ABEL: an Interactive Tool for Probabilistic Argumentative Reasoning

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Abstract. Most formal approaches to argumentative reasoning under uncertainty focus on the analysis of qualitative aspects. An exception is the framework of probabilistic argumentation systems. Its philosophy is to include both qualitative and quantitative aspects through a simple way of combining logic and probability theory. Probabilities are used to weigh arguments for and against particular hypotheses. ABEL is a language that allows to describe probabilistic argumentation systems and corresponding queries about hypotheses. It then returns arguments and counter-arguments with corresponding numerical weights.

1 Introduction

In the last couple of years, *argumentation* has gained growing recognition as a new and promising research direction in artificial intelligence. As a consequence of this increasing interest, different authors have investigated argumentation and its applications in various domains. By looking at today's literature on this subject, one realizes that argumentation is understood in fairly different ways. The common feature of most approaches is their restriction to particular types of logic. As a consequence, they are all limited in the way they combine arguments for and against a particular hypothesis.

The approach we present in this paper is known as *probabilistic argumentation systems* (PAS) [9]. The idea of the PAS framework goes back to the concept of *assumption-based truth maintenance systems* (ATMS) [6]. It is also closely related to *abduction* [4, 11]. The idea is to understand argumentation as a deductive tool that helps to judge *hypotheses*, that is open questions about the unknown or future world, in the light of the given uncertain and partial background knowledge.

The principal PAS problem is to derive *arguments* in favor and *counter-arguments* against the hypothesis of interest. There are efficient anytime algorithms in which the search is focussed on the most relevant arguments [7, 8]. The strength of the arguments is then measured by underlying probabilities. This leads to *degree of support* and *degree of possibility*, which corresponds to *belief* and *plausibility*, respectively, in the Dempster-Shafer theory of evidence [10, 13, 14]. Such a quantitative judgement is often required to decide whether a hypothesis can be accepted, rejected, or whether the available knowledge does not permit to decide.

A system called ABEL [2, 3] is an implementation of probabilistic argumentation systems (check out `http://www2-iiuf.unifr.ch/tcs/ABEL`). It includes an appropriate modeling and query language, as well as corresponding inference mechanisms. ABEL is an interactive system in which queries are answered immediately. Problems from a broad spectrum of application domains show that the ABEL system is very general and powerful [1]. It has an open architecture that permits the later inclusion of further or more advanced deduction techniques.

The aim of this paper is to provide a short introduction to probabilistic argumentation and ABEL. Our hope is to increase the recognition of PAS as a legitimate formal model and ABEL as powerful tool for reasoning under uncertainty.

2 Probabilistic Argumentation Systems

The basic ingredients for probabilistic argumentation systems (PAS) are *propositional logic* and *probability theory*. More formally, we require two disjoint sets $P = \{p_1, \ldots, p_n\}$ and $A = \{a_1, \ldots, a_m\}$ of propositional symbols. The elements of P are called *propositions* and the elements of A *assumptions*. With $\mathcal{L}_{A \cup P}$ we denote the corresponding propositional language that consist of elements of $A \cup P$ only. Furthermore, we require a propositional sentence $\xi \in \mathcal{L}_{A \cup P}$ that expresses the qualitative part of the given knowledge. The formula ξ is called *knowledge base*. Finally, a set $\mathit{\Pi} = \{p(a_i) : a_i \in A\}$ of independent probabilities is required to express the quantitative knowledge. Note how the connection between propositional logic and probability theory is established through the assumptions. A quadruple $(P, A, \xi, \mathit{\Pi})$ is called *probabilistic argumentation system* (PAS).

Example 1. Let $P = \{X, Y, Z\}$ and $A = \{a_1, a_2, a_3, a_4, a_5\}$ be the sets of propositions and assumptions, respectively. Furthermore, suppose that

$$\mathit{\Pi} = \{p(a_1) = 0.2,\ p(a_2) = 0.4,\ p(a_3) = 0.8,\ p(a_4) = 0.3,\ p(a_5) = 0.3\}$$

are the probabilities of the assumptions and

$$\begin{aligned} \xi = {} & (a_1 \rightarrow X) \wedge ((a_2 \vee \neg a_3) \rightarrow Y) \wedge ((X \wedge Y) \rightarrow Z) \wedge (\neg a_4 \rightarrow Z) \\ & \wedge ((a_5 \wedge Y) \rightarrow \neg Z) \end{aligned}$$

the given knowledge base. This forms a probabilistic argumentation system $(P, A, \xi, \mathit{\Pi})$. Note that the knowledge base ξ is a conjunction that can be represented more easily as a conjunctive set

$$\mathit{\Sigma} = \{a_1 \rightarrow X,\ (a_2 \vee \neg a_3) \rightarrow Y,\ (X \wedge Y) \rightarrow Z,\ \neg a_4 \rightarrow Z,\ (a_5 \wedge Y) \rightarrow \neg Z\}$$

of five individual formulas.

The question now is how to use a PAS for the purpose of analyzing and answering queries about *hypotheses*. A hypothesis h is usually expressed by a simple expression that includes symbols of $A \cup P$. To be most general, we consider arbitrary propositional formulas $h \in \mathcal{L}_{A \cup P}$.

The approach we promote is to construct *arguments* and *counter-arguments* based on the set of assumptions A and to weigh them with the aid of the given probabilities Π. An argument can be regarded as a defeasible proof. In other words, arguments are combinations of true or false assumptions that permit to infer the truth of the hypothesis h from the given knowledge base. Every argument provides thus a sufficient reason that proves the hypothesis in the light of the available knowledge. And it finally contributes to the possibility of believing or accepting the hypothesis. In other words, arguments *support* and counter-arguments *defeat* the hypothesis h. Note that counter-arguments can be regarded as arguments in favor of the negated hypothesis $\neg h$ and vice versa. The sets of all arguments and counter-arguments are denoted by $sp(h, \xi)$ and $sp(\neg h, \xi)$, respectively. For corresponding formal definitions and descriptions of appropriate inference techniques we refer to the literature [8, 7, 9].

Example 2. Consider the same PAS as in Example 1 and let $h = Z$ be the hypothesis of interest. There are four (minimal) arguments, namely:

$a_1 \wedge a_2 \wedge \neg a_5$	because a_1 implies X, a_2 implies Y, X and Y imply Z, and $\neg a_5$ disallows the conflict $Z \wedge \neg Z$
$a_1 \wedge \neg a_3 \wedge \neg a_5$	because a_1 implies X, $\neg a_3$ implies Y, X and Y imply Z, and $\neg a_5$ disallows the conflict $Z \wedge \neg Z$
$\neg a_4 \wedge \neg a_5$	because $\neg a_4$ implies Z and $\neg a_5$ disallows the conflict $Z \wedge \neg Z$
$\neg a_2 \wedge a_3 \wedge \neg a_4$	because $\neg a_4$ implies Z and $\neg a_2 \wedge a_3$ disallows the conflict $Z \wedge \neg Z$

Similarly, there are two counter-arguments, namely:

$\neg a_1 \wedge a_2 \wedge a_4 \wedge a_5$	because a_2 implies Y, $a_5 \wedge Y$ implies $\neg Z$, and $\neg a_1 \wedge a_4$ disallows the conflict $Z \wedge \neg Z$
$\neg a_1 \wedge \neg a_3 \wedge a_4 \wedge a_5$	because $\neg a_3$ implies Y, $a_5 \wedge Y$ implies $\neg Z$, and $\neg a_1 \wedge a_4$ disallows the conflict $Z \wedge \neg Z$

Note that $a_1 \wedge a_2 \wedge a_5$, $a_1 \wedge \neg a_3 \wedge a_5$, and $\neg a_4 \wedge a_5$ are not compatible with the knowledge base ξ. Such incompatible terms are called *conflicts.*

A quantitative judgement of the situation is obtained by considering the probabilities that the arguments and counter-arguments are valid. The *credibility* of a hypothesis is measured by the probabilities that it is supported or defeated by at least one argument or one counter-argument, respectively. Conflicts are handled through conditioning. The resulting *degree of support* $dsp(h, \xi)$ and *degree of possibility* $dps(h, \xi) = 1 - dsp(h, \xi)$ correspond to *belief* and *plausibility*, respectively, in the Dempster-Shafer theory of evidence [13, 14].

Example 3. Consider the arguments, counter-arguments, and conflicts shown in the previous example. The probabilities that at least one argument, counter-argument, or conflict holds correspond to the probabilities of the disjunctive normal forms (DNF)

$$\begin{aligned}\Phi_Z &= (a_1{\wedge}a_2{\wedge}\neg a_5) \vee (a_1{\wedge}\neg a_3{\wedge}\neg a_5) \vee (\neg a_4{\wedge}\neg a_5) \vee (\neg a_2{\wedge}a_3{\wedge}\neg a_4),\\ \Phi_{\neg Z} &= (\neg a_1{\wedge}a_2{\wedge}a_4{\wedge}a_5) \vee (\neg a_1{\wedge}\neg a_3{\wedge}a_4{\wedge}a_5),\\ \Phi_{\perp} &= (a_1{\wedge}a_2{\wedge}a_5) \vee (a_1{\wedge}\neg a_3{\wedge}a_5) \vee (\neg a_4{\wedge}a_5),\end{aligned}$$

respectively. Using the probabilities $p(a_i)$ as specified in Example 1, we get $p(\Phi_Z) = 0.612$, $p(\Phi_{\neg Z}) = 0.037$, and $p(\Phi_{\perp}) = 0.119$. For information about how to compute probabilities of DNF's we refer to the corresponding literature, in particular to Darwiche's d-DNNF compiler [5]. Finally, we get the following degree of support and degree of possibility, respectively:

$$dsp(Z,\xi) = \frac{p(\Phi_Z)}{1 - p(\Phi_{\perp})} = 0.695, \qquad dps(Z,\xi) = 1 - \frac{p(\Phi_{\neg Z})}{1 - p(\Phi_{\perp})} = 0.958.$$

These results tell us that the hypothesis Z is supported by a relatively high degree. At the same time, there are only few reasons against Z which leads to a degree of possibility close to 1.

3 ABEL

ABEL stands for "*Assumption-Based Evidential Language*". Working with ABEL typically involves two sequential steps. First, the given information is *modeled* using the command `tell`. This command is used to define the two sets A and P, the probabilities Π, and the knowledge base ξ. Second, queries about the knowledge base are expressed using the command `ask`.

The ABEL language is based on three other computer languages: (1) from *Common Lisp* [16] it adopts *prefix notation*; (2) from *Pulcinella* [12] it takes the idea of the commands `tell`, `ask`, and `empty`; and (3) from a former ABEL prototype it inherits the concept of *modules* and the syntax of the queries. Consider former publications on ABEL for a detailed language specification [3, 1]. The ABEL interface is interactive and behaves like a Common Lisp environment. The current version is based on the platform independent XEmacs environment [15].

An ABEL model usually starts with the declaration of the sets P, A, and Π. The distinction between the elements of P and A is made by using two distinct commands `var` and `ass`. Look below how it's done for the example introduced in the previous section. Assumptions with different probabilities must be defined on different lines. The keyword `binary` means that only two values are allowed (*true* and *false*). Note that ABEL also supports discrete variables with more than two values [1–3] as well as integers and reals (with some restrictions) [3].

```
(tell
  (var X Y Z binary)
```

```
  (ass a1 binary 0.2)
  (ass a2 binary 0.4)
  (ass a3 binary 0.8)
  (ass a4 a5 binary 0.3))
```

The knowledge base ξ is then described using a LISP-like prefixed language. If ξ is given as a set Σ of statements ξ_i, then every individual statement is written on a separate line. Again, consider the example of the previous section and look how it's done.

```
(tell
  (-> a1 X)
  (-> (or a2 (not a3)) Y)
  (-> (and X Y) Z)
  (-> (not a4) Z)
  (-> (and a5 Y) (not Z)))
```

Statements can also be distributed among different `tell`-commands. Furthermore, it is also possible to mix variable declarations and statements about the knowledge base. The only rule is that every variable must be declared before it is first used.

ABEL supports different types of queries. In the context of argumentative reasoning, the most important commands are `sp` (support), `dsp` (degree of support), and `dps` (degree of possibility). Let Z be the hypothesis of interest as in Example 2. Observe how `sp` can be used to compute arguments and counter-arguments for Z (the percentages indicated left to the arguments show the relative weights of their probabilities).

```
? (ask (sp Z))
  53.3% : (NOT A4) (NOT A5)
  24.0% : A1 A2 (NOT A5)
  18.7% : A1 (NOT A3) (NOT A5)
   4.0% : A3 (NOT A2) (NOT A4)

? (ask (sp (not Z)))
  56.3% : A2 A4 A5 (NOT A1)
  43.7% : A4 A5 (NOT A1) (NOT A3)
```

This corresponds to the results shown in Example 2. Note that $\neg a_4$ alone is not an argument for Z, because $\neg a_4$ together with a_5 produces a conflict. To get a quantitative evaluation of the hypothesis, we can compute corresponding degrees of support and possibility.

```
? (ask (dsp Z))
  0.695

? (ask (dps Z))
  0.958
```

These results correspond to the ones shown in Example 3.

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