providing defeasible rules "$p(X) \prec q(X)$", which provide a symbolic way of specifying "not every $q(X)$ is $p(X)$". Another way of summarizing exceptions is to assign to each proposition a numerical measure of uncertainty, and then combine these measures according to uniform syntactic principles.

When introducing numerical values for modeling uncertainty, *extensional* and *intensional* approaches can be distinguished. Extensional approaches treat uncertainty as a generalized truth value attached to formulas. Computing the uncertainty of any formula is a function of the uncertainties of its subformulas. Intensional approaches, on the other hand, are model-based: uncertainty is attached to "states of affairs" or subsets of "possible worlds". Typical examples of this extensional approaches are production systems and rule-based systems.

Extensional approaches are computationally attractive, but their semantics may be 'sloppy'. Intensional approaches are semantically clear but computationally clumsy. Most research has been directed to find a trade-off between these two kinds of formalizing uncertainty. In order to recast defeasible argumentation in terms of probabilistic reasoning, we

[1]For space reasons we only give a brief summary of the main elements of the LDS_{AR} framework. We also assume that the reader has basic knowledge about the underlying concepts in defeasible argumentation formalisms. For an in-depth treatment the reader is referred to [Che01, CML00].

will adopt an extensional approach as it can be easily integrated in the existing ontology, as we will see in the next section. Semantical issues are not discussed in this paper. However, it must be noted that Gabbay's LDS provide a sound basis for defining formal semantics associated to arbitrary logical systems using labelled deduction.[2]

4 Handling probabilities in LDS_{AR}: a first approach

Figure 1 shows the basic rules for building *generalized arguments* (*i.e.*, defeasible proofs which are non-contradictory wrt the strict knowledge $\mathsf{Strict}(\Gamma)$ for a given knowledge base Γ). Rules 1 and 2 introduce non-defeasible and defeasible information, respectively. Rules 3 and 4 account for introducing conjunction and *modus ponens*. As discussed in previous sections, these natural deduction rules propagate labels when performing inference. Note that in our case object-language wffs have the form $Label : f$, where labels convey the following information: a) name and epistemic status of the wff (n=non-defeasible, d=defeasible); b) set of support Φ (such that $\Phi \vdash_{\text{SLD}} f$).

In order to introduce an uncertainty measure in object-language wffs, a natural approach would be just adding some certainty factor cf, such that $cf(f) = 1$ whenever f corresponds to non-defeasible knowledge, and $0 < cf(f) < 1$ whenever f stands for defeasible knowledge. A formula of the form $[\alpha, cf(\alpha)]{:}\alpha$ in the knowledge base Γ would therefore stand for "α is a defeasible formula which has the certainty factor $cf(\alpha)$".[3] Similarly, the formula $[\emptyset, 1]{:}\alpha$ would stand for "α is a non-defeasible formula". Finally, performing an inference from Γ (*i.e.*, building a generalized argument) would result in inferring a formula $[\Phi, cf(\Phi)]{:}\alpha$, standing for "The set Φ provides an argument for α with a certainty factor $cf(\Phi)$".

As we can see, in this new setting every formula in Γ should be attached with a certainty factor, indicating whether the formula corresponds to non-defeasible or defeasible knowledge. Natural deduction rules propagate certainty factors as inferences are carried out. From the structure of the natural deduction rules in figure 1 we can distinguish two relevant aspects in such a new setting:

- **Propagating certainty factors:** In extensional systems, uncertainty can be treated as a generalized truth value, *i.e.* the certainty of a formula is defined as a unique function from the certainties of its subformulas. LDS allow us to proceed the same way: when performing an inference, a new label is defined in terms of existing (already inferred) labels.

  Therefore propagating certainty factors turns out to be natural in our framework. As an example, consider two formulas $[\Phi, cf(\Phi)]{:}\alpha$ and $[\Psi, cf(\Psi)]{:}\beta$. If α, β could be derived (introducing conjunction), the resulting formula would have the form

  $$[\Phi \cup \Psi, f_{\wedge}(cf(\Phi), cf(\Psi))]{:}\alpha, \beta$$

- **Handling consistency:** In the original formulation, consistency checking of a (defeasible) wff f wrt a set of arbitrary wffs Φ stands for $\Phi \cup \{f\} \not\vdash_{\text{SLD}} \perp$. Note that

[2] See [Gab96] for details.

[3] Note that it is no longer necessary to distinguish between defeasible and non-defeasible formulas, as this qualification can be inferred from their associated certainty factors.

consistency checking in defeasible argumentation involves the set of strict knowledge $\mathsf{Strict}(\Gamma)$, where all wffs are non-defeasible (*i.e.* $cf(\gamma) = 1$, $\forall \gamma \in \mathsf{Strict}(\Gamma)$. Using the approach discussed above, when a new defeasible formula f is inferred, it will have the form $[\Phi, cf(\Phi)]{:}f$. Consistency checking will involve assuming that f is "locally non-defeasible" (*i.e.*, $[\Phi, cf(1)]{:}f$. and non-contradictory wrt $\mathsf{Strict}(\Gamma)$.

Let us summarize some of the main issues which are relevant to consider when incorporating certainty factors into the argumentation process. Following [PV99], we can distinguish different levels in our analysis:

- **Argument construction**: As discussed before, the two basic aspects to be considered at this level are the propagation of certainty factors (cf) and handling consistency.
- **Counterargument / Defeat**: The counterargument relationship is defined in terms of *contradiction*. Therefore certainty factors should play no role in this case. However, defeat can be stated in terms of certainty factors as follows: an argument $\mathcal{A}{:}h$ is a proper defeater $\mathcal{B}{:}q$ if $cf(\mathcal{A}{:}h) > (\geq) cf(\mathcal{B}{:}q)$. Similarly, a blocking defeat situation would arise if $cf(\mathcal{A}{:}h) = cf(\mathcal{B}{:}q)$, or alternatively $\mid cf(\mathcal{A}{:}h) - cf(\mathcal{B}{:}q) \mid \quad \epsilon$, for ϵ arbitrarily small.
- **Dialectical analysis**: Note that the whole process of determining whether a given argument is warranted or not only relies on binary relationships between arguments (blocking defeat / proper defeat). Therefore the introduction of certainty factors does not affect the construction of the dialectical tree. However, the *labeling* of the tree T might incorporate the cf's in a natural way as follows:
  - Given an argument $\mathcal{A}{:}h$ which is a leaf node L in T, then $cf(L){=}cf(\mathcal{A})$.
  - Given an argument $\mathcal{B}{:}q$ which is an inner node in T, then

    $$cf(\mathcal{B}{:}q){=}f_{tree}(cf(\mathcal{B}), cf(T_1), ...cf(T_k))$$

    where $T_1 ... T_k$ are immediate subtrees of $\mathcal{B}{:}q$. In other words, certainty factors are propagated bottom-up according to some function f_{tree} (*e.g.*, arguments with many defeaters could be deemed weaker as those which have only one defeater).

5 Conclusions and future work

Probabilistic reasoning has been mostly neglected in the defeasible argumentation community. This is maybe due to the historical origins of argumentative reasoning, which were more related to legal (qualitative) reasoning rather than to number-based attributes as those used in rule-based production systems.

In this paper we have suggested some basic ideas on how to extend the existing LDS_{AR} framework to incorporate probabilistic reasoning. As we have shown, labels provide a flexible tool for including numeric information which can be propagated using deduction rules.

The growing success of argumentation-based approaches has caused a rich cross-breeding with other disciplines, providing interesting results in different areas such as legal reasoning,

1. $\dfrac{}{[\emptyset, \{\mathsf{n_i}\}]{:}\alpha}$ for any $[\emptyset, \{\mathsf{n_i}\}]{:}\alpha \ \in \mathsf{Strict}(\Gamma)$.

2. $\dfrac{\mathbf{\Pi}(\Gamma) \cup \Phi \not\vdash_{\mathrm{SLD}} \bot}{\Gamma,\ [\Phi, \{\mathsf{d_i}\}]{:}\alpha}$ for any $[\Phi, \{\mathsf{d_i}\}]{:}\alpha \ \in \mathsf{Defeasible}(\Gamma)$.

3. $\dfrac{\Gamma, \quad [\Phi_1, \mathsf{L_1}]{:}\alpha_1 \quad [\Phi_2, \mathsf{L_2}]{:}\alpha_2 \quad \ldots [\Phi_k, \mathsf{L_k}]{:}\alpha_k \quad \mathbf{\Pi}(\Gamma) \cup \bigcup_{i=1\ldots k} \Phi_i \not\vdash_{\mathrm{SLD}} \bot}{\Gamma, \quad [\bigcup_{i=1\ldots k} \Phi_i, \bigcup_{\mathsf{i=1\ldots k}} \mathsf{L_i}]{:}\alpha_1, \alpha_2, \ldots, \alpha_k}$

4. $\dfrac{\Gamma, [\Phi_1, \mathsf{L_1}]{:}\beta \leftarrow \alpha_1, \ldots, \alpha_k \quad [\Phi_2, \mathsf{L_2}]{:}\alpha_1, \ldots, \alpha_k \quad \mathbf{\Pi}(\Gamma) \cup \Phi_1 \cup \ \Phi_2 \not\vdash_{\mathrm{SLD}} \bot}{\Gamma, [\Phi_1 \cup \Phi_2, \mathsf{L_1} \cup \mathsf{L_2}]{:}\beta}$

Figure 1: Rules for deriving generalized arguments in LDS_{AR}

medical diagnosis and decision support systems. In this context, we contend that existing frameworks for defeasible argumentation (such as LDS_{AR}) can be enriched by integrating numeric attributes (such as probabilities or certainty values), making them more attractive and suitable for other research and application areas. Part of our current research work is focused on these aspects.

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