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Toward a More Efficient Generation of Structured Argumentation Graphs

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Abstract. To address the needs of the EU NoAW project, in this paper we solve the problem of efficiently generating the argumentation graphs from knowledge bases expressed using existential rules. For the knowledge bases without rules, we provide a methodology that allows to optimise the generation of argumentation graphs. For knowledge bases with rules, we show how to filter out a large number of arguments and reduce the number of attacks.

Keywords. Logic Based Argumentation Graphs, Existential Rules

1. Introduction

This work is motivated by the European Horizon 2020 NoAW project[2] which is aimed at turning agricultural waste into economic assets. In the framework of this project, an inconsistent knowledge base (KB) [7] expressed using existential rules [15] was constructed using the opinion of multiple stakeholders about the future uses of agricultural waste. This inconsistent KB can be used for reasoning and argumentation [18] provides one such reasoning method that has the added value of providing better explanations to users than classical methods [21]. However, one drawback of logic based argumentation frameworks (AF) [13, 2, 22] is the large number of arguments generated [27]. Indeed, the argumentative reasoning method relies on the construction of all possible derivations of facts using the rules over the KB (a derivation is called an argument). Usually the only condition one uses to filter out all possible derivations is the condition of minimality and consistency of the facts at the root of the derivation [1] (i.e. all facts are used in the reasoning and these facts will not yield contradictory results). This argument construction step can take a very long time (in the best scenario case when the KB actually allows for this step to finish [8]). The conflicts in the KB are represented using the attack relation between arguments. Once the argumentation graph is generated (in this graph the nodes represent the arguments and the attacks the binary attack relation) the reasoning step will compute the extensions using a given semantics (preferred, stable etc.). Please note that even this step is quite expensive from a computational point of view [19]. In the case of KBs expressed using existential rules and allowing for n-ary negative constraints (i.e. n-ary logical incompatibilities between the facts) the preferred, stable and semi stable argumentation semantics were proven to coincide with the repairs of the KB

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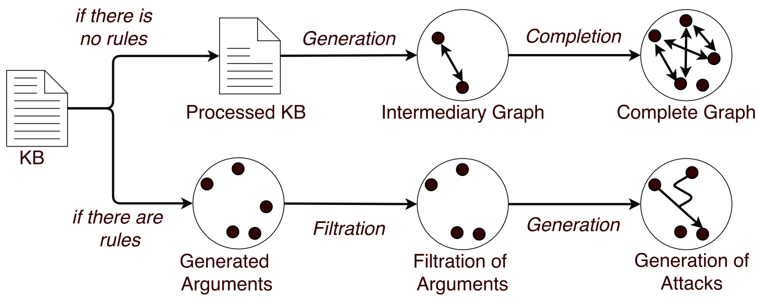

Figure 1. Approach workflow for optimising the argument generation phase.

(i.e. the maximally w.r.t. set inclusion subsets of consistent facts) [17]. This result was of practical importance as it allowed to compare the intuitiveness of logical argumentation techniques [21] and to apply them in food science applications [5, 6].

The main drawback of using argumentation as a reasoning method over inconsistent KBs relies in the large number of arguments generated. For instance, even for a modest KB composed of 7 facts, 3 rules and 1 binary negative constraint one gets an argumentation graph of 383 arguments and 32768 attacks [27]. In this paper we address this drawback and ask the following research question: "*How can one filter out the arguments generated over the KB without compromising the semantic outcome of the corresponding argumentation graph?*". We answer this question by providing a methodology adapted for KBs without rules or KBs with rules. In the first case of KBs without rules, we use the observation that free facts (i.e. facts that are not touched by any negative constraints) induce an exponential growth on the argumentation graph without any impact on its underlying structure [27]. Therefore, we will first generate the argumentation graph corresponding to the KB without the free facts and then redo the whole graph including the arguments of the free facts in an efficient manner. In the second case, of the KBs with rules, we introduce a new structure for the arguments and the attacks. In this new structure, we have less arguments (up to 73% filtered arguments in our experiments). We show that this new framework is semantically equivalent to the framework introduced in [17]. The above methodology is depicted in Figure 1.

The paper is organised as follows. After introducing the background notions needed to formally understand the paper we present the two methodologies explained above. We then provide an empirical evaluation of our work in which we benchmark our approach on the KBs introduced in [27] and show that in most cases the number of arguments and attacks of the argumentation graphs corresponding to KBs with rules is reduced (at least by 25 % for the arguments and at least 14 % for the attacks).

2. Background notions

We first introduce some notions of the existential rules language. A *fact* is a ground atom of the form $p(t_1, \ldots, t_k)$ where p is a predicate of arity k and t_i, with $i \in [1, \ldots, k]$, constants. An existential *rule* is of the form $\forall \overrightarrow{X}, \overrightarrow{Y}\ B[\overrightarrow{X}, \overrightarrow{Y}] \rightarrow \exists \overrightarrow{Z} H[\overrightarrow{Z}, \overrightarrow{X}]$ where B (called the body) and H (called the head) are existentially closed atoms or conjunctions of existentially closed atoms and $\overrightarrow{X}, \overrightarrow{Y}, \overrightarrow{Z}$ their respective vectors of variables. A *rule is applicable* on a set of facts $\mathscr{F}$ if and only if there exists a homomorphism from the body of the rule to $\mathscr{F}$. Applying a rule to a set of facts (also called *chase*) consists of adding the set of atoms of the conclusion of the rule to the facts according to the application homomorphism. The saturation $\mathscr{S}at_{\mathscr{R}}(X)$ of a set of facts X is the set of atoms obtained after successively applying the set of rules until a fixed point. Different *chase* mechanisms use different simplifications that prevent infinite redundancies [14]. We use recognisable classes of existential rules where the chase is guaranteed to stop [11]. A *negative constraint* is a rule of the form $\forall \overrightarrow{X}, \overrightarrow{Y}\ B[\overrightarrow{X}, \overrightarrow{Y}] \rightarrow \perp$ where B is an existentially closed atom or conjunctions of existentially closed atoms, $\overrightarrow{X}, \overrightarrow{Y}$, their respective vectors of variables and $\perp$ is *absurdum*. Negative constraints can be of any arity (i.e. the number of atoms in B is not bounded). A subset X of $\mathscr{F}$ is $\mathscr{R}$-inconsistent if and only if there is a negative constraint that is applicable to the saturation of X, otherwise X is $\mathscr{R}$-consistent. Thus, a KB $\mathscr{K}$ is a tuple $\mathscr{K} = (\mathscr{F}, \mathscr{R}, \mathscr{N})$ where $\mathscr{F}$ is a finite set of facts, $\mathscr{R}$ a set of existential rules and $\mathscr{N}$ a set of negative constraints. If $\mathscr{K} = (\mathscr{F}, \mathscr{R}, \mathscr{N})$ be a KB, we say that $X \subseteq \mathscr{F}$ is a *conflict* of $\mathscr{K}$ if and only if X is $\mathscr{R}$-inconsistent and for all $X' \subset X, X'$ is $\mathscr{R}$-consistent. If X is a conflict, $|X|$ is the size of the conflict. The set of all conflicts of $\mathscr{K}$ is denoted by $MI(\mathscr{K})$. The notion of conflict is the dual of the notion maximal consistent set (also called repair) since removing one element of each minimal inconsistent set restores the consistency.

We now introduce the structure of arguments and attacks defined in [17, 16, 26]. In this framework, the arguments are composed of a support and a conclusion. The attack is a particular undermining where arguments attack the support of other arguments.

Definition 1. Let $\mathscr{K}$ be a KB, the AF instantiated from $\mathscr{K}$ is the pair $\mathbb{AS}_{\mathscr{K}} = (\mathscr{A}, \mathscr{C})$ where $\mathscr{A}$ is a set of arguments and $\mathscr{C}$ a set of attacks defined as follows. An *argument* is a tuple (H, C) with H a non-empty $\mathscr{R}$-consistent subset of $\mathscr{F}$ and C a set of facts such that : $H \subseteq \mathscr{F}$ and H is $\mathscr{R}$-consistent *(consistency)*; $C \subseteq \mathscr{S}at_{\mathscr{R}}(H)$ *(entailment)*; $\nexists H' \subset H$ s.t. $C \subseteq \mathscr{S}at_{\mathscr{R}}(H')$ *(minimality)*. We say that $a = (H, C)$ attacks $b = (H', C')$ denoted by $(a, b) \in \mathscr{C}$ iff there exists $\phi \in H'$ such that $C \cup \{\phi\}$ is $\mathscr{R}$-inconsistent.

Let $a = (H, C)$ be an argument of $\mathbb{AS}_{\mathscr{K}}$, we denote by $Supp(a) = H$ the support of a and $Conc(a) = C$ its conclusion. Let E be a set of arguments, the base of E is defined as the union of the supports of the arguments in E, namely $Base(E) = \bigcup_{a \in E} Supp(a)$. Let Y be a set of facts and E be a set of arguments, the arguments of E constructed upon Y is defined as $Arg(Y, E) = \{a \in E \mid Supp(a) \subseteq Y\}$.

Once the AF is constructed, one can use some of the argumentation semantics [18, 12] to obtain sets of arguments called extensions. We quickly recall the some of the argumentation semantics defined by Dung [18]. Let $E \subseteq \mathscr{A}$ and $a \in \mathscr{A}$. We say that E is *conflict free* iff there exists no arguments $a, b \in E$ such that $(a, b) \in \mathscr{C}$. E *defends* a iff for every argument $b \in \mathscr{A}$, if we have $(b, a) \in \mathscr{C}$ then there exists $c \in E$ such that $(c, b) \in \mathscr{C}$. E is *admissible* iff it is conflict-free and defends all its arguments. E is a *preferred extension* iff it is maximal (w.r.t. set inclusion) admissible set. E is a *stable extension* iff it is conflict-free and for all $a \in \mathscr{A} \setminus E$, there exists an argument $b \in E$ such that $(b, a) \in \mathscr{C}$. For an AF $\mathbb{AS}_{\mathscr{K}} = (\mathscr{A}, \mathscr{C})$, we denote by $Ext_p(\mathbb{AS}_{\mathscr{K}})$ (resp. $Ext_s(\mathbb{AS}_{\mathscr{K}})$) the set of its preferred extensions (resp. stable extensions).

This AF possesses many desirable properties [17] such as direct/indirect consistency, closure and the one to one equivalence between preferred/stable extensions and the repairs. However, it has been shown in [27] that the number of arguments can be exponential w.r.t. the number of facts and even a KB with eight facts, six rules and two negative constraints can lead to an AF with 111775 arguments.

3. Graph Generation With No Rules

In this section, we propose an optimisation for the generation of the aforementioned AF in the case where KBs contain no rules. The idea is to process the KB before generating the argumentation graph and recreate the whole argumentation graph from this reduced graph. We first introduce the notion of free fact and dummy argument.

Definition 2. Let $\mathscr{K} = (\mathscr{F}, \mathscr{R}, \mathscr{N})$ be a KB, a fact $f \in \mathscr{F}$ is a free fact if and only if for every minimal inconsistent set $m \in MI(\mathscr{K}), f \notin m$.

We denote by $Free(\mathscr{K})$, the set of free facts of $\mathscr{K}$. An argument is called a dummy argument iff it does not attack any arguments and it is not attacked by any arguments. In the case where the KB does not contain any rules, the number of dummy arguments is exponential w.r.t. the number of free facts.

Proposition 1. Let $\mathscr{K} = (\mathscr{F}, \mathscr{R}, \mathscr{N})$ be KB such that $\mathscr{R} = \emptyset$ and $|\mathscr{F}| = n$. There are exactly $2^k - 1$ dummy arguments a in $\mathbb{AS}_{\mathscr{K}} = (\mathscr{A}, \mathscr{C})$ where $k = |Free(\mathscr{K})|$.

Please note that, as the number of free facts increases, the number of dummy arguments grows exponentially. However, a further result of [27] is that if one removes the free facts from the KB before generating the argumentation graph, this argumentation graph possesses "exponentially less arguments" than the original argumentation graph w.r.t. the number of free facts. Hence, we now propose a four step approach for generating the original argumentation graph faster and without any losses: **(1)** We identify the set $Free(\mathscr{K})$. This step can be done by finding the minimal inconsistent sets using existing algorithms [20, 24]. **(2)** We create the graph $\mathbb{AS}_{\mathscr{K}'}$ where $\mathscr{K}' = (\mathscr{F} \setminus Free(\mathscr{K}), \mathscr{R}, \mathscr{N})$ following Definition 1. Please note that this step can be achieved using the argumentation graph generator proposed by [27]. **(3)** We grow the generated graph to its original size. This can be done by copying each arguments 2^k times where $k = |Free(\mathscr{K})|$ and adding attacks following the two principles: if a attacks b then a attacks all the copies of b; if b is a copy of a then b has the same attackers and attacks the same arguments than a. **(4)** We add $2^k - 1$ dummy arguments to the generated graph.

4. Graph Generation With Rules

We now present a novel AF that is aimed at reducing the number of arguments and the number of attacks in the case where the set of rules is not empty. We show several desirable results such as the equivalence between the preferred/stable extensions of the aforementioned framework and the new one and some basic properties regarding attacks in the new framework. The idea behind this new framework is to remove, amongst the arguments with the same support, those that have conclusions that can be "decomposed".

Definition 3. Let $\mathscr{K}$ be a KB and $\mathbb{AS}_{\mathscr{K}} = (\mathscr{A}, \mathscr{C})$. Let $D(\mathbb{AS}_{\mathscr{K}}) = \{a = (H, C) \in \mathscr{A} \mid$ there exists $X \subseteq \mathscr{A} \setminus \{a\}$ such that for every $b \in X, Supp(b) = H$ and $\bigcup_{b \in X} Conc(b) = C\}$. The filtrated set of arguments is $\mathscr{A}^* = \mathscr{A} \setminus D(\mathbb{AS}_{\mathscr{K}})$.

Since we dropped some arguments, the attack relation have to be redesigned in order to keep all the conflicts. In particular, we allow for n-ary attacks where arguments with the same support can jointly attack an argument.

Definition 4. An attack is a pair (X,a) where $X \subseteq \mathscr{A}^*$ and $a \in \mathscr{A}^*$ such that X is minimal for set inclusion such that for every $x_1, x_2 \in X, Supp(x_1) = Supp(x_2)$ and there exists $\phi \in Supp(a)$ such that $(\bigcup_{x \in X} Conc(x)) \cup \{\phi\})$ is $\mathscr{R}$-inconsistent.

Definition 5. Let $\mathscr{K}$ be a KB, the corresponding filtrated AF is $\mathbb{AS}^*_{\mathscr{K}} = (\mathscr{A}^*, \mathscr{C}^*)$ where $\mathscr{A}^*$ is as defined in Definition 3 and $\mathscr{C}^*$ is the set of attacks defined in Definition 4.

$\mathbb{AS}^*_{\mathscr{K}}$ is an instantiation of the framework defined by Nielsen and Parsons [23]. For the purpose of the paper being self-contained, we recall the necessary definitions. Let $\mathbb{AS}^*_{\mathscr{K}} = (\mathscr{A}^*, \mathscr{C}^*)$ be an AF, we say that $S \subseteq \mathscr{A}^*$ is **conflict-free** if and only if there is no argument $a \in S$, such that $(S,a) \in \mathscr{C}^*$. $S_1 \subseteq \mathscr{A}^*$ attacks $S_2 \subseteq \mathscr{A}^*$ if and only if there exists $a \in S_2$ such that $(S_1, a) \in \mathscr{C}^*$. An argument a is said to be **acceptable** w.r.t. S, if S defends a from all attacking sets of arguments of a. S_1 defends $a \in \mathscr{A}^*$ if and only if for every $S_2 \subseteq \mathscr{A}^*$ such that $(S_2, a) \in \mathscr{C}^*$, we have that S_1 attacks S_2. A conflict-free set S is said to be **admissible** if each argument in S is acceptable w.r.t. S. An admissible set S is called a **preferred extension** if there is no admissible set $S' \subseteq \mathscr{A}^*$, $S \subset S'$. A conflict-free set S is a **stable extension** if S attacks all arguments in $\mathscr{A}^* \setminus S$.

With a slight abuse of notation, we use the notation $Ext_p(\mathbb{AS}^*_{\mathscr{K}})$ (resp $Ext_s(\mathbb{AS}^*_{\mathscr{K}})$) to refer to the set of all preferred extensions (resp. stable extensions) of $\mathbb{AS}^*_{\mathscr{K}}$.

Proposition 2. Let $\mathbb{AS}^*_{\mathscr{K}} = (\mathscr{A}^*, \mathscr{C}^*)$, it holds that $Ext_x(\mathbb{AS}^*_{\mathscr{K}}) = \{Arg(A', \mathscr{A}^*) \mid A'$ is a repair $\}$ for $x \in \{s, p\}$.

Corollary 1. Let $\mathbb{AS}_{\mathscr{K}}$ be an AF and $\mathbb{AS}^*_{\mathscr{K}}$ the corresponding filtrated AF. It holds that $Ext_x(\mathbb{AS}^*_{\mathscr{K}}) = \{E \cap \mathscr{A}^* \mid E \in Ext_x(\mathbb{AS}_{\mathscr{K}})$ with $x \in \{s, p\}$.

Proposition 3. Let $\mathscr{K}$ be a KB, $\mathbb{AS}_{\mathscr{K}} = (\mathscr{A}, \mathscr{C})$ the corresponding AF and $\mathbb{AS}^*_{\mathscr{K}} = (\mathscr{A}^*, \mathscr{C}^*)$ the filtrated AF. Then it holds that $|\mathscr{A}^*| \leq |\mathscr{A}|$.

Please note that it is not true that $|\mathscr{C}| \leq |\mathscr{C}^*|$ as shown by Example 1.

Example 1. Let $\mathscr{K} = (\mathscr{F}, \mathscr{R}, \mathscr{N})$ be a KB with $\mathscr{F} = \{a(m), b(m), c(m)\}$, $\mathscr{R} = \{\forall x(a(x) \to b(x))\}$ and $\mathscr{N} = \{\forall x(a(x) \wedge c(x) \to \bot)\}$. The set $\mathscr{C}$ is composed of 10 attacks whereas $\mathscr{C}^*$ has 8 attacks.

Proposition 4. Let $\mathscr{K}$ be a KB, $\mathbb{AS}_{\mathscr{K}} = (\mathscr{A}, \mathscr{C})$ and $\mathbb{AS}^*_{\mathscr{K}} = (\mathscr{A}^*, \mathscr{C}^*)$ the corresponding AFs. It holds that (1) if $a \in \mathscr{A}^*$ is not attacked in $\mathbb{AS}_{\mathscr{K}}$ if and only if a is not attacked in $\mathbb{AS}^*_{\mathscr{K}}$ and (2) if $a \in \mathscr{A}^*$ is attacked in $\mathbb{AS}_{\mathscr{K}}$ then $|Att^-_{\mathbb{AS}_{\mathscr{K}}}(a)| \leq |Att^-_{\mathbb{AS}^*_{\mathscr{K}}}(a)|$.

We now show that it is not always possible to find a set of arguments X, with the same support, after the filtration such that the conclusions of X are distinct and the union of their conclusions is equal to a filtered argument.

Example 2. Let $\mathscr{K} = (\mathscr{F}, \mathscr{R}, \mathscr{N})$ be a KB such that $\mathscr{F} = \{a(m), c(m)\}$, $\mathscr{R} = \{\forall x(a(x) \to b(x))\}$ and $\mathscr{N} = \emptyset$. The argument $d = (\{a(m), c(m)\}, \{a(m), c(m), b(m)\})$ is filtrated because of the two arguments $x_1 = (\{a(m), c(m)\}, \{a(m), c(m)\})$ and $x_2 = (\{a(m), c(m)\}, \{b(m), c(m)\})$. Note that here, it holds that $X = \{x_1, x_2\}$ satisfies $Supp(x_1) = Supp(x_2) = Supp(d)$ and $\bigcup_{x_i \in X} Conc(x_i) = Conc(d)$ but for all $x_1, x_2 \in X$, $Conc(x_1) \cap Conc(x_2) = \emptyset$ is not true.

We now show that in the case where the set of rules is empty, the set of filtrated arguments is empty and $\mathbb{AS}_{\mathscr{K}}$ is equivalent to $\mathbb{AS}^*_{\mathscr{K}}$.

Proposition 5. Let $\mathscr{K} = (\mathscr{F}, \mathscr{R}, \mathscr{N})$ be a KB such that $\mathscr{R} = \emptyset$ and $\mathbb{AS}_{\mathscr{K}} = (\mathscr{A}, \mathscr{C})$ is the corresponding AF. It holds that $D(\mathbb{AS}_{\mathscr{K}}) = \emptyset$ and $\mathbb{AS}^*_{\mathscr{K}} = (\mathscr{A}^*, \mathscr{C}^*)$ is such that $\mathscr{A}^* = \mathscr{A}$ and $(b, a) \in \mathscr{C}$ if and only if $(\{b\}, a) \in \mathscr{C}^*$.

5. Experimentation and Discussion

In this section, we show the efficiency of the new AF based on the filtration of arguments for reducing the number of arguments and attacks by comparing the number of arguments in $\mathbb{AS}_{\mathscr{K}}$ and $\mathbb{AS}^*_{\mathscr{K}}$.

We chose to work with a particular subset of 108 KBs (named b_1 to b_{108}) extracted from the study of [27]. These KBs were generated by fixing the size of the set of facts and successively adding negative constraints until saturation. This dataset is composed of KBs with two to seven facts with different characteristics as shown in Table 1.

Name of the KB	Median number of facts	Median number of rules	Median number of NC	Type of NC
b_1 to b_6	5.5	$\emptyset$	1	Binary
b_{32}	3	$\emptyset$	2	Binary
b_{33} to b_{35}	4	$\emptyset$	2	Binary
b_{36} to b_{40}	5	$\emptyset$	3	Binary
b_{41} to b_{56}	6.5	$\emptyset$	2	Ternary
b_7 to b_{12}	2	2.5	1	Binary
b_{13} to b_{18}	2	4	1	Binary
b_{19} to b_{28}	6	1,5	1	Binary
b_{29} to b_{31}	3	2	2	Binary
b_{57} to b_{58}	3	1	2	Binary
b_{59} to b_{82}	4	3	3	Binary
b_{83} to b_{84}	3	1	1	Ternary
b_{85} to b_{87}	3	2	1	Ternary
b_{88} to b_{108}	4	3	1	Ternary

Table 1. Characteristics of the KBs

We provide a generator based on the Graal Java Toolkit [10] for directly generating $\mathbb{AS}^*_{\mathscr{K}}$ from an inconsistent existential rules KB expressed in DLGP format [9]. This tool can be downloaded along with the dataset used in this paper at `https://gite.lirmm.fr/yun/paper-comma-generator`.

In Table 2, we present the number of arguments and attacks in $\mathbb{AS}_{\mathscr{K}}$ and $\mathbb{AS}^*_{\mathscr{K}}$ along with the percentage of arguments filtered and the percentage of reduction of attacks[3]. We can make the following observations. This method does not provide any advantages in the case where the KB is devoid of rules. Second, although the instance with the highest percentage of reduction of attacks (b_{12} with 88%) is also the instance with the highest percentage of arguments filtered (73%). This is not always the case. Indeed, the

[3]These two percentages are defined as $\%Arg.Filtrated = \frac{|\mathscr{A}|-|\mathscr{A}^*|}{|\mathscr{A}|}$ and $\%Att.Reduction = \frac{|\mathscr{C}|-|\mathscr{C}^*|}{|\mathscr{C}|}$.

Name of the KB	Median # of arg. $\mathbb{AS}_{\mathscr{K}}$	Median # of att. $\mathbb{AS}_{\mathscr{K}}$	Median # of arg. $\mathbb{AS}^*_{\mathscr{K}}$	Median # of att. $\mathbb{AS}^*_{\mathscr{K}}$	Median % of arg. filtrated	Median % of att. reduction
b_1 to b_6	17	80	17	80	0	0
b_{32}	4	6	4	6	0	0
b_{33} to b_{35}	8	24	8	24	0	0
b_{36} to b_{40}	17	96	17	96	0	0
b_{41} to b_{56}	36	380	36	380	0	0
b_7 to b_{12}	11	17.5	4.5	11	53.6	40.2
b_{13} to b_{18}	14	87.5	6	35	57.1	60.4
b_{19} to b_{28}	71	1280	41	704	38.7	37.5
b_{29} to b_{31}	16	29	8	21	50	26.7
b_{57} to b_{58}	8	13.5	6	11.5	25	14.8
b_{59} to b_{82}	28.5	303.5	15.5	173.5	46.2	45.9
b_{83} to b_{84}	12	34	9	24	25	30.1
b_{85} to b_{87}	24	129	12	57	50	55.8
b_{88} to b_{108}	85	1652	35	596	59.0	63.5

Table 2. Characteristics of the $\mathbb{AS}_{\mathscr{K}}$ and $\mathbb{AS}^*_{\mathscr{K}}$ generated from the KBs.

instances b_{10} and b_{13} both have a percentage of arguments filtered of 33% but they have a percentage of attacks filtered of 50% and 33% respectively. Last, in all the instances with rules, there are less arguments and less attacks in $\mathbb{AS}^*_{\mathscr{K}}$ compared to $\mathbb{AS}_{\mathscr{K}}$.

In this paper, we provide a workflow for (1) fastening the generation of the AF from a KB without rules and (2) reducing the number of arguments without loss in the case of KBs with rules. This work tackles the problem of the exponential number of arguments reported by Yun et al. [26]. It helps to enhance the performance of AFs used for human interaction [4], in food science applications [5, 3] or for allowing alternative computation methods [25].

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