On the Relationship between Carneades and Defeasible Logic

Guido Governatori
NICTA, Queensland Research Lab, Australia
guido.governatori@nicta.com.au

ABSTRACT

We study the formal relationships between the inferential aspects of Carneades (a general argumentation framework proposed for several aspects of legal reasoning) and Defeasible Logic. The outcome of the investigation is that the current proof standards proposed in the Carneades framework correspond to some known variants of Defeasible Logic.

1. INTRODUCTION

Argumentation emerged as one of the mainstream topics in the field of Artificial Intelligence and Law, and it has got recognition in the broad field of Artificial Intelligence and in that of agents. In this paper we will concentrate on two framework, Carneades, a general framework for argumentation and Defeasible Logic, a lightweight rule based computational approach to non-monotonic reasoning with an argumentation like flavour. While these are only two among many approaches to argumentation, they have been discussed in relationship to legal reasoning and legal applications (though they are not the only one).

The two systems exhibit some similarities (for example they both address sceptical reasoning, and both consider different inference mechanisms). Accordingly, the aim of the paper is to establish a formal relationships between Defeasible Logic and Carneades to make a precise comparison of the features presented by the approaches possible. In addition once mappings have been establish it is possible to study whether theoretical results for one system transfer to the other system. Finally, we hope that the theoretical comparison of the features presented by the system under analysis could led us to a better understanding of some phenomena of legal reasoning.

The paper is organised as follows: in Sections 2 and 3 we quickly review the two frameworks to be compared (Carneades and Defeasible Logic). Then in Section 4 we show how to reconstruct Carneades in Defeasible Logic. Specifically we focus on the current proof standards, i.e., the ‘inference mechanisms’ behind Carneades, and we show that these correspond to some known variant of Defeasible Logic. In Section 5 we point out some arguable aspects and limitations of the current version of Carneades.

2. CARNEADES

Carneades [12] is a general framework for argumentation, and it has received considerable attention since its inception: [10] reports that as of June 2010 [12] is among the ten most cited papers from articles published in the Artificial Intelligence Journal in the previous 5 years. Carneades combines many features of argumentation to capture dynamic as well as static aspects of argumentation such switch of burden of proof, proof standards, audience and more. The Carneades models emerged from research on argumentation in legal theory and from Walton’s theory of argumentation schemes. A tool called Carneades too has been implemented and it is under further development.

In this paper we follow the presentation of Carneades given in [10] with a simple propositional language consisting of literals only; that is atomic propositions and their negation. For a literal I we use ¬l to indicate the complement of l. Thus if p then ¬l = ¬p and if l = p, then ¬l = p.

DEFINITION 1. A Carneades argument is a structure ⟨P,E,c⟩, where P and E are disjoint sets of literals, and c is a literal.

Given and argument ⟨P,E,c⟩, the sets P and E are, respectively, the set of premises and the set of exceptions. If c = p then the argument is pro p, if c = ¬p the argument is con p. In the dynamic (full) version of Carneades arguments are evaluated in argument evaluation structures, where such structures consider the stage (or phase of the life-cycle of an argumentation), an audience (where the audience is a set of weights associated to the propositions and a set of given propositions, i.e., the assumption the evaluation depends on), and a function assigning a proof standard to each proposition involved in the arguments depending on the stage of the dispute. However, as we have pointed out in the introduction the aim of this paper is just to compare the static aspects of Carneades, thus we will abstract from stages, and audience, and we will focus on the proof standards, or in other terms, the various inference mechanisms used by Carneades to determine whether arguments and the propositions are acceptable or not.

DEFINITION 2. A Carneades Argument Evaluation Structure (CAES) is a structure ⟨Arg,Ass,W,PS⟩ where

- Arg is an acyclic\(^1\) set of arguments;
- Ass is a consistent set of literals;
- W is a weight function W: Arg → [0,1], assigning a real number in the interval [0,1] to every argument;
- PS is a function mapping propositions to a proof standard.

\(^1\)A set of arguments is acyclic if its dependency graph is. The dependency graph has a node for each propositional atom appearing in some argument. Furthermore, there is a link from q to p whenever p depends on q, that is, whenever there is an argument pro or con p with q or ¬q in its set of premises or exceptions.
Notice that in the original version of Carneades [12] the weight function was replaced by a partial order on the arguments. The change introduced in [13] was motivated by the need to introduce thresholds to model various proof standards such as ‘clear and convincing evidence’ and ‘beyond reasonable doubt’.

Whether a literal is acceptable or not depends on the its proof standard determining the strength of the derivation of the literal. To be able to derive a conclusion Carneades needs to establish whether arguments are applicable or not.

**Definition 3.** An argument \( a = \langle P,E,c \rangle \) is applicable in a CAES \( S = \langle \text{Arg}, \text{Ass}, W, PS \rangle \) iff, \( a \in \text{Arg} \) and

- \( p \in P \) implies \( p \in \text{Ass} \) or (\( \sim p \notin \text{Ass} \) and \( p \) is acceptable in \( S \));
- \( p \in E \) implies \( p \notin \text{Ass} \) and (\( \sim p \in \text{Ass} \) or \( p \) is not acceptable in \( S \)).

We are now able to define when a literal is acceptable in an evaluation structure.

**Definition 4.** Given a CAES \( S = \langle \text{Arg}, \text{Ass}, W, PS \rangle \), a literal \( l \) is acceptable in \( S \) iff the conditions associate to the proof standard for the literal \( l \) are satisfied.

The proof standards currently defined in the Carneades [13, 10] framework are:

- *scintilla of evidence*,
- *preponderance of evidence*, also called best argument in [12],
- *clear and convincing evidence*,
- *beyond reasonable doubt*,
- *dialectical validity*.

The above proof standards are listed in order of strength, this means that the conditions to satisfy them are more and more stringent. In addition a stronger proof standard includes the weaker ones.

**Definition 5 (SCINTILLA OF EVIDENCE).** The proof standard scintilla of evidence (se) for a literal \( p \) is satisfied iff there is at least one applicable argument for \( p \).

**Definition 6 (PREPONDERANCE OF EVIDENCE).** The proof standard preponderance of evidence (pe) for a literal \( p \) is satisfied iff \( p \) satisfies se and the maximum weight assigned to an applicable argument pro \( p \) is greater than the maximum weight assigned to an applicable argument con \( p \).

**Definition 7 (CLEAR AND CONVINCING EVIDENCE).** The proof standard clear and convincing evidence (ce) for a literal \( p \) is satisfied iff \( p \) satisfies pe and and the maximum weight of applicable pro arguments exceeds some threshold \( \alpha \), and the difference between the maximum weight of the applicable pro arguments and the maximum weight of the applicable con arguments exceeds some threshold \( \beta \).

**Definition 8 (BEYOND REASONABLE DOUBT).** The proof standard beyond reasonable doubt (bd) for a literal \( p \) is satisfied iff \( p \) satisfies ce and the maximum weight of the applicable con arguments is less that some threshold \( \gamma \).

**Definition 9 (DIALECTICAL VALIDITY).** The proof standard dialectical validity (dv) for a literal \( p \) is satisfied iff \( p \) satisfies se and \( \sim p \) does not satisfy se.

The proof standard dialectical validity can also be rewritten as there is an applicable argument pro \( p \) and there are no argument con \( p \).

The proof standards scintilla of evidence, best argument and dialectical validity were defined in [12] where it was claimed that scintilla of evidence is weaker than best argument and best argument is weaker than dialectical validity.

### 3. DEFEASIBLE LOGIC

Defeasible Logic [28] is a simple, efficient and flexible rule based approach to sceptical non-monotonic reasoning. In this paper we take as starting point the formalisation of the logic given in [3]. Then the logic has been generalised to provide a framework that covers several variants [5, 2] to capture the intuition behind different facets on non-monotonic reasoning. Over the years the logic has been thoroughly investigated [3, 4, 8, 25], and relationships with other formalisms established [6, 4], and the we have shown that it can characterised by argumentation semantics [15, 16]. Furthermore, the Defeasible Logic has been proposed as computational approach for application in the legal domain, modelling of contracts [14], representation of normative positions with time [20], modelling of norm dynamics [19, 18] and regulatory compliance [21, 30]. In addition several efficient implementations have been developed [27, 1, 7, 23].

The aim of this section is to give an introduction to the Defeasible Logic variants needed for the reconstruction of Carneades. Defeasible Logic has three kinds of rules, strict rules (for the monotonic part), defeasible rules and defeaters (for the non-monotonic part); for the sake of simplicity we restrict the presentation to defeasible logic.

A defeasible theory is a structure \( D = \langle F, R, > \rangle \) where \( F \) is a set of facts, represented as literals, \( R \) is a set of rules, and \( > \), the superiority relation, is a binary relations establishing the relative strength of rule. Thus given two rules, let us say \( r_1 \) and \( r_2 \), \( r_1 > r_2 \) means that \( r_1 \) is stronger than \( r_2 \), thus \( r_1 \) can override the conclusion of \( r_2 \). For a literal \( p \), the set of rules whose head is \( p \) is denoted by \( R[p] \) and \( \sim p \) denotes the complement of \( p \), that is \( \sim q = p \) and \( q \) is standard.

A conclusion of \( D \) is a tagged literal and can have one of the following forms:

1. \( +\partial p \): \( p \) is defeasibly provable in \( D \) using the ambiguity blocking variant;
2. \( -\partial p \): \( p \) is defeasibly rejected in \( D \) using the ambiguity blocking variant;
3. \( +\delta p \): \( p \) is defeasibly provable in \( D \) using the ambiguity propagation variant;
4. \( -\delta p \): \( p \) is defeasibly rejected in \( D \) using the ambiguity propagation variant;
5. \( +\alpha p \): \( p \) is supported in \( D \), i.e., there is a chain of reasoning leading to \( p \);
6. \( -\alpha p \): \( p \) is not supported in \( D \).

The proof tags determine the strength of a derivation. The proof tags \( +\delta \), \( -\delta \), \( +\theta \) and \( -\theta \) are for skeptical conclusions, and \( +\alpha \) and \( -\alpha \) capture credulous conclusions.

A proof (or derivation) \( P \) is a finite sequence \( (P(1),\ldots,P(n)) \) of proof tags, satisfying the proof conditions (corresponding to inference conditions) presented in the rest of this section. The proof conditions, given a derivation \( P(1),\ldots,P(n) \), describe the conditions under which we can extend the derivation to derive \( P(n+1) \).

We use the notation \( P(1..n) \) to denote the sequence of length \( n \) of a derivation \( P \).

\[ +\theta: \text{If } P(n+1) = +\theta q \text{ then either} \]
\[ (1.1) q \in F \]
\[ (1.2) \exists r \in R[q] \forall a \in A(r): +\theta a \in P(1..n) \]

\[ +\theta: \text{If } P(n+1) = +\theta q \text{ then either} \]
\[ (2.1) \exists r \in R[q] \forall a \in A(r): +\delta a \in P(1..n) \]
\[ (2.2) \sim q \notin F \]
\[ (2.3) \forall s \in \sim q \text{ either} \]
\[ (2.3.1) \exists r \in A(s): -\delta a \in P(1..n) \]
\[ (2.3.2) \exists r \in A[q] \text{ such that} \]
\[ \forall a \in A(r): +\delta a \in P(1..n) \text{ and } t > s. \]
The main idea of the conditions for a defeasible proof (+Δ) is that there is an applicable rule, i.e., a rule whose all antecedents are already defeasibly provable and for every rule for the opposite conclusion either the rule is discarded, i.e., one of the antecedents is not defeasibly provable, or the rule is defeated by a stronger applicable rule for the conclusion we want to prove. The conditions for −Δ show that any systematic attempt to defeasibly prove that the conclusion fails. Notice that the above conditions characterise the notion of skeptical conclusion using ambiguity blocking [5, 2, 8].

+Δ: If P(n + 1) = +Δq then
(1) q \in F or
(2.1) \forall r \in R[q] \exists a \in A(r): −Δa \in P(1..n) and
(2.2) \exists s \in R[−q] such that
(2.3.1) ∃a \in A(s): −Δa \in P(1..n) or
(2.3.2) \exists r \in R[q] such that
−Δa \in A(r): −Δa \in P(1..n) or r \not\in s.

−Δ: If P(n + 1) = −Δq then
(1) q \not\in F and
(2.1) \neg q \in F and
(2.2) \exists r \in R[q] such that
−Δa \in A(r): −Δa \in P(1..n) or
(2.3) \exists s \in R[−q] such that
(2.3.1) ∃a \in A(s): −Δa \in P(1..n) or
(2.3.2) \exists r \in R[q] such that
−Δa \in A(r): −Δa \in P(1..n) or r \not\in s.

The proof tags +Δ and −Δ capture defeasible provability using ambiguity propagation [5, 2, 8]. Their explanation is similar to that of +Δ and −Δ. The major difference is that to prove ϕ this time we make easier to attack it (clause 2.3). Instead of attacking the argument attacking it are justified arguments, i.e., rules whose premises are provable, we just ask for defensible arguments (i.e., credulous arguments), that is rules whose premises are just supported (i.e., there is a valid chain of reasoning leading to it). The definition of support, proof tags +σ and −σ is as follows:

+σ: If P(n + 1) = +σq then either
(1) q \in F; or
(2) \exists r \in R[q] such that
(2.1) ∃a \in A(r), +σa \in P(1..n), and
(2.2) ∃s \in R[−q] such that
−σa \in A(s), −Δa \in P(1..n), or (s \not\in r).

−σ: If P(n + 1) = −σq then
(1) q \not\in F, and
(2) ∀r \in R[q] such that
(2.1) ∃a \in A(r), −σa \in P(1..n); or
(2.2) ∃s \in R[−q] such that
−σa \in A(s), +Δa \in P(1..n), and s \not\in r.

The proof conditions above are essentially for forward chaining of rules to propagate the ‘support’ for arguments (rules). However, we cannot propagate the support from the premises to the conclusion in case we have a rule for the contrary unless the rule is not weaker than a rule whose premises are all provable.

It is possible to give a weaker notion of support [17], that is whether there is a simple chain of rules leading to the conclusion

+σ−: If P(n + 1) = +σ−q then either
(1) q \in F or
(2) ∃r \in R[q] ∃a \in A(r) +σ−a \in P(1..n)

−σ−: If P(n + 1) = −σ−q then
(1) q \not\in F and
(2) ∀r \in R[q] ∃a \in A(r) such that −σ−a \in P(1..n)

The above proof conditions, with the exception of σ−, allow us to form ‘teams’ of rules for a conclusion to defeat other rules.

**Example 1.** Consider a theory where we have the following rules

\[
\begin{align*}
& r_1 \implies a \\
& r_2 \implies \neg a \\
& r_3 \implies \neg a \\
& r_4 \implies \neg a
\end{align*}
\]

and the superiority relation is \( r_1 \succ r_3 \) and \( r_2 \succ r_4 \). All rules are applicable, so argue pro \( a \) using \( r_1 \), then we have to consider all possible attacks to it. \( r_3 \) is defeated by \( r_1 \) itself, and \( r_4 \) is defeated by \( r_2 \).

In case this feature, called team defeat, is not desired, Defeasible Logic provides variants of the above proof conditions. The proof conditions for the variants without team defeat can be obtained from the above proof conditions given above with the following changes [8]:

- For +Δ and +Δ, clause (2.3.2) is replaced by \( r > s \); we use +Δ and +Δ, for the proof tags thus obtained.
- For −Δ and −Δ, clause (2.3.2) is replaced by \( r \not\in s \); we use −Δ and −Δ, for the proof tags thus obtained.
- For +σ and −σ the occurrences of +Δ and −Δ must be replaced by +Δ and −Δ, for the proof tags thus obtained we use +σ and −σ.

Over the year properties of Defeasible Logic have been studied. Here we report some of the most important results for our purposes:

**Proposition 1.** [3, 4] For any theory D, proof tag # and literal l, it is not the case that \( D \vdash l \# l \) and \( D \vdash \neg l \# l \).

This means that Defeasible Logic is coherent, this means that if you prove that a literal l is provable (with a particular strength) then you cannot prove that the same literal is rejected by the theory (and the other way around).

**Proposition 2.** [3, 4] For any theory D where the transitive closure of the superiority relation is acyclic and literal l and \( \# \in \{ \Delta, \delta \} \), \( D \vdash l \# l \) and \( D \vdash \# l \# l \) if \( l, l \in F \).

This means that the inference mechanism of Defeasible Logic will produce an inconsistency only when the monotonous part of the theory is inconsistent.

Notice, however, that the the above property does not hold for \( \sigma \). \( \sigma \) corresponds to the existence of a credulous argument, thus it is possible to have credulous arguments for both \( p \) and \( \neg p \).

**Proposition 3.** [8] For any theory D and literal l, the following implications hold:

1. \( D \vdash l \# l \implies D \vdash l \# l \);
2. \( D \vdash l \# l \implies D \vdash l \# l \);
3. \( D \vdash l \# l \implies D \vdash l + \# l \);
4. \( D \vdash l + \# l \implies D \vdash l + \# l \);
5. \( D \vdash l + \# l \implies D \vdash l + \# l \);
6. \( D \vdash l + \# l \implies D \vdash l + \# l \);
7. \( D \vdash l + \# l \implies D \vdash l + \# l \).

The last three implications were not discussed in [8] but can be easily obtained with the same techniques. Given that the proof conditions for the negative proof tags are the strong negation of the positive ones [5, 2], we derived immediately the results for them as follows: if \( D \vdash l \# l \) implies \( D \vdash l \# l \), then \( D \vdash l \# l \) implies \( D \vdash l \# l \).

\[2\]The last three implications were not discussed in [8] but can be easily obtained with the same techniques. Given that the proof conditions for the negative proof tags are the strong negation of the positive ones [5, 2], we derived immediately the results for them as follows: if \( D \vdash l \# l \) implies \( D \vdash l \# l \), then \( D \vdash l \# l \) implies \( D \vdash l \# l \).
The above proposition tells us the relative strength of the various proof conditions. Graphically, the relationships among the various proof conditions are depicted in Figure 1.

![Figure 1: Relationships among the proof conditions](image)

Observing that the conditions for team defeat are more general than that for the corresponding, and include them, when we consider the ambiguity blocking variant (i.e., δ), the set of conclusions we can derive are in general different. This is not the case for ambiguity propagation (i.e., σ), where one set of conclusions is included in the other. From the picture in Figure 1 we can see that we have two chains of proof conditions, and that the set of conclusion we can derive from one proof tags in one chain are different from the set of conclusions we can derive from a proof tag in the other chain.

**Example 2.** To see the difference we extend the theory in Example 1 with the following rules:

\[
\begin{align*}
r_s : a & \Rightarrow b \\
r_e : b & \Rightarrow c \\
r_f : & \Rightarrow b
\end{align*}
\]

where \(r_s > r_f\). In this theory we can prove \(+\delta a, +\delta b\) but \(-\delta^2 a\) and \(-\delta r\). Then, accordingly we have \(+\delta b\) and \(+\delta b\) but \(-\delta^2 b\) and \(+\delta c, +\delta c, +\sigma c\) and \(-\sigma c\) but \(+\delta^2 c\).

**Remark 1.** Despite the above result, the proof conditions for team defeat include those for no team defeat. Given a set of applicable rules, that is a set rules whose premises are all applicable. Thus if we have an applicable pro rule that is stronger than any applicable con rule, then the condition for no team defeat is satisfied, but we can use that rule to instantiate the variables \(r\), clause (2.1), and \(t\), clause (2.3), in the proof conditions for the team defeat cases.

The next result is about the complexity of Defeasible Logic. The original result given by [25] for the ambiguity blocking (\(\delta\)) variant can be easily extended to the other variants presented so far.

**Proposition 4.** The set of all the conclusions (extension) of a defeasible theory can be computed in time linear to the size of the theory.

Defeasible Logic does not impose any syntactic restrictions to prevent cycles in the dependency graph, thus in theories like the theory where the only rules is \(a \Rightarrow a\) we cannot obtain any conclusion about \(a\). However, the following proposition tells us cases when this is not a problem.

**Proposition 5.** [4] Let \(D\) be a theory where the dependency graph is acyclic, then for every literal \(l\) and proof tag \(\#\), either \(D \vdash \#\) or \(D \vdash \#\).

Notice, that in general loops in the dependency graphs do not always result in not being able to derive conclusions. For example, given the theory \(a \Rightarrow b, b \Rightarrow a, \Rightarrow \neg a\), while there is a loop in the dependency graph, the loop does not prevent proving conclusions. Indeed in this theory we can prove \(+\neg a, \neg a\) and \(-\neg b\). In case one wants to ensure that a theory is always decisive (no lacks of conclusions), then one could adopt the corresponding well-founded variants of the variants proposed in this paper [26, 24]. The price to pay for this is that the complexity for deriving the extension is now quadratic instead of linear.

**Proposition 6.** [3] Let \(D = (F, R, >)\) be a defeasible theory, and let \(H_D\) be the Herbrandt University of \(D\). Then a theory \(D' = (F', R', \#)\) such that \(D \vdash \#\) if \(D' \vdash \#\) exists (for \(l \in H_D\)).

The meaning of this proposition is that, for ambiguity blocking we can remove the superiority relation from a theory without changing its expressive power. As a consequence we can rewrite the proof conditions as follows:

\(+\delta\): If \(P(a + 1) = ++a\) then either

(1) \(q \in F\) or
(2) \(\exists r \in R[q] v a \in A(r)\) : \(+\neg a \in P(1..n)\) and
(2.2) \(\sim q \notin F\) and
(2.3) \(\exists s \in R[\sim q] v a \in A(s)\) : \(-\neg a \in P(1..n)\).

\(-\delta\): If \(P(a + 1) = \sim a\) then

(1) \(q \notin F\) and
(2) \(\forall r \in R[q] v a \in A(r)\) : \(-\neg a \in P(1..n)\) or
(2.2) \(\sim q \in F\) and
(2.3) \(\exists s \in R[\sim q] v a \in A(s)\) : \(+\neg a \in P(1..n)\).

Thus, for a literal \(l\) we can conclude \(+\#l\) if there is an applicable rule for it and there are no applicable rules for its complement. Before concluding this section we give quick overlook at the relationships between Defeasible Logic and argumentation. In [15] we give a Dung like argumentation semantics for original ambiguity blocking variant (\(\#\)) of Defeasible Logic. In [16] we extended the results of [15] and we proved that the ambiguity propagation of Defeasible Logic (\(\delta\)) is characterised by Dung’s grounded semantics.

**4. Mapping Carneades to Defeasible Logic**

For mapping Carneades to Defeasible Logic we will use ideas from Modular Defeasible Logic [17]; in particular we introduce modal operators corresponding to provability operators (for the various proof standards). Thus the key concept is that if we derive \(p\) with a particular proof condition, for example, let us say we derive \(+\#p\) then we can assert \(#p\) for the proof standard \(ps\) corresponding to \(+\delta\). Accordingly the first thing to do is to extend the language to capture this.

**Definition 10.** If \(l\) is a literal, then \(#p l\) and \(-#p l\) are modal literals for \(ps \in \{se, pe, ce, bd, dv\}\).

The second thing to do is to adjust the definition of rule.

**Definition 11.** A rule is an expression \(A \Rightarrow c, \) where \(A\) is a (possibly empty) set of modal literals and \(c\) is a literal.

The final step is to revise the notion of theory to accommodate the changes above and to extend the definition of superiority relation to capture the various proof standards.

**Definition 12.** A theory \(D\) is a structure \((F, R, >, \#)\) where

- \(F\) the set of facts is a set of literals;
- \(R\) is a set of rules;
- \(\# >\) = \{\(#p\), \(ps \in \{se, ce, bd, dv\}\)\}.

The major difference with what presented in the previous section is the superiority relation: instead of a single superiority relation we have a set of superiority relations, one for each proof standard (except the proof standard scintilla of evidence). After the language we have to adjust the proof conditions. The adjustments are as follows: the proof conditions depend on whether rules are applicable or discarded. The general format for a rule to be applicable is:

\[a \text{ is applicable if } \forall a \in A(r) : +\#a \in P(1..n)\]
thus a rule is applicable in a derivation if all the elements of the
antecedent of the rule have been proved (with a particular strength).
Similarly the general format for discarding a rule is:

\[ \text{a rule } r \text{ is discarded iff } \exists a \in A(r) \text{ such that } -\theta a \in P(1..n). \]

So a rule is discarded if one of the elements of the antecedent has
been rejected (with a particular strength).

Now the elements of the antecedents are modal literals and we
have to specify what it means for a modal literal to be derivable or
rejected.

**DEFINITION 13. Let** \( P \) **be a derivation. A rule** \( r \) **is applicable at**
\( P(1+i) \) **iff** \( \forall ml \in A(r) \) **such that:

- if \( ml = \Phi \) then \( +\sigma^*l \in P(1..i) \);
- if \( ml = \neg \Phi \) then \( -\sigma^*l \in P(1..i) \);
- if \( ml = \Phi \) then \( +\sigma^*l \in P(1..i) \);
- if \( ml = \neg \Phi \) then \( -\sigma^*l \in P(1..i) \);
- if \( ml = \Phi \) then \( +\sigma^*l \in P(1..i) \);
- if \( ml = \neg \Phi \) then \( -\sigma^*l \in P(1..i) \);

The definition for when a rule is discarded is similar, namely:

**DEFINITION 14. Let** \( P \) **be a derivation. A rule** \( r \) **is applicable at**
\( P(1+i) \) **iff** \( \forall ml \in A(r) \) **such that:

- if \( ml = \Phi \) then \( +\sigma^*l \in P(1..i) \);
- if \( ml = \neg \Phi \) then \( -\sigma^*l \in P(1..i) \);
- if \( ml = \Phi \) then \( +\sigma^*l \in P(1..i) \);
- if \( ml = \neg \Phi \) then \( -\sigma^*l \in P(1..i) \);
- if \( ml = \Phi \) then \( +\sigma^*l \in P(1..i) \);
- if \( ml = \neg \Phi \) then \( -\sigma^*l \in P(1..i) \);

To complete the required modifications for the proof conditions
we have to care of the instances of the superiority relations. The
general rule is that in a derivation for a tag \( #p \) we have to use
the corresponding superiority relations, i.e., \( >p^* \). Now the proof
conditions for the Carneades Defeasible Logic are obtained from
the proof conditions for the variants of Defeasible Logic presented
in Section 3 by replacing the definitions of acceptable and discarded
with the notions defined in Definitions 13 and 14, and replacing
the instances of the superiority relation.

To illustrate the construction we provide the full proof conditions
for \( \partial p^* \):

\[ +\partial p^* : \text{if } P(n+1) = +q \text{ then either}
\]

- \( (1) q \in F \) or
- \( (2) q \notin F \)

Notice the main effect of the above construction is to nullify the
distinction between ambiguity blocking (\( \partial \)) and ambiguity propaga-
tion (\( \partial^* \)).

We are now ready to give the mapping to translate a CAES into
a defeasible theory. We begin with the transformation of an argu-
ment. Carneades arguments are mapped to defeasible rules.

**DEFINITION 15 (ARGUMENT MAPPING). Given a CAES**
\( S = \langle \text{Arg, Ass, W, PS} \rangle \), an argument mapping is a function
\( \text{marg} \) that transform an argument \( a \) in Arg into a defeasible
rules, such that given an argument \( a = \langle P, E, c \rangle \)

\[ \text{marg}(a) : [P \Phi] p_i : p_i \in P] \cup \{ \neg c E\} e_j : e_j \in E \Rightarrow c \]

The second step is to take the weights associated with arguments
an to generate the superiority relations associated with the proof
conditions.

**DEFINITION 16 (WEIGHT MAPPING). Given a CAES**
\( S = \langle \text{Arg, Ass, W, PS} \rangle \) and the threshold \( \alpha, \beta \) and \( \gamma \) as in Definitions
7 and 8, a weight mapping is a function \( \text{mwtg} \) that takes in a weight
function and produces a set of superiority relations as follows:

- \( \text{let } a = \langle P_a, E_a, c_a \rangle \) and \( b = \langle P_b, E_b, c_b \rangle \) be two arguments in Arg
such that \( c_a = \neg c_b \).
- \( \text{marg}(a) >_{p^t} \text{marg}(b) \text{ iff } W(a) > W(b) \);
- \( \text{marg}(a) >_{\alpha} \text{marg}(b) \text{ iff }
 1. W(a) > \alpha \text{ and }
 2. W(a) - W(b) > \beta; \)
- \( \text{marg}(a) >_{\beta} \text{marg}(b) \text{ iff: }
 1. W(a) > \alpha \text{ and }
 2. W(a) - W(b) > \beta \text{ and }
 3. W(b) < \gamma; \)
- \( >_{\delta} = \emptyset. \)

Finally the full transformation of a Carneades Argument Evaluation
Structure is given by the following definition.

**DEFINITION 17. Given a CAES** \( S = \langle \text{Arg, Ass, W, PS} \rangle \), the
defeasible theory obtained from \( S \) is

\[ \text{map}(S) = \langle \text{Ass}, \{ \text{marg} : a \in \text{Arg} \}, \text{mwtg}(W) \rangle \]

We are now able to give the result about the relationship between
Carneades and Defeasible Logic.

**THEOREM 7. Let** \( S \) **be a Carneades Argument Evaluation
Structure, and** \( D = \text{map}(S) \), **then

1. \( p \) is acceptable in \( S \) using proof standard scintilla of evidence
   \( \text{iff } D^+ >_{\alpha} p^* \).
2. \( p \) is acceptable in \( S \) using proof standard \( ps \) \( \in \{ pe, ce, bd, dv \} \)
   \( \text{iff } D^+ >_{\beta} p^* \).

**PROOF.** (Sketch) The proof is by induction on the length of deriv-
aion. The inductive base is straightforward given that the base of
acceptability for Carneades is whether a literal is an assumption or
not, and for Defeasible Logic for being a fact or not. But facts in the
defeasible theory corresponding to the CAES are the assumption
in CAES.

For the inductive step, the key point is the weight mapping. To
illustrate the core of the proof we sketch the proof for the case of
beyond reasonable doubt proof standard.

Suppose that we have a Carneades argument \( a \) pro \( p \) such that the
proof standard \( bd \) for \( p \) is satisfied. This means that the argument is
applicable, thus by the inductive hypothesis we have that the rule
\( \text{marg}(a) \) is applicable as well. This means that the weight \( W(a) > \alpha \).
and then for any applicable argument \( b \) con \( p \) we have \( W(a) - W(b) > \beta \)
and \( W(b) < \gamma \). Thus from \( \text{mwtg} \) we have that for every
rule corresponding to \( \text{marg}(b) \), we have \( \text{marg}(a) >_{\delta} \text{marg}(b) \). If
there are other rules con \( p \) then these correspond to non applicable
arguments in CAES and thus by inductive hypothesis those rules
are discarded. The argument for the proof in the other direction is
similar. The proof for the other proof standards is similar. \( \square \)
A consequence of the above result in conjunction with Proposition 4 give us an answer to the question raised by Gordon and Walton [13] about the computational complexity of acceptability of proposition given the current Carneades proof standards. Proposition 4 tells us that the complexity of computing the extension of Defeasible Logic has linear complexity. It is immediate to see that the mapping from a Carneades CAES to a corresponding defeasible theory is in the worst case quadratic (linear for the $dv$ proof standard), given that we have to consider the relationships between weight of the argument to derive the superiority relations.

**Corollary 8. Acceptability of a proposition in Carneades can be computed in polynomial time.**

The results in Theorem 7 shows that the inference mechanism of Carneades based on the current proof standards correspond to a simple combination of defeasible logic theories (sharing the same rules and facts) using the ambiguity blocking no team defeat variants plus a mechanism to take conclusion from another theory. In addition it shows that the proof standards preponderance or evidence, clear and convincing evidence, beyond reasonable doubt are just instances of the same inference mechanism (this can also easily been seen from Carneades alone by setting the threshold $\alpha$ and $\beta$ to 0 and $\gamma$ to $\infty$). What about dialectical validity? Based on Proposition 6 it seems it correspond to $\delta$, so it corresponds to the ambiguity blocking variant of defeasible logic. In addition since the superiority relation makes the distinction between team defeat and no-team defeat irrelevant. However, have we have shown in Example 2 the two variants ($\delta$ and $\delta'$) are in general different. Nevertheless, the use of the modal operators in the antecedents of rules (or alternatively the reliance of applicability of arguments) allows us apply the discussion in Remark 1 to specify that the proof conditions for $\delta_{pr}$ are a generalisation of that of $\delta'_{pr}$, and thus the proof standard $dv$ is not stronger than the other proof standards. Here is the issue on knowledge representation, so how to encode arguments. However, we refrain from further investigate this issue in this paper.

## 5. DEFEASIBLE LOGIC, CARNEADES AND PROOF STANDARDS

In the previous section we have seen how to capture the Carneades proof standards currently provided, and we have seen that these correspond to single inference mechanism in Defeasible Logic. In Section 3 we have seen that it is possible to give more proof conditions. Thus in this section we discuss some issues with the proof standards that could be perceived as drawback on the current proof standards.

In Section 3 we have seen that in Defeasible Logic we have a few versions of the notion of support, namely $\sigma^-$, $\sigma^*$, and we have seen that $\sigma^-$ corresponds to the proof standard scintilla of evidence. While the definition of this standard seems to conform to its use in some Common Law jurisdictions\(^3\). What about $\sigma^*$? We believe that $\sigma$ could be used to model substantial evidence, i.e., "relevant evidence as a reasonable mind might accept as adequate to support a conclusion" [9]. Now, we consider a conclusion proved with proof tag $+\sigma$ when there is a chain of reasoning leading to the conclusion, and for every argument $\alpha$, if the argument $\alpha$ is stronger than the argument $\alpha'$, then we have to show that the premises of the argument $\alpha$ do not hold (are not acceptable). We believe that it would be unreasonable to support a conclusion defeated by an argument deemed valid. For example consider the scenario, that a drunk person claims that he had a glimpse of the accused (and the accused was not know to him before) in a place different from the crime scene, but there are footage from several high definition security cameras on located in the crime scene clearly showing pictures of the accused at the crime scene at the time of the crime. In addition there it has been assess that the footage from the cameras has not been tampered with. In this case there is scintilla of evidence that the accused was not at the crime scene, but it would be unreasonable that there is substantial evidence about it, while, we think it reasonable to say that there is substantial evidence that the accuse was at the crime scene. The scenario can be modelled by the following rules:

$$r_1: \text{drunk} \Rightarrow \neg \text{crimeScene} \quad r_2: \text{camera} \Rightarrow \text{crimeScene}$$

where $r_1 < r_2$ and the antecedents of the rules are given as facts. Then we derive $+\sigma \neg \text{crimeScene}$ but $-\sigma \text{crimeScene}$ and $+\sigma \text{crimeScene}$.

As we have alluded to in Section 2 in the version of Carneades proposed in [12] the comparison of the strength of the argument depended on preference relation (a partial order on the set of arguments) while in successive versions [13, 10] it was replaced by a weight function. One of the reasons for this move was to capture additional proof standards, in particular clear and convincing evidence and beyond reasonable doubt. However, in the previous section we have seen that this is not the case, and that it is possible to capture these two proof standards (as defined in Carneades) just using different superiority relations defining the relative strength of arguments. In general we believe that a qualitative approach to preferences is more intuitive than a quantitative one. In our view it is hard to explain what is the difference between two arguments with let us say weight of 0.65 the first and 0.57 the second, and why one should accept argument whose wight is above of let us say 0.58 instead of 0.56.

The second reason, claimed by the authors, is to aggregate multiple arguments. The authors rightly argues that considering the sum of arguments pro versus the sum of arguments con leads often to counter-intuitive results, in particular when the arguments in one set might not be all independent from each other. To obviate this problem Carneades adopt the strategy to consider the maximum of the arguments pro and the maximum of arguments con. However, the use of weight cannot take into account fully independent arguments.

### Example 3. Consider a theory with the following rules

$$r_1 : a_1 \Rightarrow b \quad r_2 : a_2 \Rightarrow b$$

$$r_3 : a_3 \Rightarrow \neg b \quad r_4 : a_4 \Rightarrow \neg b$$

where $r_1 > r_3$ and $r_2 > r_4$.\(^5\)

The idea here is that we have two independent chains of reasoning. On one side we have $r_1$ and $r_3$ where $r_1$ overrides $r_3$; on the other side we have $r_2$ and $r_4$ where $r_2$ overrides $r_4$. Besides that $r_1$ and $r_4$ are independent, and so are $r_2$ and $r_3$, meaning that in absence of any other information we cannot take a decision about the conclusion. Thus if $a_1$ and $a_3$ are given then we conclude $b$, and so if $a_2$ and $a_4$ are given. Also this should be the case when all antecedents are given. However, if either $a_1$ or $a_3$ or $a_4$ and $a_2$ are given we cannot conclude $b$; similarly when we have three of the antecedents but not both $a_1$ and $a_2$.

\(^3\)The mapping given in [3] to remove the superiority relation does produce the same result for $\delta'$.

\(^4\)[9] defines scintilla of evidence as ‘the slightest bit of evidence tending to support a material issue in a lawsuit’.

\(^5\)For a less abstract example of the theory in this example, consider these rules: $r_1: \text{monotreme} \Rightarrow \text{mammal}$, $r_2: \text{hasFar} \Rightarrow \text{mammal}$, $r_3: \text{laysEggs} \Rightarrow \neg \text{mammal}$, $r_4: \text{hasBill} \Rightarrow \neg \text{mammal}$. An then we have that a platypus is a mammal, has fur, lays eggs, and has a bill.
Notice that this example essentially has the same structure of Example 1. Formally, given $a_1, a_2, a_3, a_4$ we derive $+\beta b$ and $+\beta b$ but $-\beta b$.

We would like to point out that the above example can be modelled in the [12] version of Carneades, but cannot be represented in version of Carneades using the weight functions.

Consider a Carneades Argument Evaluation Structure with the following arguments

- $a_1$ pro $b$
- $a_2$ pro $b$
- $a_3$ con $b$
- $a_4$ con $b$

where $W(a_1) > W(a_3)$ and $W(a_2) > W(a_4)$. Furthermore, we assume that $W(a_1) - W(a_3) > \gamma$, $W(a_2) - W(a_4) > \gamma$ but $W(a_1) - W(a_4) \leq \gamma$ and $W(a_2) - W(a_3) \leq \gamma$, and that $W(a_1), W(a_2) > \delta$, where $\gamma, \delta > 0$; $\delta$ and $\gamma$ are the threshold for accepting arguments pro and for the minimum difference in weight between the max for arguments pro and max arguments con.

From the description, it is immediate to see that when $a_1$ and $a_2$ are both applicable (but the other two arguments are not) we conclude pro; similarly when $a_3$ and $a_4$ are the applicable arguments, but we cannot conclude it when the applicable arguments are either $a_1$ and $a_4$, or $a_2$ and $a_3$.

Carneades, however, is not able to conclude $b$ when all four arguments are applicable. Suppose it does. Thus $\max\{W(a_1), W(a_2)\} > \delta$ and $\max\{W(a_1), W(a_2)\} = \max\{W(a_1), W(a_4)\} > \gamma$.

Suppose that $W(a_1) = \max\{W(a_1), W(a_2)\}$; this means that $W(a_1) = \max\{W(a_1), W(a_4)\}$ (since $W(a_1) - W(a_2) > \gamma$ and $W(a_1) - W(a_4) \leq \gamma$). Thus we have $W(a_1) \geq W(a_2), W(a_2) - W(a_4) > \gamma$, therefore $W(a_1) - W(a_4) > \gamma$ and thus we get a contradiction.

Suppose that $W(a_2) = \max\{W(a_1), W(a_2)\}$; this means that $W(a_3) = \max\{W(a_3), W(a_4)\}$ (since $W(a_2) - W(a_4) > \gamma$ and $W(a_2) - W(a_3) \leq \gamma$). Thus we have $W(a_2) \geq W(a_1), W(a_1) - W(a_3) > \gamma$, therefore $W(a_2) - W(a_3) > \gamma$ and thus we get a contradiction.

The impossibility to represent this scenario in the case of preponderance of evidence follows from the fact that we need to have $W(a_1) = W(a_4)$ and $W(a_2) = W(a_3)$, which then gives $W(a_1) = W(a_2)$ and $W(a_2) = W(a_3)$.

The second aspect we discuss here is about what we called combination of proof standards. Carneades associates to each stage and each proposition a proof standard to determine whether the proposition is acceptable at that stage. In addition the applicability of an argument depends on whether its premises are acceptable or not (where acceptable means acceptable at that stage). Thus, according to the formal definitions, to have an argument where some of the premises have to be accepted with one proof standard, let us say with the scintilla of evidence proof standard, while the conclusion has to be proved without reasonable doubt.

**Example 4.** Consider a CAES with the following arguments

- $a_1 : (\emptyset, \emptyset, a)$
- $a_2 : (\emptyset, \emptyset, -a)$
- $a_3 : (a, \emptyset, b)$

where $W(a_1) < W(a_2)$, and the $PS(a) = sa$ and $PS(b) = bd$. For the moment let us assume that the thresholds are satisfied. It is easy to see that the $a$ is acceptable since, trivially, there is an applicable argument. Then, the argument $a_3$ is applicable, the appropriate thresholds are reached and there are no arguments against it.\(^6\)

The above example poses a few questions. Is it appropriate to state that the proof standard for $b$ has been met? From one point of view, the proof standard has been attained, since all we needed was to establish that there were a glimpse of evidence for $a$, the premise of the argument for $b$. From another perspective, the perspective where an argument is not reduced to a rule as it is done in Carneades, but an argument is a chain a reasoning, or better a proof tree, the argument (chain) $a \cdot b$ is attacked and defeated, so while there is no doubt about the connection between $a$ and $b$, the validity of the premise is seriously questioned, and there is no substantial evidence to support $b$.

The second question is again about the use of thresholds. Suppose that the weight of argument $a_3$ does exceed $\alpha$. The proof standard dialectical validity is satisfied, but the standard beyond reasonable doubt is not. It is possible to argue that the above interpretation is not appropriate: no matter how feeble the argument for $b$ is there are no applicable argument against it, so how can one doubt it if no reasons for the opposite have been put forward? What about the mapping to Defeasible Logic? The mapping given in Definition 17 follows strictly the approach proposed by Carneades. The CAES of Example 4 is mapped the following theory:

$$r_1 : \Rightarrow a \quad r_2 : \Rightarrow -a \quad r_3 : \Box \sigma a \Rightarrow b$$

From $r_1$ we can derive $+\sigma a$, thus we can assert $\Box \sigma a$, which is what we need to establish that $r_2$ is applicable.

On the other hand, all variants of Defeasible Logic presented in Section 3 require all elements of the antecedent of a rule to be provable with at least the same strength of the strength of conclusion we want to prove.

The final aspect we want to discuss regards the beyond reasonable doubt proof standard. The issue we are going to discuss is related to the distinction between ambiguity blocking and ambiguity propagation. Intuitively, a literal is ambiguous if there is a (monotonic) chain of reasoning pro $p$ and another con $-p$, and the superiority relation does not resolve this conflict. In an ambiguity propagation setting, since we were not able to solve the conflict we want to propagate the uncertainty to conclusions depending on the ambiguous literals. In an ambiguity blocking setting, given the sceptical nature of the reasoning, the two conclusions are considered both as not provable, and we ignore the reasons why they were when we use them as premises of further arguments.

Let us illustrate the distinction with the help of the following example.

**Example 5.** Let us suppose that a piece of evidence $A$ suggests that the defendant in a legal case is not responsible while a second piece of evidence $B$ indicates that he/she is responsible; moreover the sources are equally reliable. According to the underlying legal system a defendant is presumed innocent (i.e., not guilty) unless responsibility has been proved (without reasonable doubt).

The above scenario is encoded in the following defeasible theory:

$$r_1 : \text{evidence}A \Rightarrow \neg \text{responsible}, \quad r_2 : \text{evidence}B \Rightarrow \text{responsible}, \quad r_3 : \text{responsible} \Rightarrow \text{guilty}, \quad r_4 : \Rightarrow \neg \text{guilty}.$$  

Given both $\text{evidence}A$ and $\text{evidence}B$, the literal responsible is ambiguous. There are two applicable rules ($r_1$ and $r_2$) with the same strength, each supporting the negation of the other. As a consequence $r_3$ is not applicable, and so there is no applicable rule supporting the guilty verdict. Thus according the ambiguity blocking

\(^6\)Technically if the set of arguments con is empty the maximum is not defined, thus we assume that in such a case the maximum is 0, and we further assume that $\alpha > \beta$.  

The final aspect we want to discuss regards the beyond reasonable doubt proof standard. The issue we are going to discuss is related to the distinction between ambiguity blocking and ambiguity propagation. Intuitively, a literal is ambiguous if there is a (monotonic) chain of reasoning pro $p$ and another con $-p$, and the superiority relation does not resolve this conflict. In an ambiguity propagation setting, since we were not able to solve the conflict we want to propagate the uncertainty to conclusions depending on the ambiguous literals. In an ambiguity blocking setting, given the sceptical nature of the reasoning, the two conclusions are considered both as not provable, and we ignore the reasons why they were when we use them as premises of further arguments.

Let us illustrate the distinction with the help of the following example.

**Example 5.** Let us suppose that a piece of evidence $A$ suggests that the defendant in a legal case is not responsible while a second piece of evidence $B$ indicates that he/she is responsible; moreover the sources are equally reliable. According to the underlying legal system a defendant is presumed innocent (i.e., not guilty) unless responsibility has been proved (without reasonable doubt).

The above scenario is encoded in the following defeasible theory:

$$r_1 : \text{evidence}A \Rightarrow \neg \text{responsible}, \quad r_2 : \text{evidence}B \Rightarrow \text{responsible}, \quad r_3 : \text{responsible} \Rightarrow \text{guilty}, \quad r_4 : \Rightarrow \neg \text{guilty}.$$  

Given both $\text{evidence}A$ and $\text{evidence}B$, the literal responsible is ambiguous. There are two applicable rules ($r_1$ and $r_2$) with the same strength, each supporting the negation of the other. As a consequence $r_3$ is not applicable, and so there is no applicable rule supporting the guilty verdict. Thus according the ambiguity blocking
we can obtain $+\delta \rightarrow \neg \text{guilty}$. In contrast, in an ambiguity propagation setting we propagate ambiguity of responsible thus the literals guilty and $\neg \text{guilty}$ are ambiguous; thus an undisputed conclusion cannot be drawn, so we have both $-\delta \text{guilty}$ and $-\delta \neg \text{guilty}$.

When we look at the example above is appropriate to say that we have reached a not guilty verdict without any reasonable doubt? The evidence supporting the the defendant was responsible has not been refuted.

**Example 6.** Let us extend the previous example. Suppose that the legal system allows for compensation for wrongly accused people. An a person has been wrongly accused if the defendant is found innocent, where innocent is defined as $\neg \text{guilty}$. In addition, people are entitled to compensation. The additional elements of this scenario are modelled by the rules:

$$r_5 : \neg \text{guilty} \Rightarrow \text{innocent}$$
$$r_6 : \text{innocent} \Rightarrow \text{compensation}$$
$$r_7 : \Rightarrow \neg \text{compensation}$$

where $r_6 > r_7$.

Continuing the discussion from Example 5, in the ambiguity propagation setting, so that there is some doubt about the responsibility, so we did not rule out that the defendant was wrongly accused, we conclude about the entitlement of compensation ($+\delta \text{compensation}$).

Notice that in the above two example, there was not need to use the superiority relation, thus it poses some doubts the definition of the beyond reasonable doubt given in Carneades. Indeed to obtain a positive conclusion using ambiguity propagation we have to use the superiority relation to resolve conflicts/ambiguities. But all we need is that the audience establish that one of the two sides of the conflict overrides the other, but there is no need that they quantify how much it overrides it.

To conclude this section, according to the discussion we had so far, we would like to propose alternative classifications of the proof standards proposed in Carneades:

**Definition 18.** Given a defeasible theory $D = (F,R,>)$

- $p$ is proved with proof standard scintilla of evidence iff $D \vdash \sigma \rightarrow p$;
- $p$ is proved with proof standard substantial evidence iff $D \vdash \sigma \rightarrow p$;
- $p$ is proved with proof standard preponderance of evidence iff $D \vdash +\delta p$;
- $p$ is proved with proof standard beyond reasonable doubt iff $D \vdash +\delta p$;
- $p$ is proved with proof standard dialectical validity iff $D' \vdash +\delta p$, where $D' = (F,R,>)$.

The above classification leaves out clear and convincing evidence. It is unclear to us how to define proof conditions whose strength is in between that of preponderance of evidence and beyond reasonable doubt. A possible solution would be to use a solution similar to what we did to reconstruct Carneades and to use a theory $D = (F,R,\triangleright,\triangleright)$ with two superiority relations, such that $\triangleright_2 \subset \triangleright_1$, and then preponderance of evidence corresponds to $\delta$ using $\triangleright_1$, clear and convincing evidence to $\delta$ using $\triangleright_2$, and beyond reasonable doubt to $\delta$ using $\triangleright_2$.

\footnote{Notice that removing the superiority relation without adding extra rules is different from the technique presented in [3] to show that the superiority relation does not add to the expressive power of the ambiguity blocking variant of Defeasible Logic. However, we have some concerns about the resulting variant is meaningful or nor.}

### 6. Conclusion

In the previous sections we have provided a reconstruction of the current Carneades proof standards in terms of Defeasible Logic, and we have seen that, with the exception of scintilla of evidence all these standards correspond to the ambiguity blocking no team defeat inference mechanism of Defeasible Logic. The result is twofold: (i) this means that it is possible to use implementation of Defeasible Logic as engine for computing acceptability in Carneades (ii) it was possible to use the theoretical results studied for Defeasible Logic to shed light on some Carneades features and to highlight some possible shortcomings of decision choices behind design of the current proof standards, and to propose alternative proof standards to be used in conjunction with the other aspects of Carneades.

Acceptability of arguments is only one of the aspects of (legal) argumentation. Two other important aspects are about the burden of proofs associated with the claims in a (legal) proceedings and the dialectical nature of argumentation. In [22] we have shown how to adapt Defeasible Logic to cope with dynamic burden of proofs (dynamic, in the sense that the burden of proof can be determined during the proceedings depending on the facts of the case at hand), specifically with burden of production and burden of persuasion. For the dialectical nature of argumentation in [31] we proposed a reconstruction of ALIS [29] in terms of Defeasible Logic, and in [11] we used Defeasible Logic to model dialogue games where the parties involved have to follow asymmetric protocols (the protocols for the parties involved can be different, in particular the parties have to use different proof standards to support their claims).

### Acknowledgements

I would like to thank Thomas Gordon, Henry Prakken, Antonino Rotolo and Giovanni Sartor for discussions on the relationships between Carneades and Defeasible Logic.

NICITA is funded by the Australian Government as represented by the Department of Broadband, Communications and the Digital Economy and the Australian Research Council through the ICT Centre of Excellence program.

### 7. References


