An Abstract Argumentation Framework for Handling Dynamics

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Abstract

This article introduces the notion of dynamics into the concept of abstract argumentation frameworks, by including the concept of evidence to rule the validity of arguments when considering a particular situation. The proposed formalism is a refinement of Dung's abstract argumentation framework, to which many extensions have been defined. Our claim is that this idea could be enriched by the dynamic theory we are proposing. The main subject of this paper is the definition of the Dynamic Argumentation Framework, from which a static instance can be obtained. This instance is shown to be equivalent to the widely adopted Dung's framework. Therefore, multiple frameworks can be obtained from different instances of a given dynamic framework.

Introduction and Background

In this article we present a new abstract argumentation framework capable of dealing with dynamics through the consideration of a varying set of evidence. Certain configurations of the set of evidence will determine an instance of the framework in which some arguments hold and others do not. The extended formalization, which is coherent with the original abstractions, will provide the opportunity to tackle new problems and applications.

Frameworks for abstract argumentation have gained wide acceptance, and are the basis for the implementation of concrete formalisms (Dung 1995). The original proposal by Dung defines an abstract framework and several notions of acceptability of arguments. Since then, many extensions were introduced to enrich this approach, not only by defining new semantics (*i.e.*, different ways of accepting arguments) (Baroni and Giacomin 2007), but also by adding properties to the framework (Amgoud, Cayrol, and Lagasquie-Schiex 2004; Wyner and Bench-Capon 2007; Martínez, García, and Simari 2007) thus broadening the field of application of the original contribution –a survey about the applications of argumentation can be found in (Bench-Capon and Dunne 2007). Part of the argumentation community is moving in this direction, thus evolving the notion of abstract argumentation framework, which have proven to be suitable to model dialogues, negotiation processes and decision making mechanisms. The combination of argumentation and other disciplines is also under study, like belief revision (Rotstein et al. 2008). The spread of argumentation into the knowledge representation area is very promising, and this article aims to keep up with it by exploring a new line that could contribute to the expansion of the existing subareas. That is, the objective of this article is two-fold: it provides an extension of the existing theory and it also can be used as a base to enrich current abstract models.

In this article, we extend the classic theory of abstract argumentation (Chesñevar, Maguitman, and Loui 2000; Prakken and Vreeswijk 2000) to cope with the dynamics of evidence. The framework defined here is a refinement of Dung's, attempting to take 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, whereas here arguments are also indivisible, but they play a smaller role: they are aggregated in structures. These argumental structures can be thought as if they were arguments (in the usual sense), but they do not always guarantee their actual achievement of the claim. Moreover, in the literature arguments are often considered as completely abstract entities, with no regard about their composition. Here, we not only use arguments to generate structures, but we also explicitly mention a set of premises and a claim within both arguments and structures. The consideration of these features, *i.e.*, premises, inference and claims, has been part of the literature on logic, argumentation, and critical thinking from the early stages of the area (see (Toulmin 1959; Walton 1996) and more recently in (Chesñevar et al. 2006)).

The association of a set of premises to each argument leads us to the consideration of the role of evidence. We rely on the available evidence in order to determine whether arguments actually support their claim; this notion will be translated in terms of argumental structures later on. The study of the variation of the set of evidence and its impact on the status of arguments (*i.e.*, whether they can be used to make inferences) is one of the main contributions of this article, since it is the foundation of the dynamic framework. The other important contribution is the equivalence between Dung's framework and what we call a *static instance* of the DAF. We try to move forward in this direction, provided that "static" argumentation frameworks have been analyzed quite deeply in the last few years, since Dung's seminal work. Although the dynamic framework here proposed is enriched with a number of features, we establish a relation that keeps us close to the results accomplished in the area.

The article is organized in the following way: the next section provides the theoretical elements (some of them adapted from their standard form) in order to define the dynamic framework; the second section gathers the theory previously defined and formalizes the new framework; afterwards, there is a section devoted to ongoing work regarding this research line; finally, the last section summarizes the results achieved in this paper and describes further extensions to the dynamic framework.

Preliminary Definitions

In this section we give the preliminary definitions from which the dynamic framework can be built. First, we define what an argument is, its relation with the set of evidence, and expected behavior. Then, we organize arguments in argumental structures, which provide arguments with a context when speaking of activeness (the actual availability of arguments to perform reasoning).

Argument

Arguments are pieces of reasoning that provide backing for a *claim* from a set of *premises*. These basic premises are considered as the argument's *support*. In the argumentation frameworks 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 some premises could be not satisfied. That is, we should account for what is not happening. Therefore, we must distinguish between what we call *active* and *inactive* arguments. In this article, arguments deemed as active will be those capable of actually achieving their claim. This will depend on whether the argument's premises are satisfied, *i.e.*, available either as *evidence* or claims of other active arguments. 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 believe that the notion of evidence could be related to that of a claim, we also believe it represents a different concept. We could also consider a piece of evidence as a claim that needs no argument; evidence is there, beyond discussion. In contrast to the concept of active argument we introduce the definition of inactive argument as an argument that, in concordance with the current situation, is incapable of achieving its claim.

Given an argument $\mathcal{A}$, we will identify both its claim and support through the functions $\mathtt{cl}(\mathcal{A})$ and $\mathtt{supp}(\mathcal{A})$, respectively. In the same way, given a set $Args$ of arguments, we assume a function returning the set of all the claims in $Args$: $clset(Args) = \{\mathtt{cl}(\mathcal{A}) \mid \mathcal{A} \in Args\}$, and a function returning the set of all the premises in $Args$: $suppset(Args) = \bigcup_{\mathcal{A} \in Args} supp(\mathcal{A})$. Finally, since arguments are representing reasoning steps, we assume them as being *minimal* and *self-consistent*: no premise is the claim itself[1], and the combination of claim plus premises is non-contradictory (see Definition 3). In this article, we say that two sentences are contradictory or inconsistent if they cannot be assumed together.

Definition 1 (Set of Evidence) *A* ***set of evidence*** *is a consistent set of facts representing the current state of the world.*

Evidence is considered an indivisible and self-conclusive piece of knowledge that could come from perception, communication, or might be just agent's own knowledge (*e.g.*, its role). As stated before, evidence "triggers" some arguments, which we will call active. It is important to say that, throughout this article, when we refer to a set of evidence, we assume that it is consistent.

Definition 2 (Argument Support) *Given an argument $\mathcal{A}$ the* ***argument support*** *for $\mathcal{A}$ is a set of premises $\mathtt{supp}(\mathcal{A}) = \{s_1, \ldots, s_n\}$, where each premise s_i can be either evidence or a claim of another argument.*

In what follows, arguments will be noted as a pair, where its first element is the argument's set of premises, and the second one, its claim. For instance, if $\mathtt{supp}(\mathcal{A}) = \{a, b\}$ and $\mathtt{cl}(\mathcal{A}) = y$, we will note this argument as $\mathcal{A} = \langle \{a, b\}, y \rangle$. Once the support and claim of an argument are clear (or when they are irrelevant), arguments will be called just by their name.

Definition 3 (Argument) *An* ***argument*** *$\mathcal{A}$ is a pair $\langle \{s_1, \ldots, s_n\}, \alpha \rangle$, verifying:*

- *$\{s_1, \ldots, s_n, \alpha\}$ is consistent;*
- *there is no $s_i \in \mathtt{supp}(\mathcal{A})$ such that $s_i = \alpha$.*

Example 1 *Assume an argument $\mathcal{A}$ for considering a route as being dangerous because there are known thieves in that area and the security there is poor. Then, we have that $\mathtt{supp}(\mathcal{A}) = \{th, ps\}$ and $\mathtt{cl}(\mathcal{A}) = dr$. Consider also an argument $\mathcal{B}$ saying that underpaid cops might provide poor security; then $\mathtt{supp}(\mathcal{B}) = \{upc\}$ and $\mathtt{cl}(\mathcal{B}) = ps$. These two arguments are depicted as triangles in Figure 1, each with its corresponding set of premises on its base, and the claim on top.*

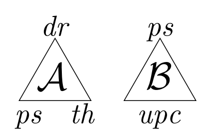


Figure 1: Arguments for dr and ps.

From the definition of argument support, it is clear that a premise of an argument could be "instantiated" in many ways; that is, by evidence or another argument's claim. The latter case gives rise to a larger, more complex structure comprising other arguments. This set of arguments will be called an *argumental structure*, as described in Definition 7.

The active/inactive status of an argument might involve other arguments: sometimes it is not evidence what will be

[1]This is not the usual restriction for minimality, but it is as far as we can go when KR is made through abstract arguments.

directly *activating* arguments, but *supporting arguments* – which are arguments achieving a part of the support of others. That is, an argument could be *activated* by other arguments, rather than by evidence; they, in turn, are to be activated by evidence or by their own supporting arguments, and so on, until the last argument is based solely on evidence.

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

The support of an argument $\mathcal{A}$ could lack some pieces of evidence, but other arguments could provide their claims as if they were evidence, so $\mathcal{A}$ should be considered active. However, there will be conditions for an argument to be considered *coherent*, thus preventing some arguments from becoming active. This will be clear next, with the (recursive) definition for an active argument, but before we introduce the notion of *coherent argument*.

Definition 5 (Coherent Argument) *An argument $\mathcal{A}$ is **coherent** wrt. a set $\mathbf{E}$ of evidence iff $\mathcal{A}$ verifies the following properties:*

- ***(Consistency wrt. E)** An argument $\mathcal{A}$ is **consistent** wrt. $\mathbf{E}$ iff $\mathtt{cl}(\mathcal{A})$ does not contradict any evidence in $\mathbf{E}$.*
- ***(Non-Redundancy wrt. E)** An argument $\mathcal{A}$ is **non-redundant** wrt. $\mathbf{E}$ iff $\mathtt{cl}(\mathcal{A}) \notin \mathbf{E}$.*

Redundant arguments wrt. evidence are not harmful, they just introduce new information that is not going to be useful –since evidence is beyond discussion and needs no reasons supporting it. In opposition, inconsistent arguments wrt. evidence may be harmful, since they could be used to activate other arguments, rendering invalid all that reasoning chain, thus requiring further restrictions in order to allow the construction of valid reasoning chains.

From now on, we will assume that any given argument is coherent wrt. the set of evidence corresponding to the context the argument is immersed into, unless stated otherwise.

Definition 6 (Active Argument) *Given a set $Args$ of arguments, a set $\mathbf{E}$ of evidence, a coherent argument $\mathcal{A} \in Args$ is **active** wrt. $\mathbf{E}$ iff for each $s \in \mathtt{supp}(\mathcal{A})$ either:*

- *$s \in \mathbf{E}$, or*
- *there is an active argument $\mathcal{B} \in Args$ that supports $\mathcal{A}$ through s.*

Example 2 *Consider Example 1. If the set of evidence is $\mathbf{E}_2 = \{th, upc\}$, then $\mathcal{A}$ is active, because it can be activated by the evidence 'th' and the active (supporting) argument $\mathcal{B}$ for 'ps'.*

Example 3 *From Example 2, if we consider a set of evidence $\mathbf{E}_{ps} = \{poor\_security\} \cup \mathbf{E}_2$, then argument $\mathcal{B}$ would be incoherent due to its redundancy wrt. $\mathbf{E}_{ps}$. In contrast, if we consider the set of evidence $\mathbf{E}_{nps} = \{\neg poor\_security\} \cup \mathbf{E}_2$, then argument $\mathcal{B}$ should also 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 E_{ps}, it becomes active directly from evidence, whereas from the set E_{nps}, it ends up being inactive since its premises are left unsupported: although $\mathcal{B}$ achieves 'ps', it is not compliant with the consistency argument constraint.

From what we have defined, an argument could be inactive because: it might not have enough evidence and/or active arguments to support it, and/or it might not comply with at least one constraint. In both cases an inactive argument fails in being a support for reaching its associated claim.

Finally, regarding attacks between arguments, there is a normality condition to be taken into account: for a given set of arguments, it must contain every pair of arguments holding claims in contradiction.

Assumption 1 *Let $Args$ be a set of arguments and $\mathbf{R} \subseteq Args \times Args$, an attack relation. Given two arguments $\{\mathcal{A}, \mathcal{B}\} \subseteq Args$, $\mathcal{A} = \langle\{\cdot\}, c_1\rangle$, $\mathcal{B} = \langle\{\cdot\}, c_2\rangle$, if c_1 and c_2 are in contradiction, then $\mathcal{A}\mathbf{R}\mathcal{B}$ or $\mathcal{B}\mathbf{R}\mathcal{A}$.*

Argumental Structures

The aggregation of arguments via the support relation needs further formalization, giving rise to the concept of *argumental structure*. Next, we will introduce this core element.

Definition 7 (Argumental Structure) *Given a set $Args$ of arguments, an **argumental structure** for a claim α from a set of arguments $\Sigma^* \subseteq Args$ is a tree of arguments Σ verifying:*

1. *The root argument $\mathcal{A}_{top} \in \Sigma^*$, called **top argument**, is such that $\mathtt{cl}(\mathcal{A}_{top}) = \alpha$;*
2. *An inner node is an argument $\mathcal{A}_i \in \Sigma^*$ such that for each of its premises $\beta \in \mathtt{supp}(\mathcal{A}_i)$ there is at most one child argument $\mathcal{A}_k \in \Sigma^*$ supporting $\mathcal{A}_i$ through β.*
3. *A leaf is an argument $\mathcal{A}_k \in \Sigma^*$ such that there is no argument $\mathcal{A}_k \in \Sigma^*$ supporting it.*

Regarding notation for an argumental structure Σ:

- *The support of Σ is defined as:*

  $\mathtt{supp}(\Sigma) = suppset(\bigcup_k(\mathcal{A}_k))$, *for every leaf $\mathcal{A}_k \in \Sigma$*
- *The claim of Σ is noted as $\mathtt{cl}(\Sigma) = \alpha$.*
- *The set of arguments belonging to Σ is noted as Σ^*.*

Note that the $\mathtt{supp}(\cdot)$ and $\mathtt{cl}(\cdot)$ functions are overloaded: now they are applied to argumental structures. This is not going to be problematic, since either usage will be rather explicit. From now on, when clear enough, we will refer to argumental structures just as 'structures'.

Example 4 *From Example 2 we have the argumental structure Σ_4, such that $\Sigma_4^* = \{\mathcal{A}, \mathcal{B}\}$ (illustrated in Figure 2), where its support is $\mathtt{supp}(\Sigma_4) = \{th, upc\}$ and its claim is $\mathtt{cl}(\Sigma_4) = \mathtt{cl}(\mathcal{A}) = dr$. Note that the support of Σ_4 is different from the set of all premises in it: $suppset(\Sigma_4) = \{upc, ps, th\}$; finally, its set of claims is $clset(\Sigma_4) = \{ps, dr\}$.*

However, the definition for an argumental structure is not enough to represent knowledge in a sensible way. For instance, it allows for contradictory claims in a pair of arguments belonging to the same structure. Therefore, we have to define what is considered a *well-formed argumental structure*, but in order to do this we need the definition for *transitive support*.

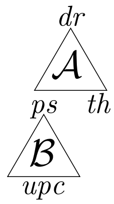


Figure 2: Argumental structure for $dangerous\_route$ (dr).

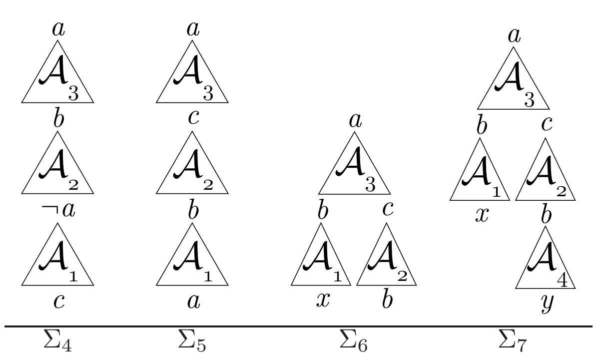
Definition 8 (Transitive Support) *An argument $\mathcal{A}_i$ **transitively supports** an argument $\mathcal{A}_j$ iff there is a sequence of arguments $[\mathcal{B}_1, \ldots, \mathcal{B}_n]$ where $\mathtt{cl}(\mathcal{A}_i) \in \mathtt{supp}(\mathcal{B}_1)$, $\mathtt{cl}(\mathcal{B}_n) \in \mathtt{supp}(\mathcal{A}_j)$ and $\mathtt{cl}(\mathcal{B}_k) \in \mathtt{supp}(\mathcal{B}_{k+1})$, with $1 \leq k \leq n-1$.*

Definition 9 (Well-Formed Argumental Structure) *An argumental structure Σ is **well-formed** iff Σ verifies the following properties:*

- ***(Consistency)** For each argument $\mathcal{A}_i \in \Sigma^*$ there is no argument $\mathcal{A}_k \in \Sigma^*$ ($i \neq k$) such that $\mathcal{A}_i \mathbf{R} \mathcal{A}_k$;*
- ***(Non-Circularity)** No argument $\mathcal{A}_i \in \Sigma^*$ transitively supports an argument $\mathcal{A}_k \in \Sigma^*$ if $\mathtt{cl}(\mathcal{A}_k) \in \mathtt{supp}(\mathcal{A}_i)$.*
- ***(Uniformity)** If a premise $\beta \in suppset(\Sigma)$ is supported by an argument $\mathcal{B} \in \Sigma^*$, then for every $\mathcal{A}_i \in \Sigma^*$ having β as a premise, $\mathcal{B}$ supports $\mathcal{A}_i$ through β.*

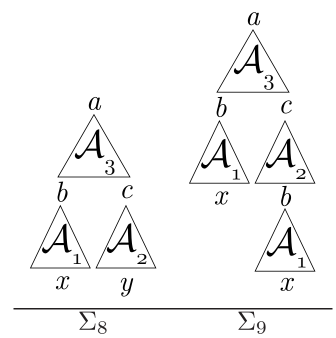
The property of *consistency* invalidates inherently contradictory argumental structures. The requirement of *non-circularity* avoids taking into consideration structures yielding a fallacious reasoning chain, where an argument ends up being transitively supported by itself. Finally, the restriction of *uniformity* refrains non-minimal structures to be deemed as well-formed, it does not allow heterogeneous support for a premise throughout a structure. These constraints are defined so we can trust a well-formed structure as a sensible reasoning chain, independently from the set of evidence. The consideration of a set of evidence is part of the notion of *active argument*, which is addressed in Definition 11.

Example 5 *The following sets of arguments are argumental structures, but they are not well-formed [2]:*



- *Σ_4 violates the* consistency *property, due to $\mathcal{A}_1$ and $\mathcal{A}_3$ achieving contradictory claims.*
- *Σ_5 violates the* non-circularity *property, since $\mathcal{A}_1 = \langle\{a\}, b\rangle$ transitively supports $\mathcal{A}_3 = \langle\{c\}, a\rangle$.*
- *Σ_6 and Σ_7 violate the* uniformity *property:*
  - *in Σ_6, the premise 'b' has two occurrences, but is supported by $\mathcal{A}_1$ in one case, and left unsupported in the other.*
  - *in Σ_7, the premise 'b' is supported by two different arguments.*

Example 6 *The following sets of arguments do compose well-formed argumental structures:*



- *Structure Σ_8 presents no controversy, is a simple argumental structure.*
- *Structure Σ_9 shows a case similar to that of Σ_8. However, premise 'b' is always supported by the same argument ($\mathcal{A}_1$) therefore verifying the* uniformity *property.*

From now on, we will assume that any given argumental structure is well-formed, unless stated otherwise.

Definition 10 *Let $\Sigma^* = \{\mathcal{A}\}$ be the set of arguments of the argumental structure Σ, then Σ is called a **primitive argumental structure** and $\mathtt{supp}(\Sigma) = \mathtt{supp}(\mathcal{A})$, $\mathtt{cl}(\Sigma) = \mathtt{cl}(\mathcal{A})$.*

The concept of primitive argumental structures shows that an argument can be seen as a particular case of an argumental structure.

Now that we have defined what a well-formed argumental structure is, we can introduce the notion of *active argumental structures*. This will allow us to recognize those structures that are capable of achieving their claims when considering the current situation.

Definition 11 (Active Argumental Structure) *Given a set* **E** *of evidence, a well-formed argumental structure Σ is **active** wrt.* **E** *iff $\mathtt{supp}(\Sigma) \subseteq \mathbf{E}$ and every $\mathcal{A} \in \Sigma^*$ is a coherent argument wrt.* **E**.

This definition states an important property: the premises 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. Note that coherence

[2] Here, we assume a propositional language for claims and premises, where strong negation indicates contradiction.

cannot be put as a requirement for a well-formed structure, since it is tied to a particular set of evidence.

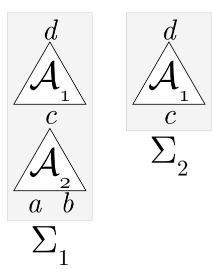
Example 7 *(Extends Example 5) Consider* $\mathbf{E}_7 = \{b, x, y\}$ *to be a set of evidence, then structure* Σ_8 *is not an active structure, because* $\mathcal{A}_1$ *is redundant wrt.* $\mathbf{E}_7$.

There is a subtle relation between active arguments and active argumental structures that will be made explicit by the following propositions.

Proposition 1 *If* Σ *is an active argumental structure wrt. a set* $\mathbf{E}$ *of evidence, then every sub-argument of* Σ *is an active argument wrt.* $\mathbf{E}$.
Proof: By construction of an active structure Σ *wrt.* $\mathbf{E}$*, let* $\mathcal{A}_{top}$ *be its active (thus coherent) top argument. Therefore, either* $\mathtt{supp}(\mathcal{A}_{top}) \subseteq \mathbf{E}$*, or some premise* $\beta \in \mathtt{supp}(\mathcal{A}_{top})$ *is supported by an active argument* $\mathcal{A}_i$*. In the latter case,* $\mathcal{A}_i$ *is included into* Σ*, and then the same analysis is made regarding the premises of* $\mathcal{A}_i$*. The construction of the tree of arguments is performed recursively, and in each step an active argument is included into* Σ*. Therefore,* Σ *contains only active arguments wrt.* $\mathbf{E}$ $\square$

The reverse of the latter proposition is not true, as shown in the following example.

Example 8 *Consider a set of evidence* $\mathbf{E}_8 = \{a, b\}$*, and two structures* Σ_1 *and* Σ_2 *such that* $\Sigma_1^* = \{\mathcal{A}_1, \mathcal{A}_2\}$ *and* $\Sigma_2^* = \{\mathcal{A}_1\}$*, where* $\mathcal{A}_1 = \langle\{c\}, d\rangle$*,* $\mathcal{A}_2 = \langle\{a, b\}, c\rangle$*, as depicted below.*



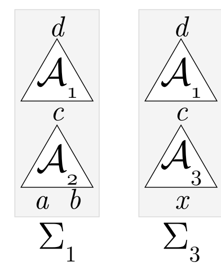
From $\mathbf{E}_8$*, structure* Σ_1 *is active, but* Σ_2 *is not. Clearly, both argumental structures contain active arguments, but this condition does not ensure them to be active.*

Example 8 shows that, in a way, argumental structures have to be 'complete' in order for them to be active. That is, they must include all of the necessary arguments for their top argument to be active. Only then the support of these structures will be composed by evidence. This statement is made clear by the results of the following two propositions.

Proposition 2 *Every active argument wrt. a set* $\mathbf{E}$ *of evidence is the top argument of at least one active argumental structure wrt.* $\mathbf{E}$.
Proof: Let assume that there is an argument $\mathcal{A}$ *active wrt.* $\mathbf{E}$ *that is not the top argument of any argumental structure active wrt.* $\mathbf{E}$*. Since* $\mathcal{A}$ *is active, either (1) its premises are a subset of* $\mathbf{E}$*, or (2) some premise is supported by an active argument* $\mathcal{B}$*. Case (1) clashes with the assumption of* $\mathcal{A}$ *not being the top argument of any active structure, since the primitive structure composed just by* $\mathcal{A}$ *would be active wrt.* $\mathbf{E}$*. Case (2) indicates that a structure could be built containing at least* $\mathcal{A}$ *and* $\mathcal{B}$*, and then the analysis made over* $\mathcal{A}$ *is also applicable to* $\mathcal{B}$*, because it should also be active wrt.* $\mathbf{E}$*, in order for* $\mathcal{A}$ *to be active. Hence, the recursive consideration of new arguments while including them into a new hypothetical structure ends when all the premises of the last argument is a subset of* $\mathbf{E}$*. This would mean that the hypothetical structure is active wrt.* $\mathbf{E}$*, leading to absurdity. This is due to the assumption of* $\mathcal{A}$ *not being the top argument of any argumental structure active wrt.* $\mathbf{E}$ $\square$

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

Example 9 *Consider* Σ_1 *from Example 8, an argument* $\mathcal{A}_3 = \langle\{x\}, c\rangle$*, and a set of evidence* $\mathbf{E}_9 = \{a, b, x\}$*. Then, the following active argumental structures can be built:*



Note that both are well-formed active argumental structures wrt. $\mathbf{E}_9$ *and have the same top argument.*

Proposition 3 *Given an active argumental structure* Σ *wrt. a set* $\mathbf{E}$ *of evidence, there is no proper substructure* Σ_i *of* Σ *such that* Σ_i *is active wrt.* $\mathbf{E}$.
Proof: Let assume that Σ_i *is an active structure wrt.* $\mathbf{E}$*. Then* $\mathtt{supp}(\Sigma_i) \subseteq \mathbf{E}$*. Now assume that* Σ *is also active wrt.* $\mathbf{E}$*. Therefore, there is at least one premise of* Σ_i *that, in* Σ*, is supported by an argument* $\mathcal{B}$*. Consequently, one of the following holds: (1)* $\mathcal{B}$ *is redundant wrt.* $\mathbf{E}$ *and* Σ *is not an active structure wrt.* $\mathbf{E}$*; (2)* Σ_i *has a premise that is not evidence. Either of these cases leads to absurdity. This is due to the assumption of* Σ_i *being an active proper substructure of* Σ $\square$

The Dynamic Argumentation Framework

Now that we have defined the main components of our theory, we will put them together in the definition of the *dynamic argumentation framework*. In the literature, argumentation frameworks are usually static, in the sense that every argument in them participates in the argumentative interplay, without regard to the actual validity of the arguments in the current situation. This is so because they do not consider such a thing as a possibly changing situation, but instead are restricted to a single snapshot.

Almost every new approach to abstract argumentation is built on top of Dung's argumentation framework (Dung 1995) (from now on, simply 'AF'). This framework is defined as a pair with 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 what arguments can be used to make inferences. If we follow Dung's approach, the consideration of a changing set of arguments would involve passing from a framework to another, but this cannot be performed lightly: what is the relation between these frameworks? Where do the new arguments come from and where do the old ones go to? Furthermore, if we are incorporating a set of evidence that activates arguments: how does the set of evidence change? How does the set of evidence affect the status of arguments? These questions have to be properly addressed in order to build a coherent dynamic framework. Therefore, next we define the notion of attack between structures, and then, we introduce the dynamic argumentation framework.

The notion of argumental substructure allows us to redefine attacks, now in terms of structures. Before this definition, we introduce the notion of *argumental substructure*.

Definition 12 (Argumental Substructure) *Given an argumental structure Σ from a set of arguments $Args$, the set Σ_i is an **argumental substructure** of Σ iff $\Sigma_i^* \subseteq \Sigma^*$ and Σ_i is an argumental structure from $Args$. If $\Sigma_i^* \subsetneq \Sigma^*$ then Σ_i is a **proper argumental substructure** of Σ.*

Note that an argumental structure is an argumental substructure of itself. As with the former, we will refer to the latter just as a 'substructure', when convenient.

Definition 13 (Attack Between Argumental Structures) *Given a set $Args$ of arguments, an attack relation $\mathbf{R} \subseteq Args \times Args$ between arguments, and two argumental structures Σ_1 and Σ_2 from $Args$, the structure Σ_1 **attacks** Σ_2 iff there is a substructure Σ_2' of Σ_2 such that $top(\Sigma_1)\mathbf{R}top(\Sigma_2')$.*

The attack relation between arguments is composed of pairs of arguments; that is, given two arguments $\mathcal{A}$ and $\mathcal{B}$, if $\mathcal{A}\mathbf{R}\mathcal{B}$ ($(\mathcal{A},\mathcal{B}) \in \mathbf{R}$), then we have that $\mathcal{A}$ attacks (or defeats) $\mathcal{B}$. Equivalently, we will say that $\mathcal{A}$ is a defeater for $\mathcal{B}$. When speaking of argumental structures, we use the same vocabulary.

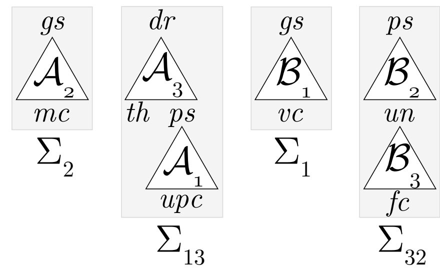
Remark 1 *Given an argument $\mathcal{A}$ from an active argumental structure Σ, if $\mathcal{A}$ is defeated by an active argument $\mathcal{B}$, then Σ is defeated by an argumental structure whose top argument is $\mathcal{B}$.*

The statement made by this remark was referred as *conflict inheritance* in (Martínez, García, and Simari 2007).

Definition 14 (Dynamic Argumentation Framework (DAF)) *A **DAF** is a pair $\langle \mathbf{E}, (\mathbf{U}, \mathbf{R})\rangle$, composed by a set $\mathbf{E}$ of **evidence**, and a framework $(\mathbf{U}, \mathbf{R})$, where $\mathbf{U}$ is the **universal set of arguments** and $\mathbf{R} \subseteq \mathbf{U} \times \mathbf{U}$ is the **attack relation** between arguments.*

Different instances of the set of evidence determine different instances of the DAF. Thus, when "restricting" a framework $(\mathbf{U}, \mathbf{R})$ to its associated set of evidence, we can obtain a (static) framework in the classical sense, *i.e.*, a pair in which every argument is active, and the attack relation contains pairs of them. This "restriction" will be called a *static instance*, and is addressed below.

Example 10 *Consider the argumental structure of Example 4, in which knowing that there are thieves in a place and that cops there are underpaid leads us to think that that route is going to be dangerous. Let us assume that there are many cops (noted as 'mc') in the location, therefore we have a reason to think that security there is good ('gs'). Another argument leading us to think of good security is that the cops could be volunteer ('vc'), thus more motivated to do a good job. Nonetheless, if cops are foreigners ('fc'), then they are probably not acquainted with the place (un), and that could give the idea of poor security there ('ps'). Then, we can build the following argumental structures:*



Thus, we have a DAF $\langle \mathbf{E}_{10}, (\mathbf{U}_{10}, \mathbf{R}_{10})\rangle$, where the universal set of arguments is $\mathbf{U}_{10} = \{\mathcal{A}_1, \mathcal{A}_2, \mathcal{A}_3, \mathcal{B}_1, \mathcal{B}_2, \mathcal{B}_3\}$, and we will consider a set of evidence $\mathbf{E}_{10} = \{many\_cops, underpaid\_cops, thieves\}$, along with an empty attack relation $\mathbf{R}_{10} = \emptyset$. Then, from set $\mathbf{U}_{10}$, arguments $\mathcal{A}_1$, $\mathcal{A}_2$ and $\mathcal{A}_3$ are active wrt. $\mathbf{E}_{10}$, thus reaching their claims $good\_security$, $poor\_security$ and $dangerous\_route$. 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. $\mathbf{E}_{10}$ and thus cannot reach their claims.

A subset of the universal set will be 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 perform reasoning in concordance with the current situation.

Definition 15 (Set of Active Arguments) *Given a DAF $F = \langle \mathbf{E}, (\mathbf{U}, \mathbf{R})\rangle$, the **set of active arguments** in F is $\mathbb{A} = \{\mathcal{A} \in \mathbf{U} \mid \mathcal{A}$ is active wrt. $\mathbf{E}\}$.*

Given the universal set $\mathbf{U}$ of arguments and the set $\mathbb{A}$ of active arguments we can derive *the set of inactive arguments* as $\mathbf{U} \setminus \mathbb{A}$. This latter set would be very useful when reasoning about possible worlds, potential situations, or even goals and the plausibility of reaching them. Moreover, since the attack relation is given over the universal set, there will be active and inactive attacks. The latter relation (involving at least one inactive argument) would allow us to, say, activate defeaters for currently active arguments. These concepts can be translated into terms of argumental structures.

Definition 16 (Set of Active Argumental Structures) *Given a DAT T and the set $\mathbb{A}$ of active arguments in T, the **set of active argumental structures** in T is the maximal set $\mathbb{S}$ of argumental structures from $\mathbb{A}$.*

Proposition 4 *Given a set $\mathbb{A}$ of active arguments and a set $\mathbb{S}$ of active argumental structures from $\mathbb{A}$, then $\bigcup_{\Sigma^* \in \mathbb{S}}(\Sigma^*) = \mathbb{A}$. Proof: Trivial from Definition 16.*

As in the case of arguments, the set of active structures allows us to distinguish the set $\mathbb{S}^{\mathbb{I}}$ of inactive argumental structures, as a set of arguments composing an argumental structure, but containing at least one argument that is not active.

Example 11 *From Example 10, the set of active argumental structures is: $\mathbb{S}_{11} = \{\Sigma_{13}, \Sigma_2\}$. An inactive argumental structure would be Σ_{32}.*

Definition 17 (Inactive/Active Attacks) *Given a DAF $\langle \mathbf{E}, (\mathbf{U}, \mathbf{R})\rangle$ and the set of active (inactive) argumental structures $\mathbb{S}$ ($\mathbb{S}^{\mathbb{I}}$) from $\mathbf{U}$ wrt. $\mathbf{E}$, we have:*

- *The **active attack relation**:* $\mathbb{R} = \{(\Sigma_1, \Sigma_2) \mid \{\Sigma_1, \Sigma_2\} \subseteq \mathbb{S}, \Sigma_1 \textit{ attacks } \Sigma_2\}$
- *The **inactive attack relation**:* $\mathbb{R}^{\mathbb{I}} = \{(\Sigma_1, \Sigma_2) \mid \Sigma_1 \in \mathbb{S}^{\mathbb{I}} \textit{ or } \Sigma_2 \in \mathbb{S}^{\mathbb{I}}, \Sigma_1 \textit{ attacks } \Sigma_2\}$

Static Instance of a DAF

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

Definition 18 (Static Instance) *Given a DAF $\langle \mathbf{E}, (\mathbf{U}, \mathbf{R})\rangle$, the **static instance** of $\langle \mathbf{E}, (\mathbf{U}, \mathbf{R})\rangle$ is the AF $(\mathbb{S}, \mathbb{R})$, where $\mathbb{S}$ is the set of active argumental structures from $\mathbf{U}$ wrt. $\mathbf{E}$, and $\mathbb{R}$ is the active attack relation between structures in $\mathbb{S}$. The notation is $(\mathbf{U}, \mathbf{R})|_{\mathbf{E}} = (\mathbb{S}, \mathbb{R})$.*

Every DAF, at any moment, has an associated static instance, which is an AF. Therefore, all the work done on acceptability of arguments and argumentation frameworks semantics can be applied to the DAF here defined, just by finding its static instance. Moreover, since we added some structure to the notion of argument, we can go a step further and consider justification of claims, either in a skeptical or a cautious way.

DAFs can be seen as a template for generating multiple AFs representing the same knowledge applied to different situations. The number of static instances that can be obtained from a single DAF is quite large. Provided that each argument has at least one premise (*i.e.*, a possible evidence), then the amount of possible evidence equals or exceeds the amount of arguments in the universal set. Let $\mathbb{E}$ be this set of possible evidence, then if we consider a universal set $\mathbf{U}$ of arguments we have: $|\mathbb{E}| \geq |\mathbf{U}|$. Considering that each possible subset of evidence composes a different static instance of the DAF, we have that the amount of static instances is in the order of $2^{\mathbb{E}}$. Finally, it is now clear that there is a large number of AFs associated to a single DAF.

Updating Evidence in a DAF

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 operation performed over a DAF is the *evidence update*. This mechanism should ensure the DAF reflects the new (consistent) state of the world. To ease the legibility of the next definition, we use the complement notation to indicate contradiction between pieces of evidence.

Definition 19 (Evidence Update (resp., Erasure)) *Given a DAF $\langle \mathbf{E}, (\mathbf{U}, \mathbf{R})\rangle$, 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 such that $\langle \mathbf{E} \cup \mathbf{E}_1, (\mathbf{U}, \mathbf{R})\rangle$ (resp., $\langle \mathbf{E} \backslash \mathbf{E}_1, (\mathbf{U}, \mathbf{R})\rangle$).*

The evidence update/erasure changes the *instance* of the DAF: it makes the set of active arguments vary. In that sense, it could be seen as a form of revision: the specification of what holds in the world is represented by active arguments and attacks. However, the impact of the evidence update in these sets neither performs nor is intended as a formal revision of the theory whatsoever.

With updates and erasures we do not change the representation (or specification) of the knowledge about the world, but what is perceived. Our update and erasure operations to change the set of evidence are so far treated shallowly, since it suffices to prove the usefulness of the theory presented in this article. However, ongoing work is devoted to reinforce this aspect, inspired by the original definitions given in (Katsuno and Mendelzon 1991).

Example 12 *Consider Example 10 and a DAF $\langle \mathbf{E}_{10}, (\mathbf{U}_{10}, \mathbf{R}_{12})\rangle$, where $\mathbf{R}_{12} = \{(\mathcal{A}_2, \mathcal{A}_1), (\mathcal{B}_1, \mathcal{A}_1), (\mathcal{B}_2, \mathcal{B}_1)\}$, as depicted in Figure 3[3]. Note that arrows represent the attack relation, and gray dashed triangles are inactive arguments.*

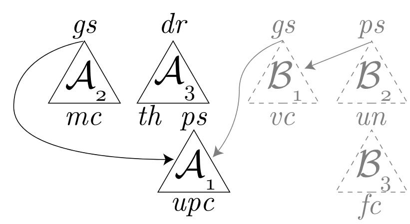


Figure 3: DAF from Example 12.

Then we have:

- $\mathbb{S}_{12} = \{\Sigma_2, \Sigma_{13}\}$ *are active argumental structures;*
- $\mathbb{S}^{\mathbb{I}}_{12} = \{\Sigma_1, \Sigma_{32}\}$ *are inactive argumental structures;*
- $\mathbb{R}_{12} = \{(\Sigma_2, \Sigma_{13})\}$ *are active attacks;*
- $\mathbb{R}^{\mathbb{I}}_{12} = \{(\Sigma_1, \Sigma_{13}), (\Sigma_{32}, \Sigma_1)\}$ *are inactive attacks.*

The static instance $(\mathbf{U}_{10}, \mathbf{R}_{12})|_{\mathbf{E}_{10}}$ is the AF $(\mathbb{S}_{12}, \mathbb{R}_{12})$, which is illustrated in Figure 4(a).

If we update the set of evidence by adding knowledge about the cops saying that they 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 static instance of the updated DAF is depicted in Figure 4(b).

[3]Primitive argumental structures composed of $\mathcal{A}_1$, $\mathcal{A}_3$, $\mathcal{B}_2$ and $\mathcal{B}_3$ were not represented separately for the sake of simplicity.

Now consider we find out that the cops are foreigners, and that there is not as many as we were told before. Therefore, 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 static instance is shown in Figure 4(c).

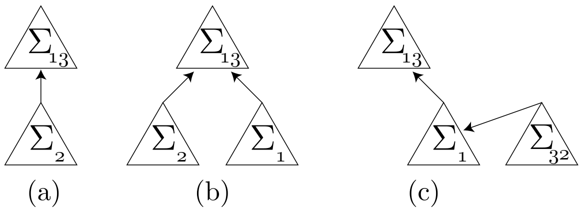


Figure 4: Static instances from Example 12.

Each static instance yields a particular set of accepted arguments. If we pick the grounded *semantics (Dung 1995): the static instance (a) accepts just the structure Σ_2; the static instance (b) accepts Σ_2 and Σ_1; the static instance (c) accepts Σ_{32} and Σ_{13}. Therefore, with this semantics, the last one is the only scenario in which we would believe the path we are analyzing to pass through is dangerous.*

In order to complete the relation between our work and Dung's there is also a way to obtain the associated DAF from a static framework. We only require the static framework to include arguments with an explicit set of premises and a claim, so they can be organized in primitive argumental structures (those containing just one argument). Then, the union of the sets of support of each argumental structure in the system is the set of evidence, and thus we have a DAF. However, this part of the relation is somehow weak: obtaining premises and claim out of an abstract argument may be difficult to do in a standard way. Therefore, the obtention of a DAF from a static framework is not currently in our focus. We are more interested in the reverse relation, so that you can specify a DAF and capture each of its static instances in the well-known AF format, and then make the analysis of acceptability of arguments in the usual way. The static instance of a DAF contains only active argumental structures (*i.e.*, all of them are used to make inferences) and an active attack relation connecting them, so the association between a DAF's static instance and an AF is quite direct. This is captured by Lemma 1.

Lemma 1 *The static instance of a DAF is* ***equivalent*** *to Dung's definition for an abstract argumentation framework.*
Proof: Trivial from Definition 18.

On the Applications of the DAF

This section describes some ongoing research lines that would take advantage of the DAF. Having a dynamic set of evidence that has a direct correlation with the set of active arguments allows reasoning about possible situations.

Argument Theory Change

Let us consider an argumentation-based agent with a certain goal G expressed in the form of a set of accepted arguments. Thus, we wish to know how should we *change* the set of evidence in order to reach G. In a recent paper (Rotstein et al. 2008), we presented a preliminary version of the DAF (that can be easily evolved to the current form) along with the basics of *argument theory change*. In that article, a *warrant-prioritized revision operator* is introduced: it introduces a new argument to a DAF seeking to be accepted; it does so by removing those arguments that interfere with this warrant, on behalf of a minimal change criterion. Hence, we would be able to tell which pieces of evidence are to be dropped for an argument to be accepted. Moreover, this approach could be extended by going in the opposite direction: bringing up the necessary evidence to activate those arguments that (because of the attacks they activate) would ensure the new argument to be accepted. In this way, we could go further and tell which pieces of evidence are to be added and which are to be dropped in order for a whole set of arguments to be accepted, whenever possible.

Argumentation-based Agent Architecture

An agent architecture is defined over a number of components, as the BDI model is composed by the three components handling beliefs, desires and intentions. If the components of an architecture are represented through a DAF, the agent is thus capable of not only updating its perception of the world (*i.e.*, the set of evidence), but also change its preferences and knowledge accordingly by adding/dropping the necessary pieces of evidence to activate/deactivate the corresponding arguments. An agent immersed in a dynamic environment should be prepared to incorporate changes in the world's rules (*i.e.*, the way things are interpreted); for instance, an agent dedicated to schedule processes in an agent-oriented operative system must be able to change the schedule policy. If the set of evidence is kept up-to-date, the agent will make inferences based on the current state of the world, but it could also hypothesize about possible states representing variations of the current one, thus being able to move towards its goal. Finally, the dynamic modification of a particular subset of evidence could allow the agent to learn from its own experience in order to adapt.

Analysis of Legal Cases

Another application that could benefit from the usage of the dynamic argumentation framework is the analysis of legal cases. Assume that a verdict has been reached regarding a certain case and that the accused was found guilty. We have a number of allegations (*i.e.*, arguments) that were posed against the presumption of innocence, and arguments against them, and so on, yielding a graph of arguments interrelated by the attack relation. The argument graph is a visualization of the framework that justifies the verdict. Note that the semantics chosen should be sensible as to classify the presumption of innocence as a rejected argument. We also have the set of evidence from which arguments were based. All the arguments posed should be active, since they were accepted at the trial. Now an appropriate mechanism could be used in order to vary the set of evidence and discover under which circumstances the convict could have been found innocent (for instance, we could use the warrant-prioritized revision operator mentioned above, in ‘Argument Theory Change’). Moreover, we could even add to the framework those arguments that did not have enough support from available evidence (which are inactive), and play with the possibility of actually having that evidence. The dynamic framework plus an appropriate mechanism could be a useful tool to hypothesize about possible scenarios and outcomes of an actual legal case.

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 framework (AF) and represents an extension that is the basis of several research lines, some of which were introduced in the previous section. The main subject of this paper is the definition of the Dynamic Argumentation Framework, from which a static instance can be obtained. This instance was shown to be equivalent to the AF. However, throughout several examples, it was shown that the DAF allows for a more general representation of knowledge than the mentioned framework: it considers a varying set of evidence that changes the base to make inferences (*i.e.*, the underlying static instance); therefore, multiple AFs can be obtained from different instances of a given DAF.

Regarding future work, besides what was already discussed in the previous section, we are also interested in exploring the capability of reasoning about possible situations, and establishing a relation with the area of modal logics. This work is currently underway. Although this research line is mainly theoretical, one of its main goals is to make an implementation out of each application for the DAF. This is likely to be done in Defeasible Logic Programming (DeLP) (García and Simari 2004) or an extension of it. For instance, the formalism defined in (Rotstein et al. 2008) found its DeLP reification in (Moguillansky et al.).

Finally, we will explore two extensions of the DAF: (1) a more natural way to specify and build the attack relation between arguments from constraints and preferences; (2) change operators to modify the universal set of arguments and the attack relation. The first extension will involve a slight change in the definition of the framework: it will build the attack relation from the specification of a set of constraints among claims (each constraint is an n-tuple of claims), stating which claims cannot hold together. As expected, some constraints are implicit, such as pairs of complementary claims. Once conflicts among arguments are obtained, a preference function will decide, for each pair, which argument prevails. The second extension acts as a meta-level debugging tool, allowing the dynamic modification of the sets of arguments and attacks. Note that the modification of the universal set of arguments turns it into a working set instead. Special care has to be taken regarding the addition of attacks, since this may introduce new arguments. The same applies to the deletion of arguments, since some attacks will no longer be valid.

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