A Theoretical Model to Handle Ontology Debugging & Change Through Argumentation

Martín O. Moguillansky, Nicolás D. Rotstein, and Marcelo A. Falappa

Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET)
Department of Computer Science and Engineering (DCIC)
Artificial Intelligence Research and Development Laboratory (LIDIA)
Universidad Nacional del Sur (UNS), Bahía Blanca, ARGENTINA
{mom,ndr,maf}@cs.uns.edu.ar

Abstract. A dynamic argumentation framework based on $\mathcal{ALC}$ description logics is presented by extending notions from argumentation. Since argumentation frameworks reason over graphs that relate arguments through attack, a methodology is proposed to bridge ontology-specific concepts to argumentation notions. In this way, inconsistency in the former will be represented as an attack in the latter. This approach benefits from (argumentation) acceptability semantics to restore consistency to ontologies. Finally, a model of ontology change is presented along with a rational characterization.

1 Introduction

In this article we adapt the abstract version of the dynamic argumentation framework (DAF) originally presented in [18] and [17] to deal with a specific logic for arguments: $\mathcal{ALC}$ description logics (DLs). Some classical argumentation elements [4] are extended to be properly applied on such a specialized DAF. For instance, attack and support in argumentation are here related to identify different levels of inconsistency in ontologies [6]. Therefore, an acceptability semantics [3] applied to the DAF, determines a methodology for ontology debugging.

Afterwards, a model of change for ontologies is presented. Such model prioritizes the new knowledge to be incorporated, in a way that the evolved ontology will fully accept the new information, while ending up consistent at all levels. That is, (ontology) consistency as well as (terminology) coherency will be assured. Rationality of change in ontologies is stated in an abstract manner by the proposal of a set of postulates adapted from [6] and [1]. Afterwards, the model of change proposed in this article is studied under the light of the presented postulates, and an axiomatization is finally determined.

It is important to note that the argumentation machinery here proposed is semantically determined –by effect of the semantic entailment– and prepared to deal with $\mathcal{ALC}$ fragments of knowledge. This means that tableaux technics may be easily reused towards further implementations. Consequently, the actual model could recognize the sources of inconsistency directly, with no need to any translation to a DAF. In this sense, this methodology could be implemented on top of the DL reasoner. A different practical approach will be analyzed in Sect. 5.

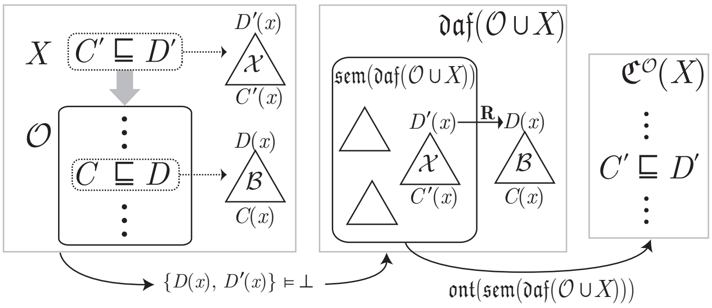


Fig. 1. Schema of the theoretical model of ontology change.

In Fig. 1 a schema of the presented theoretical model of change is shown (arguments are depicted as triangles). Its full understanding will be made clear throughout this paper but, on the other hand, the understanding of this paper will be made clearer by referring to the figure from time to time. In general, we define a `DAF` interpreting ontology concept descriptions as arguments. The reader should be aware that the actual translation from concepts to arguments has some subtleties that are not depicted in the figure. An $\mathcal{ALC}$ ontology $\mathcal{O}$ will be required to accept in a consistent and coherent manner a second $\mathcal{ALC}$ ontology X by means of the change operation $\mathfrak{C}^{\mathcal{O}}(X)$. A `DAF` determined by a function "$\mathfrak{daf}$" will return the `DAF` associated to the union of both ontologies. Afterwards, the argumentation machinery manages to recognize argument defeaters, that is arguments that are contradictory in some way. Consequently, the set of attack relations $\mathbf{R}$ is identified, leading to a graph of arguments. An acceptability semantics "$\mathfrak{sem}$" determines a consistent set of accepted arguments, thus yielding a disconnected graph. Finally, the translation back "$\mathfrak{ont}$" is done obtaining the new evolved consistent-coherent ontology $\mathfrak{C}^{\mathcal{O}}(X)$.

2 Description Logics Brief Overview

The following constitutes a very brief overview of the description logics (DLs) used in this paper, for more detailed information refer to [2]. An interpretation $\mathcal{I} = (\Delta^{\mathcal{I}}, \cdot^{\mathcal{I}})$ consists of a nonempty domain $\Delta^{\mathcal{I}}$, and an interpretation function $\cdot^{\mathcal{I}}$ that maps every concept to a subset of $\Delta^{\mathcal{I}}$, every role to a subset of $\Delta^{\mathcal{I}} \times \Delta^{\mathcal{I}}$, and every individual to an element of $\Delta^{\mathcal{I}}$.

The description language $\mathcal{ALC}$ is formed by concept definitions according to the syntax $C, D ::= A|\bot|\top|\neg C|C \sqcap D|C \sqcup D|\forall R.C|\exists R.C$ where A is an atomic concept, R is an atomic role; and the interpretation function $\cdot^{\mathcal{I}}$ is extended to the universal concept as $\top^{\mathcal{I}} = \Delta^{\mathcal{I}}$; the bottom concept as $\bot^{\mathcal{I}} = \emptyset$; the full negation or complement as $(\neg C)^{\mathcal{I}} = \Delta^{\mathcal{I}} \backslash C^{\mathcal{I}}$; the intersection as $(C \sqcap D)^{\mathcal{I}} = C^{\mathcal{I}} \cap D^{\mathcal{I}}$; the union as $(C \sqcup D)^{\mathcal{I}} = C^{\mathcal{I}} \cup D^{\mathcal{I}}$; the universal quantification as $(\forall R.C)^{\mathcal{I}} = \{a \in \Delta^{\mathcal{I}} | \forall b.(a, b) \in R^{\mathcal{I}} \rightarrow b \in C^{\mathcal{I}}\}$; and the full existential quantification as $(\exists R.C)^{\mathcal{I}} = \{a \in \Delta^{\mathcal{I}} | \exists b.(a, b) \in R^{\mathcal{I}} \wedge b \in C^{\mathcal{I}}\}$.

An ontology is a pair $\mathcal{O} = \langle \mathcal{T}, \mathcal{A} \rangle$, where $\mathcal{T}$ represents the TBox, containing the terminologies (or axioms) of the application domain, and $\mathcal{A}$, the ABox, which contains assertions about named individuals in terms of these terminologies. Regarding the TBox $\mathcal{T}$, axioms are sketched as $C \sqsubseteq D$ and $C \equiv D$, therefore, an interpretation $\mathcal{I}$ satisfies them whenever $C^{\mathcal{I}} \subseteq D^{\mathcal{I}}$ and $C^{\mathcal{I}} = D^{\mathcal{I}}$ respectively. An interpretation $\mathcal{I}$ is a model for the TBox $\mathcal{T}$ if $\mathcal{I}$ satisfies all the axioms in $\mathcal{T}$. Thus, the TBox $\mathcal{T}$ is said to be satisfiable if it admits a model. Besides, in the ABox $\mathcal{A}$, $\mathcal{I}$ satisfies $C(a)$ if $a \in C^{\mathcal{I}}$, and $R(a, b)$ if $(a, b) \in R^{\mathcal{I}}$. An interpretation $\mathcal{I}$ is said to be a model of the ABox $\mathcal{A}$ if every assertion of $\mathcal{A}$ is satisfied by $\mathcal{I}$. Hence, the ABox $\mathcal{A}$ is said to be satisfiable if it admits a model. Finally, regarding the entire ontology, an interpretation $\mathcal{I}$ is said to be a model of $\mathcal{O}$ if every statement in $\mathcal{O}$ is satisfied by $\mathcal{I}$, and $\mathcal{O}$ is said to be satisfiable if it admits a model. An ontology contains implicit knowledge that is made explicit through inferences. The notion of semantic entailment is given by $\mathcal{O} \models \alpha$, meaning that every model of the ontology $\mathcal{O}$ is also a model of the statement α. Formally, **(semantic entailment)** $\mathcal{O} \models \alpha$ *iff* $\mathcal{M}(\mathcal{O}) \subseteq \mathcal{M}(\{\alpha\})$. Just for simplicity, we shall abuse notation writing $\mathcal{O} = \mathcal{T} \cup \mathcal{A}$ (*eg.*, $\mathcal{O} = \{C \sqsubseteq D, A(a)\}$) to identify an ontology $\mathcal{O} = \langle \mathcal{T}, \mathcal{A} \rangle$ (*eg.*, $\mathcal{O} = \langle \{C \sqsubseteq D\}, \{A(a)\} \rangle$). Throughout this paper, inferences will be obtained following the notion of semantic entailment.

3 $\mathcal{ALC}$-Based Dynamic Argumentation Framework

In the rest of this article we will use symbols $A, A_1, A_2, \ldots$ and $B, B_1, B_2, \ldots$ to denote atomic DL concepts, $C, C_1, C_2, \ldots$ and $D, D_1, D_2, \ldots$ to denote general DL concepts, $R, R_1, R_2, \ldots$ to denote atomic DL roles, x, y to denote free variables, and a, b to denote individual names. The following grammars are necessary to specify the language used to represent $\mathcal{ALC}$-based ontologies into a dynamic argumentation framework (`DAF`) for description logics. It is important to mention that the `DAF` is an extension of the abstract argumentation framework proposed by Dung [4]. In this work, the original `DAF` formalism [17,18] requires to be extended in order to handle knowledge represented by $\mathcal{ALC}$ DL statements.

$$
\begin{array}{ll}
\phi ::= \top | A | \neg A | \forall R.\mathcal{L}_{disj} | \exists R.\mathcal{L}_{conj} & \\
\mathcal{L}_{conj} ::= \phi | \mathcal{L}_{conj} \sqcap \mathcal{L}_{conj} & \mathcal{L}_{disj} ::= \phi | \mathcal{L}_{disj} \sqcup \mathcal{L}_{disj} \\
\mathcal{L}_{\mathcal{T}} ::= \mathcal{L}_{conj} \sqsubseteq \mathcal{L}_{disj} & \mathcal{L}_{\mathcal{A}} ::= A(\mathcal{L}_{var}) | \neg A(\mathcal{L}_{var}) | R(\mathcal{L}_{var}, \mathcal{L}_{var}) \\
\mathcal{L}_{\mathtt{pr}} ::= \phi(\mathcal{L}_{var}) & \mathcal{L}_{\mathfrak{cl}} ::= \mathcal{L}_{disj}(\mathcal{L}_{var}) | R(\mathcal{L}_{var}, \mathcal{L}_{var}) \\
\mathcal{L}_{var} ::= a | b | x | y & \mathbb{A}\mathtt{rgs} ::= 2^{\mathcal{L}_{\mathtt{pr}}} \times \mathcal{L}_{\mathfrak{cl}}
\end{array}
$$

An argument is interpreted as an atomic (indivisible) piece of knowledge. To the argumentation machinery, an argument is a primitive element of reasoning supporting a claim from its set of premises. Usually, argumentation frameworks consider ground arguments, that is, a claim is directly inferred if the set of premises are conformed. In our framework, we will consider two different kinds of arguments: ground and schematic. In this sense, a set of premises might consider free variables, meaning that the claim, and therefore the inference, will depend on them. When an argument has its premises supported, its variables may be instantiated as a result of that. These notions are carefully detailed throughout this section. Next we formalize the notions of argument and `DAF` for DLs.

Definition 1 (Argument). *An argument $\mathcal{B} \in \mathbb{A}\mathtt{rgs}$ is a pair $\langle P, c\rangle$, where $P \in 2^{\mathcal{L}_{\mathfrak{pr}}}$ is the finite set of premises from $\mathcal{L}_{\mathfrak{pr}}$, and $c \in \mathcal{L}_{\mathfrak{cl}}$, the claim. An argument $\mathcal{B}$ guarantees $P \cup \{c\} \not\models \bot$* **(consistency)***. Both premises and claims are represented as finite formulae from their respective language.*

Definition 2 (Dynamic Argumentation Framework for DLs). *Let $T \subseteq \mathbb{A}\mathtt{rgs} \times \mathbb{A}\mathtt{rgs}$ be a Dynamic Argumentation Framework for DLs* (DAF)*, specified by a pair $\langle \mathbf{U}, \mathbf{A}\rangle$, where $\mathbf{U} \subseteq \mathbb{A}\mathtt{rgs}$ is the universal set of arguments, and $\mathbf{A} \subseteq \mathbf{U}$ is the framework's active set containing the unique set of arguments considered by the argumentation reasoning process.*

As usual in argumentation, pairs of conflictive arguments may appear. Such pairs will be contained in an attack relation set $\mathbf{R}$, dynamically recognized from the current DAF specification. This notion will be made clear later. Besides, inactive arguments –ignored by the reasoning process– might be identified by means of a set $\mathbf{I} = \mathbf{U} \setminus \mathbf{A}$. Some arguments may count with no premises to be satisfied. Such arguments, referred as evidence, will be individually considered a self-conclusive piece of knowledge, and will be enclosed by a set $\mathbf{E} \subseteq \mathbf{A}$. However, there could be inactive arguments with an empty set of premises which will be recognized as non-evidential facts, enclosed in a set $\mathbf{F} \subseteq \mathbf{I}$.

Definition 3 (Evidence & Non-Evidential Fact). *Given a* DAF *$\langle \mathbf{U}, \mathbf{A}\rangle \subseteq \mathbb{A}\mathtt{rgs} \times \mathbb{A}\mathtt{rgs}$. An argument $\mathcal{B} \in \mathbf{U}$ such that $\mathcal{B} = \langle\{\}, c\rangle$ and $c \in \mathcal{L}_{\mathcal{A}}$, is referred either as:* ***Evidence*** *iff $\mathcal{B} \in \mathbf{A}$, or* ***Non-Evidential Fact*** *iff $\mathcal{B} \notin \mathbf{A}$.*

Given an argument $\mathcal{B} \in \mathbb{A}\mathtt{rgs}$, its claim and set of premises are identified by the functions $\mathfrak{cl} : \mathbb{A}\mathtt{rgs} \rightarrowtail \mathcal{L}_{\mathfrak{cl}}$, and $\mathfrak{pr} : \mathbb{A}\mathtt{rgs} \rightarrowtail 2^{\mathcal{L}_{\mathfrak{pr}}}$, respectively. For instance, given $\mathcal{B} = \langle\{p_1, p_2\}, c\rangle$, its premises are $\mathfrak{pr}(\mathcal{B}) = \{p_1, p_2\}$, and its claim, $\mathfrak{cl}(\mathcal{B}) = c$.

In order to obtain a DAF from an $\mathcal{ALC}$ ontology $\mathcal{O}$, it is needed to translate each axiom in $\mathcal{O}$ to *negation normal form*, so that negation appears only in front of atomic concepts. Afterwards, each axiom should turn to *disjunctive normal form* for the left-hand-side (*lhs*) part of the description, and to *conjunctive normal form* for its right-hand-side (*rhs*), conforming axioms *lhs* $\sqsubseteq$ *rhs* or *lhs* $\equiv$ *rhs*, where *lhs* $::= \bot | \mathcal{L}_{conj} \sqcup \ldots \sqcup \mathcal{L}_{conj}$ and *rhs* $::= \bot | \mathcal{L}_{disj} \sqcap \ldots \sqcap \mathcal{L}_{disj}$, referred as *pre-argumental normal form* (pANF). An ontology in pANF could trigger multiple arguments from each axiom, as states the following intuition: each *lhs* disjunction (in $\mathcal{L}_{conj}$) is interpreted as a set of premises $\mathcal{L}_{\mathfrak{pr}}$–one for each conjunction– and each *rhs* conjunction (in $\mathcal{L}_{disj}$), as a claim in $\mathcal{L}_{\mathfrak{cl}}$ (*c.f.* Ex. 1). Concept equivalences as $C_1 \equiv C_2$, are assumed as pairs $C_1 \sqsubseteq C_2$ and $C_2 \sqsubseteq C_1$. Inclusions $\bot \sqsubseteq C$ and $C \sqsubseteq \bot$, are assumed as $\neg C \sqsubseteq \top$ and $\top \sqsubseteq \neg C$, respectively, given that arguments cannot accept $\bot$ in any of their components (*c.f. consistency* in Def. 1). Finally, assertions as $A(a)$, trigger evidential arguments as $\langle\{\}, A(a)\rangle$. A formal specification of a systematic translation was left out due to space reasons.

Example 1. Let $(A_1 \sqcap A_2) \sqcup (\forall R_1.A_3 \sqcap \exists R_2.\forall R_3.\neg A_4) \sqsubseteq (A_1 \sqcup A_2) \sqcap A_5$ be an axiom conforming the pANF. Four arguments appear in the related DAF: $\langle\{A_1(x), A_2(x)\}, (A_1 \sqcup A_2)(x)\rangle$, $\langle\{(\forall R_1.A_3)(x), (\exists R_2.\forall R_3.\neg A_4)(x)\}, (A_1 \sqcup A_2)(x)\rangle$, $\langle\{A_1(x), A_2(x)\}, A_5(x)\rangle$, and $\langle\{(\forall R_1.A_3)(x), (\exists R_2.\forall R_3.\neg A_4)(x)\}, A_5(x)\rangle$.

Given an $\mathcal{ALC}$ ontology $\mathcal{O}$, a function $\mathfrak{daf} : \mathcal{ALC} \rightarrowtail \mathbb{A}\mathtt{rgs} \times \mathbb{A}\mathtt{rgs}$, is the mapping $\mathfrak{daf}(\mathcal{O}) = \langle \mathbf{U}, \mathbf{A} \rangle$, which follows the translation methodology described before. That is, $\mathcal{O}$ is turned into pANF, and consequently the DAF is obtained, where each argument identified is considered active, *i.e.*, $\mathbf{A} = \mathbf{U}$.

We will define as $\mathcal{ALC}^{\mathbb{A}\mathtt{rgs}}$ to the logic for ontologies $\mathcal{O} \subseteq \mathcal{L}_{\mathcal{T}} \times \mathcal{L}_{\mathcal{A}}$, using $\mathcal{L}_{\mathcal{T}}$ for axioms and $\mathcal{L}_{\mathcal{A}}$ for assertions. It is clear that any $\mathcal{ALC}^{\mathbb{A}\mathtt{rgs}}$ ontology conforms the $\mathcal{ALC}$ DL, and it is always in pANF. Moreover, we will assume a function $\mathfrak{af} : \mathcal{ALC} \rightarrowtail \mathcal{ALC}^{\mathbb{A}\mathtt{rgs}}$, the *argumental-DL function* that translates any $\mathcal{ALC}$ ontology $\mathcal{O}$ into an equivalent $\mathcal{ALC}^{\mathbb{A}\mathtt{rgs}}$ ontology $\mathfrak{af}(\mathcal{O})$. A desirable property of an $\mathcal{ALC}^{\mathbb{A}\mathtt{rgs}}$ ontology is that each statement in it generates a single argument in its related DAF, except for obvious unsatisfiable inclusions as $A \sqsubseteq \neg A$, which are filtered by *consistency* in Def. 1 –triggering no related argument in the DAF.

Proposition 1. [1] *Let $\mathcal{O}$ and $\mathcal{O}'$ be two ontologies. If $\mathcal{O}$ conforms the logic $\mathcal{ALC}$, and $\mathcal{O}'$ conforms $\mathcal{ALC}^{\mathbb{A}\mathtt{rgs}}$ then*

a) $\mathcal{O}'$ conforms the logic $\mathcal{ALC}$ and is in pANF*,*
b) If $\mathfrak{af}(\mathcal{O}) = \mathcal{O}'$ then $\mathcal{O}$ is equivalent to $\mathcal{O}'$, and
c) If $\mathcal{O}$ conforms the logic $\mathcal{ALC}^{\mathbb{A}\mathtt{rgs}}$ then $|\mathcal{O}| \geq |\mathbf{U}|$ where $\mathfrak{daf}(\mathcal{O}) = \langle \mathbf{U}, \mathbf{A} \rangle$.

3.1 The Argumentation Machinery

An argument needs to find its premises supported as a functional part of the reasoning process to reach its claim. In this framework, due to the logic used to represent arguments derived from that of the ontology languages, a single argument is sometimes not enough to support a premise. This is the reason why we introduce the notion of coalitions: to identify a minimal set of arguments verifying some specific properties. For instance, a coalition $\widehat{\mathcal{C}} \subseteq \mathbb{A}\mathtt{rgs}$ may provide support for an argument $\mathcal{B} \in \mathbb{A}\mathtt{rgs}$ through some of its premises. For that matter, we present the functions $\widehat{\mathfrak{clset}}(\widehat{\mathcal{C}}) = \{\mathfrak{cl}(\mathcal{B}) | \mathcal{B} \in \widehat{\mathcal{C}}\}$, and $\widehat{\mathfrak{prset}}(\widehat{\mathcal{C}}) = \bigcup_{\mathcal{B} \in \widehat{\mathcal{C}}} \mathfrak{pr}(\mathcal{B})$.

Definition 4 (Supporter). *Given a* DAF $\langle \mathbf{U}, \mathbf{A} \rangle \subseteq \mathbb{A}\mathtt{rgs} \times \mathbb{A}\mathtt{rgs}$*, and an argument $\mathcal{B} \in \mathbf{U}$ such that $p \in \mathfrak{pr}(\mathcal{B})$. A set of arguments $\widehat{\mathcal{C}} \subseteq \mathbf{U}$ is a supporting-coalition, or just a **supporter**, of $\mathcal{B}$ through p iff it guarantees:*

(support) $\widehat{\mathfrak{clset}}(\widehat{\mathcal{C}}) \models p$,
(consistency) $\widehat{\mathfrak{prset}}(\widehat{\mathcal{C}}) \cup \widehat{\mathfrak{clset}}(\widehat{\mathcal{C}}) \cup \mathfrak{pr}(\mathcal{B}) \cup \{\mathfrak{cl}(\mathcal{B})\} \not\models \bot$, *and*
(minimality) *no $\widehat{\mathcal{C}}' \subset \widehat{\mathcal{C}}$ is a supporter of $\mathcal{B}$ through p.*

Definition 5 (Free Premise). *Given a* DAF $\langle \mathbf{U}, \mathbf{A} \rangle \subseteq \mathbb{A}\mathtt{rgs} \times \mathbb{A}\mathtt{rgs}$ *and an argument $\mathcal{B} \in \mathbf{U}$, a premise $p \in \mathfrak{pr}(\mathcal{B})$ of $\mathcal{B}$ is **free** wrt. $\mathbf{U}$ iff there is no supporting-coalition $\widehat{\mathcal{C}} \subseteq \mathbf{U}$ of $\mathcal{B}$ through p.*

Example 2. Suppose we have a set $\mathbf{U} = \{\mathcal{B}_1, \mathcal{B}_2, \mathcal{B}_3\}$, where arguments $\mathcal{B}_1 = \langle \{(\exists R.A_1)(x),\ A_2(x)\},\ B(x) \rangle$, $\mathcal{B}_2 = \langle \{\}, R(a,b) \rangle$, and $\mathcal{B}_3 = \langle \{\}, A_1(b) \rangle$. The set $\widehat{\mathcal{C}} = \{\mathcal{B}_2, \mathcal{B}_3\}$ is a supporting-coalition of $\mathcal{B}_1$ given that $\{R(a,b), A_1(b)\} \models (\exists R.A_1)(x)$. Note that premise $A_2(x)$ is free wrt. $\mathbf{U}$.

[1] In this work, proofs will be omitted due to space reasons.

Example 3. Assume $\mathbf{U} = \{\mathcal{B}_1, \mathcal{B}_2, \mathcal{B}_3, \mathcal{B}_4\}$, where $\mathcal{B}_1 = \langle\{A_1(x)\}, B_1(x)\rangle$, $\mathcal{B}_2 = \langle\{A_1(x)\}, B_2(x)\rangle$, $\mathcal{B}_3 = \langle\{A_2(x)\}, (A_1 \sqcup B_1)(x)\rangle$, and $\mathcal{B}_4 = \langle\{A_3(x)\}, \neg B_1(x)\rangle$. The set $\widehat{\mathcal{C}} = \{\mathcal{B}_3, \mathcal{B}_4\}$ is a supporting-coalition of $\mathcal{B}_2$. Note that $\widehat{\mathcal{C}}$ cannot be a supporting-coalition of $\mathcal{B}_1$ since it violates (supporter) consistency.

Definition 6 (Supporting-Chain). *Given a* DAF $\langle \mathbf{U}, \mathbf{A}\rangle \subseteq \mathbb{A}\mathtt{rgs} \times \mathbb{A}\mathtt{rgs}$*, and a sequence* $\lambda = \mathcal{B} \xleftarrow{p} \widehat{\mathcal{C}}_1 \xleftarrow{p_1} \widehat{\mathcal{C}}_2 \xleftarrow{p_2} \cdots$*, where* $(\bigcup_{i\geq 1} \widehat{\mathcal{C}}_i) \cup \{\mathcal{B}\} \subseteq \mathbf{U}$*,* $p \in \mathfrak{pr}(\mathcal{B})$*,* $\widehat{\mathcal{C}}_1$ *is a supporting-coalition of* $\mathcal{B}$ *through* p*, and for every* $i > 1$*,* $p_{i-1} \in \widehat{\mathfrak{prset}}(\widehat{\mathcal{C}}_{i-1})$*, and* $\widehat{\mathcal{C}}_i$ *is a supporting-coalition of* $\widehat{\mathcal{C}}_{i-1}$ *through* p_{i-1}*. Thus,* λ *is referred as a (possible infinite)* ***supporting-chain for*** p *of* $\mathcal{B}$ *wrt.* $\mathbf{U}$.

Whenever λ *has a last identifiable element* $\widehat{\mathcal{C}}_n$*, it follows that every premise in* $\widehat{\mathfrak{prset}}(\widehat{\mathcal{C}}_n)$ *is free wrt.* $\mathbf{U}$*, or* $\widehat{\mathfrak{prset}}(\widehat{\mathcal{C}}_n) = \emptyset$*. In such a case,* λ *is said to be a* ***finite supporting-chain for*** p *of length* n *wrt.* $\mathbf{U}$.

Definitions 4 and 5 are reviewed in Ex. 2 and 3. The iterated aggregation of arguments via the support relation (*c.f.* Def. 4) may conform both, chains of supporting-coalitions for a premise in some argument (*c.f.* Def. 6), as well as sets of interrelated arguments (*c.f.* Def. 7). We will refer to such sets as structures and will be a core part of the argumentation machinery for the proposed DAF.

Definition 7 (Structure). *Given a* DAF $\langle \mathbf{U}, \mathbf{A}\rangle \subseteq \mathbb{A}\mathtt{rgs} \times \mathbb{A}\mathtt{rgs}$*,* $\mathbb{S} \subseteq \mathbf{U}$ *is a* ***structure for*** c *iff it guarantees:*

(top argument) *there exists a unique* $\mathcal{B}^{top} \in \mathbb{S}$ *such that* $\mathfrak{cl}(\mathcal{B}^{top}) = c$*,*
(connectivity) *for every* $\mathcal{B} \in \mathbb{S} \setminus \{\mathcal{B}^{top}\}$*, there exists a unique subset* $\widehat{\mathcal{C}} \subseteq \mathbb{S}$ *such that* $\mathcal{B} \in \widehat{\mathcal{C}}$ *where* $\widehat{\mathcal{C}}$ *is a supporting-coalition of an argument in* $\mathbb{S}$*,*
(self-consistency) $\widehat{\mathfrak{prset}}(\mathbb{S}) \cup \widehat{\mathfrak{clset}}(\mathbb{S}) \not\models \bot$*, and*
(acyclicity) *every supporting-chain for every* p *of every* $\mathcal{B} \in \mathbb{S}$ *wrt.* $\mathbb{S}$ *is finite.*

The claim and premises of $\mathbb{S}$ *are determined by the functions* $\mathfrak{cl}(\mathbb{S}) = c$ *and* $\mathfrak{pr}(\mathbb{S}) = \{p \in \widehat{\mathfrak{prset}}(\mathbb{S}) \mid p$ *is a free premise wrt.* $\mathbb{S}\}$*, respectively.*

Note that functions "$\mathfrak{pr}$" and "$\mathfrak{cl}$" are overloaded and can be applied both to arguments and structures. This is not going to be problematic since either usage will be rather explicit. In addition to that, we will identify the top argument of a structure $\mathbb{S}$ using the function $\mathtt{top} : 2^{\mathbb{A}\mathtt{rgs}} \rightarrowtail \mathbb{A}\mathtt{rgs}$. Note that $\mathfrak{cl}(\mathtt{top}(\mathbb{S})) = \mathfrak{cl}(\mathbb{S})$. Next, it is shown how our theory manages to handle $\mathcal{ALC}$ cyclic terminologies.

Example 4. Given an $\mathcal{ALC}$ ontology $\mathcal{O} = \{A \equiv B\}$, after applying $\mathfrak{Daf}(\mathcal{O})$ arguments $\mathcal{B}_1 = \langle\{A(x)\}, B(x)\rangle$, and $\mathcal{B}_2 = \langle\{B(x)\}, A(x)\rangle$, appear. However, a set $\{\mathcal{B}_1, \mathcal{B}_2\}$ cannot be part of any structure since the infinite supporting-chain $\lambda = \mathcal{B}_1 \xleftarrow{A(x)} \{\mathcal{B}_2\} \xleftarrow{B(x)} \{\mathcal{B}_1\} \xleftarrow{A(x)} \cdots$ for $A(x)$ would violate (structure) acyclicity.

A structure $\mathbb{S}$ trivially formed by a single argument is referred as *primitive iff* $|\mathbb{S}| = 1$. Thus, if $\mathbb{S} = \{\mathcal{B}\}$ then $\mathfrak{pr}(\mathcal{B}) = \mathfrak{pr}(\mathbb{S})$ and $\mathfrak{cl}(\mathcal{B}) = \mathfrak{cl}(\mathbb{S})$. However, not every single argument has an associated primitive structure. For instance, from an axiom $A \sqsubseteq A$, no structure could contain its related argument given that it would violate (structure) acyclicity. Depending on the condition of the set of premises in a structure we may identify two different kinds of structures.

Definition 8 (Schematic & Argumental Structure). *Given a* $\mathtt{DAF}$ $\langle \mathbf{U}, \mathbf{A} \rangle \subseteq \mathbb{A}\mathtt{rgs} \times \mathbb{A}\mathtt{rgs}$, *a structure* $\mathbb{S} \subseteq \mathbf{U}$ *is referred either as:* ***Argumental*** *iff* $\mathfrak{pr}(\mathbb{S}) = \emptyset$, *or* ***Schematic*** *iff* $\mathfrak{pr}(\mathbb{S}) \neq \emptyset$.

When no distinction is needed, we refer to primitive, schematic, or argumental structures, simply as structures. A **sub-structure relation** "$\trianglelefteq$" relating structures $\mathbb{S} \subseteq \mathbb{A}\mathtt{rgs}$ is defined as stated by the following intuition: given a structure $\mathbb{S}$ for a claim c, if it contains a subset $\mathbb{S}'$ verifying the conditions in Def. 7 for a claim c', then $\mathbb{S}'$ is a structure for c' and $\mathbb{S}' \trianglelefteq \mathbb{S}$.

From a schematic structure and a supporting-coalition for it, a new structure is formed. If this new structure has no free premises, it means that a *variable substitution* was made over the schematic structure leading to an argumental structure. In general, a structure that adds some evidential argument about an individual name, say a, as part of the support for a schematic structure, provokes a variable substitution in the latter. In that case, the argumental structure ends up asserting some property –through its claim– about the individual a. Finally, it is clear that if a structure states a property about some element of the world by means of a free variable x then it is schematic.

Two argumental structures $\mathbb{S}_1$ and $\mathbb{S}_2$ are in conflict whenever they cannot be assumed together. This notion may be made extensive to sets of argumental structures, namely coalition of argumental structures. Coalition of structures is analogous to that of arguments; its formalization is not given due to lack of space. Therefore, the functions "$\widehat{\mathfrak{clset}}$" and "$\widehat{\mathfrak{prset}}$" are overloaded and can be applied both to coalitions $\widehat{\mathcal{C}}$ of arguments and to coalitions $\widehat{\mathbb{C}}$ of structures. Formally, $\widehat{\mathfrak{clset}}(\widehat{\mathbb{C}}) = \{\mathfrak{cl}(\mathbb{S}) | \mathbb{S} \in \widehat{\mathbb{C}}\}$, and $\widehat{\mathfrak{prset}}(\widehat{\mathbb{C}}) = \bigcup_{\mathbb{S} \in \widehat{\mathbb{C}}} \mathfrak{pr}(\mathbb{S})$. Next, we specify the notion of conflict between coalitions of structures as a generalization, since one of them has to be necessarily a singleton. This is required to preserve conflict minimality.

Definition 9 (Conflict). *Let* $\langle \mathbf{U}, \mathbf{A} \rangle \subseteq \mathbb{A}\mathtt{rgs} \times \mathbb{A}\mathtt{rgs}$ *be a* $\mathtt{DAF}$, *and* $\widehat{\mathbb{C}}_1$ *and* $\widehat{\mathbb{C}}_2$, *two* ***minimal,*** *and* ***consistent*** *coalitions of structures in* $\mathbf{U}$ *verifying:*

a) $|\widehat{\mathbb{C}}_1| = 1$, *or* $|\widehat{\mathbb{C}}_2| = 1$, *and*
b) $\widehat{\mathfrak{prset}}(\widehat{\mathbb{C}}_1) \models \widehat{\mathfrak{prset}}(\widehat{\mathbb{C}}_2)$ ***(dependency)***, *or* $\widehat{\mathfrak{clset}}(\widehat{\mathbb{C}}_1) \models \widehat{\mathfrak{prset}}(\widehat{\mathbb{C}}_2)$ ***(support)***.

Coalitions $\widehat{\mathbb{C}}_1$ *and* $\widehat{\mathbb{C}}_2$ *are in* ***conflict*** *iff every structure* $\mathbb{S} \subseteq (\widehat{\mathbb{C}}_1 \cup \widehat{\mathbb{C}}_2)$, *is the* ***smallest*** $\mathbb{S}$ *needed to guarantee either:*

(claim-conflict) $\widehat{\mathfrak{clset}}(\widehat{\mathbb{C}}_1) \cup \widehat{\mathfrak{clset}}(\widehat{\mathbb{C}}_2) \models \bot$, *or*
(premise-conflict) $\widehat{\mathfrak{clset}}(\widehat{\mathbb{C}}_1) \cup \widehat{\mathfrak{prset}}(\widehat{\mathbb{C}}_2)) \models \bot$.

Example 5. Assume we have $A_1 \sqcap A_2 \sqsubseteq B$, $A_3 \sqsubseteq A_1$, and $A_3 \sqsubseteq \neg A_2$. Hence, from arguments $\mathcal{B}_1 = \langle \{A_1(x), A_2(x)\}, B(x) \rangle$, $\mathcal{B}_2 = \langle \{A_3(x)\}, A_1(x) \rangle$, and $\mathcal{B}_3 = \langle \{A_3(x)\}, \neg A_2(x) \rangle$, two structures $\mathbb{S}_1 = \{\mathcal{B}_1, \mathcal{B}_2\}$ and $\mathbb{S}_2 = \{\mathcal{B}_3\}$ appear. The trivial coalitions $\widehat{\mathbb{C}}_1 = \{\mathbb{S}_1\}$ and $\widehat{\mathbb{C}}_2 = \{\mathbb{S}_2\}$ model a **premise-conflict**. Note that $\widehat{\mathfrak{prset}}(\widehat{\mathbb{C}}_1) = \{A_3(x), A_2(x)\}$, $\widehat{\mathfrak{prset}}(\widehat{\mathbb{C}}_2) = \{A_3(x)\}$, and $\widehat{\mathfrak{clset}}(\widehat{\mathbb{C}}_2) = \{\neg A_2(x)\}$.

Assume now that we have the same axioms determining arguments $\mathcal{B}_1$ and $\mathcal{B}_2$, and $A_3 \sqsubseteq \neg B$ triggering $\mathcal{B}_3' = \langle \{A_3(x)\}, \neg B(x) \rangle$. It is easy to verify that a **claim-conflict** will be modeled from $\widehat{\mathbb{C}}_1$ and $\{\{\mathcal{B}_3'\}\}$.

Note that both conflicts in Ex. 5 come from *dependency* (*c.f.* Def. 9*b*). Examples of *claim-conflict* from *support* appear from an ontology $\{\top \sqsubseteq A, \neg A(a)\}$, or either in Ex. 3. It is clear that no *premise-conflict from support* is possible since both support and premise-conflict conditions cannot be mutually verified.

Deciding which coalition of structures succeeds between a conflicting pair, requires a comparison criterion. Such a criterion should be defined upon (a) entrenchment of knowledge and (b) novelty. For the former case, the ontology engineer may decide to give different levels of importance to individual pieces of knowledge, and for the latter, to prefer new knowledge to older one.

In that sense, we will assume there exists a partial order of arguments called *argument comparison criterion* "$\succcurlyeq$", such that $\mathcal{B}_1 \succcurlyeq \mathcal{B}_2$ states that $\mathcal{B}_1$ has more priority than $\mathcal{B}_2$. Afterwards, two conflictive coalitions of structures $\widehat{\mathbb{C}}_1$ and $\widehat{\mathbb{C}}_2$ are assumed to be ordered by a function "$\mathfrak{pref}$" relying on "$\succcurlyeq$", where $\mathfrak{pref}(\widehat{\mathbb{C}}_1, \widehat{\mathbb{C}}_2) = (\widehat{\mathbb{C}}_1, \widehat{\mathbb{C}}_2)$ implies the attack relation $\widehat{\mathbb{C}}_1 \mathbf{R} \widehat{\mathbb{C}}_2$, *i.e.*, $\widehat{\mathbb{C}}_1$ is a defeater of (or it defeats) $\widehat{\mathbb{C}}_2$. Note that when no pair of arguments is related by "$\succcurlyeq$", both $\widehat{\mathbb{C}}_1 \mathbf{R} \widehat{\mathbb{C}}_2$ and $\widehat{\mathbb{C}}_2 \mathbf{R} \widehat{\mathbb{C}}_1$ appear from any conflicting pair $\widehat{\mathbb{C}}_1$ and $\widehat{\mathbb{C}}_2$.

Definition 10 (Attack Relation Set). *Given a* $\mathtt{DAF}$ $\langle \mathbf{U}, \mathbf{A} \rangle \subseteq \mathbb{A}\mathtt{rgs} \times \mathbb{A}\mathtt{rgs}$*, the set* $\mathbf{R}$ *of attack relations is defined as* $\mathbf{R} = \{(\widehat{\mathbb{C}}_1, \widehat{\mathbb{C}}_2) \mid \widehat{\mathbb{C}}_1 \subseteq 2^{\mathbf{U}}$ *and* $\widehat{\mathbb{C}}_2 \subseteq 2^{\mathbf{U}}$ *are two conflictive coalitions of structures and* $\mathfrak{pref}(\widehat{\mathbb{C}}_1, \widehat{\mathbb{C}}_2) = (\widehat{\mathbb{C}}_1, \widehat{\mathbb{C}}_2)\}$.

Regarding the active condition of the components of the framework, a structure is active *iff* all its arguments are active. This notion is also extended to coalitions of structures by considering a coalition $\widehat{\mathbb{C}}$ active *iff* all its structures are active. Finally, an attack relation $\widehat{\mathbb{C}}_1 \mathbf{R} \widehat{\mathbb{C}}_2$ is active *iff* both $\widehat{\mathbb{C}}_1$ and $\widehat{\mathbb{C}}_2$ are active. That is, if $(\widehat{\mathbb{C}}_1, \widehat{\mathbb{C}}_2) \in \mathbf{R}^{\mathbf{A}} \subseteq \mathbf{R}$ then $\widehat{\mathbb{C}}_1 \subseteq 2^{\mathbf{A}}$ and $\widehat{\mathbb{C}}_2 \subseteq 2^{\mathbf{A}}$, where $\mathbf{R}^{\mathbf{A}}$ is the set standing for every active attack relation in $\mathbf{R}$.

3.2 Acceptability Analysis

In an ontology, inconsistency implies that there are contradictory concept definitions, or assertions that will lead to conflicting arguments within the equivalent DAF. Thus, once the translation is performed, each inconsistency in the original ontology will be reflected as an attack in the resulting DAF. Since the objective of converting an ontology to an argumentation framework is to remove inconsistency from the former, there is a need for a mechanism that allows us to obtain those arguments that prevail over the rest. That is, those arguments that can be consistently assumed together, following some policy. For instance, structures with no defeaters should always prevail, since there is nothing strong enough to be posed against them. The tool we need to resolve inconsistency of concept definitions via an argumentation framework is the notion of *acceptability of arguments*, which is defined on top of an *argumentation semantics* [3]. There are several well-known argumentation semantics, such as the grounded, the stable, and the preferred semantics [4]. These semantics ensure the obtention of a consistent set of arguments, namely an extension. That is, the set of accepted arguments calculated following any of these semantics is such that no pair of conflictive arguments appears in that same extension. Finally, when we translate an ontology to a DAF, all what is left to do to resolve inconsistencies is to calculate the set of accepted arguments following some semantics, which is going to be translated back to a consistent ontology. It is important to notice that the chosen semantics will greatly affect the resulting ontology. Moreover, problems like multiple extensions from semantics like both the *stable* and the *preferred* may appear, requiring to make a choice among them. On the other hand, the outcome of the *grounded semantics* is always a single extension, which could be empty. Finally, since dealing with multiple extensions is a problem that falls outside the scope of this article, we will choose the grounded semantics, which can be implemented with a simple algorithm. Consequently, we define a mapping $\mathfrak{sem} : 2^{\mathbb{A}\mathtt{rgs}} \times 2^{\mathbb{A}\mathtt{rgs}} \rightarrowtail 2^{\mathbb{A}\mathtt{rgs}} \times 2^{\mathbb{A}\mathtt{rgs}}$, that intuitively behaves as follows.

For every pair of active attack $(\widehat{\mathbb{C}}_1, \widehat{\mathbb{C}}_2) \in \mathbf{R}^{\mathbf{A}}$, if there is no active coalition of structures defeating $\widehat{\mathbb{C}}_1$ **(undefeat)**, then we deactivate some argument from some structure in $\widehat{\mathbb{C}}_2$ **(deactivation)**. As a side-effect, any attack $(\widehat{\mathbb{C}}_2, \widehat{\mathbb{C}}_3)$ will disappear. This process is recursively applied on $\mathbf{R}^{\mathbf{A}}$ until every attack relation is deactivated. As stated before, the outcome of a grounded semantics could be an empty extension. Such an issue arises when there is a loop in the structures attack graph. To overcome this, if *undefeat* is not verified for any $(\widehat{\mathbb{C}}_1, \widehat{\mathbb{C}}_2) \in \mathbf{R}^{\mathbf{A}}$, then *deactivation* is applied to some active attack. Thus, the loop is broken, and the process determined by applying "$\mathfrak{sem}$" can be reconsidered.

Proposition 2. *Given a* DAF $T \subseteq \mathbb{A}\mathtt{rgs} \times \mathbb{A}\mathtt{rgs}$*, if* $\mathfrak{sem}(T) = \langle \mathbf{U}, \mathbf{A} \rangle$ *then* $\mathbf{R}^{\mathbf{A}} = \emptyset$*.*

4 Ontology Debugging & Change Through the DAF

In order to provide an ontology change model, we will formalize some properties regarding the relation between the DAF here proposed and its related ontology. Such properties are relevant also as a repairing methodology for terminologies, and in general in the area of ontology debugging. In this sense, we will first characterize the different classes of inconsistencies in an ontology.

Given an ontology $\mathcal{O}$, a concept C is *unsatisfiable iff* for each interpretation $\mathcal{I} \in \mathcal{M}(\mathcal{O})$, $C^{\mathcal{I}} = \emptyset$. As stated in [6], an ontology $\mathcal{O}$ is *incoherent iff* there exists an unsatisfiable concept in $\mathcal{O}$. An incoherence may be considered a kind of inconsistency in the TBox. However, the incoherence does not replace the classical meaning of inconsistency, given that an incoherent ontology may admit models. Hence, an ontology $\mathcal{O}$ is *inconsistent iff* it admits no model.

Let "$\mathfrak{ont}$" be a mapping from a DAF $\langle \mathbf{U}, \mathbf{A} \rangle \subseteq \mathbb{A}\mathtt{rgs} \times \mathbb{A}\mathtt{rgs}$ to an $\mathcal{ALC}$ ontology $\mathfrak{ont}(\langle \mathbf{U}, \mathbf{A} \rangle)$, following backwards the intuitions given to obtain a DAF by "$\mathfrak{daf}$". Consistency-coherency of the $\mathfrak{ont}$-outcome is related to the attacks in the DAF by Prop. 3. Such relation along with that in Prop. 2 motivates Lemma 1.

Proposition 3. *Given a* DAF $\langle \mathbf{U}, \mathbf{A} \rangle \subseteq \mathbb{A}\mathtt{rgs} \times \mathbb{A}\mathtt{rgs}$*,* $\mathbf{R}^{\mathbf{A}} = \emptyset$ *iff* $\mathfrak{ont}(\langle \mathbf{U}, \mathbf{A} \rangle)$ *is a consistent-coherent* $\mathcal{ALC}$ *ontology.*

Lemma 1. *Given a* DAF $T \subseteq \mathbb{A}\mathtt{rgs} \times \mathbb{A}\mathtt{rgs}$*,* $\mathfrak{ont}(\mathfrak{sem}(T))$ *specifies a consistent-coherent* $\mathcal{ALC}$ *ontology.*

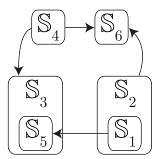
The main contribution of the DAF regarding ontology debugging is sated by Theorem 1, afterwards, Corollary 1 relates that result through "$\mathfrak{af}$" (*c.f.* Sect. 3).

Theorem 1. *Given an $\mathcal{ALC}$ ontology $\mathcal{O}$, if $\mathcal{O}$ is inconsistent and\or incoherent then $\mathtt{ont}(\mathfrak{sem}(\mathfrak{daf}(\mathcal{O})))$ is a consistent-coherent $\mathcal{ALC}$ ontology.*

Corollary 1. *Given an inconsistent-incoherent $\mathcal{ALC}$ ontology $\mathcal{O}$, there exists a consistent-coherent ontology $\mathcal{O}'$, such that $\mathfrak{af}(\mathcal{O}') \subseteq \mathfrak{af}(\mathcal{O})$.*

Example 6. Let $\mathcal{O} = \{A_1 \sqsubseteq B_1 \sqcap B_2,\ A_2 \sqsubseteq A_1 \sqcap \neg B_2,\ A_1(a),\ B_1(a),\ \neg B_2(a),\ A_2(a)\}$ be an $\mathcal{ALC}$ ontology, we want to debug $\mathcal{O}$ to obtain a related consistent-coherent ontology $\mathcal{O}^R$. Applying $\mathfrak{daf}(\mathcal{O})$, a DAF $\langle \mathbf{U}, \mathbf{A} \rangle$, where $\mathbf{U} = \mathbf{A}$ appears:

Statement	Args.
$A_1 \sqsubseteq B_1 \sqcap B_2$	$\{\mathcal{B}_1, \mathcal{B}_2\}$
$A_2 \sqsubseteq A_1 \sqcap \neg B_2$	$\{\mathcal{B}_3, \mathcal{B}_4\}$
$A_1(a)$	$\{\mathcal{B}_5\}$
$B_1(a)$	$\{\mathcal{B}_6\}$
$\neg B_2(a)$	$\{\mathcal{B}_7\}$
$A_2(a)$	$\{\mathcal{B}_8\}$



$$\left\{ \begin{array}{l} \mathcal{B}_1 = \langle \{A_1(x)\}, B_1(x) \rangle \\ \mathcal{B}_2 = \langle \{A_1(x)\}, B_2(x) \rangle \\ \mathcal{B}_3 = \langle \{A_2(x)\}, A_1(x) \rangle \\ \mathcal{B}_4 = \langle \{A_2(x)\}, \neg B_2(x) \rangle \\ \mathcal{B}_5 = \langle \{\}, A_1(a) \rangle \\ \mathcal{B}_6 = \langle \{\}, B_1(a) \rangle \\ \mathcal{B}_7 = \langle \{\}, \neg B_2(a) \rangle \\ \mathcal{B}_8 = \langle \{\}, A_2(a) \rangle \end{array} \right\}$$

Consider the structures $\mathbb{S}_1 = \{\mathcal{B}_3, \mathcal{B}_2\}$, $\mathbb{S}_2 = \{\mathcal{B}_8\} \cup \mathbb{S}_1$, $\mathbb{S}_3 = \{\mathcal{B}_8, \mathcal{B}_4\}$, and $\mathbb{S}_4 = \{\mathcal{B}_5, \mathcal{B}_2\}$; and the primitive structures $\mathbb{S}_5 = \{\mathcal{B}_4\}$ and $\mathbb{S}_6 = \{\mathcal{B}_7\}$.Assuming $\mathcal{B}_2 \succcurlyeq \mathcal{B}_4$ and $\mathcal{B}_2 \succcurlyeq \mathcal{B}_7$, the attack relation set is $\mathbf{R} = \{(\{\mathbb{S}_1\}, \{\mathbb{S}_5\}),\ (\{\mathbb{S}_2\}, \{\mathbb{S}_6\}),\ (\{\mathbb{S}_4\}, \{\mathbb{S}_6\}),\ (\{\mathbb{S}_4\}, \{\mathbb{S}_3\})\}$ (see the graph depicted above). Note that $(\{\mathbb{S}_2\}, \{\mathbb{S}_3\})$ is not in $\mathbf{R}$ given that $\mathbb{S}_1 \trianglelefteq \mathbb{S}_2$, $\mathbb{S}_5 \trianglelefteq \mathbb{S}_3$, and $(\{\mathbb{S}_1\}, \{\mathbb{S}_5\}) \in \mathbf{R}$ (*c.f.* Def. 9).

The acceptability analysis determines $\mathbb{S}_3$, $\mathbb{S}_5$, and $\mathbb{S}_6$ to be deactivated, and since $\mathbb{S}_5 \trianglelefteq \mathbb{S}_3$, deactivating $\mathcal{B}_4$ and $\mathcal{B}_7$ is enough. Afterwards, $\mathfrak{sem}(\mathfrak{daf}(\mathcal{O}))$ determines the new set of active arguments $\{\mathcal{B}_1, \mathcal{B}_2, \mathcal{B}_3, \mathcal{B}_5, \mathcal{B}_6, \mathcal{B}_8\}$. Finally, following the table above, the operation $\mathtt{ont}(\mathfrak{sem}(\mathfrak{daf}(\mathcal{O})))$ constructs the repaired ontology $\mathcal{O}^R = \{A_1 \sqsubseteq B_1 \sqcap B_2,\ A_2 \sqsubseteq A_1,\ A_1(a),\ B_1(a),\ A_2(a)\}$.

Note that, assuming $\mathcal{B}_7 \succcurlyeq \mathcal{B}_2 \succcurlyeq \mathcal{B}_4$, conflicts involving $\mathbb{S}_6$ are inverted leading to $(\{\mathbb{S}_6\}, \{\mathbb{S}_2\})$ and $(\{\mathbb{S}_6\}, \{\mathbb{S}_4\})$. In such a case, only $\mathcal{B}_2$ would be deactivated.

In the sequel, we propose an ontology change operator "$\mathfrak{C}$" for $\mathcal{ALC}$ ontologies wrt. a consistent-coherent ontology X. Afterwards, its rationality is analyzed.

Definition 11 (Ontology Change Operation). *Let $\mathcal{O}$ and X be two $\mathcal{ALC}$ ontologies, where X is consistent-coherent. The **ontology change operator** "$\mathfrak{C}$" is defined as $\mathfrak{C}^{\mathcal{O}}(X) = \mathtt{ont}(\mathfrak{sem}(\mathfrak{daf}(\mathcal{O} \cup X)))$.*

A prioritized approach of change is assumed given that each piece of knowledge from X is considered the ultimate perception of the world, consequently, X will be fully accepted in the evolved ontology $\mathfrak{C}^{\mathcal{O}}(X)$. In this sense, $\mathcal{X} \succcurlyeq \mathcal{B}$ is assumed for any argument $\mathcal{X}$ determined from X, and any $\mathcal{B}$ from $\mathcal{O}$. Afterwards, if $\mathcal{X}$ appears in some conflicting coalition, the function "$\mathfrak{sem}$" will deactivate some other $\mathcal{B}$ involved in the attack. Since X is required to be consistent-coherent, the previous statement is verified given that no pair of arguments from X will be in direct conflict. Finally, every argument generated from X will be kept active.

Example 7. Let $\mathcal{O} = \{R(a,b),\ R(b,c),\ R(c,d),\ A(a),\ \neg A(c),\ \neg A(d)\}$ be an ontology where R and A stand for "supervised-by" and "researcher", respectively. Now suppose that a new regulation poses that no academic researcher might be supervised by a non-researcher. Therefore, we would need to provoke the ontology to evolve by an operation $\mathfrak{C}^{\mathcal{O}}(X)$, where $X = \{A \sqsubseteq \forall R.A\}$.

Applying $\mathfrak{daf}(\mathcal{O} \cup X)$, the DAF $\langle \mathbf{U}, \mathbf{A} \rangle$ is determined as $\mathbf{U} = \mathbf{A} = \{\mathcal{B}_1, \mathcal{B}_2, \mathcal{B}_3, \mathcal{B}_4, \mathcal{B}_5, \mathcal{B}_6, \mathcal{X}_1\}$, where $\mathcal{B}_1 = \langle \{\}, R(a,b) \rangle$, $\mathcal{B}_2 = \langle \{\}, R(b,c) \rangle$, $\mathcal{B}_3 = \langle \{\}, R(c,d) \rangle$, $\mathcal{B}_4 = \langle \{\}, A(a) \rangle$, $\mathcal{B}_5 = \langle \{\}, \neg A(c) \rangle$, $\mathcal{B}_6 = \langle \{\}, \neg A(d) \rangle$, $\mathcal{X}_1 = \langle \{A(x)\}, (\forall R.A)(x) \rangle$.

Since the new information is prioritized it follows $\mathcal{X}_1 \succcurlyeq \mathcal{B}_i$, $i \in \{1, \ldots, 6\}$. The argumental structure $\mathbb{S}_1 = \{\mathcal{B}_4, \mathcal{X}_1\}$ appears. Later on, the set $\widehat{\mathcal{C}}_1 = \{\mathcal{X}_1, \mathcal{B}_1\}$ is a supporting-coalition of $\mathcal{X}_1$ through $A(b)$, $\widehat{\mathcal{C}}_2 = \{\mathcal{X}_1, \mathcal{B}_2\}$ is a supporting-coalition of $\mathcal{X}_1$ through $A(c)$, and $\widehat{\mathcal{C}}_3 = \{\mathcal{X}_1, \mathcal{B}_3\}$ is a supporting-coalition of $\mathcal{X}_1$ through $A(d)$. Hence, the schematic structures $\mathbb{S}_2 = \{\mathcal{X}_1, \mathcal{B}_1\}$, $\mathbb{S}_3 = \{\mathcal{X}_1, \mathcal{B}_2\}$, and $\mathbb{S}_4 = \{\mathcal{X}_1, \mathcal{B}_3\}$, appear with claims $\mathfrak{cl}(\mathbb{S}_2) = (\forall R.A)(b)$, $\mathfrak{cl}(\mathbb{S}_3) = (\forall R.A)(c)$, and $\mathfrak{cl}(\mathbb{S}_4) = (\forall R.A)(d)$; and premises $\mathfrak{pr}(\mathbb{S}_2) = A(a)$, $\mathfrak{pr}(\mathbb{S}_3) = A(b)$, and $\mathfrak{pr}(\mathbb{S}_4) = A(c)$. Thus, appear the related argumental structures $\mathbb{S}_5 = \{\mathcal{B}_4, \mathcal{X}_1, \mathcal{B}_1\}$, $\mathbb{S}_6 = \{\mathcal{B}_4, \mathcal{X}_1, \mathcal{B}_1, \mathcal{B}_2\}$, and $\mathbb{S}_7 = \{\mathcal{B}_4, \mathcal{X}_1, \mathcal{B}_1, \mathcal{B}_2, \mathcal{B}_3\}$, where $\mathbb{S}_2 \trianglelefteq \mathbb{S}_5$, $\mathbb{S}_3 \trianglelefteq \mathbb{S}_6$, and $\mathbb{S}_4 \trianglelefteq \mathbb{S}_7$, as well as $\mathbb{S}_5 \trianglelefteq \mathbb{S}_6$, and $\mathbb{S}_6 \trianglelefteq \mathbb{S}_7$. Note also that, $\mathbb{S}_1$ is sub-structure of $\mathbb{S}_5$, $\mathbb{S}_6$, and $\mathbb{S}_7$.

Consider now the coalitions of structures $\widehat{\mathbb{C}}_1 = \{\{\mathcal{B}_2\}, \{\mathcal{B}_5\}\}$, and $\widehat{\mathbb{C}}_2 = \{\{\mathcal{B}_3\}, \{\mathcal{B}_6\}\}$. The following attack relations appear: $\{\mathbb{S}_5\}\mathbf{R}\widehat{\mathbb{C}}_1$ and $\{\mathbb{S}_6\}\mathbf{R}\widehat{\mathbb{C}}_2$ (refer to Fig. 2). Later on, considering also the coalitions of structures $\widehat{\mathbb{C}}_3 = \{\mathbb{S}_5, \{\mathcal{B}_2\}\}$, and $\widehat{\mathbb{C}}_4 = \{\mathbb{S}_6, \{\mathcal{B}_3\}\}$, attacks $\widehat{\mathbb{C}}_3\mathbf{R}\{\{\mathcal{B}_5\}\}$ and $\widehat{\mathbb{C}}_4\mathbf{R}\{\{\mathcal{B}_6\}\}$ appear.

The acceptability analysis determines coalitions $\widehat{\mathbb{C}}_1$, $\widehat{\mathbb{C}}_2$, $\{\{\mathcal{B}_5\}\}$, and $\{\{\mathcal{B}_6\}\}$ to deactivate. Later on, the deactivation of $\mathcal{B}_5$ and $\mathcal{B}_6$ deactivates every attack. Afterwards, $\mathfrak{sem}(\mathfrak{daf}(\mathcal{O} \cup X))$ determines the set of active arguments as $\{\mathcal{B}_1, \mathcal{B}_2, \mathcal{B}_3, \mathcal{B}_4, \mathcal{X}_1\}$. Finally, the operation $\mathfrak{ont}(\mathfrak{sem}(\mathfrak{daf}(\mathcal{O} \cup X)))$ constructs the evolved ontology $\mathcal{O}^R = \{A \sqsubseteq \forall R.A,\ R(a,b),\ R(b,c),\ R(c,d),\ A(a)\}$.

Assuming also $\mathcal{B}_5 \succcurlyeq \mathcal{B}_2$ and $\mathcal{B}_6 \succcurlyeq \mathcal{B}_6$, $\{\{\mathcal{B}_5\}\}\mathbf{R}\widehat{\mathbb{C}}_3$ and $\{\{\mathcal{B}_6\}\}\mathbf{R}\widehat{\mathbb{C}}_4$ appear along with the attacks from Fig. 2. Hence, only $\mathcal{B}_2$ and $\mathcal{B}_3$ would be deactivated.

In the last few years, different ontology change operations have been proposed usually along with some characterization for its rationality. Some examples may be found in [15,16,14,12]. Particularly, in [6], a set of rationality postulates is analyzed abstracting away from the definition of any change operation. In this work, we analyze the model of change proposed wrt. the following general set of basic postulates for an ontology change operation $\mathcal{O} * X$.

($\mathcal{O} * 1$) $X \subseteq \mathcal{O} * X$.
($\mathcal{O} * 2$) If $\mathcal{O} \cup X$ is consistent-coherent then $\mathcal{O} * X = \mathcal{O} \cup X$.
($\mathcal{O} * 3$) If X is consistent-coherent then $\mathcal{O} * X$ is consistent-coherent.
($\mathcal{O} * 4$) If $X \cong Y$ then $\mathcal{O} * X \cong \mathcal{O} * Y$ (assuming "$\cong$" as logically equivalent to).
($\mathcal{O} * 5$) $\mathcal{O} * X \subseteq \mathcal{O} \cup X$.

Properties ($\mathcal{O}*1$) to ($\mathcal{O}*4$) are adapted from the revision postulates proposed in [6] which in turn follow the original basic AGM postulates for revision exposed in [1]. Besides, ($\mathcal{O} * 5$) is adapted from [9].

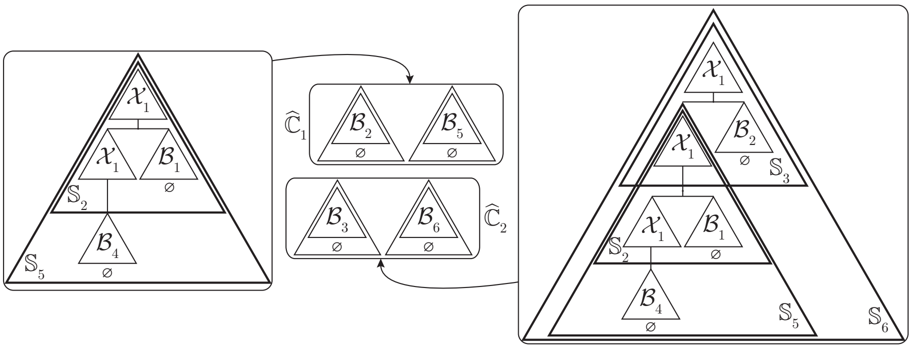


Fig. 2. Some attacks from Ex. 7. Multiple occurrences of an argument within a structure refer to its different instances determined by every possible variable substitution.

Lemma 2. *Given two ontologies $\mathcal{O}$ and X, and assuming $\mathfrak{C}^{\mathcal{O}}(X)$ as $\mathcal{O} * X$:*

a) If $\mathcal{O}$ and X conform the $\mathcal{ALC}^{\mathbb{A}\mathtt{rgs}}$ DL then "$\mathfrak{C}$" satisfies $(\mathcal{O} * 1)$ *to* $(\mathcal{O} * 5)$.
b) If $\mathcal{O}$ and X conform the $\mathcal{ALC}$ DL then "$\mathfrak{C}$" satisfies $(\mathcal{O} * 1)$ *to* $(\mathcal{O} * 4)$.

As stated by Lemma 2*b*), "$\mathfrak{C}$" fails to satisfy $(\mathcal{O} * 5)$ for $\mathcal{ALC}$ ontologies. For instance, assume two $\mathcal{ALC}$ ontologies $\mathcal{O} = \{A \sqsubseteq B_1 \sqcap B_2, A(a)\}$, and $X = \{\neg B_1(a)\}$. If assertional loss is required to be avoided, then we prefer (via "$\succcurlyeq$") evidential arguments over any other argument. Finally, the evolved ontology would end up as $\mathfrak{C}^{\mathcal{O}}(X) = \{A \sqsubseteq B_2, A(a), \neg B_1(a)\}$.

Proposition 4. *Given the $\mathcal{ALC}$ ontologies $\mathcal{O}$, and X, "$\mathfrak{af}$" is distributable wrt. the ontology change operator "$\mathfrak{C}$". That is,* $\mathfrak{af}(\mathfrak{C}^{\mathcal{O}}(X)) = \mathfrak{C}^{\mathfrak{af}(\mathcal{O})}(\mathfrak{af}(X))$.

Since every $\mathcal{ALC}$ ontology $\mathcal{O}$ can be translated into an equivalent $\mathcal{ALC}^{\mathbb{A}\mathtt{rgs}}$ $\mathfrak{af}(\mathcal{O})$ (*c.f.* Prop. 1), Theorem 2 captures the change operator "$\mathfrak{C}$" in a rational manner by means of $(\mathcal{O} * 1)$ to $(\mathcal{O} * 5)$, Theorem 1, Lemma 2, and Prop. 4.

Theorem 2. *Given the $\mathcal{ALC}$ ontologies $\mathcal{O}$, and X, an ontology change operator "$\mathfrak{C}$" satisfies* $(\mathcal{O} * 1)$ $(\mathcal{O} * 5)$ *through "$\mathfrak{af}$" iff* $\mathfrak{af}(\mathfrak{C}^{\mathcal{O}}(X)) = \mathfrak{af}(\mathcal{O}) * \mathfrak{af}(X)$.
Finally, "$\mathfrak{C}$" is said to be ***rational through argumental-DL form****.*

5 Related and Future Work

Debugging of terminologies is usually focused on the recognition of sources of concept-unsatisfiability. In this sense, the union of conflictive coalitions of structures presented in this work, may be related to constructions like Kernel Sets [8] or, *minimal inconsistent preserving sub-terminologies* (MIPS) [20], which have been previously used in ontology debugging [19] and change [14]. MIPS may be also related to works in ontology integration [10], and debugging like [11], where *maximally concept-satisfiable subsets* (MCSS) were proposed for that matter.

As minimal sets inferring $\perp$, kernel sets are also similar to the union of conflictive coalitions of structures. Moreover, in works like [16,14,12], incision functions are used to cut the appropriate piece of knowledge from every kernel such that they do not appear in the evolved ontology. In that sense, the function "$\mathfrak{sem}$" deactivates the appropriate argument from each attack in order to deactivate every possible argument conflict from the $\mathtt{DAF}$, just like incision functions do.

As stated before, further implementations of the model here presented could be done (1) as a module to be incorporated to the DL reasoner, or (2) as a DL-argumentation reasoner. For the second option, a DL reasoner based on argumentation could be an interesting alternative to those like RACER, FaCT, and FaCT++. An approach relying on defeasible logic to enrich ontologies with argumentation is presented in [21], but our proposal differs in that we abstract away from the logic to specify arguments, and also in the argumentation framework and machinery proposed to handle ontology dynamics. A dynamic argumentative approach could decide "on the fly" what to keep or discard from different sources without applying any changes to them. Moreover, an ontology may keep inconsistencies leaving its resolution up to the argumentation process, that is, the ontology reasoner would manage to dynamically handle inconsistency.

It also seems interesting to further investigate this proposal from a theoretical point of view. This would allow, to relate it to other approaches of ontology change like [15,16,14,12], and even to investigate the existence of equivalences regarding other models of change beyond the scope of the semantic web, like the classical AGM model [1]. To this matter, works like [7,5] should be considered. In this sense, since the approach here presented was constructed as an extension of widespread accepted argumentation methodologies [4], it could benefit from previous results in that area. Moreover, a preliminary abstract $\mathtt{DAF}$ was presented in [17], and formalized in detail in [18]. Besides, a model of change in argumentation systems was recently proposed in [17], known as Argument Theory Change, and reified to defeasible logic programming in [13], meaning that properties and methodologies from that model of change could also be adapted to the model here proposed, and even implemented.

As mentioned before, the grounded semantics [4] could return empty extensions. For instance, refer to Ex. 6 assuming an empty comparison criterion "$\succcurlyeq$". Thus, the usage of different semantics [3] could be studied to overcome this issue.

6 Conclusion

A novel theoretical approach to handle ontology debugging through argumentation was presented. Such approach manages ontology dynamics by proposing an ontology change operator along with a characterization for its rationality.

The methodology here proposed was deemed as theoretical given the complexity to translate ontologies into a $\mathtt{DAF}$. In this sense, we claimed this proposal to be a starting point to two different practical approaches: a specialized ontology reasoner based on argumentation, and the theoretical model at issue. The former case exposes an interesting proposal to incorporate to the semantic web the most characteristic feature of argumentation reasoners: to keep inconsistency while managing to reason on top of it.

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