A Dynamic Argumentation Framework

Nicolás D. ROTSTEIN[1], Martín O. MOGUILLANSKY,
Alejandro J. GARCÍA, Guillermo R. SIMARI
National Research Council (CONICET), AI R&D Lab (LIDIA)
Department of Computer Science and Engineering (DCIC)
Universidad Nacional del Sur (UNS), Argentina
e-mail: nico.rotstein@abdn.ac.uk, {mom, ajg, grs}@cs.uns.edu.ar

Abstract. This article introduces the notion of dynamics for abstract argumentation frameworks. We consider evidence as the basis from which arguments may be considered valid. The proposed Dynamic Argumentation Framework (DAF) is a refinement of Dung's abstract framework (AF), enriched with additional features. Since an instance of a DAF is equivalent to an AF, the former could be viewed as a template to build different AFs, applying the same knowledge to different situations. This equivalence is important, as we can take advantage of the vast amount of study on argumentation semantics for AFs to apply it to our approach. The DAF's aim is to provide a well-structured knowledge representation tool that allows for the definition of dynamics-aware argumentation-based systems.

1. Introduction and Background

In this article we present a new abstract argumentation framework, the Dynamic Argumentation Framework (DAF), capable of dealing with dynamics through the consideration of a varying set of evidence. Depending on the contents of the set of evidence, an instance of the framework will be determined, in which some arguments hold and others do not. The extended formalisation, which is coherent with classical abstractions, will provide the opportunity to tackle new problems and applications involving dynamics, in a natural manner. Lately, frameworks for abstract argumentation have gained wide acceptance, and are the basis for the implementation of concrete formalisms. The original proposal by Dung [7] defines an abstract framework along with several notions of acceptability of arguments. Since then, many extensions were introduced to enrich this approach, not only by defining new semantics (*i.e.*, ways of accepting arguments) [2], but also by adding properties to the framework [8,14], thus broadening the field of application of the original contribution. The objective of this paper is thus two-fold: to extend the existing theory, but also to enrich current abstract models.

The DAF's purpose is to extend the usual representational capabilities of argumentation in order to model knowledge dynamics in a proper way. So far the DAF has proved to be appropriate as the basis for "argument theory change", an argumentation-based model of change that incorporates concepts from belief revision into the field of argu-

[1]Employed by the University of Aberdeen (Scotland, UK) for dot.rural Digital Economy Research, under the RCUK Digital Economy Programme, `http://www.dotrural.ac.uk`

mentation [9,11]. Similarly, ongoing work constitutes the DAF being used as the foundation to formalise dialogue, which can be implemented as an argumentation framework common to all participants. As will be clear throughout the article, the DAF allows to cope with the progression of the dialogue, providing simple operations to incorporate new arguments and conflicts, as well as to change preferences. These modifications could be triggered by the dialogue itself.

The framework defined here is a refinement of Dung's, and takes a step forward into a not-so-abstract form of argumentation. In the literature, an argument is treated as an indivisible entity that suffices to support a claim; here arguments are also indivisible, but they play a smaller role: they are aggregated into structures. These *argumental structures* can be thought as if they were arguments (in the usual sense), but we will see that they do not always guarantee the actual achievement of a claim. We will explicitly distinguish a set of premises and a claim in each argumental structure. The consideration of these features (*i.e.*, premises, inference and claim) has been part of the literature on logic and argumentation from the early stages of the area (see [12,13] and more recently in [5]). Finally, an equivalence to Dung's classical framework is provided through what we call the *active instance* of the DAF. In this way, instead of presenting a particular formalisation for argumentation semantics, we reutilise the results achieved in the literature.

2. Arguments, Argumental Structures

In this section we give the preliminary definitions from which the dynamic framework can be built, namely evidence, argument, and argumental structures.

2.1. Evidence and Arguments

Arguments are pieces of reasoning that provide backing for a *claim* from a set of *premises*. In argumentation theory, it is usually assumed that these premises (thus, the arguments they belong to) always hold, since frameworks show a snapshot of what is happening. However, as we are defining a dynamic system, it is natural to consider that evidence is in continuous change, therefore some premises could be eventually unsatisfied. We must distinguish between what we call *active* and *inactive* arguments. An argument is deemed as active if it is capable of achieving its claim. This depends on whether the argument's premises are satisfied, *i.e.*, available either as *evidence* or claims of other active arguments. The difference is that evidence is beyond discussion, whereas an argument's claim could be dismissed if that argument is defeated. On this matter, a piece of evidence could be considered as a claim supported by an "empty" argument, or it could be treated separately, as a unique entity. In this article, we choose the latter option; although we accept that the notion of evidence could be related to that of a claim, we also believe it represents a different concept. If, for instance, an argument is devised to represent that a reason for a sentence α holds with no support for it, an "empty" argument for α may be used. Such an argument could be thought as a *presumption*.

Evidence, premises and claims are assumed to belong to a common domain, an abstract language "$\mathfrak{L}$". A similar argumentation framework (without capabilities for handling dynamics) considering $\mathfrak{L}$ as first-order logic was introduced in [10]. Throughout this article, we will assume sentences in $\mathfrak{L}$ as literals, and use the complement notation to express contradictory literals such as α and $\overline{\alpha}$. As said before, an argument's premises provide backing for the claim, however, this does not mean that the claim is inferred (or entailed) from its premises. In turn, an argument is considered an indivisible reasoning step, abstracting away from the concrete connection behind premises and claim.

When speaking of a *set of evidence*, we will assume that it is a consistent set of sentences in $\mathfrak{L}$ representing the current state of the world. Evidence is considered an indivisible and self-conclusive piece of knowledge that could come, for instance, from perception or communication, or might be just an agent's own knowledge (*e.g.*, its role). As stated before, evidence "triggers" some arguments, rendering them active.

Definition 1 (Argument) *Given a language $\mathfrak{L}$, an **argument** $\mathcal{A}$ is a reasoning step for a claim $\alpha \in \mathfrak{L}$ from a set of premises $\{\beta_1, \ldots, \beta_n\} \in 2^{\mathfrak{L}}$ such that $\beta_i \neq \alpha, \beta_i \neq \overline{\alpha}, \beta_i \neq \overline{\beta_j}$, for every $i, j, 1 \leq i, j \leq n$.*

Given an argument $\mathcal{A}$, we will identify both its claim and set of premises through the functions $\mathsf{cl}(\mathcal{A})$ and $\mathsf{pr}(\mathcal{A})$, respectively. Given $\mathsf{pr}(\mathcal{A}) = \{\beta_1, \ldots, \beta_n\}$ and $\mathsf{cl}(\mathcal{A}) = \alpha$, the *interface* of $\mathcal{A}$ is denoted as the pair $\langle\{\beta_1, \ldots, \beta_n\}, \alpha\rangle$.

Example 1 *Assume an argument $\mathcal{A}$ for considering a route as being dangerous (noted 'dr') because there are known thieves in that area ('th') and security there is poor ('ps'); the interface of $\mathcal{A}$ is $\langle\{th, ps\}, dr\rangle$. Consider also an argument $\mathcal{B}$ saying that underpaid cops might provide poor security; the interface of $\mathcal{B}$ is $\langle\{upc\}, ps\rangle$.*

The notion of conflict is central in any argumentation system, and the DAF will be provided with a set containing every pair of conflicting arguments. Since the domain $\mathfrak{L}$ could include positive and negative sentences, some conflicts will automatically belong to such a set, as formalised in Def. 2. However, the conflict relation should allow for conflicts beyond the ones that are syntactically distinguishable. For instance, arguments for *go_right* and *go_left* could be declared as conflicting, rather than building artificial arguments to derive the negation of the other's claim.

Definition 2 (Conflict between Arguments) *Given a set $Args$ of arguments, the set $\bowtie\ \subseteq Args \times Args$ denotes a **conflict relation** over $Args$, verifying $\bowtie\ \supseteq \{(\mathcal{A}, \mathcal{B}) \mid \mathcal{A}, \mathcal{B} \in Args,$ and either $\mathsf{cl}(\mathcal{A}) = \overline{\mathsf{cl}(\mathcal{B})}$ or $\overline{\mathsf{cl}(\mathcal{A})} \in \mathsf{pr}(\mathcal{B})\}$.*

Pairs representing conflicts between arguments model a symmetrical relation, *i.e.*, $(\mathcal{A}, \mathcal{B}) = (\mathcal{B}, \mathcal{A})$; in the examples only one of these pairs will be indicated. Following Def. 2, we will consider not only arguments whose claims/premises are syntactically in conflict, but also those specified by the knowledge engineer.

The following definition imposes conditions for an argument to be considered *coherent*. This will prevent fallacious arguments from becoming active. This will be clear next, with the definition for an active argument.

Definition 3 (Coherent Argument) *An argument $\mathcal{A}$ is **coherent** wrt. a set $\mathbf{E}$ of evidence iff $\mathcal{A}$ verifies: **(consistency wrt. E)** $\overline{\mathsf{cl}(\mathcal{A})} \notin \mathbf{E}$; **(non-redundancy wrt. E)** $\mathsf{cl}(\mathcal{A}) \notin \mathbf{E}$.*

Redundant arguments wrt. evidence are not harmful, they just introduce unnecessary information –evidence is beyond discussion and needs no reasons supporting it. In opposition, inconsistent arguments wrt. evidence may be harmful, since they could be activating other arguments, turning that reasoning chain into a fallacy, requiring further restrictions for the construction of valid reasoning chains.

As stated before, the active/inactive status of an argument might involve other arguments: sometimes it is not evidence what will be directly *activating* arguments, but *supporting arguments*, *i.e.*, arguments achieving a premise of others.

Definition 4 (Supporting Argument) *An argument $\mathcal{B}$ is a **supporting argument** of an argument $\mathcal{A}$ iff $\mathsf{cl}(\mathcal{B}) \in \mathsf{pr}(\mathcal{A})$. Let $\mathsf{cl}(\mathcal{B}) = \beta$, then we say that $\mathcal{B}$ supports $\mathcal{A}$ through β.*

Definition 5 (Active Argument) *Given a set $Args$ of arguments and a set $\mathbf{E}$ of evidence, an argument $\mathcal{A} \in Args$ is **active** wrt. $\mathbf{E}$ iff $\mathcal{A}$ is coherent and for each $\beta \in \mathsf{pr}(\mathcal{A})$ either $\beta \in \mathbf{E}$, or there is an active argument $\mathcal{B} \in Args$ that supports $\mathcal{A}$ through β.*

Example 2 *From Ex. 1, given a set of evidence $\mathbf{E}_2 = \{th, upc\}$, then $\mathcal{A}$ is active, because it can be activated by the evidence 'th' and the active (supporting) argument $\mathcal{B}$ for 'ps'. Instead, if we consider a set of evidence $\mathbf{E}_{ps} = \{ps\} \cup \mathbf{E}_2$, then argument $\mathcal{B}$ would be incoherent due to its redundancy wrt. $\mathbf{E}_{ps}$. In contrast, if we consider the set of evidence $\mathbf{E}_{nps} = \{\overline{ps}\} \cup \mathbf{E}_2$, then argument $\mathcal{B}$ will again be incoherent, because it would be inconsistent wrt. $\mathbf{E}_{nps}$. In both cases, $\mathcal{B}$ would not be active because is incoherent. Regarding $\mathcal{A}$, from the set $\mathbf{E}_{ps}$, it becomes active directly from evidence, whereas from the set $\mathbf{E}_{nps}$, it ends up being inactive since its premise 'ps' is left unsupported.*

An argument could be inactive because: it might not have enough evidence and/or active arguments to support it, and/or it might not be coherent. In both cases an inactive argument fails in being a support for reaching its associated claim.

2.2. Argumental Structures

The aggregation of arguments via the support relation needs further formalisation, giving rise to the concept of *argumental structure*. This is a core element of the framework.

Definition 6 (Argumental Structure) *Given a set $Args$ of arguments, an **argumental structure** for a claim α from $Args$ is a tree of arguments Σ verifying:*

1. *The root argument $\mathcal{A}_{top} \in Args$, called **top argument**, is such that $\mathsf{cl}(\mathcal{A}_{top}) = \alpha$, and is noted as $\mathsf{top}(\Sigma)$;*
2. *A **node** is an argument $\mathcal{A}_i \in Args$ such that for each premise $\beta \in \mathsf{pr}(\mathcal{A}_i)$ there is at most one **child** argument in $Args$ supporting $\mathcal{A}_i$ through β.*

Regarding notation for an argumental structure Σ:

- *The set of arguments belonging to Σ is noted as $\mathsf{args}(\Sigma)$.*
- *The set of premises of Σ is: $\mathsf{pr}(\Sigma) = \bigcup_{\mathcal{A} \in \mathsf{args}(\Sigma)}(\mathsf{pr}(\mathcal{A})) \setminus \bigcup_{\mathcal{A} \in \mathsf{args}(\Sigma)}(\mathsf{cl}(\mathcal{A}))$.*
- *The claim of Σ is noted as $\mathsf{cl}(\Sigma) = \alpha$.*

Note that the $\mathsf{pr}(\cdot)$ and $\mathsf{cl}(\cdot)$ functions are overloaded: now they are applied to argumental structures. This is not going to be problematic, since either usage will be rather explicit. It is important to stress that, within an argumental structure, a premise of an argument cannot be supported by more than one argument. Leaves are arguments in which all premises are not supported by any other argument in the argumental structure. From now on, when clear enough, we will refer to argumental structures just as "structures".

The notion of argumental structure is similar to an argument in the argumentation system proposed in [3]. That system uses a propositional knowledge base, and an argument is a pair $\langle \phi, \alpha \rangle$, where ϕ is a minimal consistent set of formulae that derives the sentence α. Set ϕ resembles the set of arguments in an argumental structure of the DAF, and the derivation is analogous to the tree of arguments where premises are supported by either evidence or other arguments. The properties of consistency and minimality will be fulfilled by Def. 8 for a well-formed argumental structure, and Lemma 1 proving the minimality of active argumental structures.

Example 3 *From Ex. 2 we have the argumental structure* Σ_3*, such that* $\mathsf{args}(\Sigma_3) = \{\mathcal{A}, \mathcal{B}\}$*, where its set of premises is* $\mathsf{pr}(\Sigma_3) = \{th, upc\}$ *and its claim is* $\mathsf{cl}(\Sigma_3) = \mathsf{cl}(\mathcal{A}) = dr$.

The definition for an argumental structure is not enough to ensure a sensible knowledge representation, *e.g.*, it allows for contradictory claims in a pair of arguments in the same structure. Next we define what is considered a *well-formed argumental structure*, establishing properties ensuring a sensible knowledge representation, independently from any set of evidence. Hence, all knowledge can be validated, active or not.

Definition 7 (Transitive Support) *Given a set* $Args$ *of arguments, an argument* $\mathcal{A}_i$ ***transitively supports*** *an argument* $\mathcal{A}_k$ *within* $Args$ *iff there is a sequence* $[\mathcal{A}_i, \ldots, \mathcal{A}_k]$ *of arguments in* $Args$ *where* $\mathsf{cl}(\mathcal{A}_j) \in \mathsf{pr}(\mathcal{A}_{j+1})$*, for every* j *such that* $i \leq j \leq k-1$.

Definition 8 (Well-Formed Argum. Structure) *Given a set* $Args$ *of arguments and a conflict relation* $\bowtie$ *over* $Args$*, a structure* $\Sigma \in Args$ *is* ***well-formed*** *wrt.* $\bowtie$ *iff it verifies:*

- ***(Premise Consistency)*** *There are no* $\alpha, \beta \in \mathsf{pr}(\Sigma)$ *such that* $\overline{\alpha} = \beta$*;*
- ***(Consistency)*** *For each argument* $\mathcal{A} \in \mathsf{args}(\Sigma)$ *there is no argument* $\mathcal{B} \in \mathsf{args}(\Sigma)$ *such that* $\mathcal{A} \bowtie \mathcal{B}$*;*
- ***(Non-Circularity)*** *No argument* $\mathcal{A} \in \mathsf{args}(\Sigma)$ *transitively supports an argument* $\mathcal{B} \in \mathsf{args}(\Sigma)$ *if* $\mathsf{cl}(\mathcal{B}) \in \mathsf{pr}(\mathcal{A})$*;*
- ***(Uniformity)*** *If* $\mathcal{A} \in \mathsf{args}(\Sigma)$ *is a child of* $\mathcal{B} \in \mathsf{args}(\Sigma)$ *in* Σ*'s tree and* $\mathcal{A}$ *supports* $\mathcal{B}$ *through* β*, then* $\mathcal{A}$ *is a child of every* $\mathcal{B}_i \in \mathsf{args}(\Sigma)$ *in* Σ*'s tree such that* $\beta \in \mathsf{pr}(\mathcal{B}_i)$*, supporting* $\mathcal{B}_i$ *through* β*.*

The domain of all well-formed argumental structures wrt. $Args$ *and* $\bowtie$ *is denoted as* $\mathfrak{str}_{(Args, \bowtie)}$.

Since a set of evidence is always consistent, a structure with *inconsistent premises* would never become active (see Def. 14). However, as stated above, it is useful to validate also inactive argumental structures, for instance, when performing hypothetical or abductive reasoning. The property of *consistency* invalidates inherently contradictory argumental structures. The requirement of *non-circularity* avoids taking into consideration structures yielding infinite reasoning chains. Finally, the restriction of *uniformity* does not allow heterogeneous support for a premise throughout a structure. These constraints are defined so that we can trust a well-formed structure as a sensible reasoning chain, independently from the set of evidence. The role of the set of evidence is considered by the concept of *active argument*, which is addressed by Def. 14.

Definition 9 (Argumental Substructure) *Given two argumental structures Σ, Σ_i from a set of arguments $Args$, Σ_i is an **argumental substructure** of Σ iff* $\mathsf{args}(\Sigma_i) \subseteq \mathsf{args}(\Sigma)$. *If* $\mathsf{args}(\Sigma_i) \subsetneq \mathsf{args}(\Sigma)$ *then Σ_i is a **proper argumental substructure** of Σ.*

Note that not any subset of the set of arguments of a given structure is a substructure of it. When convenient, argumental substructures will be referred just as "substructures". In the literature, a defeat relation is usually assumed, establishing ordered pairs in which the first component defeats the second one. In the DAF, the defeat relation between argumental structures is obtained through the application of a preference function over conflicting pairs. Conflict is propagated from arguments up to structures, and a preference function determines which argument (supported by the corresponding structure) prevails.

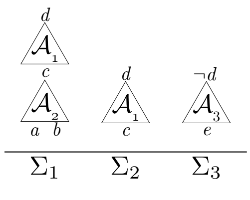
Definition 10 (Conflict between Argumental Structures) *Given a set $Args$ of arguments, a conflict relation $\bowtie$ over $Args$, and two argumental structures $\Sigma_1, \Sigma_2 \in \mathfrak{str}_{(Args,\bowtie)}$, structure Σ_1 is in **conflict** with Σ_2 iff* $\mathsf{top}(\Sigma_1) \bowtie \mathsf{top}(\Sigma_2)$. *Conflict between structures is denoted as "$\asymp$".*

It could be natural to assume that a conflict $\Sigma_1 \asymp \Sigma_2$ should be inherited up to every structure containing Σ_2. However, we are interested in the recognition of the precise argumental structures that are the source of conflict.

Definition 11 (Preference Function) *Given a set $Args$ of arguments, a conflict relation $\bowtie$ over $Args$, and two argumental structures $\Sigma_1, \Sigma_2 \in \mathfrak{str}_{(Args,\bowtie)}$, the **preference function** is $\mathfrak{pref} : \mathfrak{str}_{(Args,\bowtie)} \times \mathfrak{str}_{(Args,\bowtie)} \rightarrow \mathfrak{str}_{(Args,\bowtie)} \cup \{\epsilon\}$ such that $\mathfrak{pref}(\Sigma_1, \Sigma_2) = [\Sigma_1 \mid \Sigma_2 \mid \epsilon]$ determines the preferred argumental structure; if none is preferred, the function returns ϵ.*

The preference function is defined over argumental structures and not over arguments, since, in order to decide which argument prevails, all the knowledge giving support to them should be considered. Moreover, when facing different scenarios, the same argument might be active from different active argumental structures and, consequently, the preference could change along with evidence. In this article no particular preference function will be analysed, in the examples, preferences will be given explicitly.

Example 4



Consider the argumental structures on the right, and assume the conflict relation includes only the pair $(\mathcal{A}_1, \mathcal{A}_3)$ and that the preference function determines: $\mathfrak{pref}(\Sigma_1, \Sigma_3) = \Sigma_1$ and $\mathfrak{pref}(\Sigma_2, \Sigma_3) = \Sigma_3$. For the set of evidence $\{a, b, e\}$, Σ_1 and Σ_3 are active, in conflict, and Σ_1 prevails. If the set of evidence changes to $\{c, e\}$, Σ_1 would be inactive because $\mathcal{A}_2$ becomes redundant wrt. evidence, Σ_2 would turn to active, and Σ_3 remains active. In this case, Σ_3 is preferred to Σ_2. If the preference function had been defined over arguments, this would had been impossible to represent, since there would be no means to model that $\mathcal{A}_1$ is preferred to $\mathcal{A}_3$ at one moment, and that this relation is later on inverted.

Definition 12 (Defeat between Argumental Structures) *Given a set $Args$ of arguments and a conflict relation $\bowtie$ over $Args$, an argumental structure $\Sigma_1 \in \mathfrak{str}_{(Args,\bowtie)}$ **defeats** $\Sigma_2 \in \mathfrak{str}_{(Args,\bowtie)}$ iff there is an argumental substructure Σ_i of Σ_2 such that $\Sigma_1 \asymp \Sigma_i$ and $\mathfrak{pref}(\Sigma_1, \Sigma_i) = \Sigma_1$. The structures defeat relation is denoted as "$\Rightarrow$".*

When a structure defeats another, the attack comes from the claim of the former to any claim of a substructure of the latter. The attack is not directed to an argument, but to a substructure, which is the actual portion of the structure under attack.

3. The Dynamic Argumentation Framework

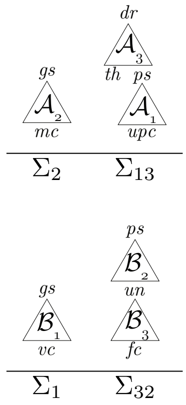
We have built our approach as a refinement of Dung's argumentation framework [7] (from now on, simply "AF"). This framework is defined as a pair containing a set of arguments and a defeat relation ranging over pairs of them. The objective of our approach is to extend this theory to handle dynamics. To cope with this, we consider a set of available evidence, which determines which arguments can be used to make inferences. In Dung's approach, the consideration of a changing set of arguments would involve passing from a framework to another, but how do these frameworks relate to one another? As explained later, they could be considered as instances of a more general framework.

Definition 13 (Dynamic Argumentation Framework (DAF)) *A* ***DAF*** *is a tuple* $\langle \mathbf{E}, \mathbf{W}, \bowtie, \mathfrak{pref} \rangle$*, composed by a set* $\mathbf{E}$ *of evidence, a working set* $\mathbf{W}$ *of arguments, a conflict relation* $\bowtie \subseteq \mathbf{W} \times \mathbf{W}$*, and a preference function* $\mathfrak{pref}$ *defined over* $\mathfrak{str}_{(\mathbf{W},\bowtie)}$.

The *working set of arguments* contains every argument that is available for use by the reasoning process. At a given moment, only the subset of active arguments will represent the current situation. The acquisition or removal of knowledge can be reflected into the working set, which would automatically affect the set of active arguments. Different instances of the set of evidence determine different instances of the DAF. Thus, when "restricting" a DAF to its associated set of evidence, we can obtain an AF in the classical sense, *i.e.*, a pair in which every argument is active, and the attack relation contains pairs of them. This "restriction" is called *active instance*, addressed in Sec. 3.1.

Example 5

Consider the structure of Ex. 3, in which knowing that there are thieves in a place and that cops in that area are underpaid leads us to think that that route is going to be dangerous (noted as 'dr'). Assuming that there are many cops ('mc*') in the location, we have a reason to think that security there is good ('*gs*'). Another argument for this claim is that cops are volunteer ('*vc*'), thus more motivated to do a good job. Nonetheless, if cops are foreigners ('*fc*'), thus unacquainted with the place (*un*), they might give the idea of poor security there ('*ps*'). From this knowledge we can build the structures depicted on the right.*



Thus, we have a DAF $\langle \mathbf{E}_5, \mathbf{W}_5, \bowtie_5, \mathfrak{pref}_5 \rangle$*, where the working set of arguments is* $\mathbf{W}_5 = \{\mathcal{A}_1, \mathcal{A}_2, \mathcal{A}_3, \mathcal{B}_1, \mathcal{B}_2, \mathcal{B}_3\}$*. Let consider a set of evidence* $\mathbf{E}_5 = \{mc, upc, th\}$ *along with an empty attack relation* $\mathbf{R}_5 = \emptyset$*. Then, from set* $\mathbf{W}_5$*, arguments* $\mathcal{A}_1$*,* $\mathcal{A}_2$ *and* $\mathcal{A}_3$ *are active wrt.* $\mathbf{E}_5$*, thus reaching their claims* gs*,* ps *and* dr*. The latter claim is achieved via the argumental structure* Σ_{13}*, whose top argument is* $\mathcal{A}_3$*. The remaining arguments* $\mathcal{B}_1$*,* $\mathcal{B}_2$ *and* $\mathcal{B}_3$ *are inactive, as well as structures* Σ_1 *and* Σ_{32}*, since they have unfulfilled supports wrt.* $\mathbf{E}_5$ *and thus cannot reach their claims.*

3.1. Active Instance of a DAF

A subset of the working set is considered as the *set of active arguments* wrt. the set of evidence. This set will contain those arguments that are to be taken into account to reason in concordance with the current situation: given a DAF $\langle \mathbf{E}, \mathbf{W}, \bowtie, \mathfrak{pref} \rangle$, $\mathbb{A} = \{\mathcal{A} \in \mathbf{W} \mid \mathcal{A}$ is active wrt. $\mathbf{E}\}$. Next we define the notion of *active argumental structure*. This will allow us to recognise those structures that are capable of achieving their claims when considering the current situation.

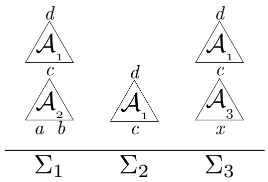
Definition 14 (Active Argumental Structure) *Given a set* $\mathbf{E}$ *of evidence, a well-formed argumental structure* Σ *is **active** wrt.* $\mathbf{E}$ *iff* $\mathsf{pr}(\Sigma) \subseteq \mathbf{E}$ *and every* $\mathcal{A} \in \mathsf{args}(\Sigma)$ *is a coherent argument wrt.* $\mathbf{E}$.

This definition states an important property: the support of an active argumental structure is composed just by evidence. This puts this concept nearer to the notion of active argument, showing that argumental structures can be seen as arguments in the usual way if their inner composition is abstracted away. The definition also requires every argument to be coherent wrt. the set of evidence, therefore some well-formed structures having their support satisfied by evidence will not be active due to some argument being redundant and/or inconsistent wrt. the evidence.

Proposition 1 *If* Σ *is an active argumental structure wrt. a set* $\mathbf{E}$ *of evidence, then every argument in* $\mathsf{args}(\Sigma)$ *is an active argument wrt.* $\mathbf{E}$.

Proofs were left out of this presentation due to the lack of space. Note that the reverse of this proposition is not true, as shown in the following example.

Example 6 *Consider the set of evidence* $\mathbf{E}_6 = \{a, b\}$*, and three structures* Σ_1, Σ_2 *and* Σ_3 *such that* $\mathsf{args}(\Sigma_1) = \{\mathcal{A}_1, \mathcal{A}_2\}$, $\mathsf{args}(\Sigma_2) = \{\mathcal{A}_1\}$, $\mathsf{args}(\Sigma_3) = \{\mathcal{A}_1, \mathcal{A}_3\}$*, where* $\mathcal{A}_1 = \langle \{c\}, d \rangle$, $\mathcal{A}_2 = \langle \{a, b\}, c \rangle$ *and* $\mathcal{A}_3 = \langle \{x\}, c \rangle$*, as shown on the right. From* $\mathbf{E}_6$, Σ_1 *is active, but* Σ_2 *and* Σ_3 *are not. Note that both* Σ_1 *and* Σ_2 *contain active arguments, but this condition does not ensure them to be active.*



Ex. 6 shows that, in a way, argumental structures have to be "complete" in order to be active. That is, they must include all the necessary arguments for their top argument to be active. Only then the premises of these structures will be satisfied by evidence.

Proposition 2 *Given a set* $\mathbf{E}$ *of evidence, an argument* $\mathcal{A}$ *is active wrt.* $\mathbf{E}$ *iff there exists an active argumental structure* Σ *wrt.* $\mathbf{E}$ *such that* $\mathsf{top}(\Sigma) = \mathcal{A}$.

Note that Prop. 2 allows for an active argument to be top argument of more than one active argumental structure, which is correct, as described in the following example.

Example 7 *Consider Ex. 6, and a set of evidence* $\mathbf{E}_7 = \{a, b, x\}$*. Now both* Σ_1 *and* Σ_3 *are active argumental structures wrt.* $\mathbf{E}_7$ *and have the same top argument.*

Definition 15 (Set of Active Argum. Structures) *Given a DAF* $F = \langle \mathbf{E}, \mathbf{W}, \bowtie, \mathfrak{pref} \rangle$*, the **set of active argumental structures** in* F *wrt.* $\mathbf{E}$ *is the maximal set* $\mathbb{S}$ *of active argumental structures from* F.

Proposition 3 *Given a DAF $F = \langle \mathbf{E}, \mathbf{W}, \bowtie, \mathfrak{pref} \rangle$, the set $\mathbb{A}$ of active arguments in F wrt. $\mathbf{E}$, and the set $\mathbb{S}$ of active structures in F wrt. $\mathbf{E}$, then $\bigcup_{\Sigma \in \mathbb{S}} (\mathsf{args}(\Sigma)) = \mathbb{A}$.*

Argumental structures are minimal in the sense that they include not more than the necessary arguments to determine their top argument is active. This is an important property in an argumentation setting: to prevent superfluous knowledge/information from being able to build a reason for a claim. Additionally, the incorporation of irrelevant arguments to an active structure would weaken it, providing extra points of attack.

Lemma 1 *Given an argumental structure Σ active wrt. a set $\mathbf{E}$ of evidence, there is no argumental structure Σ_i active wrt. $\mathbf{E}$ such that $\mathsf{cl}(\Sigma) = \mathsf{cl}(\Sigma_i)$ and $\mathsf{args}(\Sigma_i) \subsetneq \mathsf{args}(\Sigma)$.*

This lemma states that minimality is a consequence of the definition for an active argumental structure, which requires it to be well-formed.

Definition 16 (Active Defeat Relation) *Given a DAF F, the defeat relation "$\Rightarrow$" over argumental structures, and the set $\mathbb{S}$ of active argumental structures, the **active defeat relation** in F is $\mathbb{R} = \{(\Sigma_1, \Sigma_2) \in \Rightarrow \mid \Sigma_1, \Sigma_2 \in \mathbb{S}\}$.*

Next, we define the *active instance* of a given DAF, which we will show that is equivalent to an AF in the classical sense.

Definition 17 (Active Instance) *Given a DAF $F = \langle \mathbf{E}, \mathbf{W}, \bowtie, \mathfrak{pref} \rangle$, the **active instance** of F is the AF $(\mathbb{S}, \mathbb{R})$, where $\mathbb{S}$ is the set of active argumental structures from $\mathbf{W}$ wrt. $\mathbf{E}$, and $\mathbb{R}$ is the active attack relation between structures in $\mathbb{S}$.*

Every DAF, at any moment, has an associated active instance –an AF. Therefore, all the work done on acceptability of arguments and argumentation semantics can be applied to the DAF here defined, just by finding its active instance the set of accepted argumental structures can be obtained. Moreover, since structures hold a claim, we can go a step further and consider justification of claims, either sceptically or cautiously.

DAFs can be seen as a template for generating multiple AFs representing the same knowledge, applied to different situations. The number of active instances that can be obtained from a single DAF is quite large. Considering that each possible subset of evidence composes a different active instance of the DAF, we have that the amount of active instances is in the order of $2^{|p|}$, where $p = \bigcup_{\mathcal{A} \in \mathbf{W}} (\mathsf{pr}(\mathcal{A}))$ is the set of all premises present in the DAF.

Lemma 2 *The active instance of a DAF is **equivalent** to Dung's definition for an abstract argumentation framework.*

3.2. Updating Evidence, Working Set and Conflicts

Since the set of evidence is dynamic, it defines the particular instance of the DAF that corresponds with the current situation. In order to cope with this, the basic operations performed over a DAF are the *evidence update* and *erasure*. This mechanism should ensure the DAF reflects the new (consistent) state of the world.

Definition 18 (Evidence Update/Erasure) *Given a DAF $\langle \mathbf{E}, \mathbf{W}, \bowtie, \mathfrak{pref} \rangle$, and $\mathbf{E}_1$, a set of evidence such that for every $\beta \in \mathbf{E}_1$, $\overline{\beta} \notin \mathbf{E}$ (resp., $\beta \in \mathbf{E}$). A (multiple) evidence update (resp., erasure) operation is $\langle \mathbf{E} \cup \mathbf{E}_1, \mathbf{W}, \bowtie, \mathfrak{pref} \rangle$ (resp., $\langle \mathbf{E} \backslash \mathbf{E}_1, \mathbf{W}, \bowtie, \mathfrak{pref} \rangle$).*

The evidence update/erasure changes the *instance* of the DAF: it makes the set of active arguments vary. Hence, it could be seen as a form of revision [1]. However, the impact of evidence change in these sets neither performs nor is intended to be a formal revision of the theory whatsoever. Furthermore, evidence change does not modify the representation (or specification) of the knowledge about the world, but what is perceived.

Sometimes it will be mandatory to modify the working set of arguments and/or the current attack relation in order to represent changes in the knowledge specification about the world. Such a re-instantiation could be triggered by an external preference-handling mechanism, or a change operation, such as those described in [9,11]. Next, we define the expansion and contraction of a DAF by an argument, and then the analogous definitions are given for the attack relation.

Definition 19 (Argument Expansion/Contraction) *Given a DAF* $F = \langle \mathbf{E}, \mathbf{W}, \bowtie, \mathfrak{pref} \rangle$, *the result of the* ***expansion*** *(resp.,* ***contraction****) of* F *by an* ***argument*** $\mathcal{A} \notin \mathbf{W}$ *(resp.,* $\mathcal{A} \in \mathbf{W}$*) is the DAF* $\langle \mathbf{E}, \mathbf{W} \cup \{\mathcal{A}\}, \bowtie', \mathfrak{pref} \rangle$ *(resp.,* $\langle \mathbf{E}, \mathbf{W} \setminus \{\mathcal{A}\}, \bowtie', \mathfrak{pref} \rangle$*, where* $\bowtie'$ *is defined over* $\mathbf{W} \cup \{\mathcal{A}\}$ *(resp.,* $\mathbf{W} \setminus \{\mathcal{A}\}$*).*

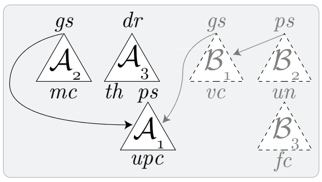
Both the argument expansion and contraction have an impact on the set of conflicts. For instance, the incorporation of a new argument for α could bring about new conflicts with every argument for $\overline{\alpha}$. The opposite occurs when removing an argument: all of its associated conflicts disappear for the DAF to remain well-defined over the new working set. Those conflicts that are not syntactically detectable can be manually added or removed via the following operations.

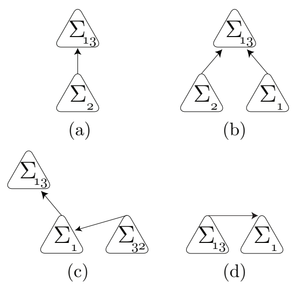
Definition 20 (Conflict Expansion/Contraction) *Given a DAF* $F = \langle \mathbf{E}, \mathbf{W}, \bowtie, \mathfrak{pref} \rangle$, *the result of the* ***expansion*** *(resp.,* ***contraction****) of* F *by a* ***conflict*** $(\mathcal{A}, \mathcal{B})$ *is the DAF* $\langle \mathbf{E}, \mathbf{W}, \bowtie \cup \{(\mathcal{A}, \mathcal{B})\}, \mathfrak{pref} \rangle$ *(resp.,* $\langle \mathbf{E}, \mathbf{W}, \bowtie \setminus \{(\mathcal{A}, \mathcal{B})\}, \mathfrak{pref} \rangle$*), with* $\{\mathcal{A}, \mathcal{B}\} \subseteq \mathbf{W}$.

The argument/conflict expansion/contraction operations allow to change the knowledge represented by the DAF. The argument expansion allows for the addition of a new reason for a certain claim. Analogously, the deletion of a reason is allowed when it is no longer considered as valid. It is important to note that both expansion and contraction of arguments are independent from the availability of evidence, but instead refers to the rationale behind the argument. In the same way, conflicts between arguments can be added/suppressed, since new conflicts can arise, and old conflicts can be no longer justified. (This also is independent from in/active attacks.) Change over the preference function is left out of this article, as it requires just a replacement of the original function.

These operations can be thought as the building blocks for a large number of more complex operations. For instance, the expansion/contraction of a DAF by a framework $(\mathbf{W}, \mathbf{R})$, where defeat pairs in $\mathbf{R}$ are obtained from "$\bowtie$" and $\mathfrak{pref}$. A merge operation between frameworks can be defined, either in a prioritised or non-prioritised fashion. One of the tasks when merging frameworks involves the determination of the new, crossed conflicts that had arisen. The kind of prioritisation would tell how to deal with inconsistency over the union of (1) the sets of evidence, (2) the working sets of arguments. A solution for (1) is to convert the conflicting pieces of evidence (*e.g.*, α) into arguments (*e.g.*, $\langle \{\}, \alpha \rangle$), while for (2) the preference function could be tweaked so that structures containing arguments in the prioritised operand are preferred to the other's. The complete formalisation of this operation is left out due to space reasons. A similar operation is defined in [6], but performed over Dung AFs (where knowledge representation is less complex than in the DAF). There, each AF is associated to an agent and the defeat relation depends on the type of merge: it might contain only those defeats accepted by all agents, or simply the ones they do not reject.

Example 8 *Consider Ex. 5 and the defeat relation* $\{(\mathcal{A}_2, \mathcal{A}_1), (\mathcal{B}_1, \mathcal{A}_1), (\mathcal{B}_2, \mathcal{B}_1)\}$:





The active instance is the AF shown on the right, in (a). If we update the set of evidence by adding knowledge stating that cops are volunteer, we have that Σ_1 *becomes active, as well as its attack against* Σ_{13}*, leaving* Σ_{32} *as the only inactive structure, and* (Σ_{32}, Σ_1) *is the only inactive attack. The active instance of the updated DAF is depicted in (b). Now consider we find out that cops are foreigners and that there are few of them. We make an update of the piece of evidence '*fc*' and an erasure of '*mc*'. This activates* Σ_{32} *and the attack* (Σ_{32}, Σ_1)*, and inactivates* Σ_2 *along with its attack against* Σ_{13}*. This active instance is shown in (c).*
Each active instance yields a particular set of accepted arguments. If we pick the grounded semantics*: the active instance (a) accepts just the structure* Σ_2*; the active instance (b) accepts* Σ_2 *and* Σ_1*; and the active instance (c) accepts* Σ_{32} *and* Σ_{13}*. Therefore, with this semantics, only in the latter scenario we would believe the path we are analyzing to pass through is dangerous.*
Now consider a new scenario, in which argument $\mathcal{B}_3$ *is dismissed due to the risk of being taken as xenophobic (though this was certainly not the intention), and suppose the preference between* $\mathcal{A}_1$ *and* $\mathcal{B}_1$ *is inverted. This means that* $\mathcal{B}_3$ *has to be contracted from the working set of arguments, and that the preference over* $(\mathcal{B}_1, \mathcal{A}_1)$ *has to be inverted. This new active instance is shown in (d).*

4. Conclusions and Future Work

In this article we have presented a new approach to abstract argumentation frameworks. Our model, as many others, is based on Dung's AF and represents an extension that is the basis of several research lines. From the Dynamic Argumentation Framework here defined an active instance can be obtained. This instance was shown to be equivalent to an AF; however, examples have shown that the DAF allows for a more powerful knowledge representation than the AF, by accepting the representation of change at different levels: evidence, arguments, conflicts, and preference. We contend that the DAF also yields a more realistic model, by setting apart evidence from arguments, which represent different kinds of knowledge. Agent architectures using this framework therefore could give an explicitly separate treatment to perception and reasoning. Finally, the equivalence between the active instance of the DAF and the AF is important to make the DAF compatible with the usual argumentation semantics.

Recently, some work has been done on dynamics in argumentation; in [4], the authors propose a series of principles to determine under what conditions an extension does not change when faced to a change in the framework. This article studies another aspect of the dynamics, centred on the impact of change over extensions. In our work, instead, we focus on the knowledge representation, providing constraints to avoid fallacious reasoning chains, and leaving evidence as a separate entity. As future work, results like in [4] will be helpful to provide an improved control of dynamics within the DAF.

Regarding future work, we are also interested in exploring the capability of reasoning about possible situations, and establishing a relation with the area of modal logics. The research line involving the intersection between belief change theory and argumentation will continue benefiting from the results accomplished in this dynamic framework, specially from the formalisation of distinct sources of change. Finally, the next step is to establish the theoretical foundations that relate the DAF with the classical argumentation semantics notions. The main difficulty relies on the acceptance/rejection of substructures wrt. their superstructures; for instance, it is interesting to define under what conditions the acceptance of an argumental structure implies the acceptance of all its substructures, and *vice versa*.

References

[1] Carlos Alchourrón, Peter Gärdenfors, and David Makinson. On the logic of theory change: Partial meet contraction and revision functions. *The Journal of Symbolic Logic*, 50:510–530, 1985.

[2] Pietro Baroni and Massimiliano Giacomin. On principle-based evaluation of extension-based argumentation semantics. *Artificial Intelligence*, 171(10-15):675–700, 2007.

[3] Philippe Besnard and Anthony Hunter. *Elements of Argumentation*. The MIT Press, 2008.

[4] Guido Boella, Souhila Kaci, and Leendert van der Torre. Dynamics in argumentation with single extensions: Abstraction principles and the grounded extension. In *ECSQARU*, pages 107–118, 2009.

[5] C. Chesñevar, J. McGinnis, S. Modgil, I. Rahwan, C. Reed, G. Simari, M. South, G. Vreeswijk, and S. Willmott. Towards an argument interchange format. *Knowl. Eng. Rev.*, 21(4):293–316, 2006.

[6] S. Coste-Marquis, C. Devred, S. Konieczny, M. Lagasquie-Schiex, and P. Marquis. On the merging of Dung's argumentation systems. *Artificial Intelligence*, 171(10-15):730–753, 2007.

[7] Phan Minh Dung. On the Acceptability of Arguments and its Fundamental Role in Nonmonotonic Reasoning, Logic Programming and n-person Games. *AIJ*, 77:321–357, 1995.

[8] Diego Martínez, Alejandro García, and Guillermo Simari. Modelling well-structured argumentation lines. In *IJCAI*, pages 465–470, 2007.

[9] Martín Moguillansky, Nicolás Rotstein, Marcelo Falappa, Alejandro García, and Guillermo Simari. Argument Theory Change Applied to Defeasible Logic Programming. In *AAAI*, pages 132–137, 2008.

[10] Martín Moguillansky, Nicolás Rotstein, Marcelo Falappa, and Guillermo Simari. Generalized abstract argumentation: Handling arguments in FOL fragments. *Symbolic and Quantitative Approaches to Reasoning with Uncertainty*, pages 144–155, 2009.

[11] Nicolás Rotstein, Martín Moguillansky, Marcelo Falappa, Alejandro García, and Guillermo Simari. Argument theory change: Revision upon warrant. In *COMMA*, pages 336–347, 2008.

[12] Stephen Toulmin. *The Uses of Argument*. Cambridge University Press, 1959.

[13] Douglas Walton. *Argument Structure: A Pragmatic Theory (Toronto Studies in Philosophy)*. Univ. of Toronto Press, 1996.

[14] Adam Wyner and Trevor Bench-Capon. Towards an extensible argumentation system. In *ECSQARU*, pages 283–294, 2007.