Modelling Time and Reliability in Structured Argumentation Frameworks

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Abstract

Argumentation is a human-like reasoning mechanism contributing to the formalization of commonsense reasoning. In the last decade, several argument-based formalisms have emerged, with application in many areas, such as legal reasoning, autonomous agents and multi-agent systems; many are based on Dung's seminal work characterizing Abstract Argumentation Frameworks (AF). Recent research in the area has led to Temporal Argumentation Frameworks (TAF) that extend Dung's by considering the temporal availability of arguments. In this work we introduce a novel framework, called Extended Temporal Argumentation Framework (E-TAF), extending TAF with the capability of modeling availability of attacks among arguments, which allows for instance to model reliability of arguments varying over time. We show how E-TAF can be enriched by considering *Structured* Abstract Argumentation, adding compositional elements to the abstract arguments involved based on a simplified version of the recently introduced Dynamic Argumentation Frameworks.

1 Introduction

Argumentation is a human-like reasoning mechanism contributing to the formalization of commonsense reasoning. In a general sense, argumentation can be associated with the interaction of arguments for and against conclusions with the purpose of determining which conclusions are acceptable. Several argument-based formalisms have emerged with application in many areas involving autonomous agents and multi-agent systems Many of those frameworks are based on Dung's seminal work characterizing Abstract Argumentation Frameworks (Dung 1995).

Reasoning about time is a main concern in commonsense reasoning, and is also a valuable feature when modeling argumentation capabilities for intelligent agents (Mann and Hunter 2008; Augusto and Simari 2001). Recent research has led to Temporal Argumentation Frameworks (TAF) that extend Dung's AF by considering the temporal availability of arguments (Cobo, Martínez, and Simari 2010; 2011). In TAF, arguments are valid only during specific time intervals (called *availability intervals*). Thus, when identifying the set of acceptable arguments the outcome associated with a TAF may vary in time. Even though arguments in TAF are associated with availability intervals, their attacks are assumed to be static and permanent in time.

In this paper we introduce a novel framework, called Extended Temporal Argumentation Framework (E-TAF), extending TAF with the capability of modeling the availability of attacks among arguments. This additional feature of E-TAF allows for instance to model reliability of arguments varying over time, where an attack can be only available in a given time interval (meaning that the attacking argument is more reliable than the attacked one on this interval). We show how E-TAF can on its turn be enriched by considering *Structured* Abstract Argumentation, adding compositional elements to the abstract arguments involved based on a simplified version of the recently introduced Dynamic Argumentation Frameworks (Rotstein et al. 2010). In this formalization arguments are conceived as structures standing for chains (or trees) of smaller abstract entities representing individual reasoning steps. We will show that the resulting framework E-TAF* is powerful enough to provide a suitable model for different time-dependent issues (e.g. reliability) associated with arguments, with application in several real-world situations. The central contribution of this paper is thus to advance in the integration of time and reliability in the context of argumentation systems. We are interested in preserving as much as possible the generality of the approach, maintaining it independent from any particular representation language and considering as well the internal structure of the arguments involved.

2 Abstract Argumentation

Dung (Dung 1995) introduced the notion of *Argumentation Framework (AF)* as an abstraction of a defeasible argumentation system. In the AF an argument is considered as an abstract entity with unspecified internal structure, and whose role is determined only by its attack relations with other arguments.

Definition 1 (Argumentation Framework (Dung 1995)) *An argumentation framework (AF) is a pair* $\langle AR, Attacks \rangle$*, where* AR *is a set of arguments, and* $Attacks$ *is a binary relation on* AR *i.e.,* $Attacks \subseteq AR \times AR$.

Given an AF, an argument A is considered *acceptable* if it can be defended of all its attackers (arguments) with other arguments in AR. This intuition is formalized in the following definitions, originally presented in (Dung 1995).

Definition 2 (Acceptability (Dung 1995)) *Let* $AF = \langle AR, Attacks\rangle$ *be an argumentation framework.*

- *A set* $S \subseteq AR$ *is called* conflict-free *if there are no arguments* $A, B \in S$ *such that* $(A, B) \in Attacks$.
- *An argument* $A \in AR$ *is* acceptable *with respect to a set* $S \subseteq AR$ *iff for each* $B \in AR$*, if* B *attacks* A *then* B *is attacked by* S.
- *A conflict-free set* $S \subseteq AR$ *is* admissible *iff each argument in* S *is acceptable with respect to* S.
- *An admissible set* $E \subseteq AR$ *is a* complete extension *of* AF *iff* E *contains each argument that is acceptable with respect to* E.
- *A set* $E \subseteq AR$ *is the* grounded extension *of* AF *iff* E *is minimal with respect to set inclusion, such that is admissible and complete.*

Dung also presented a fixed-point characterization of the grounded semantics based on the characteristic function F defined below.

Definition 3 (Characteristic Function (Dung 1995)) *Let* $\langle AR, Attacks\rangle$ *be an AF. The associated characteristic function is defined as follows:* $F : 2^{AR} \rightarrow 2^{AR}$, $F(S) =_{def} \{A \in AR \mid A \text{ is acceptable w.r.t. } S\}$.

The following proposition suggests how to compute the grounded extension associated with a *finitary* AF (*i.e.*, such that each argument is attacked by at most a finite number of arguments) by iteratively applying the characteristic function starting from $\emptyset$.

Proposition 1 ((Dung 1995)) *Let* $\langle AR, Attacks\rangle$ *be a finitary AF. Let* $i \in \mathbb{N} \cup \{0\}$ *such that* $F^i(\emptyset) = F^{i+1}(\emptyset)$*. Then* $F^i(\emptyset)$ *is the least fixed point of* F*, and corresponds to the grounded extension associated with the AF.*

3 Modeling Temporal Argumentation with TAF

The Timed Abstract Framework (TAF) (Cobo, Martínez, and Simari 2010; 2011) is a recent argumentation formalism where arguments are valid only during specific intervals of time (called availability intervals). Attacks between arguments are considered *only* when both the attacker and the attacked arguments are available. Thus, when identifying the set of acceptable arguments the outcome associated with a TAF may vary in time.

Definition 4 (Time Interval) *A time interval, or just interval, is a real interval* $[a - b]$ *(we use '−' instead of ',' as a separator for legibility reasons).*

As is usual for real intervals, to indicate that one of the endpoints (extremes) of the interval is to be excluded, the corresponding square bracket will be replaced with a parenthesis (*e.g.*, $(a, b]$ to exclude the endpoint a).

Now, to model discontinuous periods of time we introduce the notion of *time intervals set*. Although a time intervals set suggests a representation as a set of sets (set of intervals), we chose a flattened representation as a set of reals

Definition 5 (Time Intervals Set) *A time intervals set, or just intervals set, is a subset* $S \subseteq \Re$.

Now we formally introduce the notion of *Timed Argumentation Framework* (Cobo, Martínez, and Simari 2010; 2011), which extends the AF of Dung by incorporating an additional component, the availability function, which will be used to capture those time intervals where arguments are available.

Definition 6 (Timed Argumentation Framework) *A timed argumentation framework (or simply TAF) is a 3-tuple* $\langle AR, Attacks, Av\rangle$ *where* AR *is a set of arguments,* $Attacks$ *is a binary relation defined over* AR *and* Av *is an availability function for timed arguments, defined as* $Av : AR \longrightarrow \wp(\Re)$*, such that* $Av(A)$ *is the set of availability intervals of an argument* A.

The following definitions formalize argument acceptability in TAF, and are extensions of the acceptability notions presented in section 2 for AF. Firstly we present the notion of t-profile, binding an argument to a set of time intervals, which constitutes a fundamental component for the formalization of time-based acceptability.

Definition 7 (T-Profile) *Let* $\Phi = \langle AR, Attacks, Av\rangle$ *be a TAF. A* timed argument profile *in* Φ*, or just* t-profile*, is a pair* $\rho = (A, \tau)$ *where* $A \in AR$ *and* τ *is a set of time intervals. The t-profile* $(A, Av(A))$ *is called the* basic *t-profile of* A.

Since the availability of arguments varies in time, the acceptability of a given argument A will also vary in time.

Definition 8 (Defense of A from B w.r.t. S) *Let* S *be a set of t-profiles. Let* A *and* B *be arguments. The defense t-profile of* A *from* B *w.r.t.* S *is* $\rho_A = (A, \tau_A^B)$*, where:* $\tau_A^B =_{def} Av(A) - Av(B) \bigcup_{\{(C,\tau_C) \in S \mid C \text{ } Attacks \text{ } B\}} (Av(A) \cap Av(B) \cap \tau_C)$

Intuitively, A is defended from the attack of B when B is not available ($Av(A) - Av(B)$), but also in those intervals where, although the attacker B is available, it is in turn attacked by an argument C in the base set S. The following definition captures the defense profile of A, but considering all its attacking arguments.

Definition 9 (Acceptable t-profile of A w.r.t. S) *Let* S *be a set of t-profiles. The acceptable t-profile for* A *w.r.t. a set* S *is* $\rho_A = (A, \tau_A)$*, where* $\tau_A =_{def} \cap_{\{B \text{ } Attacks \text{ } A\}} \tau_A^B$ *and* (A, τ_A^B) *is the defense t-profile of* A *from* B *w.r.t.* S.

Since an argument must be defended of all its attacks to be considered acceptable, we have to intersect the set of time intervals in which it is defended of each of its attackers.

Definition 10 (Acceptability) *Let* $AF = \langle AR, Attacks, Av\rangle$ *be a temporal argumentation framework.*

- *A set* S *of t-profiles is called* t-conflict-free *if there are no t-profiles* $(A, \tau_A), (B, \tau_B) \in S$ *such that* $(A, B) \in Attacks$ *and* $\tau_A \cap \tau_B \neq \emptyset$.
- *A t-conflict-free set* S *of t-profiles is a t-admissible set iff* $\forall\ (A, \tau_A) \in S$ *it holds that* (A, τ_A) *is the acceptable t-profile of* A *w.r.t.* S.

- *A t-admissible set S is a* t-complete extension *of TAF iff S contains all the t-profiles that are acceptable with respect to S.*
- *A set S is the* t-grounded extension *of TAF iff S is minimal with respect to set inclusion such that is t-admissible and t-complete.*

In particular, the fixed point characterization for grounded semantics proposed by Dung can be directly applied to TAF by considering the following modified version of the characteristic function.

Definition 11 *Let $\langle AR, Attacks, Av\rangle$ be a TAF. Let S be a set of t-profiles. The associated characteristic function is defined as follows: $F(S) =_{def} \{(A, \tau) \mid A \in AR$ and (A, τ) is the acceptable t-profile of A w.r.t. $S\}$.*

4 E-TAF: Extending TAF with time intervals for attacks

In this section we present an extension of TAF in order to take into account the availability of attacks, besides the availability of the arguments. Adding time intervals to attacks is meaningful in several contexts; consider for example the notion of *statute of limitations* applied in law. A statute of limitations is an enactment in a common law legal system that sets the maximum time after an event that legal proceedings based on that event may be initiated. One reason for having a statute of limitations is that over time evidence can be corrupted or disappear; thus, the best time to bring a lawsuit is while the evidence is not lost and as close as possible to the alleged illegal behavior. Consider the following situation: John has left debts unpaid in Alabama, US, during 2008. He has canceled them in 2009, but paying with counterfeited US dollars, committing fraud. This fraud was detected on Jan 1, 2010. A possible argument exchange for prosecuting John could be as follows:

- Arg_1: (Plaintiff) John left debts unpaid in Alabama in 2008 [Jan 1, 2008-$+\infty$)
- Arg_2: (Defendant) John paid all his debts in Alabama for 2008 [Jan 1,2009-$+\infty$)
- Arg_3: (Plaintiff) John did not cancel his debts in Alabama for 2008, as he paid them with counterfeited US dollars, committing fraud [Jan 1,2010-$+\infty$)

According to the statute of limitations for Alabama,[1] the attack from Arg_3 to Arg_2 would be valid only until Jan 1, 2012 (for 2 years from the moment it was discovered). Note that Arg_3 is valid by itself (as the fraud was committed anyway), but the statute of limitations imposes a time-out on the attack relationship between arguments Arg_3 and Arg_2. Thus, John would be not guilty of committing fraud if the dialogue would have taken place in 2012, as the attack from Arg_3 to Arg_2 would not apply.

Next we formalize the definition of *extended* TAF, which provides the elements required to capture timed attacks between timed arguments.

[1]The statute of limitations may vary in different countries; for the case of the U.S. see e.g. www.statuteoflimitations.net“fraud.html

Definition 12 (Extended TAF) *An extended timed abstract argumentation framework (or simply E-TAF) is a 4-tuple $\langle AR, Attacks, ARAv, ATAv\rangle$ where:*

- *AR is a set of arguments,*
- *$Attacks$ is a binary relation defined over AR,*
- *$ARAv : AR \longrightarrow \wp(\Re)$ is the availability function for timed arguments, and*
- *$ATAv : Attacks \longrightarrow \wp(\Re)$ is the availability function for timed attacks, where $ATAv((A, B)) \subseteq ARAv(A) \cap ARAv(B)$.*

The condition $ATAv((A, B)) \subseteq ARAv(A) \cap ARAv(B)$ ensures that the availability of the attack cannot exceed the availability of the arguments involved.

Example 1 *Consider the E-TAF depicted in Fig. 1, where availability time intervals are also attached to attacks.*

The following definitions are extensions of the definitions 8 and 9, taking into account the availability of attacks.

Definition 13 (Defense t-profile of A from B) *Let S be a set of t-profiles. Let A and B be arguments. The defense t-profile of A from B w.r.t. S is $\rho_A = (A, \tau_A^B)$, where $\tau_A^B = [ARAv(A) - ATAv((B, A))] \cup \bigcup_{\{(C,\tau_C)\in S \mid C\ Attacks\ B\}} (ARAv(A) \cap ATAv((B, A)) \cap ATAv((C, B)) \cap \tau_C)$.*

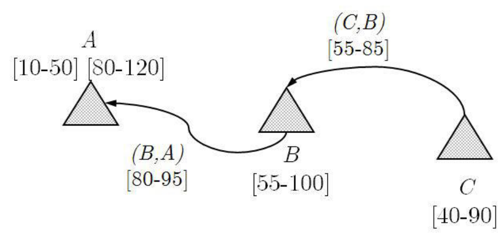

Figure 1: E-TAF: example

From the previous definitions, the notion of acceptable t-profile of A w.r.t. S remains unchanged in E-TAF with respect to the corresponding definition in TAF.

Definition 14 (Acceptable t-profile of A) *Let $\langle AR, Attacks, ARAv, ATAv\rangle$ be an E-TAF. Let S be a set of t-profiles. The acceptable t-profile for A w.r.t. S is $\rho_A = (A, \tau_A)$, where $\tau_A = \cap_{\{B\ Attacks\ A\}} \tau_A^B$ and (A, τ_A^B) is the defense t-profile of A from B w.r.t. S.*

The acceptability formalization for TAF directly applies to E-TAF, except for the conflict-free notion which has to be recast as shown in the next definition.

Definition 15 (Conflict-freeness. Characteristic function) *Let $\langle AR, Attacks, ARAv, ATAv\rangle$ be an E-TAF. A set S of t-profiles is called* conflict-free *if there are no t-profiles (A, τ_A), $(B, \tau_B) \in S$ such that $(A, B) \in Attacks$ and $\tau_A \cap \tau_B \cap ATAv((B, A)) \neq \emptyset$.*
The associated characteristic function for $\langle AR, Attacks, ARAv, ATAv\rangle$ is defined as follows: $F(S) =_{def} \{(A, \tau) \mid A \in AR$ and (A, τ) is the acceptable t-profile of A w.r.t. $S\}$.

5 Adding Structure to Abstract Argumentation: Structured Argumentation Framework

In this section we present a refinement of Dung's framework, called *Structured* Abstract Argumentation (or SAF for short). This framework is based on a simplified version of the recently introduced Dynamic Argumentation Framework (DAF) (Rotstein et al. 2010). In this formalization arguments are conceived as structures standing for chains (or trees) of smaller abstract entities representing individual reasoning steps. The original DAF is capable of dealing with dynamics through the consideration of a varying set of evidence. Depending on the contents of the set of evidence, some arguments will be *active* and some others will not, determining an AF instance of the framework. In SAF, we will not require to maintain a body of evidence that varies over time, as the dynamics of the framework will be associated with the temporal availability associated with the arguments, as shown in the next section.

In our context, a SAF $\mathcal{S}$ is just an enriched AF $\langle AR, Attacks\rangle$, in which structure for arguments is added, as well as a preference criterion $\gtrsim$ for attacks. In SAF the arguments with structure are called *argumental structures*, and the constituent elements are called arguments, where an argument is an abstract entity representing an indivisible reasoning step connecting a set of premisses with a claim (an argument's premises provide backing for the claim). Premises and claim are assumed to belong to a common domain, an abstract language $\mathfrak{L}$.

Definition 16 (Argument. Conflict between Arguments) *Given a language $\mathfrak{L}$, an argument A is a reasoning step for $\alpha \in \mathfrak{L}$ from a set of premises $\{\beta_1, ..., \beta_n\} \in 2^{\mathfrak{L}}$ 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 a set $Args$ of arguments, the set $\bowtie \subseteq Args \times Args$ denotes a conflict relation over $Args$, verifying $A_1 \bowtie A_2$ iff $cl(A_1) = \overline{cl(A_2)}$, where α and $\overline{\alpha}$ denote contradictory literals.

Given an argument A, we will write $cl(A)$ and $pr(A)$ to denote its claim and set of premises, respectively. We can say that an argument A supports an argument B if the claim of the argument A is part of the premises that support the claim of the argument B. Formally:

Definition 17 (Supporting Argument) *An argument B is a* supporting argument *of an argument A iff $cl(B) \in pr(A)$. Let $cl(B) = \beta$, then we say that B supports A through β.*

In SAF arguments can be aggregated into argumental structures, which are defined as follows:

Definition 18 (Argumental Structure) *Given a set $Args$ of arguments and a conflict relation $\bowtie$ over $Args$, an argumental structure for a claim α from $Args$ is a tree of arguments Σ verifying:*[2]

- *The root argument $A_{top} \in Args$, called top argument, is such that $cl(A_{top}) = \alpha$, and is noted as $top(\Sigma)$;*
- *A node is an argument $A_i \in Args$ such that for each premise $\beta \in pr(A_i)$ there is exactly one child argument in $Args$ supporting A_i through β;*
- *(Premise Consistency) There are no $\alpha, \beta \in pr(\Sigma)$ such that $\overline{\alpha} = \beta$;*
- *Let $args(\Sigma)$ be the set of arguments in Σ, there exists no tree Σ' satisfying the above conditions such that $args(\Sigma') \subset args(\Sigma)$.*

For any argumental structure Σ, we will write $cl(\Sigma) = \alpha$ to denote the claim of Σ and $pr(\Sigma)$ to denote the set of premises of arguments in Σ.

The domain of all argumental structures w.r.t. $Args$ and $\bowtie$ is denoted as $str_{(Args,\bowtie)}$. For the sake of simplicity, in the sequel we will refer to argumental structures just as "structures". As in AF, the defeat relation in SAF can be captured through the application of a preference relation over conflicting pairs of structures (attacks). When adding a preference criterion over attacks, this relationship can be refined into defeat between arguments. Formally:

Definition 19 (Attack and Defeat between structures) *Let $Args$ be a set of arguments and let $\bowtie$ be a conflict relation over $Args$. Given two argumental structures Σ, Σ_i from $Args$, we will say that Σ_i is an* argumental substructure *of Σ iff $args(\Sigma_i) \subseteq args(\Sigma)$.*
We will say that $\Sigma_1 \in str_{(Args,\bowtie)}$ attacks $\Sigma_2 \in str_{(Args,\bowtie)}$, denoted as $\Sigma_1 \asymp \Sigma_2$, iff there is an argumental substructure Σ_i of Σ_2 such that $top(\Sigma_1) \bowtie top(\Sigma_i)$. The structure Σ_i es called disagreement substructure.
Given a pre-order relation '$\gtrsim$' over argumental structures (standing for 'at least as preferred'), we will say that $\Sigma_1 \in str_{(Args,\bowtie)}$ defeats $\Sigma_2 \in str_{(Args,\bowtie)}$, iff $\Sigma_1 \asymp \Sigma_2$ with disagreement structure Σ_i of Σ_2 such that $\Sigma_1 \gtrsim \Sigma_i$.

Acceptability in SAF is defined just by instantiating Dung's abstract framework AF with the set of all argumental structures as the set $Args$ and the defeat relation among structures as the $Attacks$ relation.

5.1 Extending E-TAF with Structure: E-TAF*

In real application domains of argumentation requiring the explicit treatment of time, temporal information is not in general directly associated with arguments, but instead it is attached to the basic pieces of knowledge (in general, logical rules) from which arguments are built. Reliability of arguments (or in general, argument strength) may also vary in time, causing availability of attacks to change in time either. As with temporal information, reliability is also naturally associated with formulas composing arguments, rather than be directly defined for arguments.

Our research has taken this direction by instantiating E-TAF arguments with SAF argumental structures. To achieve this, we added structure to E-TAF, based on the notions characterizing SAF, in order to formalize the notion of reliability for an argument varying on time. The new, enhanced E-TAF* framework (Budán et al. 2011), is expressive enough to capture temporal availability, a well as the notion of reliability varying over time, associated with individual steps from which the argumental structures are built. Availability and reliability for argumental structures is synthesized from the corresponding information attached to the

[2]These constraints correspond to sound, non-fallacious argument structures. For details see (Rotstein et al. 2010).

arguments composing them; the information then is used to define temporal availability of attacks. This framework is powerful enough to model different time-dependent issues associated with arguments, with application in several real-world situations.

6 Conclusions. Related and Future Work

Dung's AF has proven to be fruitful for developing several extensions with application in different contexts (e.g. (Brewka and Woltran 2010), (Brewka, Dunne, and Woltran 2011), (Caminada and Pigozzi 2011), among many others). As discussed in this paper, recent extensions for abstract argumentation were focused on adding time (resulting in TAF) and structure (as characterized in SAF) to abstract arguments. Recent research has been also oriented in a similar direction. In (Villata et al. 2011), an argumentative approach to reasoning about the trustworthiness of information sources is presented. In contrast with our approach, time is not considered explicitly, and *meta-argumentation* (Boella, van der Torre, and Villata 2009) (which allows Dung's AF to reason about itself) is used to model trust. In contrast, our approach considers reliability functions whose outcomes are based on time intervals.

In (Modgil and Prakken 2010), Prakken & Modgil present a very rich formalization for adding structure to abstract argumentation. His research has some parallels with the underlying notions in SAF, although it is much more encompassing than ours (considering argument schemes, rationality postulates, etc.). In contrast, our main motivation for structuring arguments was to empower the expressivity of our approach when dealing with reliability.

As discussed in the introduction, there have been also recent advances in modelling time in argumentation frameworks (e.g. (Cobo, Martínez, and Simari 2011; Mann and Hunter 2008)). However, to the best of our knowledge, there exists no other abstract argumentation approach for reasoning jointly with time and reliability factors as the one presented in this paper, combining features of TAF and SAF in a single, unified framework. In our formalization, we have first characterized E-TAF, an extension of TAF to consider time intervals associated with attacks. Second, we added structure to E-TAF, based on the notions characterizing SAF, in order to formalize the notion of reliability for an argumental structure varying on time. The resulting framework E-TAF* is able to represent temporal availability and reliability factors associated with the arguments from which the argumental structures are built; this information reaches the level of argumental structures, and is used to define temporal availability of attacks. Several properties associated with our formalization has been studied (Budán et al. 2011).

An implementation of E-SAF using the existing DeLP system (García and Simari 2004) as a basis is being developed;[3] The resulting system will be exercised in different domains that require to model agents associated with a reliability factor varying over time. We are also interested in analyzing the salient features of our formalization in the context of other argumentation frameworks and considering rationality postulates over these frameworks.

[3]See http://lidia.cs.uns.edu.ar/delp

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