

Resolving Incompatibilities among Procedural Goals under Uncertainty

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Abstract. By considering rational agents, we focus on the problem of selecting goals out of a set of incompatible ones. We consider two forms of incompatibility introduced by Castelfranchi and Paglieri, namely the terminal and the superfluity. We represent the agent’s plans by means of structured arguments whose premises are pervaded with uncertainty. We measure the strength of such arguments in order to determine the set of compatible goals. In this settings, we represent a novel strength value defined by a three-dimensional vector determined from a probabilistic interval associated with each argument. The vector represents the precision of the interval, the location of it, and the combination of precision and location. This type of representation and treatment of the strength of a structured argument has not been defined before by the state of the art. Considering our novel approach for measuring the strength of structured arguments, we propose a semantics for the selection of plans and goals that is based on Dung’s abstract argumentation theory.

Keywords: argumentation · goals selection · uncertainty.

1 Introduction

An intelligent agent may in general pursue multiple procedural goals at the same time³. In this situation, some conflicts between goals could arise, in the sense that it is not possible to pursue them simultaneously. Reasons for not pursuing some goals simultaneously are generally related to the fact that plans for reaching such goals may block each other. Consider the well-known “cleaner world” scenario, where a set of robots have the task of cleaning the dirt of an environment. Although the main goal of the robots is to clean the environment, during the execution of this task they may pursue some other goals. Furthermore, consider that there exist uncertainties in both actions and sensing.

According to [6], at least two forms of incompatibility could emerge:

³ A goal is procedural when there is a set of plans for achieving it. These goals are also known as achievement goals [4].

- *Terminal incompatibility*: Suppose that one of the robots – let us call him *BOB* – has a technical defect and he begins to pursue the goal “*being fixed*”. *BOB* is already pursuing the goal “*cleaning the environment*”. However, for being fixed he has to stop cleaning. Hence, *BOB* cannot pursue both goals at the same time because he needs to be operative to continue cleaning and non-operative to be fixed.

- *Superfluity*: Suppose that *BOB* is in slot (2,2) and he detects dirt in slot (4,5), due to the distance, he has no certainty about the kind of dirt and he begins to pursue the goal “*cleaning slot (4,5)*”. Another cleaner robot – *TOM* – also detects the same dirty slot and he has the certainty that it is liquid dirt and sends a message to *BOB* to mop slot (4,5). Thus, *BOB* begins to pursue the goal “*mopping slot (4,5)*”. It is easy to notice that both goals have the same end, which is that slot (4,5) to be cleaned.

Argumentation is an appropriate approach for reasoning with inconsistent information [7]. The process of argumentation is based on the construction and the comparison of arguments (considering the so-called attacks among them). Argumentation has been applied for practical reasoning for the generation of desires and plans (e.g., [1][2][8][13]). In [2] and [13], the authors represent the agent’s plans by means of arguments (these arguments are called instrumental arguments) and the conflicts between plans are expressed in form of attacks.

In our example, we can have an argument *A* representing plan *p*, an argument *B* representing plan *p'*, and both attack each other. The question is: what argument will be selected? According to [3], one can measure the strength of the arguments to refine the notion of acceptability (selection) of arguments. Thus, each argument is measured and a strength value is assigned to it. Then, the arguments’ strengths determines the preference of one of them.

In [2], [8], and [13], the authors use instrumental arguments to represent plans and define possible attacks; however, the agent’s beliefs are not pervaded with uncertainty and the actions are not taken into account in the structure of the arguments. The strength of an instrumental argument is measured in [2] based on the worth of the goals that make it up and the cost of the plan with respect to the resources it needs to be achieved.

Against this background, the aim of this article is to study and propose a way of measuring the strength of instrumental arguments whose premises are pervaded of uncertainty. This will lead us to determine the set of non-conflicting plans and non-conflicting goals the agent can continue pursuing. Thus, the research questions that are addressed in this article are:

1. How to measure the strength of an instrumental argument considering that its premises have uncertain elements?, and
2. Given that we use instrumental arguments to determine the incompatibilities between goals, how the uncertainty of the elements of instrumental arguments impact on determining the set of compatible goals?

In addressing the first question, we use a coherence-based probability logic approach [12]. We assign and/or calculate a probabilistic interval for each element of the argument and the interval of the argument is calculated based on

the uncertainty of its premises. Lastly, the argument's strength is calculated from this interval. Regarding the second question, we use Dung's argumentation semantics in order to obtain the set of compatible goals. Thus, the main contributions of this article are:

- A way of measuring the strength of structured arguments whose premises are pervaded with uncertainty,
- A three-dimensional strength representation that allows the agent to compare the argument in more than one way.
- The way of goal selection based on abstract argumentation semantics.

The rest of the paper is organized as follows. Next section presents some necessary technical background related to probabilistic logic. In Section 3, the main building blocks on which this approach is based are defined. In Section 4, we study and present the strength calculation proposal. Section 5 is devoted to the kinds of attacks that may occur between arguments. Section 6 is focused on the definition of the argumentation framework and on studying how to determine the set of compatible goals by means of argumentation semantics. Finally, the conclusions and future work are presented in Section 7.

2 Probabilistic background

In this section some necessary technical background is presented. It is based on probabilistic logic inference in the settings of [9] and [11].

Let \mathcal{L} be a propositional vocabulary that contains a finite set of propositional symbols. \wedge and \neg denote the logical connectives conjunction and negation. An *event* is defined as follows. The propositional constants *false* and *true*, denoted by \perp and \top , respectively, are events. An atomic formula or *atom* is an event. If ϕ and ψ are events, then also $\neg\phi$ and $(\phi\wedge\psi)$. A *conditional event* is an expression of the form $\psi|\phi$ and a *conditional constraint* is an expression of the form $(\psi|\phi)[l, u]$ where $l, u \in [0, 1]$ are real numbers. The event ψ is called the consequent (or head) and the event ϕ its antecedent (or body). *Purely probabilistic conditional constraints* are of the form $(\psi|\phi)[l, u]$ with $l < 1$ and $u > 0$.

An event ϕ is *conjunctive* iff ϕ is either \top or a conjunction of atoms. A *conditional event* $\psi|\phi$ is conjunctive (respectively, *1-conjunctive*) iff ψ is a conjunction of atoms (respectively, an atom) and ϕ is conjunctive. A conditional constraint $(\psi|\phi)[l, u]$ is conjunctive (respectively, *1-conjunctive*) iff $\psi|\phi$ is conjunctive (respectively, *1-conjunctive*).

Conjunctive conditional constraints $(\psi|\phi)[l, u]$ with $l \leq u$ are also called *probabilistic Horn clauses*, from which can be defined *probabilistic facts* and *probabilistic rules*, which are of the form $(\psi|\top)[l, u]$ and $(\psi|\phi)[l, u]$, respectively, where $\phi \neq \top$.

We use the coherence-based probability logic to propagate the uncertainty of the premises to the conclusion, more specifically, we use probabilistic *MODUS PONENS (MP)*. We denote the probabilistic closure *MP* inference by \vdash_P . Finally, the calculation of the conclusion interval is given by $\{(\psi|\phi)[l, u], (\phi|\top)[l', u']\} \vdash_P (\psi|\top)[l * l', 1 - l' + u * l']$ [11].

3 Basics of the proposal

In this section, we present the main mental states of the agent; and define the arguments that represent plans.

In this work, the main mental states of an agent are the following finite bases: \mathcal{B} is a finite base of the beliefs, \mathcal{A} is a finite base of the actions, and \mathcal{G} is a finite base of the goals. Elements of \mathcal{B} and \mathcal{A} are probabilistic facts and elements of \mathcal{G} are atomic formulas. It holds that \mathcal{B} , \mathcal{A} , and \mathcal{G} are pairwise disjoint. Let $\mathcal{B}^* = \{b|(b|\top)[l, u] \in \mathcal{B}\}$ and $\mathcal{A}^* = \{a|(a|\top)[l, u] \in \mathcal{A}\}$ be the projections sets of \mathcal{B} and \mathcal{A} , respectively. That is, the elements of \mathcal{B}^* and \mathcal{A}^* are atomic formulas, which have their correspondent probabilistic conditional constraints in \mathcal{B} and \mathcal{A} , respectively. Furthermore, the agent is also equipped with a function $\text{PREF} : \mathcal{G} \rightarrow [0, 1]$, which returns a real value that denotes the preference value of a given goal (0 stands for the null preference value and 1 for the maximum one).

The agent has also a set of probabilistic plans, which are represented by instrumental arguments. The basic building block of an instrumental argument is a probabilistic plan rule.

Definition 1. A *probabilistic plan rule* is denoted by a probabilistic rule $(\psi|\phi)[l, u]$ such that $\phi = b_1 \wedge \dots \wedge b_n \wedge g_1 \wedge \dots \wedge g_m \wedge a_1 \wedge \dots \wedge a_l$ and $\psi = g$ where $b_i \in \mathcal{B}^*$ (for all $1 \leq i \leq n$), $g_j \in \mathcal{G}$ (for all $1 \leq j \leq m$), $a_k \in \mathcal{A}^*$ (for all $1 \leq k \leq l$), and $g \in \mathcal{G}$. In order to avoid cycles, we require that $\psi \neq g_1 \dots \psi \neq g_m$. Besides, the number of elements of ϕ is finite.

- (clean | be_oper \wedge clean_1_1 \wedge ... \wedge clean_4_4)[u, 1]

Like in [13], we represent instrumental arguments by using a tree structure; however, in our definition the root is made up of a probabilistic plan rule and the leaves are either beliefs or actions. We can consider these last elements as elementary arguments, since they do not generate sub-trees.

Definition 2. An *elementary probabilistic argument* is a tuple $\langle H, (\psi|\top)[l, u] \rangle$ where: $(\psi|\top)[l, u] \in \mathcal{A}$ and $H = \emptyset$, or $(\psi|\top)[l, u] \in \mathcal{B}$ and $H = \emptyset$.

Function CLAIM returns the claim ψ of a given elementary probabilistic argument. Unlike beliefs and actions, the goals that make up the premise of a probabilistic plan rule generate a tree-structure.

Definition 3. A *probabilistic instrumental argument* is a tuple $\langle \mathcal{T}, g \rangle$, where \mathcal{T} is a finite tree such that:

- The root of the tree is a structure of the form $\langle H, g[l_g, u_g] \rangle$ where:
 - $H = (g|b_1 \wedge \dots \wedge b_n \wedge g_1 \wedge \dots \wedge g_m \wedge a_1 \wedge \dots \wedge a_l)[l, u]$,
 - $l_g, u_g \in [0, 1]$ are real numbers that represent the upper and lower probabilities of g .

- Since $H = (g|b_1 \wedge \dots \wedge b_n \wedge g_1 \wedge \dots \wedge g_m \wedge a_1 \wedge \dots \wedge a_l)[l, u]$, it has exactly $(n+m+l)$ children, such that $\forall b_i$ ($1 \leq i \leq n$) and $\forall a_k$ ($1 \leq k \leq l$) there exists an elementary probabilistic argument, and $\forall g_j$ ($1 \leq j \leq m$) there exists a probabilistic instrumental argument, we can call these last arguments of sub-arguments.
- $H, (b_1|\top[l_{b_1}, u_{b_1}]), \dots, (b_n|\top[l_{b_n}, u_{b_n}]), H_{g_1}, \dots, H_{g_m}, (a_1|\top[l_{a_1}, u_{a_1}]), \dots, (a_l|\top[l_{a_l}, u_{a_l}]) \vdash_P g[l_g, u_g]$.

Let Arg be the set of all arguments⁴ that are associated to the goals in \mathcal{G} . We assume that each goal has at least one argument and there could be more than one argument for each goal. Function $SUPPORT(A)$ returns the set of elementary probabilistic arguments, the main root of the argument, and the roots of the sub-arguments of A , $CLAIM(A)$ returns the claim g of A , and $SUB(A)$ returns the set of sub-arguments of A .

In order to obtain the probabilistic interval of the claim of an argument, the probabilistic MP from the leaves to the root has to be applied.

4 Strength calculation

We base on the approach of Pfeifer [10] to calculate the strength of the arguments. This approach uses the values of the probabilistic interval of the claim of the arguments to make the calculation and is based on two criteria: the *precision* and the *location* of the interval. Thus, the higher the precision of the interval is and the closer to 1 the location of the interval is, the stronger the argument is. We use the notions of precision, location and the combination of both to measure the arguments from different point of views.

Definition 4. Let $A = \langle \mathcal{T}, g \rangle$ be an argument and $\langle H, g[l_g, u_g] \rangle$ be the root of \mathcal{T} . The **strength** of A is a three-dimensional vector $STRENGTH(A) = \langle CO(A), PR(A), LO(A) \rangle$ where: $PR(A) = 1 - (u_g - l_g)$, $LO(A) = \frac{l_g + u_g}{2}$, and $CO(A) = PR(A) \times LO(A)$.

We can compare two arguments based on these values. This comparison determines the preference between arguments. Taking into account these three dimensions is specially useful when there is a tie in the value of $CO(A)$.

Definition 5. (Preferred argument) Given two arguments A and B . We say that argument A is more preferred than argument B (denoted by $A \succeq B$) iff:

- $CO(A) > CO(B)$, or
- $CO(A) = CO(B)$ and $LO(A) = LO(B)$ and $PR(A) > PR(B)$, or
- $CO(A) = CO(B)$ and $PR(A) = PR(B)$ and $LO(A) > LO(B)$.

The election of which value the agent has to compare first (either the precision value or the location one) depends on his interests.

⁴ Hereafter, we use only argument to refer to a probabilistic instrumental argument.

5 Attacks between arguments

In this section, we focus on the identification of attacks between arguments, which will lead to the identification of incompatibility among goals. The kind of attack depends on the form of incompatibility. The conflicts between arguments are defined over $\mathcal{A}rg$ and are captured by the binary relation $\mathcal{R}_x \subseteq \mathcal{A}rg \times \mathcal{A}rg$ (for $x \in \{t, s\}$) where each sub-index denotes the form of incompatibility. Thus, t denotes the attack for terminal incompatibility and s the attack for superfluity. We denote with (A, B) the attack relation between arguments A and B . In other words, if $(A, B) \in \mathcal{R}_x$, it means that argument A attacks argument B .

Definition 6. (*Support rebuttal* - \mathcal{R}_t) Let $A, B \in \mathcal{A}rg$, $[H, \psi] \in \text{SUPPORT}(A)$ and $[H', \psi'] \in \text{SUPPORT}(B)$. We say that $(A, B) \in \mathcal{R}_t$ occurs when: (i) $\text{CLAIM}(A) \neq \text{CLAIM}(B)$, and (ii) $\psi = \neg\psi'$ such that $\psi, \psi' \in \mathcal{B}$ or $\psi, \psi' \in \mathcal{A}$, or $\psi, \psi' \in \mathcal{G}$. Sub-arguments of arguments that are involved in a support rebuttal are also involved in a support rebuttal. Formally: if $(A, B) \in \mathcal{R}_t$ and $\exists C \in \text{SUB}(B)$, then $(A, C) \in \mathcal{R}_t$ and $(C, A) \in \mathcal{R}_t$. Finally, it holds that \mathcal{R}_t is symmetric.

Definition 7. (*Superfluous attack* - \mathcal{R}_s) Let $A, B \in \mathcal{A}rg$. We say that $(A, B) \in \mathcal{R}_s$ occurs when: (i) $\text{CLAIM}(A) = \text{CLAIM}(B)$, and (ii) $\text{SUPPORT}(A) \neq \text{SUPPORT}(B)$.

Sub-arguments of arguments that are involved in a support rebuttal are also involved in a support rebuttal. Formally: if $(A, B) \in \mathcal{R}_s$ and $\exists C \in \text{SUB}(B)$, then $(A, C) \in \mathcal{R}_t$ and $(C, A) \in \mathcal{R}_s$. Finally, it holds that \mathcal{R}_s is symmetric.

6 Goals selection

In this section, we present an argumentation framework that will be used to determine the set of compatible goals.

Definition 8. An *argumentation framework* is a tuple $\mathcal{AF} = \langle \mathcal{A}rg, \mathcal{R} \rangle$, where $\mathcal{A}rg = \mathcal{A}rg_t \cup \mathcal{A}rg_s$ and $\mathcal{R} = \mathcal{R}_t \cup \mathcal{R}_s$ such that

Regarding \mathcal{R} , it could happen that two arguments attack each other in more than one way. In these cases, we consider multiple attacks between two arguments as a unique attack in \mathcal{AF} .

Hitherto, we have considered that all attacks are symmetrical. However, the strength values of the arguments allow the agent to break such symmetry. Therefore, depending on these values some attacks may be considered successful. Thus, the process of goals selection starts by modifying the attack relation \mathcal{R} taking into account the successful attacks.

Definition 9. Let $A, B \in \mathcal{A}rg$ be two arguments, we say that A *successfully attacks* B when $A \succ B$.

The next step of the selection process is applying an argumentation semantics on the resultant AF. In argumentation theory, acceptability semantics are in charge of returning sets of arguments called extensions which are internally consistent. In order to obtain the set of goals that have no conflicts among them, we will apply the notion of conflict-freeness over the set of arguments to guarantee that no incompatible argument (i.e., plan) is returned by the semantics, and consequently no incompatible goal. Another notion, that we believe is important, is related to the number of compatible goals the agent can continue pursuing; in this way, the idea is to maximize this number. Thus, we propose to apply a semantics based on the notion of conflict-freeness and that also returns those extensions that maximize the number of goals to be pursued.

Definition 10. Given $\mathcal{AF} = \langle \text{Arg}, \mathcal{R}' \rangle$ where $\mathcal{R}' \subseteq \mathcal{R}$ is the modified attack relation after considering the successful attack. Let $\mathcal{E} \subseteq \text{Arg}$:

- \mathcal{E} is conflict-free if $\forall A, B \in \mathcal{E}, (A, B) \notin \mathcal{R}'$. Let \mathcal{CF} be the set of all the conflict-free extensions,
- $\text{MAX_GOAL} : \mathcal{CF} \rightarrow \mathcal{CF}'$, where $\mathcal{CF}' = 2^{\mathcal{CF}}$. This function returns those maximal (w.r.t set inclusion) sets that allow the agent to achieve the greatest number of pursuable goals. Sub-goals are not taken in to account in this function.
- $\text{MAX_UTIL} : \mathcal{CF}' \rightarrow 2^{\mathcal{CF}'}$. This function returns those with the maximum utility for the agent in terms of preference value. The utility of each extension is calculated by summing up the preference value of the main goals of the extension. In this function, sub-goals are not taken in to account either.

The final step of the selection process is to obtain the set of compatible goals from the set of compatible plans.

Definition 11. Let \mathcal{CF}'' be a set of extensions returned by MAX_UTIL . The **projection function** $\text{COMP_GOALS} : \mathcal{CF}'' \rightarrow 2^{\mathcal{G}}$ takes as input an extension of \mathcal{CF}' and returns the set of compatible goals that are associated to the arguments in the extension.

Notice that function COMP_GOALS is applied to each extension of \mathcal{CF}' ; hence, there could be more than one different set of compatible goals. In such case, the agent has to choose the set of compatible goals he will continue to pursue according to his interests.

7 Conclusions and future work

This work presents a way for measuring instrumental arguments whose components are pervaded of uncertainty and an argumentation-based approach for selecting compatible goals from a set of incompatible ones.

In order to represent the uncertainty of the elements of an argument, we use probabilistic intervals, which express the certainty degree of the beliefs, actions, and goals that made up the argument. We apply probabilistic *MODUS*

PONENS to obtain the probabilistic interval of the goal that is the claim of the argument. At last, we represent the strength of an argument by means of a three-dimensional vector.

The uncertainty of the elements that made up an argument impacts on the attacks definition. We consider that an attack occurs under some conditions and when an argument is more (or equal) preferred than other. This means that the certainty degree determines if an attack exists or not.

As future work, we want to study other approaches of probabilistic logic in order to obtain tighter intervals, if possible. Another form of incompatibility takes into account the resources necessary for performing a plan. We are working on it, specially on how it impacts on the strength calculation. Finally, we also want to study the rationality postulates proposed in [5] considering that arguments are pervaded of uncertainty.

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