An Approach to Argumentation Considering Attacks through Time

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Abstract. 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 AF by considering the temporal availability of arguments. A new framework was introduced in subsequent research, called Extended Temporal Argumentation Framework (E-TAF), extending TAF with the capability of modeling the availability of attacks among arguments. E-TAF is powerful enough to model different time-dependent properties associated with arguments; moreover, we will present an instantiation of the abstract framework E-TAF on an extension of Defeasible Logic Programming (DeLP) incorporating the representation of temporal availability and strength factors of arguments varying over time, associating these characteristics with the language of DeLP. The strength factors are used to model different more concrete measures such as reliability, priorities, etc.; the information is propagated to the level of arguments, then the E-TAF definitions are applied establishing their temporal acceptability.

Keyword: Argumentation, Temporal Argumentation, Defeasible Logic Programming, Argument and Computation.

1 Introduction

Argumentation represents a powerful paradigm to formalize commonsense reasoning. In a general sense, argumentation can be defined as the study of the interaction of arguments for and against conclusions, with the purpose of determining which conclusions are acceptable [6,21]. Several argument-based formalisms have emerged finding application in building autonomous agents and multi-agent systems. An agent may use argumentation to perform individual reasoning to resolve conflicting evidence or to decide between conflicting goals [2,5]; Multiple agents may also use dialectical argumentation to identify and reconcile differences between themselves, through interactions such as negotiation, persuasion, and joint deliberation [18,22,20].

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Reasoning about time is a central issue in commonsense reasoning, thus becoming a valuable feature when modeling argumentation capabilities for intelligent agents [3,15]. Recent research has introduced Temporal Argumentation Frameworks (TAF) extending Dung's AF with the consideration of argument's temporal availability [10,11]. In TAF, arguments are valid only during specific time intervals (called *availability intervals*). Thus, the set of acceptable arguments associated with a TAF may vary over time. Even though arguments in TAF are only available on certain time intervals, their attacks are assumed to be static and permanent over these intervals.

Recently, in [9] a novel framework, called Extended Temporal Argumentation Framework (E-TAF) was introduced, enriching a TAF with the capability of modeling the availability of attacks among arguments. This additional feature of E-TAF permits to model strength of arguments varying over time, *i.e.*, an attack can be only available in a given time interval signifying that the attacking argument is stronger than the attacked one on this attack interval. The notion of argument strength is a generalization of different possible measures for comparing arguments, such as reliability, priorities, etc.

In this work, to provide a concrete, fully specified (non-abstract) knowledge representation and reasoning formalism. We present an instantiation of the abstract framework E-TAF based on the argumentation formalism *Defeasible Logic Programming* (*DeLP*), a logic programming approach to argumentation that has proven to be successful for real-world applications (*e.g.*, [13,5,7]). This instantiation, called ST-DeLP, incorporates the representation of temporal availability and strength factors varying over time associated with the elements of the language of DeLP, following a different intuition from the one presented in [17]. It also specifies how arguments are built, and how availability and strength of arguments are obtained from the corresponding information attached to the language elements from which are built. After determining the availability of attacks by comparing strength of conflicting arguments over time, E-TAF definitions are applied to establish temporal acceptability of arguments. Thus, the main contribution of this paper lies on the integration of time and strength in the context of argumentation systems.

2 Abstract Argumentation

We will summarize the abstract argumentation framework introduced in Dung's seminal work [12]; the reader is directed to that reference for a complete presentation. To simplify the representation and analysis of pieces of knowledge, Dung introduced the notion of *Argumentation Framework (AF)* as a convenient abstraction of a defeasible argumentation system. In the *AF*, an argument is considered as an abstract entity with unspecified internal structure, and its role in the framework is completely determined by the relation of attack it maintains with other arguments.

Definition 1 (Argumentation Framework [12]). *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 by arguments in AR of all the arguments in AR that attack it (attackers). This intuition is formalized in the following definitions, originally presented in [12].

Definition 2 (Acceptability). *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 there is* $C \in S$ *such that* $(C, B) \in Attacks$*; in such case it is said that* 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 a complete extension that is minimal with respect to set inclusion.*

Dung [12] also presented a fixed-point characterization of the grounded semantics based on the characteristic function F defined below.

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

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 $\emptyset$. See [4,16] for details on semantics of AFs.

Proposition 1 ([12]). *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 Defeasible Logic Programming

Defeasible Logic Programming (DeLP), is a formalism that combines results of *Logic Programming* and *Defeasible Argumentation*. DeLP provides representational elements able to represent information in the form of strict and weak rules in a declarative way, from which arguments supporting conclusions can be constructed, providing a defeasible argumentation inference mechanism for obtaining the *warranted* conclusions. The defeasible argumentation characteristics of DeLP supplies means for building applications dealing with incomplete and contradictory information in real world, dynamic domains. Thus, the resulting approach is suitable for representing agents' knowledge and for providing an argumentation based reasoning mechanism to these agents.

Below we present the essential definitions of DeLP, see [14] for full details.

Definition 4 (DeLP program). *A DeLP program $\mathcal{P}$ is a pair (Π, Δ) where (1) Δ is a set of defeasible rules of the form $L \prec P_1, \ldots, P_n$, with $n > 0$, and (2) Π is a set of strict rules of the form $L \longleftarrow P_1, \ldots, P_n$, with $n \geq 0$. In both cases L and each P_i are literals, i.e., a ground atom A or a negated ground atom $\sim A$, where '$\sim$' represents the strong negation.*

Pragmatically, strict rules can be used to represent strict (non defeasible) information, while defeasible rules are used to represent tentative or weak information. It is important to remark that the set Π must be consistent as it represents strict (undisputed) information.

Definition 5 (Defeasible derivation). *Let $\mathcal{P}$ be a DeLP program and L a ground literal. A defeasible derivation of L from $\mathcal{P}$ consists of a finite sequence $L_1, \ldots, L_n = L$ of ground literals, such that for each i, $1 \leq i \leq n$, L_i is a fact or there exists a rule R_i in $\mathcal{P}$ (strict or defeasible) with head L_i and body $B_1, \ldots, B_m$, such that each literal on the body of the rule is an element L_j of the sequence appearing before L_i $(j \leq i)$. We will use $\mathcal{P} \mathrel{|\!\!\sim} L$ to denote that there exists a defeasible derivation of L from $\mathcal{P}$.*

We say that a given set S of DeLP clauses is contradictory if and only if $S \mathrel{|\!\!\sim} L$ and $S \mathrel{|\!\!\sim} \sim L$ for some literal L.

Definition 6 (Argument). *Let L be a literal and $\mathcal{P} = (\Pi, \Delta)$ be a DeLP program. An* argument *for L is a pair $\langle A, L \rangle$, where A is a minimal (w.r.t. set inclusion), non contradictory set of defeasible rules of Δ, such that $A \mathrel{|\!\!\sim} L$. We say that an argument $\langle B, L \rangle$ is a* sub-argument *of $\langle A, L \rangle$ iff $B \subseteq A$.*

DeLP provides an argumentation based mechanism to determine *warranted* conclusions. This procedure involves constructing arguments from programs, identifying conflicts or *attacks* among arguments, evaluating pairs of arguments in conflict to determine if the attack is successful, becoming a *defeat*, and finally analyzing defeat interaction among all relevant arguments to determine warrant [14].

Definition 7 (Disagreement). *Let $\mathcal{P} = (\Pi, \Delta)$ be a DeLP program. Two literals L and L' are in* disagreement *if and only if the set $\Pi \cup \{L, L'\}$ is contradictory.*

Definition 8 (Attack). *Let $\mathcal{P} = (\Pi, \Delta)$ be a DeLP program. Let $\langle A_1, L_1 \rangle$ and $\langle A_2, L_2 \rangle$ be two arguments in $\mathcal{P}$. We say that $\langle A_1, L_1 \rangle$* counter-argues, rebuts, *or* attacks *$\langle A_2, L_2 \rangle$ at the literal L if and only if there is a sub-argument $\langle A, L \rangle$ of $\langle A_2, L_2 \rangle$ such that L and L_1 are in* disagreement. *The argument $\langle A, L \rangle$ is called* disagreement sub-argument, *and the literal L will be the counter-argument point.*

In this work, a complete presentation of the inference mechanism of DeLP is not necessary since our formalization will be based on an extension of Dung's approach to argumentation semantics.

4 Modeling Temporal Argumentation with TAF

A *Timed Abstract Framework* (TAF) [10,11] is a recent extension of Dung's formalism where arguments are active only during specific intervals of time; this intervals are 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.

To represent time we assume that a correspondence was defined between the time line and the set $\mathbb{R}$ of real numbers. A *time interval*, representing a period of time without interruptions, will be represented as a real interval $[a - b]$ (we use '$-$' instead of ',' as a separator for readability reasons). To indicate that one of the endpoints (extremes) of the interval is to be excluded, following the notation for real intervals, the corresponding square bracket will be replaced with a parenthesis, *e.g.*, $(a - b]$ to exclude the endpoint a.

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 (the set of all real numbers contained in any of the individual time intervals). In this way, we can directly apply traditional set operations and relations on time intervals sets.

Definition 9 (Time Intervals Set). *A* time intervals set *is a subset $S \subseteq \mathbb{R}$.*

When convenient we will use the set of sets notation for time intervals sets; that is, a time interval set $S \subseteq \mathbb{R}$ will be denoted as the set of all disjoint and $\subseteq$-maximal individual intervals included in the set. For instance, we will use $\{(1 - 3],\ [4.5 - 8)\}$ to denote the time interval set $(1 - 3]\ \cup\ [4.5 - 8)$

Now we formally introduce the notion of *Timed Argumentation Framework*, which extends the *AF* of Dung by adding the availability function. This additional component will be used to capture those time intervals where arguments are available.

Definition 10 (Timed Argumentation Framework). *A* timed argumentation framework *(or 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 $Av : AR \longrightarrow \wp(\mathbb{R})$, such that $Av(A)$ is the set of availability intervals of an argument A.*

Example 1. *Consider the TAF $\Phi = \langle AR, Attacks, Av\rangle$ where:*
$AR = \{A, B, C, D, E, F, G\}$
$Attacks = \{(B, A), (C, B), (E, A), (G, E), (F, G), (G, D)\}$
$Av = \{(A, \{[10 - 50], [80 - 120]\}); (B, \{[55 - 100]\}); (C, \{[40 - 90]\}); (D, \{[10 - 30]\}); (E, \{[20 - 75]\}); (F, \{[5 - 30]\});\ (G, \{[10 - 40]\})\}$ *(See Fig. 1)*

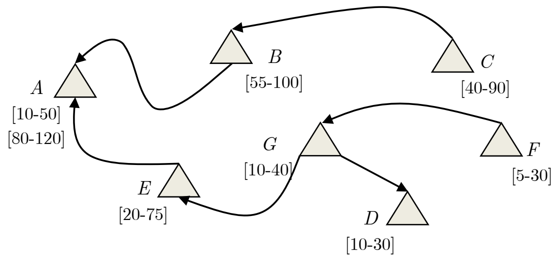

Fig. 1. TAF corresponding to example 1

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 timed argument profile, t-profile, that binds an argument to a set of time intervals; these profiles constitute a fundamental component for the formalization of time-based acceptability.

Definition 11 (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; $(A, Av(A))$ 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. The following definitions extend Dung's original formalization for abstract argumentation by considering t-profiles instead of arguments.

Definition 12 (Defense of A from B w.r.t. S). *Let A and B be arguments. Let S be a set of t-profiles. The defense t-profile of A from B w.r.t. S is $\rho_A = (A, \tau_A^B)$, where: $\tau_A^B =_{def} (Av(A) - Av(B)) \bigcup_{\{(C,\tau_C)\in S \ \mid \ C \ Attacks \ B\}} (Av(A) \cap Av(B) \cap \tau_C)$.*

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, B is in turn attacked by an argument C in the base set S of t-profiles. The following definition captures the defense profile of A, but considering all its attacking arguments.

Definition 13 (Acceptable t-profile of A w.r.t. S). *Consider a set S of t-profiles. The acceptable t-profile for A w.r.t. a set S is $\rho_A = (A, \tau_A)$, where $\tau_A =_{def} \bigcap_{\{B \ Attacks \ A\}} \tau_A^B$ and (A, τ_A^B) is the defense t-profile of A from B w.r.t. S.*

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

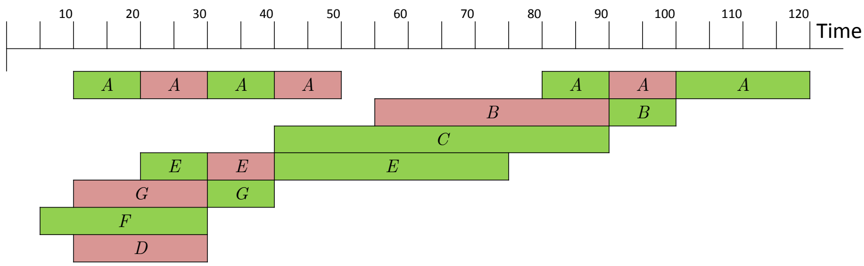

Fig. 2. Representation of the arguments associated with Ex. 2 in a time line

Definition 14 (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, τ_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 for all* $(A, \tau_A) \in S$ *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 t-complete and minimal with respect to set inclusion.*

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 15. *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.* $S\}$.

Example 2. *Suppose we want to establish the acceptability of* A *in the TAF* Φ *presented in example 1. Let us obtain the t-grounded extension of* Φ *by applying the fixed point characterization.*

$F^0(\emptyset) = \emptyset$
$F^1(\emptyset) = \{(A, \{[10-20), (100-120]\}); (C, \{[40-90]\}); (F, \{[5-30]\}); (B, \{(90-100]\}); (E, \{(40-75]\}; (G, \{(30-40]\})\}$
$F^2(\emptyset) = \{(A, \{[10-40], [80-90], (100-120]\}); (C, \{[40-90]\}); (F, \{[5-30]\}); (B, \{(90-100]\}); (E, \{[20-30], (40-75]\}); (G, \{(30-40]\})\}$
$F^3(\emptyset) = \{(A, \{[10-20), (30-40), [80-90), (100-120]\}); (C, \{[40-90]\}); (F, \{[5-30]\}); (B, \{(90-100]\}); (E, \{[20-30], (40-75]\}); (G, \{(30-40]\})\}$
$F^4(\emptyset) = F^3(\emptyset)$
Consequently, $F^3(\emptyset)$ *is the t-grounded extension of* Φ. *Next we describe how the temporal availability of* A *in* $F^3(\emptyset)$ *was obtained from* $F^2(\emptyset)$. *By applying definition 12:*
$\tau_A^B = (Av(A) - Av(B)) \bigcup_{\{(C,\tau_C)\}} (Av(A) \cap Av(B) \cap \tau_C) =$

$= (\{[10-50],[80-120]\} - \{[55-100]\}) \cup (\{[10-50],[80-120]\} \cap \{[55-100]\} \cap \{[40-90]\}) =$
$= \{[10-50],(100-120]\} \cup [80-90] = \{[10-50],[80-90],(100-120]\}$

$\tau_A^E = (Av(A) - Av(E)) \bigcup_{\{(G,\tau_G)\}} (Av(A) \cap Av(B) \cap \tau_G) =$
$= \{[10-20),(30-40],[80-120]\}$

By applying definition 13:
$\tau_A = \cap_{\{X\ Attacks\ A\}} \tau_A^X = \tau_A^B \cap\ \tau_A^E =$
$= \{[10-50],[80-90],(100-120]\} \cap \{[10-20),(30-40],[80-120]\} =$
$= \{[10-20),(30-40],[80-90],(100-120]\}$

5 E-TAF: A TAF Extension with Time Intervals for Attacks

In this section we present E-TAF [9], an extension of TAF that takes in consideration not only the availability of the arguments but also looks into the availability of attacks. Adding time intervals to attacks is a meaningful extension for several domains; consider for example the notion of *statute of limitations* common in the law of many countries. 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 still acceptable and as close as possible to the alleged illegal behavior. Consider the following situation: (1) *John has left debts unpaid in Alabama, US, during 2008*, (2) *He has canceled them in 2009, but paying with counterfeited US dollars, committing fraud*, (3) *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`

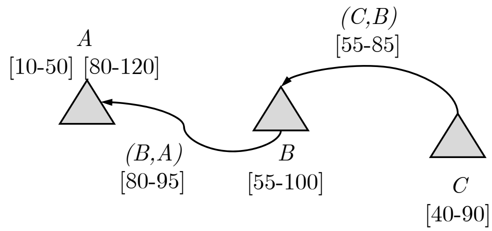

Fig. 3. E-TAF: example

Definition 16 (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*,*
- $ARAv : AR \longrightarrow \wp(\mathbb{R})$ *is the availability function for timed arguments, and*
- $ATAv : Attacks \longrightarrow \wp(\mathbb{R})$ *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 3. *E-TAF=* $\langle AR, Attacks, ARAv, ATAv \rangle$
$AR = \{A, B, C\}$
$Attacks = \{(B, A); (C, B)\}$
$ARAv = \{(A, \{[10 - 50], [80 - 120]\}); (B, \{[55 - 100]\}); (C, \{[40 - 90]\})\}$
$ATAv = \{((B, A), [80 - 95]); ((C, B), [55 - 85])\}$ *(See Fig. 3)*

The following definitions are extensions of the definitions 12 and 13, taking into account the availability of attacks.

Definition 17 (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* $\tau_A^B = [ARAv(A) - ATAv((B, A))] \cup \bigcup_{\{(C,\tau_C) \in S \ \mid \ C \ Attacks \ B\}} (ARAv(A) \cap ATAv((B, A)) \cap ATAv((C, B)) \cap \tau_C)$*.*

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 18 (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* $\tau_A = \bigcap_{\{B \ Attacks \ A\}} \tau_A^B$ *and* (A, τ_A^B) *is the defense t-profile of* A *from* B *w.r.t.* S*.*

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

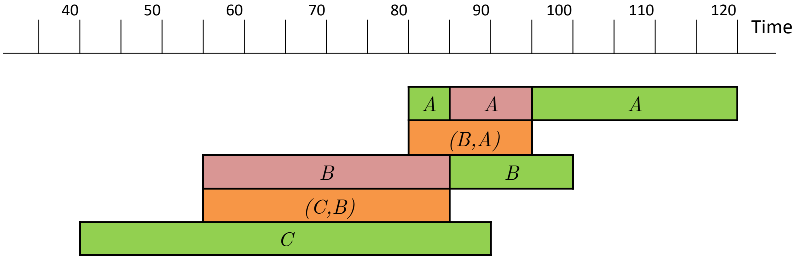

Fig. 4. Representation of the temporal attacks relations

Definition 19 (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. $S\}$.

Example 4. *Suppose we want to establish the acceptability of A in the E-TAF in example 3. In this case, for simplicity, we will restrict the temporal availability of A to the interval $[80 - 120]$. Let us obtain the t-grounded extension of E-TAF by applying the fixed point characterization:*

$F^0(\emptyset) = \emptyset$
$F^1(\emptyset) = \{(A, \{(95 - 120]\}); (C, \{[40 - 90]\}); (B, \{(85 - 100]\})\}$
$F^2(\emptyset) = \{(A, \{[80 - 85], (95 - 120]\}); (C, \{[40 - 90]\}); (B, \{(85 - 100]\})\}$
$F^3(\emptyset) = F^2(\emptyset)$

Consequently, $F^3(\emptyset)$ is the t-grounded extension of the E-TAF. Next we describe how the temporal availability of A was obtained in $F^3(\emptyset)$ by applying the definitions 17 and 18 from $F^2(\emptyset)$. By applying definition 17, we get:
$\tau_A^B = (ARAv(A) - ATAv(B, A)) \bigcup_{\{(C, \tau_C)\}} (ARAv(A) \cap ATAv((B, A)) \cap ATAv((C, B)) \cap \tau_C) =$
$= (\{[80 - 120]\} - \{[80 - 95]\}) -_{\{(C, \tau_C)\}} (\{[80 - 120]\} \cap \{[80 - 95]\} \cap \{[55 - 85]\} \cap \{[40 - 90]\}) = \{(95 - 120]\} \cup \{[80 - 85]\} = \{[80 - 85], (95 - 120]\}$

By applying definition 18: $\tau_A = \cap_{\{X \ Attacks \ A\}} \tau_A^X$, where $\tau_A^B = \{[80 - 85], (95 - 120]\}$

6 Temporal Availability and Strength variation on DeLP

In this section we present ST-DeLP, an instantiation of the abstract framework E-TAF based on the rule-based argumentation framework DeLP. This instantiation incorporates the ability to represent temporal availability and strength factors varying over time, associated with rules composing arguments. This information is then propagated to the level of arguments, and will be used to define temporal availability of attacks in E-TAF.

This association of temporal and strength information to DeLP clauses is formalized through the definition of ST-program, presented below.

Definition 20 (ST-program). *A ST-program $\mathcal{P}$ is a set of clauses of the form (γ, τ, υ), called ST-clauses, where:* (1) *γ is a DeLP clause,* (2) *τ is a set of time intervals for a ST-clause, and* (3) *$\upsilon : \mathbb{R} \longrightarrow [0, 1]$ is a function that determines the strength factor for a ST-clause.*

We will say that (γ, τ, υ) is a strict (defeasible) ST-clause iff γ is a strict (defeasible) DeLP clause. Then, given a ST-program $\mathcal{P}$ we will distinguish the subset Π of strict ST-clauses, and the subset Δ of defeasible ST-clauses.

Next we will introduce the notion of argument and sub-argument in ST-DeLP. Informally, an argument A is a tentative proof (as it relies on information with different strength) from a consistent set of clauses, supporting a given conclusion Q, and specifying its strength varying on time. Given a set S of ST-clauses, we will use $Clauses(S)$ to denote the set of all DeLP clauses involved in ST-clauses of S. Formally, $Clauses(S) = \{\gamma \mid (\gamma, \tau, \upsilon) \in A\}$.

Definition 21 (ST-argument). *Let Q be a literal, and $\mathcal{P}$ be a ST-program. We say that $\langle A, Q, \tau, \upsilon \rangle$ is an ST-argument for a goal Q from $\mathcal{P}$, if $A \subseteq \Delta$, where:*

(1) *$Clauses(\Pi \cup A) \mid\!\sim Q$*
(2) *$Clauses(\Pi \cup A)$ is non contradictory.*
(3) *$Clauses(A)$ is such that there is no $A_1 \subsetneq A$ such that A_1 satisfies conditions* (1) *and* (2) *above.*
(4) *$\tau \ = \tau_1 \cap, ..., \cap \ \tau_n$ for each ST-clause $(\gamma_i, \tau_i, \upsilon_i) \in A$.*
(5) *$\upsilon : \mathbb{R} \longrightarrow [0, 1]$, such that $\upsilon(\alpha) = MIN(\upsilon_1(\alpha), ..., \upsilon_n(\alpha))$, for each $(\gamma_i, \tau_i, \upsilon_i) \in A$, where $\alpha \in \mathbb{R}$.*

Definition 22 (ST-subargument). *Let $\langle A, L, \tau_1, \upsilon_1 \rangle$ and $\langle B, Q, \tau_2, \upsilon_2 \rangle$ be two arguments. We will say that $\langle B, Q, \tau_2, \upsilon_2 \rangle$ is a ST-subargument of $\langle A, L, \tau_1, \upsilon_1 \rangle$ if and only if $B \subseteq A$. Notice that the goal Q may be a sub-goal associated with the proof of goal L from A.*

As in DeLP, ST-arguments may be in conflict. However in ST-DeLP we must also take into account the availability of conflicting arguments. Then, two ST-arguments involving contradictory information will be in conflict only when their temporal availability intersects.

Definition 23 (Counter-arguments). *Let $\mathcal{P}$ be an ST-program, and let $\langle A_1, L_1, \tau_1, \upsilon_1 \rangle$ and $\langle A_2, L_2, \tau_2, \upsilon_2 \rangle$ be two ST-arguments w.r.t. $\mathcal{P}$. We will say that $\langle A_1, L_1, \tau_1, \upsilon_1 \rangle$ counter-argues $\langle A_2, L_2, \tau_2, \upsilon_2 \rangle$ if and only if there exists a ST-subargument $\langle A, L, \tau, \upsilon \rangle$ (called disagreement ST-subargument) of $\langle A_2, L_2, \tau_2, \upsilon_2 \rangle$ such that L_1 and L disagree, provided that $\tau_1 \cap \tau_2 \neq \emptyset$.*

To define the acceptability of arguments in ST-DeLP we will just construct an E-TAF based on the available ST-arguments. The E-TAF defined will capture the temporal availability and the strength of ST-arguments. Let $\mathcal{P}$ be a ST-program. The E-TAF obtained from $\mathcal{P}$ is $\Psi = \langle AR, Attacks, ARAv, ATAv \rangle$ where:

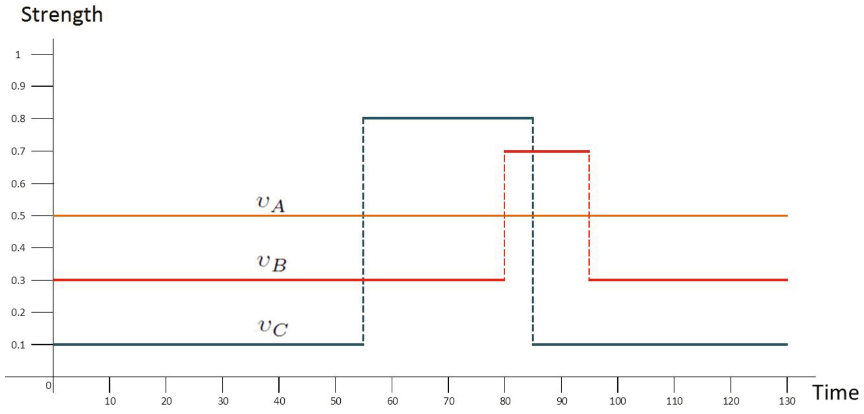

Fig. 5. Representation of the strength functions υ_A, υ_B, υ_C

- AR represents the set of all the ST-arguments from $\mathcal{P}$.
- $Attacks$ represents the counter-argument relation among ST-arguments.
- $ARAv(A) =_{def} \tau_A$, where $A \in AR$ and τ_A is the time-intervals set associated with A in $\mathcal{P}$.
- $ATAv((B, A)) =_{def} \{\alpha \in \mathbb{R} \mid \alpha \in \tau_A \cap \tau_B \textit{ and } \upsilon_B(\alpha) \geq \upsilon_A(\alpha)\}$

Notice that an attack from B to A is available only in the time intervals where the strength of B is grater or equal than the strength of A.

Example 5. *Let us consider the following ST-program:*

$$\mathcal{P} = \left\{ \begin{array}{ll} (a \prec s, k,\ \{[75-140]\},\ \upsilon_1) & (t,\ \{[0-150]\},\ \upsilon_6) \\ (k \prec m,\ \{[0-70],[80-120]\},\ \upsilon_2) & (j,\ \{[0-150]\},\ \upsilon_7) \\ (\sim k \leftarrow p,\ \{[55-120]\},\ \upsilon_3) & (l,\ \{[0-150]\},\ \upsilon_8) \\ (p \prec t, l,\ \{[30-100]\},\ \upsilon_4) & (\sim p \prec j,\ \{[40-90]\},\ \upsilon_9) \\ (s,\ \{[0-150]\},\ \upsilon_5) & (m,\ \{[0-150]\},\ \upsilon_1 0) \end{array} \right\}$$

where the strength functions are defined below:

$\upsilon_1(\alpha) = 0.5$	$\upsilon_6(\alpha) = 1$
$\upsilon_2(\alpha) = 0.9$	$\upsilon_7(\alpha) = 1$
$\upsilon_3(\alpha) = 1$	$\upsilon_8(\alpha) = 1$
$\upsilon_4(\alpha) = \begin{cases} 0.3 & \alpha < 80 \\ 0.7 & 80 \leq \alpha \leq 95 \\ 0.3 & \alpha > 95 \end{cases}$	$\upsilon_9(\alpha) = \begin{cases} 0.1 & \alpha < 55 \\ 0.8 & 55 \leq \alpha \leq 85 \\ 0.1 & \alpha > 85 \end{cases}$
$\upsilon_5(\alpha) = 1$	$\upsilon_3(\alpha) = 1$

Now we construct the E-TAF corresponding to the previous ST-program.

AR= $\{A, B, C\}$, where A stands for $\langle A, a, [80, 120], \upsilon_A\rangle$, B stands for $\langle B, \sim k, [55, 100], \upsilon_B\rangle$ and C stands for $\langle C, \sim p, [40, 90], \upsilon_C\rangle$ and where the strength functions υ_A, υ_B and υ_C are depicted in Fig. 5.

$Attacks = \{(B,A),\ (C,B)\}$
$ARAv(A) = \{[80,\ 120]\}$ $\quad ARAv(B) = \{[55,\ 100]\}$ $\quad ARAv(C) = \{[40,\ 90]\}$
$ATAv((B,A)) = \{\alpha \in \mathbb{R} \mid \alpha \in \{[80,95]\}\ \textit{and}\ v_B(\alpha) \geq v_A(\alpha)\} = \{[80,95]\}$
$ATAv((C,B)) = \{[55,\ 85]\}$

This framework coincides with the E-TAF presented in example 3, Fig. 4, for which argument acceptability was already analyzed.

7 Conclusions – Related and Future Work

Argumentation based formalisms has been successfully applied for reasoning in a single agent, and in multi-agent domains. Dung's AF has been proven fruitful for developing several extensions with application in different contexts (*e.g.*, [8,1]). Reasoning about time is a main concern in many areas, *e.g.*, automated agent deliberation, and recently, an abstract argument based formalization has been defined, called *Temporal Abstract Framework* (TAF), that extends the Dung's formalism by introducing the temporal availability of arguments into account.

In a recent work, a novel extension of TAF called *Extended Temporal Argumentation Framework* (E-TAF [9]) was introduced; this extension takes into account not only the availability of arguments but also the availability of attacks, allowing to model strength of arguments varying over time (strength understood as a generalization of different possible measures for comparing arguments, such as reliability, priorities, etc.).

In this paper we proposed an instantiation of E-TAF with the argumentation formalism *Defeasible Logic Programming* (DeLP), obtaining a formalization we called ST-DeLP. This instantiation provides a concrete knowledge representation and reasoning formalism that allows to specify temporal availability and strength of knowledge at the object language level. This information is propagated to the level of arguments, and acceptability is analyzed as formalized in E-TAF.

As future work we will develop an implementation of ST-DeLP by using the existing DeLP system [2] as a basis. The resulting implementation will be exercised in different domains requiring to model strength varying over time. We are also interested in analyzing the salient features of our formalization in the context of other argumentation frameworks, such as the ASPIC+ framework [19], where rationality postulates for argumentation are explicitly considered.

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

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