Ranking Transition-based Medical Recommendations using Assumption-based Argumentation

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Abstract. We present a general framework to rank assumption in assumption-based argumentation frameworks (ABA frameworks), relying on their relationship to other assumptions and the syntactical structure of the ABA framework. We propose a new family of semantics for ABA frameworks that is using reductions to the abstract argumentation setting and leveraging existing ranking-based semantics for abstract argumentation. We show the suitability of these semantics by investigating a case study based on medical recommendations for patients with multiple health conditions and show that the relationship of the recommendations are enough to establish a ranking between the recommendations.

Keywords: ABA · Ranking-based semantics · TMR

1 Introduction

In recent years, the use of artificial intelligence in medicine has become increasingly popular [1, 23, 3]. An AI system can be used to support the decision-making process of practitioners, in particular by recommending treatments for patients with specific health conditions. A particularly challenging task is finding good recommendations for patients with several different health conditions (*multimorbidities*), where the different health conditions require different treatment approaches [12, 13]. In this case, treatments need to be combined, but such a combination is not always trivial. It may be that two treatments do not mix well, or worse, that they counteract each other. Therefore, an AI system needs to take into account the interaction between different treatment approaches in order to recommend the best course of action.

The *Transition-based Medical Recommendation model* (TMR) is used to represent clinical guideline recommendations and their interactions. These recommendations consist of an action and a corresponding effect on a property. The actions of two recommendations may contradict each other. However, the TMR model is constructed based on a generic database and cannot be used directly to reason wrt. a specific patient and their health conditions. To overcome this disadvantage and reason with TMR on specific patient data, Cyras et al. [12, 13] proposed to use formal argumentation [4] as the foundation for a decision-making model. Formal argumentation is concerned with the representation of arguments and their relationships. One important approach is the abstract argumentation framework (AF) by Dung [15]. This framework uses directed graphs to represent arguments as nodes and attacks between two arguments as edges between these two arguments, where the source of an edge *attacks* the target. One way of reasoning with AFs is to use *extension-based semantics*, which specify when a set of arguments is *acceptable*.

In addition to AFs, other models of rational decision-making using argumentative reasoning have been explored in the literature. One of these are the *assumption-based argumentation frameworks* (ABA frameworks) [7, 6, 16, 26]. These are based on deductive systems over a formal language with rules. One important component of the formal language are the so-called *assumptions*, which are used as the basis for deriving further pieces of information. Similar to AFs, one reasoning method for ABA frameworks are extension-based semantics that define when a set of assumptions is *acceptable*. Abstract argumentation frameworks and ABA frameworks are closely related; the standard approach to reasoning with ABA frameworks involves deriving an AF and a translation for the other direction exists as well [14].

The classical semantics of both AFs and ABA frameworks induce a binary classification of arguments resp. assumptions: an argument or assumption is either accepted or not. This may be considered too restrictive in real-world scenarios such as the treatment recommendation scenario from above. For AFs, *ranking-based semantics* [8, 2] have been introduced to overcome this limitation, where a ranking of arguments is established based on their individual strength. Thus, we can not only state that an argument is part of an acceptable set or not, but also infer that one argument is “better” than another one.

In this paper we introduce *ranking-based semantics* for the ABA setting to rank assumptions based on their strength. Using these semantics, we can state whether one assumption is stronger than another. We present a family of ranking-based semantics based on ideas for AFs. For an ABA framework, we look at the induced AF and compute a ranking over arguments, then lift the resulting ranking back to ABA, and then re-evaluate the result in the context of ABA. In addition, we look at a case study based on [28] using the TMR model to rank medical recommendations and show that the proposed ranking formalism behaves in line with other recent AI systems for finding medical recommendations.

This paper is organised as follows. We recall the necessary background information about AFs, ranking-based semantics, ABA frameworks and the TMR model in Section 2. In Section 3, we introduce ranking-based semantics for ABA frameworks and propose a family of ranking-based semantics for ABA frameworks based on ranking-based semantics for AFs. In Section 4, we investigate a case study based on the TMR model to show the intuitive behaviour of our proposed semantics. Related work is discussed in Section 5 and Section 7 concludes

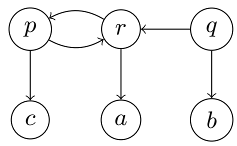

Fig. 1: Abstract argumentation framework F from Example 1.

the paper. This paper is a continuation of the workshop paper (with informal proceedings) [25] and extended with a case study in Section 4.

2 Preliminaries

In this section we recall the necessary preliminaries for this work. We start with *abstract argumentation framework* and their *extension-based semantics*, since they are the most basic notion we will need. After that we recall *ranking-based semantics* as an alternative the extension-based semantics. Finally we denote *assumption-based argumentation frameworks*, which uses abstract argumentation frameworks and their extension-based semantics to reason about sets of assumptions.

2.1 Abstract Argumentation Frameworks

An *abstract argumentation framework* (*AF*) is a directed graph $F = (Arg, Att)$ where Arg is a finite set of *arguments* and $Att \subseteq Arg \times Arg$ is an *attack relation* [15]. An argument a is said to *attack* an argument b if $(a, b) \in Att$. We say that an argument a is *defended by a set* $E \subseteq Arg$ if every argument $b \in Arg$ that attacks a is attacked by some $c \in E$. For $a \in Arg$ we define $a^-_F = \{b \mid (b, a) \in Att\}$ and $a^+_F = \{b \mid (a, b) \in Att\}$, so the sets of attackers of a and the set of arguments attacked by a in F. For a set of arguments $E \subseteq A$ we extend these definitions to E^-_F and E^+_F via $E^-_F = \bigcup_{a \in E} a^-_F$ and $E^+_F = \bigcup_{a \in E} a^+_F$, respectively. If the AF is clear in the context, we will omit the index.

Example 1. Consider the argumentation framework $F = (Arg, Att)$ with

$$Arg = \{a, b, c, p, q, r\} \qquad Att = \{(r, a), (q, b), (p, c), (p, r), (r, p), (q, r)\}.$$

F is depicted as a directed graph in Figure 1, with the nodes corresponding to arguments, and the edges corresponding to attacks.

Most semantics [5] for abstract argumentation are relying on two basic concepts: *conflict-freeness* and *admissibility.* Given $F = (Arg, Att)$, a set $E \subseteq Arg$ is

- *conflict-free* iff $\forall a, b \in E$, $(a, b) \notin Att$;
- *admissible* iff it is conflict-free, and every element of E is defended by E.

We use $cf(F)$ and $ad(F)$ for denoting the sets of conflict-free and admissible sets of an argumentation framework F, respectively. The intuition behind these concepts is that a set of arguments may be accepted only if it is internally consistent (conflict-freeness) and able to defend itself against potential threats (admissibility). The semantics proposed by Dung [15] are then defined as follows.

Definition 1. *Given $F = (Arg, Att)$, an admissible set $E \subseteq Arg$ is*

- *a* complete *extension (co) iff it contains every argument that it defends;*
- *a* preferred *extension (pr) iff it is a $\subseteq$-maximal complete extension;*
- *a* grounded *extension (gr) iff it is a $\subseteq$-minimal complete extension;*
- *a* stable *extension (stb) iff $E^+_F = A \setminus E$.*

The sets of extensions of an argumentation framework F, for these four semantics, are denoted (respectively) $co(F)$, $pr(F)$, $gr(F)$ and $stb(F)$. Note that the grounded extension is uniquely determined [15].

2.2 Ranking-based Semantics

While extension-based semantics can only differentiate between acceptance and non-acceptance of arguments, *ranking-based semantics* [2] allow to rank arguments based on their strength.

Definition 2. *A* ranking-based semantics *ρ is a function, which maps an argumentation framework $F = (Arg, Att)$ to a preorder*[3] *$\succeq^\rho_F$ on Arg.*

Intuitively, $a \succeq^\rho_F b$ means that a is at least as strong as b in F. We further define $a \succ^\rho_F b$ to denote $a \succeq^\rho_F b$ and $b \not\succeq^\rho_F a$ and $a \simeq^\rho_F b$ to denote $a \succeq^\rho_F b$ and $b \succeq^\rho_F a$.

An example for a ranking-based semantics is the *Burden-based semantics* [2], which is based on *burden numbers* that assess the strength of an argument in relation to the strengths of its attackers. Let $\succeq_{lex}$ be the *lexicographical preference order*, which for (possibly infinite) real-valued vectors $V = (V_1, V_2, \ldots)$ and $V' = (V'_1, V'_2, \ldots)$ is defined as $V \succ_{lex} V'$ iff $\exists i$ s.t. $V_i < V'_i$ and $\forall j < i$, $V_j = V'_j$ (and $V \simeq_{lex} V'$ iff $\forall i$, $V_i = V'_i$).

Definition 3. *Let $F = (Arg, Att)$ be an AF, $a \in Arg$, and $i \in \mathbb{N}$. The* burden number *$bur_i(a)$ for argument $a \in Arg$ in iteration i is defined as*

$$bur_i(a) := \begin{cases} 1 & \text{if } i = 0 \\ 1 + \sum_{b \in a^-_F} \frac{1}{bur_{i-1}(b)} & \text{otherwise} \end{cases}$$

Let $bur(a) = (bur_0(a), bur_1(a), bur_2(a), \ldots)$ and define the Burden-based semantics *(Bbs) ranking $\succeq^{Bbs}_F$ via $a \succeq^{Bbs}_F b$ iff $bur(a) \succeq_{lex} bur(b)$ for all $a, b \in Arg$.*

[3] A preorder is a (binary) relation that is *reflexive* and *transitive*.

Example 2. Consider again the AF F from Example 1. Argument q is unattacked, hence $bur(q) = (1, 1, 1, \dots)$. The remaining burden numbers are

$$bur(a) = (1, 2, \frac{4}{3}, \dots) \quad bur(b) = (1, 2, 2, \dots) \quad bur(c) = (1, 2, \frac{2}{3}, \dots)$$
$$bur(p) = (1, 2, \frac{4}{3}, \dots) \quad bur(r) = (1, 3, 2.5, \dots).$$

Since a and p have the same attacker r, they receive in each step the same value. We obtain the ranking $q \succ_F^{Bbs} a \simeq_F^{Bbs} p \succ_F^{Bbs} c \succ_F^{Bbs} b \succ_F^{Bbs} r$.

2.3 Assumption-based Argumentation Frameworks

Assumption-based Argumentation (ABA) frameworks builds on a deductive system $(\mathcal{L}, \mathcal{R})$, where $\mathcal{L}$ is a formal language and $\mathcal{R}$ a set of rules of the form $r = a_0 \leftarrow a_1, ..., a_n$ with $a_i \in \mathcal{L}$. We say that a_0 is the head of the rule ($head(r) = a_0$) and the set $\{a_1, ..., a_n\}$ is the body ($body(r) = \{a_1, ..., a_n\}$).

Definition 4. *An* ABA framework *is a tuple* $(\mathcal{L}, \mathcal{R}, \mathcal{A}, ^-)$*, where* $(\mathcal{L}, \mathcal{R})$ *is a deductive system,* $\mathcal{A} \subseteq \mathcal{L}$ *a non-empty set of assumptions, and* $^- : \mathcal{A} \to \mathcal{L}$ *is a so-called contrary function.*

We focus in this work on *flat* ABA frameworks, i. e., $head(r) \notin \mathcal{A}$ for each rule $r \in \mathcal{R}$.

A sentence $s \in \mathcal{L}$ is derivable from a set of assumptions $X \subseteq \mathcal{A}$ and rules $\mathtt{R} \subseteq \mathcal{R}$, denoted by $X \vdash_{\mathtt{R}} s$, if there is a finite rooted labelled tree T with the root being labelled with s, the set of labels for the leaves of T is equal to X or $X \cup \{\top\}$, and the internal nodes are labelled with $head(r)$ according to a rule $r \in \mathtt{R}$ s.t. the children are labelled with $body(r)$ or $\top$ if the body is empty. Each assumption $x \in X$ has an associated leaf labelled with x and each rule $r \in \mathtt{R}$ has an associated node in the tree. For a tree T, we denote by $asm(T)$ the set of assumptions used to derive the conclusion denoted $cl(T)$ with rules $ru(T)$.

Similar to AFs, ABA frameworks can be used as a rational argumentation-based decision-making model. Here, a set of assumptions S *attacks* a set of assumptions $Q \subseteq \mathcal{A}$ if there is $S' \subseteq S$, $\mathtt{R} \subseteq \mathcal{R}$, s.t. $S' \vdash_R \overline{a}$ for some $a \in Q$. S is *conflict-free* if S does not attack S. S *defends* assumption s if S attacks each assumption set Q that attacks $\{s\}$.

Definition 5. *For* $D = (\mathcal{L}, \mathcal{R}, \mathcal{A}, \_)$ *be an ABA framework and a conflict-free set of assumptions* $S \subseteq \mathcal{A}$*, we say* S *is*

- admissible *in* D *(*$S \in ad(D)$*) if* S *defends itself,*
- complete *in* D *(*$S \in co(D)$*) if* S *is admissible and contains every assumptions set it defends,*
- grounded *in* D *(*$S \in gr(D)$*) if* S *is* $\subseteq$*-minimally complete,*
- preferred *in* D *(*$S \in pr(D)$*) if* S *is* $\subseteq$*-maximally complete, and*
- stable *in* D *(*$S \in st(D)$*) iff* S *attacks every assumption* $a \in \mathcal{A} \setminus S$*.*

Example 3. Consider the ABA framework D with assumptions $\mathcal{A} = \{a, b, c\}$ and rules:

$$r_1 : \; r \leftarrow b, c \qquad\qquad r_2 : \; q \leftarrow \qquad\qquad r_3 : \; p \leftarrow q, a$$

with $\overline{a} = r, \overline{b} = q, \overline{c} = p$. We can, e. g., derive p from $\{a\}$ with rules r_2 and r_3 and since $p = \overline{c}$ we see that $\{a\}$ attacks $\{c\}$. Furthermore, $\{a\}$ and $\emptyset$ are admissible.

AFs and ABA frameworks are closely related [14], and we can define an AF as an instance of an ABA framework and the other way around.

Definition 6. *The associated AF $F_D = (Arg, Att)$ of an ABA framework $D = (\mathcal{L}, \mathcal{R}, \mathcal{A}, ^-)$ is given by $Arg = \{T \mid T$ is a tree for $s \in \mathcal{L}$ with $cl(T) = s\}$ and attack relation $(T, T') \in Att$ iff there is $c \in asm(T')$ s.t. $\overline{c} = cl(T)$.*

Definition 7. *Let $F = (Arg, Att)$ be an AF. The associated ABA framework of F is $ABA(F) = (\mathcal{L}, \mathcal{R}, \mathcal{A}, ^-)$ with*

$$\mathcal{A} = Arg \qquad \mathcal{L} = \mathcal{A} \cup \{a^c | a \in \mathcal{A}\} \qquad \mathcal{R} = \{b^c \leftarrow a | (a, b) \in Att\}$$

and $\overline{a} = a^c$, for all $a \in \mathcal{A}$.

It can be shown [14] that if a set of assumptions S is acceptable in the ABA framework D, then S is also acceptable in the corresponding AF F_D (in the form of conclusions of an extension).

Example 4. Continuing Example 3, we can construct the corresponding AF $F_D = (Arg, Att)$ of D, with $Arg = \{\mathtt{a}, \mathtt{b}, \mathtt{c}, \mathtt{p}, \mathtt{q}, \mathtt{r}\}$ where

- $\mathtt{a}$ is a tree with $asm(\mathtt{a}) = \{a\}$, $cl(\mathtt{a}) = a$, and $ru(\mathtt{a}) = \emptyset$,
- $\mathtt{b}$ is a tree with $asm(\mathtt{b}) = \{b\}$, $cl(\mathtt{b}) = b$, and $ru(\mathtt{b}) = \emptyset$,
- $\mathtt{c}$ is a tree with $asm(\mathtt{c}) = \{c\}$, $cl(\mathtt{c}) = c$, and $ru(\mathtt{c}) = \emptyset$,
- $\mathtt{p}$ is a tree with $asm(\mathtt{p}) = \{a\}$, $cl(\mathtt{p}) = p$, and $ru(\mathtt{p}) = \{r_3\}$,
- $\mathtt{q}$ is a tree with $asm(\mathtt{q}) = \emptyset$, $cl(\mathtt{q}) = q$, and $ru(\mathtt{q}) = \{r_2\}$,
- $\mathtt{r}$ is a tree with $asm(\mathtt{r}) = \{b, c\}$, $cl(\mathtt{r}) = r$, and $ru(\mathtt{r}) = \{r_1\}$

and the attack relation $Att = \{(\mathtt{q}, \mathtt{b}), (\mathtt{q}, \mathtt{r}), (\mathtt{r}, \mathtt{a}), (\mathtt{r}, \mathtt{p}), (\mathtt{p}, \mathtt{r}), (\mathtt{p}, \mathtt{c})\}$.

The corresponding graph representation can be found in Figure 2. So, for each derivable sentence in an ABA framework, we create an argument in the corresponding AF. We know that p is derivable from $\{a\}$ by rules r_2 and r_3, hence $\mathtt{p} \in Arg$ and additionally the attacks in the AF are representing the attacks from one set of assumptions to another set of assumptions. For example, the attack $(\mathtt{p}, \mathtt{r}) \in Att$ is representing the fact, that $\{a\}$ attacks $\{b\}$.

Note that in the following, we call argument $\mathtt{a}$, based on a tree of the form $asm(\mathtt{a}) = \{a\}$, $cl(\mathtt{a}) = a$ and $ru(\mathtt{a}) = \emptyset$, where a is an assumption, the *assumption argument* of a.

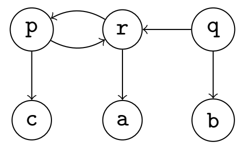

Fig. 2: Graph representation of Example 4

3 Ranking Assumptions

As with extension-based semantics in AFs, reasoning in ABA only distinguishes between acceptable and non-acceptable assumptions. Next we explore the applicability of ranking-based semantics for AFs to rank assumptions in ABA by defining a family of ranking-based semantics for ABA frameworks that relies on the reduction of an ABA framework to its corresponding AF, an application of a ranking-based semantics for AFs on this derived AF, and a re-interpretation of the resulting ranking over arguments in terms of assumptions. Finally, we conduct a thorough case study that illustrates the usefulness of our approach.

Definition 8. *A ranking-based semantics τ is a function that maps an ABA framework $D = (\mathcal{L}, \mathcal{R}, \mathcal{A}, ^-)$ to a preorder $\succeq^\tau_D$ on $\mathcal{A}$.*

Intuitively, $a \succeq^\tau_D b$ means, that assumption a is at least as strong as b in D. We define the abbreviations $\succ^\tau_D$ and $\simeq^\tau_D$ as before.

We instantiate the above definition by reducing the problem in ABA to a ranking problem in AFs and utilising existing ranking-based semantics for AFs.

Definition 9. *Let $D = (\mathcal{L}, \mathcal{R}, \mathcal{A}, ^-)$ be an ABA framework, $F_D = (Arg, Att)$ the corresponding AF, $a, b \in \mathcal{A}$, $\mathtt{a}$, $\mathtt{b}$ the corresponding assumption arguments, and ρ a ranking-based semantics for AFs. The ranking-based semantics ABA-ρ returns $a \succeq^{ABA\text{-}\rho}_D b$ iff $\mathtt{a} \succeq^\rho_{F_D} \mathtt{b}$.*

In other words, assumption a is at least as strong as b in D if the corresponding assumption argument $\mathtt{a}$ is at least as strong as $\mathtt{b}$ in the corresponding AF of D.

For the remainder of this paper, in particular for examples, we will use the Burden-based semantics from Definition 3 as a specific instance for a ranking-based semantics, but other existing ranking-based semantics [8] can be used instead as well.

Example 5. Consider the ABA framework D from Example 3 and its corresponding AF F_D constructed in Example 4. The ranking over arguments in F_D is then

$$\mathtt{q} \succ^{Bbs}_{F_D} \mathtt{p} \simeq^{Bbs}_{F_D} \mathtt{a} \succ^{Bbs}_{F_D} \mathtt{c} \succ^{Bbs}_{F_D} \mathtt{b} \succ^{Bbs}_{F_D} \mathtt{r}.$$

Restricting the ranking to assumption arguments gives us $\mathtt{a} \succ^{Bbs}_{F_D} \mathtt{c} \succ^{Bbs}_{F_D} \mathtt{b}$. We can project this ranking back to ABA:

$$a \succ^{\text{ABA-}Bbs}_D c \succ^{\text{ABA-}Bbs}_D b$$

Hence, a is the strongest assumption, then c, and b is the weakest assumption. The preferred extension of D is $\{a\}$, thus it is intuitive that a is the strongest assumption. While b is attacked by a fact $q \leftarrow$ meaning that b is not really strong and therefore should be ranked below c.

So the corresponding AF of an ABA framework gives us insight into the relationship between each assumption. We see that if the corresponding argument is strong or highly ranked in the corresponding AF, then the assumption will also be strong in the ABA framework. In addition, we can compare b and c with each other, which is not possible by using extension-based semantics, since both assumptions are not acceptable.

In the remainder of this section we discuss the behaviour of $\succeq^{\text{ABA-}\rho}$ in relation to the underlying ranking-based semantics ρ. If ρ behaves in a certain way, then it was shown that $\succeq^{\text{ABA-}\rho}$ satisfies proposed properties. The first property states that assumptions for which we can not derive the contrary should be ranked better than any other assumption.

Theorem 1. *If for ρ it holds that for any AF $F = (Arg, Att)$ and for all $\mathtt{a}, \mathtt{b} \in Arg$ with $\mathtt{a}_F^- = \emptyset$ and $\mathtt{b}_F^- \neq \emptyset$, $\mathtt{a} \succ_F^\rho \mathtt{b}$, then for every ABA framework $D = (\mathcal{L}, \mathcal{R}, \mathcal{A}, ^-)$ it holds that for every assumption $a \in \mathcal{A}$ s.t. $\overline{a}$ is not derivable from any set of assumptions $Q \subseteq \mathcal{A}$ and for every assumption $b \in \mathcal{A}$ s.t. $\overline{b}$ is derivable it holds that $a \succ_D^{ABA\text{-}\rho} b$.*

Proof. Let $D = (\mathcal{L}, \mathcal{R}, \mathcal{A}, ^-)$ be an ABA framework, $F_D = (A, R)$ the corresponding AF, $a, b \in \mathcal{A}$, $\mathtt{a}$, $\mathtt{b}$ the corresponding assumptions arguments, and ρ a ranking-based semantics for AFs.

Assume for ρ it holds that for any AF $F = (Arg, Att)$ and for all $a, b \in Arg$ with $a_F^- = \emptyset$ and $b_F^- \neq \emptyset$, $a \succ_F^\rho b$. Assume $\overline{a}$ is not derivable and $\overline{b}$ is derivable. Since $\overline{a}$ is not derivable, we know that $\mathtt{a}$ can not be attacked in F_D, because we do not have any argument $\mathtt{x}$ in F_D with $cl(\mathtt{x}) = \overline{a}$. Hence, $\mathtt{a}_{F_D}^- = \emptyset$. Additionally, we know that $\mathtt{b}$ is attacked at least once, because $\overline{b}$ is derivable in D, so there has to be an argument $\mathtt{x}'$ s.t. $cl(\mathtt{x}') = \overline{b}$. Hence, $\mathtt{b}_{F_D}^- \neq \emptyset$. So, we know that $\mathtt{a} \succ_{F_D}^\rho \mathtt{b}$ and therefore also $a \succ_D^{\text{ABA-}\rho} b$.

Adding attacks to an assumption, should not raise the strength of the assumption.

Theorem 2. *Let $D = (\mathcal{L}, \mathcal{R}, \mathcal{A}, ^-)$ be an ABA framework and $a \in \mathcal{A}$. Let r_{add}^- be a rule with $r_{add}^- \notin \mathcal{R}$ and $head(r_{add}^-) = \overline{a}$. D_{add}^- is a copy of D with r_{add}^- added, i. e., $D_{add}^- = (\mathcal{L}, \mathcal{R} \cup \{r_{add}^-\}, \mathcal{A}, ^-)$.*

If for ρ it holds that for any AF $F = (Arg, Att)$, it holds that for all $\mathtt{a}, \mathtt{b} \in Arg$ with $|\mathtt{a}^-| < |\mathtt{b}^-|$, $\mathtt{a} \succ_F^\rho \mathtt{b}$ and for all $\mathtt{c}, \mathtt{d} \in Arg$ either $\mathtt{c} \succeq_F^\rho \mathtt{d}$ or $\mathtt{d} \succeq_F^\rho \mathtt{c}$, then for all ABA frameworks $D = (\mathcal{L}, \mathcal{R}, \mathcal{A}, ^-)$ it holds for all $a, b \in \mathcal{A}$ with $a \neq b$ that $a \succeq_{D_{add}^-}^\tau b$ implies $a \succeq_D^{ABA\text{-}\rho} b$.

Proof. Let $D = (\mathcal{L}, \mathcal{R}, \mathcal{A}, ^-)$ be an flat ABA framework, $F_D = (Arg, Att)$ the corresponding AF and ρ a ranking-based semantics for AFs. Let r_{add}^- is a new rule for $a \in \mathcal{A}$, where $r^{-}_{add} \notin \mathcal{R}$ and $head(r^{-}_{add}) = \overline{a}$ and D^{-}_{add} is a copy of D with r^{-}_{add} added, i.e. $D^{-}_{add} = (\mathcal{L}, \mathcal{R} \cup \{r^{-}_{add}\}, \mathcal{A}, ^{-})$ and let $F_{D^{-}_{add}}$ be the corresponding AF.

Assume for ρ it holds that for all $\mathtt{a}, \mathtt{b} \in Arg$ with $|\mathtt{a}^{-}| < |\mathtt{b}^{-}|$, $\mathtt{a} \succ^{\rho}_{F} \mathtt{b}$ and for all $\mathtt{c}, \mathtt{d} \in Arg$ either $\mathtt{c} \succeq^{\rho}_{F} \mathtt{d}$ or $\mathtt{d} \succeq^{\rho}_{F} \mathtt{c}$. Assume $a \succeq^{\text{ABA-}\rho}_{D^{-}_{add}} b$ for $b \in \mathcal{A}$ and the corresponding assumption arguments $\mathtt{a}$ and $\mathtt{b}$. First, we look at the case that r^{-}_{add} can not be activated, so there is no tree $\mathtt{x}$ s.t. $r^{-}_{add} \in ru(\mathtt{x})$ meaning that, $body(r^{-}_{add}) \nsubseteq \mathcal{A}$ and there is no sequence of rules $(r_1, ..., r_n, r^{-}_{add})$ from $\mathcal{R}$ s.t. $body(r^{-}_{add}) \subseteq \bigcup_{i=1}^{n} head(r_i) \cup \mathcal{A}$. Then the addition of r^{-}_{add} does not change the corresponding AF, i.e. $F_D = F_{D^{-}_{add}}$ and therefore $a \succeq^{\text{ABA-}\rho}_{F_{D^{-}_{add}}} b$ implies $a \succeq^{\text{ABA-}\rho}_{F_D} b$.

Next, we look at the case, where r^{-}_{add} can be activated. The addition of any attack into an AF can only raise the number of attackers for an argument and can not lower the number of attackers. Similar hold for ABA frameworks, the addition and activation of a new rule does not yield to deactivation of other rules. Hence, it holds that $|\mathtt{x}^{-}_{F_D}| \leq |\mathtt{x}^{-}_{F_{D^{-}_{add}}}|$ for any $x \in \mathcal{A}$ and its corresponding assumption argument $\mathtt{x}$. Since $a \succeq^{\rho}_{D^{-}_{add}} b$ holds, we know that $|\mathtt{a}^{-}_{F_{D^{-}_{add}}}| \leq |\mathtt{b}^{-}_{F_{D^{-}_{add}}}|$.

If $|\mathtt{b}^{-}_{F_D}| = |\mathtt{b}^{-}_{F_{D^{-}_{add}}}|$, then it is clear that $|\mathtt{a}^{-}_{F_D}| \leq |\mathtt{b}^{-}_{F_D}|$ and it holds that $\mathtt{a} \succeq^{\rho}_{F_D} \mathtt{b}$ and therefore also $a \succeq^{\text{ABA-}\rho}_{D} b$.

For $|\mathtt{b}^{-}_{F_D}| < |\mathtt{b}^{-}_{F_{D^{-}_{add}}}|$ we know that we can derive $\overline{a}$ in $F_{D^{-}_{add}}$ and this activates a rule r' with $\overline{a} \in body(r')$ and this rule is needed to activate rule r'' with $head(r'') = \overline{b}$. This implies that $\overline{a}$ can not be derived in D otherwise we could activate r' in D as well and that means that $|\mathtt{b}^{-}_{F_D}| < |\mathtt{b}^{-}_{F_{D^{-}_{add}}}|$ could not hold. Since $\overline{a}$ can not be derived this implies $|\mathtt{a}^{-}_{F_D}| = 0$ and therefore $|\mathtt{a}^{-}_{F_D}| \leq |\mathtt{b}^{-}_{F_D}|$ and also $\mathtt{a} \succeq^{\rho}_{F_D} \mathtt{b}$, which implies $a \succeq^{\text{ABA-}\rho}_{D} b$.

Cyras and Toni [14] have shown that the acceptance of extension-based semantics coincides for ABA frameworks and their corresponding AFs. However, the transformation from an ABA framework to an AF and back to an ABA framework does add new rules and therefore changes the framework. However, transforming an ABA framework to an AF and back should not change the ranking.

Theorem 3. *If for ρ it holds that for any AF $F = (Arg, Att)$, it holds that for all $\mathtt{a}, \mathtt{b} \in Arg$ with $|\mathtt{a}^{-}| < |\mathtt{b}^{-}|$, $\mathtt{a} \succ^{\rho}_{F} \mathtt{b}$ and for all $\mathtt{c}, \mathtt{d} \in Arg$ either $\mathtt{c} \succeq^{\rho}_{F} \mathtt{d}$ or $\mathtt{d} \succeq^{\rho}_{F} \mathtt{c}$, then for every ABA framework $D = (\mathcal{L}, \mathcal{R}, \mathcal{A}, ^{-})$ and F_D the corresponding AF to D, and $ABA(F_D)$ the corresponding ABA framework to F_D, it holds for any pair $a, b \in \mathcal{A}$ that we have $a \succeq^{\tau}_{D} b$ iff $a \succeq^{ABA\text{-}\rho}_{ABA(F_D)} b$.*

Proof. Let $D = (\mathcal{L}, \mathcal{R}, \mathcal{A}, ^{-})$ be a flat ABA framework, $F_D = (Arg, Att)$ the corresponding AF, $ABA(F_D)$ the corresponding ABA framework of F_D, $F_{ABA(F_D)}$ the corresponding AF to $ABA(F_D)$ and ρ a ranking-based semantics for AFs. Let $a, b \in \mathcal{A}$, $\mathtt{a}$ be the corresponding assumptions argument of a and $\mathtt{b}$ be the corresponding assumption argument of b.

Assume for ρ it holds that that for all $\mathtt{a},\mathtt{b} \in Arg$ with $|\mathtt{a}^-| < |\mathtt{b}^-|$, $\mathtt{a} \succ^\rho_F \mathtt{b}$ and for all $\mathtt{c},\mathtt{d} \in Arg$ either $\mathtt{c} \succeq^\rho_F \mathtt{d}$ or $\mathtt{d} \succeq^\rho_F \mathtt{c}$ and $a \succeq^{\text{ABA-}\rho}_D b$. If a sentence is derivable in D, then there is a corresponding argument in F_D and every argument in F_D is an assumption in $ABA(F_D)$ and since assumptions are always derivable, we know that everything, which is derivable in D is also derivable in $ABA(F_D)$. This implies that the number of attacker for any assumption argument $\mathtt{a}$ in F_D is equal to the number of attacker for the corresponding assumption argument in $F_{ABA(F_D)}$. Since ρ satisfies CP and Total and $a \succeq^{ABA-\rho}_D b$, we know $|\mathtt{a}^-_{F_D}| \leq |\mathtt{b}^-_{F_D}|$ and since the number of attacker is the same in F_D and $F_{ABA(F_D)}$, i.e. $|(a)^-_{F_D}| = |(a)^-_{F_{ABA(F_D)}}|$, we have $|\mathtt{a}^-_{F_{ABA(F_D)}}| \leq |\mathtt{b}^-_{F_{ABA(F_D)}}|$. Then $\mathtt{a} \succeq^\rho_{F_{ABA(F_D)}} b$ and therefore also $a \succeq^{\text{ABA-}\rho}_{ABA(F_D)} b$.

A self-contradicting assumption should be ranked worse than any other assumption.

Theorem 4. *If for ρ it holds that for any AF $F = (Arg, Att)$, it holds that for all $\mathtt{a},\mathtt{b} \in Arg$ with $(\mathtt{a},\mathtt{a}) \notin Att$ and $(\mathtt{b},\mathtt{b}) \in Att$, $\mathtt{a} \succ^\rho_F \mathtt{b}$, then for every ABA framework $D = (\mathcal{L}, \mathcal{R}, \mathcal{A}, ^-)$ the following holds for every assumptions $a, b \in \mathcal{A}$, if $\{a\} \not\vdash_\mathcal{R} \overline{a}$ and $\{b\} \vdash_\mathcal{R} \overline{b}$ then $a \succ^{ABA\text{-}\rho}_D b$.*

Proof. Let $D = (\mathcal{L}, \mathcal{R}, \mathcal{A}, ^-)$ be an ABA framework, $F_D = (Arg, Att)$ the corresponding AF, $a, b \in \mathcal{A}$, the corresponding assumptions arguments $\mathtt{a}$, $\mathtt{b}$, and ρ a ranking-based semantics for AFs.

Assume for ρ it holds that for any AF $F = (Arg, Att)$, it holds that for all $\mathtt{a},\mathtt{b} \in Arg$ with $(\mathtt{a},\mathtt{a}) \notin Att$ and $(\mathtt{b},\mathtt{b}) \in Att$, $\mathtt{a} \succ^\rho_F \mathtt{b}$ and $\{a\} \not\vdash_\mathcal{R} \overline{a}$ and b with $\{b\} \vdash_\mathcal{R} \overline{b}$. This implies that $(\mathtt{b},\mathtt{b}) \in R$ and $(\mathtt{a},\mathtt{a}) \notin R$. So, $\mathtt{b}$ attacks itself and also an assumption argument $\mathtt{x}$ for $x \in \mathcal{A}$ can only attack it self if $\{x\} \vdash_\mathcal{R} \overline{x}$, hence $\mathtt{a}$ can not attack it self. Hence, we know $\mathtt{a} \succ^\rho_{F_D} \mathtt{b}$ and this implies $a \succ^{\text{ABA-}\rho}_D b$.

4 Case study

First, we recall the *Transition-based Medical Recommendation (TMR)* model introduced in [28] and used to construct ABA frameworks in [12, 13].

The TMR model is used to represent clinical guideline recommendations for multimorbidity situations, i. e. situations where multiple health conditions need to be managed simultaneously. In addition, TMR can identify recommendations that are in conflict with each other. Using this conflict information we construct ABA frameworks as proposed in [12, 13].

Definition 10. *A* recommendation *R is a tuple $R = (A, \delta, \mathcal{C})$ where:*

- *R is a* name*;*
- *A is an associated* action*;*
- *$\delta \in [-1, 1]$ is the* deontic strength*, where $\delta \geq 0$ means R recommends* performing *A and $\delta < 0$ recommends* avoiding *A;*

– $\mathcal{C} = \langle c^1, \ldots, c^n \rangle$ *is a set of* contributions *with contribution* c^i *being a tuple* $(\mathcal{P}, \mathcal{E}, v_I, v_T, o)$ *with:*
  - *affected* property $\mathcal{P}$*,*
  - effect $\mathcal{E}$ *of* A *on* $\mathcal{P}$*,*
  - initial value v_I *of* $\mathcal{P}$*,*
  - target value v_T *of* $\mathcal{P}$ *after* A *was applied,*
  - *value* $o \in \{-, \_, +\}$ *of contribution indicating importance.*

We denote with R *the set of recommendations.*

Note that our definitions are a simplification of the original formal description, which can be found in [28].

Example 6. Consider recommendations

$$R_1 = (\text{Adm. NSAID}, 0.5, (\text{Blood Coag}, \text{decrease}, \text{normal}, \text{low}, +))$$
$$R_2 = (\text{Adm. Aspirin}, -0.5, (\text{Gastro. Bleeding}, \text{increase}, \text{normal}, \text{high}, -))$$

from [28]. For recommendation R_1 we have action *administering NSAID* with a strength of 0.5, which means that this action should take place, the effect of the action is to *decrease* the property *Blood Coagulation* form start value *normal* to *low*. In other words, recommendation R_1 can be translated to: *NSAID should be administered to decrease Blood Coagulation from normal to low.* while recommendation R_2 states: *Aspirin should not be administered, because it increases Gastrointestinal bleeding.*

The TMR can be used to identify conflicts or contradictions between recommendations. For example, one recommendation may suggest an action, while another recommendation urges avoiding the same action. A clinician should not follow two conflicting recommendations.

Definition 11. *A* contradiction interaction *between recommendations* $R, R' \in \mathbb{R}$ *is a tuple* (R, R')*.*

The set of interactions is denoted with I.

Example 7. The two recommendations from Example 6 are contradictions to each other, since *administering NSAID* means that one should administer *Aspirin* and *Ibuprofen.* So, R_1 recommends administering Aspirin, while R_2 suggest to avoid administering Aspirin. Hence $(R_1, R_2) \in \mathsf{I}$.

The TMS recommendation and the interactions between these recommendations are for general patients. In general, however, the choice of guidelines should be based on the patient's specific medical background. Not every drug combination is suitable for every patient. A patient may be allergic to a particular drug, so that drug should not be administered. So the reasoning behind the recommendations should be based on a specific *context* or patient. We denote the *context* of a patient by S.

Next, we present a case study based on data from [28] to show that our proposed ranking over assumptions behaves intuitively in the context of medical recommendations. Similar to [12], we focus on the contradiction interactions between breast cancer (BC) and hypertension (HT) guidelines.

To construct an ABA framework based on TMS recommendations, we use the formalism of [12]. The authors defined ABA^+G frameworks, which are extensions of ABA frameworks, where additional information like a preference order over the set of assumptions as well as goals and a preoder over these goals are needed to construct an ABA^+G framework. Our approach does not need these additional information to reason and to find the best recommendations, a simple ABA framework is sufficient. Not only additional information is needed for ABA^+G but also the computational complexity of the credulous resp. sceptical acceptance problems for ABA^+G frameworks are higher than for ABA frameworks [19].[4] Recommendations are represented by assumptions, while the corresponding actions and effects are modelled by rules and the context of a patient is represented by facts.

Definition 12 ([12, 13]). *Given recommendations* R*, interactions* I *and context* S*, the* ABA patient framework *is defined via* $D_p = (\mathcal{L}, \mathcal{R}, \mathcal{A}, ^-)$*, where:*

$A = \{R : (A, \delta, \mathcal{C}) \in \mathsf{R}\}$*, assumptions are the recommendations;*
$\mathcal{R}_a = \mathcal{R}_a^+ \cup \mathcal{R}_a^-$*, rules representing actions of recommendations, where*

$$\mathcal{R}_a^+ = \{A \leftarrow R : (A, \delta, \mathcal{C}) \in \mathsf{R}, \delta \geq 0\},$$
$$\mathcal{R}_a^- = \{not\ A \leftarrow R : (A, \delta, \mathcal{C}) \in \mathsf{R}, \delta < 0\};$$

$\mathcal{R}_e = \mathcal{R}_e^+ \cup \mathcal{R}_e^-$*, rules representing effects on properties brought about by actions, where*

$$\mathcal{R}_e^+ = \{\mathcal{E}\mathcal{P} \leftarrow A : (A, \delta, \mathcal{C}) \in \mathsf{R}, \delta \geq 0, (\mathcal{P}, \mathcal{E}, v_I, v_T, o) \in \mathcal{C}\},$$
$$\mathcal{R}_e^- = \{not\ \mathcal{E}\mathcal{P} \leftarrow not\ A : (A, \delta, \mathcal{C}) \in \mathsf{R}, \delta < 0, (\mathcal{P}, \mathcal{E}, v_I, v_T, o) \in \mathcal{C}\};$$

$\mathcal{R}_s = \{v_I\mathcal{P} \leftarrow\ : v_I\mathcal{P} \in \mathcal{S}\}$*, facts representing the patient's state* $\mathcal{S}$*, where*

$$\mathcal{S} \subseteq \bigcup_{R \in \mathsf{R}} \{v_I\mathcal{P} : (\mathcal{P}, \mathcal{E}, v_I, v_T, o) \in \mathcal{C}, R = (A, \delta, \mathcal{C})\};$$

$\mathcal{R}_c = \mathcal{R}_c^+ \cup \mathcal{R}_c^-$*, rules representing contradicting interactions between recommendations, where*

$$\mathcal{R}_c^+ = \{\overline{R_j} \leftarrow R_i, int_{i,j} : (R_i, R_j, \mu) \in \mathsf{I}, \delta_i \geq 0\},$$
$$\mathcal{R}_c^- = \{\overline{R_i} \leftarrow R_j, int_{i,j}, v_{I,j}\mathcal{P}_j : (R_i, R_j, \mu) \in \mathsf{I}, (R_j, A_j, \delta_j, \mathcal{C}_j) \in \mathsf{R}, (\mathcal{P}_j, \mathcal{E}_j, v_{I,j}, v_T, -) \in \mathcal{C}_j, \delta_i < 0\};$$

$\mathcal{R} = \mathcal{R}_a \cup \mathcal{R}_e \cup \mathcal{R}_s \cup \mathcal{R}_c \cup \{int_{i,j} \leftarrow\ : (R_i, R_j) \in \mathsf{I}\}$*;*

[4] An assumption a is credulously (sceptically) accepted wrt. a given semantics iff it is contained in at least one (all) acceptable sets of assumptions (wrt. that semantics).

By convention, $\mathcal{L}$ and $^-$ are implicit from $\mathcal{A}$ and $\mathcal{R}$ as follows: unless $\overline{x}$ appears in either $\mathcal{A}$ or $\mathcal{R}$, it is different from the sentences appearing in $\mathcal{A}$ or $\mathcal{R}$; thus, $\mathcal{L}$ consists of all the sentences appearing in $\mathcal{R}$, $\mathcal{A}$ and $\{\overline{\alpha} : \alpha \in \mathcal{A}\}$.

Example 8. Taking the recommendations of the case study from [28] focusing on the contradicting interactions between breast cancer and hypertension we get following recommendations: Let $\mathsf{R} = \{R_2, R_3, R_4, R_8\}$ with:

- $R_2 = (\text{Std. Exercise}, 0.5, \{$

$$
\begin{aligned}
&(\text{Fatigue, decrease, high, normal}, +)\\
&(\text{Fitness, decrease, high, normal}, +)\\
&(\text{Pain, decrease, high, normal}, +)\}
\end{aligned}
$$

- $R_3 = (\text{Low Int. Exercise}, 0.5, \{$

$$
\begin{aligned}
&(\text{Fatigue, decrease, high, normal}, +)\\
&(\text{Fitness, decrease, high, normal}, +)\\
&(\text{Pain, decrease, high, normal}, +)\}
\end{aligned}
$$

- $R_4 = (\text{Exercise}, -1, \{(\text{Body Temp, increase, high, very high}, -)\})$
- $R_8 = (\text{High Int. Exercise}, -0.5, \{(\text{Blood Pressure, increase}, ?, ?, -)\}$

The interactions between these recommendations are then: $\mathsf{I} = \{(R_2, R_4), (R_3, R_4), (R_2, R_8)\}$. So, recommendations R_2 and R_4 are in a conflict and should not be followed simultaneously. To model patient-orientated reasoning let us consider *Patient A* from [12]. *Patient A* has increased *Blood Pressure* and *high Body Temperature*. The corresponding ABA framework to *Patient A* is: $D_{P_a} =$

$(\mathcal{L}, \mathcal{R}, \mathcal{A}, ^{-})$:

$$
\begin{aligned}
\mathcal{A} =& \{R_2, R_3, R_4, R_8\} \\
\mathcal{R} =& \{\text{Std. Exercise} \leftarrow R_2, \\
& \text{Low Int. Exercise} \leftarrow R_3, \\
& \textit{not}\ \text{Exercise} \leftarrow R_4, \\
& \textit{not}\ \text{High Int. Exercise} \leftarrow R_8\} \cup \\
& \{\text{increase Body Temp} \leftarrow \text{Std. Exercise}, \\
& \text{decrease Fatigue} \leftarrow \text{Std. Exercise}, \\
& \text{decrease Pain} \leftarrow \text{Std. Exercise}, \\
& \text{decrease Fatigue} \leftarrow \text{Low Int. Exercise}, \\
& \text{decrease Pain} \leftarrow \text{Low Int. Exercise}, \\
& \textit{not}\ \text{increase Blood Pressure} \leftarrow \textit{not}\ \text{High Int. Exercise}\}, \\
& \textit{not}\ \text{increase Body Temp} \leftarrow \textit{not}\ \text{Exercise}\} \cup \\
& \{\text{Blood Pressure} \leftarrow\ , \text{high Body Temp.} \leftarrow\ \} \cup \\
& \{\overline{R_4} \leftarrow R_2, int_{2,4}, \\
& \overline{R_2} \leftarrow R_4, init_{2,4}, \text{high Body Temp.}, \\
& \overline{R_4} \leftarrow R_3, init_{3,4}, \\
& \overline{R_3} \leftarrow R_4, init_{3,4}, \text{high Body Temp.}, \\
& \overline{R_8} \leftarrow R_2, init_{2,8}, \\
& \overline{R_2} \leftarrow R_8, init_{2,8}, \text{Blood Pressure}\} \cup \\
& \{init_{2,4} \leftarrow\ , init_{3,4} \leftarrow\ , init_{2,8} \leftarrow\ \}
\end{aligned}
$$

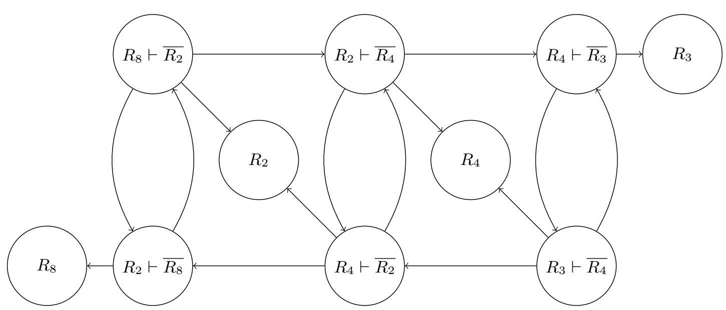

Fig. 3: Simplified graph representation of the case study, where only arguments with a recommendation or their contrary in the conclusion are depicted.

A simplified graph representation of the corresponding AF to D_{P_a} can be found in Figure 3, where only arguments are depicted, which are relevant for the reasoning process, i. e., only arguments with recommendations or their contrary in their conclusion. The remaining arguments are only leaf arguments with terms like *Std. Exercise* and not relevant to the acceptance of other arguments. The preferred extensions of D_{P_a} are $\{R_3, R_8\}, \{R_4, R_8\}$ and $\{R_2, R_3\}$. These extensions do not give us any insight of which recommendation to follow, as all recommendations are credulously accepted but none of them are sceptically accepted. To identify the 'best' recommendations, we use the formalism proposed in Definition 9 and use again *Burden-based semantics* as the underlying ranking-based semantics. The resulting ranking of the four recommendations is

$$R_8 =^{ABA\text{-}Bbs}_{D_{P_a}} R_3 \succ^{ABA\text{-}Bbs}_{D_{P_a}} R_4 =^{ABA\text{-}Bbs}_{D_{P_a}} R_2$$

Recommendations R_8 and R_3 are the best recommendations to follow. These two recommendations are not in a conflict with each other and actually form a preferred extension, so we can follow both these recommendations together without any problem. Hence, for patient A we recommend to *not do High Intensive Exercise*, because this will increase their *Blood Pressure*, but the patient should do *low Intensive Exercise*, because this *decreases Fatigue, Fitness and Pain.*

The results of the case study in Example 8 are consistent with the informal discussion of [28] as well as the resulting reasoning of [12], both of which suggest following R_8 and R_3. The case study shows that the individual strength of each recommendation are already enough to reason with and we do not need additional information like a preference order over the recommendations like needed in the approach of [12]. In general recommendations with less interaction with other recommendations will be ranked highly, since in the corresponding AF these recommendations only have small number of attackers. Thinking a bit further we realise that avoiding following two contradicting recommendation is the main motivation of TMR.

5 Related Work

One of the most discussed topics in structured argumentation are preferences over uncertain information. These preferences state that information a is better or more believable than information b. A number of frameworks that work with preferences can be found in the literature such as ASPIC$^+$ [21, 10, 24, 20, 22], ABA$^+$ [14, 11] or p_ABA [27]. While ABA$^+$ and p_ABA are extensions of ABA, ASPIC$^+$ is a general-purpose structure argumentation framework, with focus on preferences. Prakken [24] has shown that flat ABA frameworks can be instantiated as ASPIC$^+$ frameworks. In addition to an ABA framework, ABA$^+$ receives a preference over the assumptions as input. Using these preferences a new attack relation is defined. Similar to ABA$^+$, p_ABA receives a preference as input in addition to the ABA framework. However, the preference in p_ABA is over the sentences $\mathcal{L}$. In these frameworks, the preferences are preorders over rules and ordinary premises (ASPIC$^+$), assumptions (ABA$^+$) or sentences (p_ABA). Hence, these preferences are similar to our rankings over assumptions. All these preferences can be seen as a notion of strength, if an assumption a is preferred to an assumption b in an ABA$^+$ framework, then this relationship between a and

b can be seen as a being better than b. However, all these frameworks receive their preferences as an input rather than calculating the preorders.

In ASPIC$^+$ and ABA$^+$ preferences are used to disable or reverse attacks. If the target of an attack is considered better than the attacker, the attack is discarded or reversed so that the attacker becomes the attacker.

Another application is to use the underlying ranking over assumptions to construct the corresponding ABA$^+$ framework for an ABA framework. So, we take an ABA framework and compute a ranking over the assumption with any ranking-based semantics like ABA-*Bbs* to then construct an ABA$^+$ framework using our ranking as a preference order. An ABA$^+$ framework constructed in such a way has similarities with the underlying ABA framework for example the conflict-free sets are the same. Thus, we can transform any ABA framework into an ABA$^+$ framework without additional information such as a preference order.

p_ABA uses preferences to discredit sets of assumptions. Wakaki [27] proposes preorders over sets of assumptions. However, their approach has two major differences: first, in p_ABA preferences are part of the input, and second, they can only distinguish sets of assumptions satisfying an extension-based semantics.

In the literature, ranking-based semantics are used to refine extension-based reasoning for AFs. For example Bonzon et al. [9] use the aggregated strength values of each argument of a set to compare two sets. Whereas Konieczny et.al. [18] compare two sets of arguments using a pairwise comparison based on a criterion like the number of arguments within the first set that are not attacked by the second set. Thus, the presented ranking-based semantics for ABA frameworks are the first step towards refining extension-based reasoning for ABA frameworks.

Heyninck et.al. [17] have discussed ranking-based semantics for ABA frameworks as well, however their focus is more on the numerical strength value each assumptions receives rather than the relationship between each assumption with respect to their strength like presented in this paper.

6 Limitations

The biggest limitation of the approach discussed in this paper is the initial construction of the ABA framework based on the recommendation data given. In Example 8 we already see such limitations, even-though our case study only contains four recommendations the corresponding ABA framework has already 21 rules. Hence, with an increasing number of recommendations the corresponding ABA framework could be to big to handle.

7 Conclusion

In this paper, we discussed the problem of individual strength of assumptions in ABA frameworks. We proposed a general framework to rank assumptions based on their strength within an ABA framework without additional information such as a preference order. We also defined a family of ranking-based semantics for ABA based on approaches and ideas for AFs. For an ABA framework we construct the corresponding AF then apply known ranking-based semantics in order to rank arguments in the corresponding AF to finally re-interpret this ranking in the ABA setting. In addition, we used the proposed semantics on a case study to rank recommendations in the TMR model.

As for future work, we want to look at other structured argumentation frameworks such as ASPIC$^+$ and apply similar ideas in order to rank individual elements of the ASPIC$^+$ framework based on their strength alone. Our current approach uses AFs in order to rank assumptions. As a follow-up we want to propose direct approaches using only the ABA framework without the help of the corresponding AF.

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