Assumption-Based Argumentation for Decision-Making with Preferences: A Medical Case Study

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Abstract. We present a formal decision-making framework, where decisions have multiple attributes and meet goals, and preferences are defined over individual goals and sets of goals. We define decision functions to select 'good' decisions according to an underlying decision criteria. We also define an argumentation-based computational mechanism to compute and explain 'good' decisions. We draw connections between decision-making and argumentation semantics: 'good' decisions are admissible arguments in a corresponding argumentation framework. To show the applicability of our approach, we use medical literature selection as a case study. For a given patient description, we select the most relevant medical papers from the medical literature and explain the selection.

1 Introduction

Argumentation-based decision making has attracted considerable research interest in recent years [1, 8, 7, 10]. In this paper, we give a formal treatment of decision-making with argumentation.

We define *extended decision frameworks*, used to model the agents' knowledge bases, including the agents' preferences. We allow a decision framework to have multiple *decisions* and a set of *goals*, such that each decision can have a number of different *attributes* and each goal can be satisfied by some attributes. We define *preferences* over (sets of) *goals*. We define *extended decision functions* to select 'good' decisions. To compute and explain the selected decisions, we map decision frameworks and decision functions into assumption-based argumentation (ABA) frameworks [3]. We prove that selected decisions with respect to a given decision function are claims of arguments in an admissible extension in the corresponding ABA framework.

We use medical literature selection as a case study for this work. We are given a set of medical research papers and patient descriptions. Each papers contains the results of a clinical trial, and a patient description gives a set of patient properties. The aim of the decision-making process is to select the most relevant papers for a patient. In this way, a specific candidate decision is the use of a given paper. Trial criteria are extracted from each piece of medical literature and are used as attributes. Patient properties are collected from patient descriptions and are used as goals. This defines the use of medical literature as a decision-making problem. We show the decision-making framework selects the most relevant papers for the patient and explains the selection.

This paper is organised as follows. Background on ABA is in Section 2. We present extended decision frameworks and decision functions for preference over single goals in Section 3. We show the treatment of preference over combined goals in Section 4. We present the case study on relevant medical literature selection in Section 5. Related work is in Section 6. We conclude in Section 7.

2 Background

An ABA framework [3, 5] is a tuple $\langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \mathcal{C} \rangle$ where

- $\langle \mathcal{L}, \mathcal{R} \rangle$ is a deductive system, with $\mathcal{L}$ the *language* and $\mathcal{R}$ a set of *rules* of the form $s_0 \leftarrow s_1, \dots, s_m$ $(m \geq 0)$;
- $\mathcal{A} \subseteq \mathcal{L}$ is a (non-empty) set, referred to as the *assumptions*;
- $\mathcal{C}$ is a total mapping from $\mathcal{A}$ into $2^{\mathcal{L}}$, where $\mathcal{C}(\alpha)$ is the *contrary* of $\alpha \in \mathcal{A}$.

When presenting an ABA framework, we omit giving $\mathcal{L}$ explicitly as we assume $\mathcal{L}$ contains all sentences appearing in $\mathcal{R}$, $\mathcal{A}$ and $\mathcal{C}$. Given a rule $s_0 \leftarrow s_1, \dots, s_m$, we use the following notation: $Head(s_0 \leftarrow s_1, \dots, s_m) = s_0$ and $Body(s_0 \leftarrow s_1, \dots, s_m) = \{s_1, \dots, s_m\}$. As in [3], we enforce that ABA frameworks are *flat*: assumptions do not occur as the heads of rules.

In ABA, *arguments* are deductions of claims using rules and supported by assumptions, and *attacks* are directed at assumptions. Informally, following [3]:

- *an argument for (the claim)* $c \in \mathcal{L}$ *supported by* $S \subseteq \mathcal{A}$ ($S \vdash c$ in short) is a (finite) tree with nodes labelled by sentences in $\mathcal{L}$ or by the symbol τ[3], such that the root is labelled by c, leaves are either τ or assumptions in S, and non-leaves s have as many children as elements in the body of a rule with head s, in a one-to-one correspondence with the elements of this body.
- *an argument* $S_1 \vdash c_1$ *attacks an argument* $S_2 \vdash c_2$ if and only if $c_1 = \mathcal{C}(\alpha)$ for $\alpha \in S_2$.

Attacks between arguments correspond in ABA to attacks between sets of assumptions, where *a set of assumptions* A *attacks a set of assumptions* B if and only if an argument supported by $A' \subseteq A$ attacks an argument supported by $B' \subseteq B$.

When there is no ambiguity, we also say a sentence b attacks a sentence a when a is an assumption and b is a claim of an argument B such that a is in the support of some argument A and B attacks A.

With argument and attack defined, standard argumentation semantics can be applied in ABA [3]. We focus on the admissibility semantics: *a set of assumptions is admissible* (in $\langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \mathcal{C} \rangle$) if and only if it does not attack itself and it attacks all $A \subseteq \mathcal{A}$ that attack it; *an argument* $S \vdash c$ *belongs to an admissible extension supported by* $\Delta \subseteq \mathcal{A}$ (in $\langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \mathcal{C} \rangle$) if and only if $S \subseteq \Delta$ and Δ is admissible.

[3] As in [3], $\tau \notin \mathcal{L}$ stands for "true" and is used to represent the empty body of rules.

3 Extended Decision Frameworks and Decision Functions

In this paper, we consider the following structure of decision problems: there are a set of possible decisions $\mathtt{D}$, a set of attributes $\mathtt{A}$, and a set of goals $\mathtt{G}$, such that a decision $d \in \mathtt{D}$ may *have* some attributes $A \subseteq \mathtt{A}$, and each goal $g \in \mathtt{G}$ is *satisfied* by some attributes $A' \subseteq \mathtt{A}$. *Preferences* $\mathtt{P}$ are defined as a partial order over *goals*. Decisions are selected based on *extended decision functions*. The relations between decisions, attributes, goals and preferences jointly form an *extended decision framework*, represented as follows:

Definition 1. *[6] An* extended decision framework $\langle \mathtt{D}, \mathtt{A}, \mathtt{G}, \mathtt{DA}, \mathtt{GA}, \mathtt{P} \rangle$*, has:*

- *a set of decisions* $\mathtt{D} = \{d_1, \ldots, d_n\}, n > 0$*;*
- *a set of attributes* $\mathtt{A} = \{a_1, \ldots, a_m\}, m > 0$*;*
- *a set of goals* $\mathtt{G} = \{g_1, \ldots, g_l\}, l > 0$*;*
- *a partial order over goals,* $\mathtt{P}$*, representing the preference ranking of goals;*
- *two tables:* $\mathtt{DA}$*, of size* $(n \times m)$*, and* $\mathtt{GA}$*, of size* $(l \times m)$*, such that*
  - *for every* $\mathtt{DA}_{i,j}$[4]$, 1 \leq i \leq n, 1 \leq j \leq m$*,* $\mathtt{DA}_{i,j}$ *is either* 1*, representing that decision* d_i has *attributes* a_j*, or* 0*, otherwise;*
  - *for every* $\mathtt{GA}_{i,j}, 1 \leq i \leq l, 1 \leq j \leq m$*,* $\mathtt{GA}_{i,j}$ *is either* 1*, representing that goal* g_i *is* satisfied *by attribute* a_j*, or* 0*, otherwise.*

We assume that the column order in both $\mathtt{DA}$ *and* $\mathtt{GA}$ *is the same, and the* indices *of decisions, goals, and attributes in* $\mathtt{DA}$ *and* $\mathtt{GA}$ *are the row numbers of the decision and goals and the column number of attributes in* $\mathtt{DA}$ *and* $\mathtt{GA}$*, respectively. We use* $\mathcal{DEC}$ *and* $\mathcal{EDF}$ *to denote the set of all possible decisions and the set of possible extended decision frameworks.*

We represent $\mathtt{P}$ as a set of constraints $g_i > g_j$ for $g_i, g_j \in \mathtt{G}$. We illustrate Definition 1 in the following example, adopted from [9].

Example 1. An agent is to choose accommodation in London. $\mathtt{DA}$ and $\mathtt{GA}$, are given in Table 1. The preference $\mathtt{P}$ is: *near* > *cheap* > *quiet*.

	£50	£70	inSK	backSt
jh	0	1	1	1
ic	1	0	1	0

	£50	£70	inSK	backSt
cheap	1	0	0	0
near	0	0	1	0
quiet	0	0	0	1

Table 1. $\mathtt{DA}$(left) and $\mathtt{GA}$(right).

Decisions ($\mathtt{D}$) are: hotel (jh) and Imperial College Halls (ic). Attributes ($\mathtt{A}$) are: £50, £70, in South Kensington (inSK), and in a backstreet (backSt). Goals

[4] We use $\mathtt{X}_{i,j}$ to represent the cell in row i and column j in $\mathtt{X} \in \{\mathtt{DA}, \mathtt{GA}\}$.

($\mathtt{G}$) are: cheap, near, and quiet. The indices are: 1-jh; 2-ic; 1-cheap; 2-near; 3-quiet; 1-£50; 2-£70; 3-inSK; 4-backSt. The preference order is such that *near* is higher than *cheap* than *quiet*.

In this example, jh is £70, is in South Kensington and is in a backstreet; ic is £50 and is in South Kensington; £50 is cheap, accommodations in South Kensington are near and accommodations in a backstreet are quiet.

We define a decision's *meeting* a goal as the follows:

Definition 2. *[6] Given* $\langle \mathtt{D}, \mathtt{A}, \mathtt{G}, \mathtt{DA}, \mathtt{GA}, \mathtt{P} \rangle$*, a decision* $d \in \mathtt{D}$ *with row index* i *in* $\mathtt{DA}$ meets *a goal* $g \in \mathtt{G}$ *with row index* j *in* $\mathtt{GA}$ *if and only if there exists an attribute* $a \in \mathtt{A}$ *with column index* k *in both* $\mathtt{DA}$ *and* $\mathtt{GA}$*, such that* $\mathtt{DA}_{i,k} = 1$ *and* $\mathtt{GA}_{j,k} = 1$*.*

We use $\gamma(d) = S$*, where* $d \in \mathtt{D}, S \subseteq \mathtt{G}$*, to denote the set of goals met by* d*.*

Example 2. In Example 1, jh meets *near* and *quiet* as jh has the attributes $inSK$ and $backSt$; and $inSK$ fulfils *near* whereas $backSt$ fulfils *quiet*. Similarly, ic meets *cheap* and *near*.

Extended decision frameworks capture the relations among decisions, goals, attributes, and preferences. We can now define *extended decision function* to select 'good' decisions.

Definition 3. *[6] An* extended decision function *is a mapping* $\psi^E : \mathcal{EDF} \mapsto 2^{\mathcal{DEC}}$*, such that, given* $edf = \langle \mathtt{D}, \mathtt{A}, \mathtt{G}, \mathtt{DA}, \mathtt{GA}, \mathtt{P} \rangle$*,* $\psi^E(edf) \subseteq \mathtt{D}$*. For any* $d, d' \in \mathtt{D}$*, if* $\gamma(d) = \gamma(d')$ *and* $d \in \psi^E(df)$*, then* $d' \in \psi^E(df)$*. We say that* $\psi^E(edf)$ *are* selected *with respect to* ψ^E*. We use* Ψ^E *to denote the set of all extended decision functions.*

Definition 3 gives the basis of an extended decision function. An extended decision function selects a set of decisions from an extended decision framework. When two decisions meet the same set of goals, and one of those decisions belongs to the value of an extended decision function, then the other decision also belongs to the value of the same extended decision function.

We instantiate the basis definition to give the *most-preferred extended decision function*. It selects decisions meeting the more preferred goals that no other decisions meet.

Definition 4. *A* most-preferred extended decision function $\psi^E \in \Psi^E$ *is such that given an extended decision framework* $edf = \langle \mathtt{D}, \mathtt{A}, \mathtt{G}, \mathtt{DA}, \mathtt{GA}, \mathtt{P} \rangle$*, for every* $d \in \mathtt{D}$*,* $d \in \psi^E(edf)$ *if and only if the following holds for all* $d' \in \mathtt{D} \setminus \{d\}$*:*

- *for all* $g \in \mathtt{G}$*, if* $g \notin \gamma(d)$ *and* $g \in \gamma(d')$*, then there exists* $g' \in \mathtt{G}$*, such that:*
  - $g' > g$ *in* $\mathtt{P}$*,*
  - $g' \in \gamma(d)$*, and*
  - $g' \notin \gamma(d')$*.*

We say d *is a* most-preferred *(in* edf*). We refer to a generic most-preferred decision function as* ψ^E_x*.*

Thus, to select a decision d, we check against all other d' to ensure that: for any g, if d' meets g but d does not, then there exists some g' more preferred than g such that g' is met by d but not d'.

Example 3. Suppose we have two decisions d_1, d_2 and five goals $g_1, g_2, \ldots, g_5$, such that $g_1 > g_2 > \ldots > g_5$. The relations between decisions and goals are illustrated in Table 2. Here, neither d_1 nor d_2 meets the most preferred goal g_1; both of d_1 and d_2 meet g_2, the next preferred goal. Hence, by this point, d_1 and d_2 are considered equally good. However, g_3, the third preferred goal, is only met by d_2, hence d_2 is considered a better decision than d_1. Note that though d_1 meets both g_4 and g_5 where neither is met by d_2, but since they are both less preferred than g_3, d_2 is still considered a better decision here. Definition 4

	g_1	g_2	g_3	g_4	g_5
d_1	0	1	0	1	1
d_2	0	1	1	0	0

Table 2. Illustration of the most-preferred extended decision function.

corresponds to the above intuition as follows. Directly from Definition 4, d_2 is selected as for $d = d_2, d' = d_1$, both g_4 and g_5 meet the conditions $g_4, g_5 \notin \gamma(d_2)$ and $g_4, g_5 \in \gamma(d_1)$ and no other goals meet these two conditions. However, for both g_4 and g_5, there exists g_3 such that $g_3 > g_4$, $g_3 > g_5$, $g_3 \in \gamma(d_2)$ and $g_3 \notin \gamma(d_1)$. d_1 is not selected as for $d = d_1, d' = d_2$, g_3 is the only goal that meets the conditions: $g_1 \notin \gamma(d_1)$ and $g_1 \in \gamma(d_2)$. However, there is no g' meets the 3 conditions: $g' > g$ in $\mathtt{P}$, $g' \in \gamma(d)$, and $g' \notin \gamma(d')$.

Definition 4 gives a criterion for selecting decisions. We construct ABA frameworks to implement this selection, as follows.

Definition 5. *Given an extended decision framework edf* $= \langle \mathtt{D}, \mathtt{A}, \mathtt{G}, \mathtt{DA}, \mathtt{GA}, \mathtt{P} \rangle$, *the* most-preferred ABA framework corresponds to *edf is AF* $= \langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \mathcal{C} \rangle$*:*

– $\mathcal{R}$ *is such that:*
for all k, j, i *such that* $1 \leqslant k \leqslant n$, $1 \leqslant j \leqslant m$ *and* $1 \leqslant i \leqslant l$*:*

- *if* $\mathtt{DA}_{k,i} = 1$ *then* $d_k a_i \leftarrow \in \mathcal{R}$*;*
- *if* $\mathtt{GA}_{j,i} = 1$ *then* $g_j a_i \leftarrow \in \mathcal{R}$*;*
- $d_k g_j \leftarrow d_k a_i, g_j a_i \in \mathcal{R}$*;*

for all g_1, g_2 *in* $\mathtt{G}$, *if* $g_1 > g_2 \in \mathtt{P}$, *then* $P g_1 g_2 \leftarrow \in \mathcal{R}$*;*
if $1 \leqslant k \leqslant n$, $1 \leqslant r \leqslant n$, $k \neq r$, $1 \leqslant j \leqslant m$*:* $Nd^k \leftarrow d_r g_j, N d_k g_j, N X_j^{rk} \in \mathcal{R}$*;*
if $1 \leqslant k \leqslant n$, $1 \leqslant r \leqslant n$, $k \neq r$, $1 \leqslant j \leqslant m$, $1 \leqslant t \leqslant m$, $j \neq t$, *then:* $X_j^{rk} \leftarrow d_k g_t, N d_r g_t, P g_t g_j \in \mathcal{R}$*;*
there are no more members of $\mathcal{R}$.

– $\mathcal{A}$ *is such that:*
if $1 \leqslant k \leqslant n$, *then* $d_k \in \mathcal{A}$;
if $1 \leqslant k \leqslant n$, $1 \leqslant r \leqslant n$, $k \neq r$, $1 \leqslant j \leqslant m$, *then* $NX_j^{rk} \in \mathcal{A}$;
if $1 \leqslant k \leqslant n$, $1 \leqslant j \leqslant m$, *then* $Nd_k g_j \in \mathcal{A}$;
nothing else is in $\mathcal{A}$.
– $\mathcal{C}$ *is such that:*
if $1 \leqslant k \leqslant n$, *then* $\mathcal{C}(d_k) = \{Nd^k\}$;
if $1 \leqslant k \leqslant n$, $1 \leqslant r \leqslant n$, $k \neq r$, $1 \leqslant j \leqslant m$, *then* $\mathcal{C}(NX_j^{rk}) = \{X_j^{rk}\}$;
if $1 \leqslant k \leqslant n$, $1 \leqslant j \leqslant m$, *then* $\mathcal{C}(Nd_k g_j) = \{d_k g_j\}$.

Here, d_k is read as "select d_k"; $d_k g_j$ is read as "d_k meets g_j"; X_j^{rk} is read as "there is some $g_t, g_t > g_j$, such that d_k meets g_t and d_r does not". All variables starting with N are read as "it is not the case". We illustrate the notion of most-preferred ABA framework in the following example.

Example 4. (Example 1, continued.) The most-preferred ABA framework corresponds to the extended decision framework shown in Example 1 is as follows.[5]
$\mathcal{R}$:

$PNrCp \leftarrow$	$PNrQt \leftarrow$	$PCpQt \leftarrow$
$jh70 \leftarrow$	$jhSK \leftarrow$	$jhBST \leftarrow$
$ic50 \leftarrow$	$icSK \leftarrow$	
$cp50 \leftarrow$	$nrSK \leftarrow$	$qtBST \leftarrow$
$jhCp \leftarrow jh50, cp50$	$jhNr \leftarrow jh50, nr50$	$jhQt \leftarrow jh50, qt50$
$jhCp \leftarrow jh70, cp70$	$jhNr \leftarrow jh70, nr70$	$jhQt \leftarrow jh70, qt70$
$jhCp \leftarrow jhSK, cpSK$	$jhNr \leftarrow jhSK, nrSK$	$jhQt \leftarrow jhSK, qtSK$
$jhCp \leftarrow jhBST, cpBST$	$jhNr \leftarrow jhBST, nrBST$	$jhQt \leftarrow jhBST, qtBST$
$icCp \leftarrow ic50, cp50$	$icNr \leftarrow ic50, nr50$	$icQt \leftarrow ic50, qt50$
$icCp \leftarrow ic70, cp70$	$icNr \leftarrow ic70, nr70$	$icQt \leftarrow ic70, qt70$
$icCp \leftarrow icSK, cpSK$	$icNr \leftarrow icSK, nrSK$	$icQt \leftarrow icSK, qtSK$
$icCp \leftarrow icBST, cpBST$	$icNr \leftarrow icBST, nrBST$	$icQt \leftarrow icBST, qtBST$

$Nd^{jh} \leftarrow icCp, NjhCp, NX^{icjh}_{cheap}$	$Nd^{ic} \leftarrow jhCp, NicCp, NX^{jhic}_{cheap}$
$Nd^{jh} \leftarrow icQt, NjhQt, NX^{icjh}_{quiet}$	$Nd^{ic} \leftarrow jhQt, NicQt, NX^{jhic}_{quiet}$
$Nd^{jh} \leftarrow icNr, NjhNr, NX^{icjh}_{near}$	$Nd^{ic} \leftarrow jhNr, NicNr, NX^{jhic}_{near}$
$X^{icjh}_{cheap} \leftarrow jhNr, NicNr, PnearCp$	$X^{icjh}_{cheap} \leftarrow jhQt, NicQt, PquietCp$
$X^{icjh}_{near} \leftarrow jhCp, NicCp, PcheapNr$	$X^{icjh}_{near} \leftarrow jhQt, NicQt, PquietNr$
$X^{icjh}_{quiet} \leftarrow jhCp, NicCp, PcheapQt$	$X^{icjh}_{quiet} \leftarrow jhNr, NicNr, PnearQt$
$X^{jhic}_{cheap} \leftarrow icNr, NjhNr, PnearCp$	$X^{jhic}_{cheap} \leftarrow icQt, NjhQt, PquietCp$
$X^{jhic}_{near} \leftarrow icCp, NjhCp, PcheapNr$	$X^{jhic}_{near} \leftarrow icQt, NjhQt, PquietNr$
$X^{jhic}_{quiet} \leftarrow icCp, NjhCp, PcheapQt$	$X^{jhic}_{quiet} \leftarrow icNr, NjhNr, PnearQt$

$\mathcal{A}$:

jh	NX^{icjh}_{cheap}	NX^{icjh}_{quiet}	NX^{icjh}_{near}	NX^{jhic}_{cheap}	NX^{jhic}_{quiet}	NX^{jhic}_{near}
ic	$NicCp$	$NicQt$	$NicNr$	$NjhCp$	$NjhQt$	$NjhNr$

[5] Nr and nr stand for *near*; Cp and cp stand for *Cheap*; Qt and qt stand for *Quiet*.

$\mathcal{C}$:

$\mathcal{C}(jh) = \{Nd^{jh}\}$	$\mathcal{C}(ic) = \{Nd^{ic}\}$	
$\mathcal{C}(NX^{icjh}_{cheap}) = \{X^{icjh}_{cheap}\}$	$\mathcal{C}(NX^{icjh}_{quiet}) = \{X^{icjh}_{quiet}\}$	$\mathcal{C}(NX^{icjh}_{near}) = \{X^{icjh}_{near}\}$
$\mathcal{C}(NX^{jhic}_{cheap}) = \{X^{jhic}_{cheap}\}$	$\mathcal{C}(NX^{jhic}_{quiet}) = \{X^{jhic}_{quiet}\}$	$\mathcal{C}(NX^{jhic}_{near}) = \{X^{jhic}_{near}\}$
$\mathcal{C}(NicCp) = \{icCp\}$	$\mathcal{C}(NicQt) = \{icQt\}$	$\mathcal{C}(NicNr) = \{icNr\}$
$\mathcal{C}(NjhCp) = \{jhCp\}$	$\mathcal{C}(NjhQt) = \{jhQt\}$	$\mathcal{C}(NjhNr) = \{jhNr\}$

Here, $\{ic\} \vdash ic$ is admissible. Though both ic and jh are *near*, ic is cheap but jh is not. A graphical illustration is shown in Figure 1.

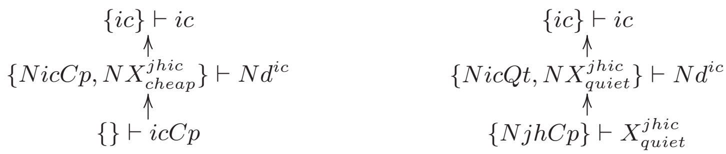

Fig. 1. Graphical illustration of Example 4. Here, $\{ic\} \vdash ic$ is admissible. The two figures (left & right) show two ways of attacking $\{ic\} \vdash ic$. This figure is read as follows. **Left:** ic should be selected (root argument). ic should not be selected as it is not *cheap* but jh is. Moreover, there is no more preferred goal than *cheap* (middle argument). ic is cheap (bottom argument). **Right:** ic should be selected (root argument). ic should not be selected as it is not *quiet* and there is no more preferred goal than *quiet*, which is met by jh (middle argument). jh is no better than ic as though it is *quiet*, it is not *cheap* and *cheap* is more preferred than *quiet*.

Selected decisions can be found by computing admissible arguments in a corresponding ABA framework, as follows.

Theorem 1. *Given an extended decision framework* $edf = \langle \mathtt{D}, \mathtt{A}, \mathtt{G}, \mathtt{DA}, \mathtt{GA}, \mathtt{P} \rangle$*, let* $AF = \langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \mathcal{C} \rangle$ *be the most-preferred ABA framework corresponding to* edf*. Then, for all* $d \in \mathtt{D}$*,* $d \in \psi^E_x(edf)$ *if and only if the argument* $\{d\} \vdash d$ *belongs to an admissible set in* AF*.*

Proof. Let d be d_k (k is the index of d in $\mathtt{DA}$).

(**Part I.**) We first prove that if d_k is most-preferred, then $\{d_k\} \vdash d_k$ is in an admissible extension. To show $\{d_k\} \vdash d_k$ is admissible, we need to show:

1. $\{d_k\} \vdash d_k$ is an argument.
2. Using the arguments Δ, $\{d_k\} \vdash d_k$ withstands all attacks.
3. $\{\{d_k\} \vdash d_k\} \cup \Delta$ is conflict-free.

Since d_k is an assumption, $\{d_k\} \vdash d_k$ is an argument. Since $\mathcal{C}(d_k) = \{Nd^k\}$, attackers of $\{d_k\} \vdash d_k$ are arguments with claim Nd^k. Since rules with head Nd^k are of the form $Nd^k \leftarrow d_r g_j, Nd_k g_j, NX^{rk}_j$, attackers of $\{d_k\} \vdash d_k$ are arguments of the form $\{Nd_k g_j, NX^{rk}_j\} \vdash Nd^k$ ($d_r g_j$ is not an assumption and there is no assumption involved in "proving" $d_r g_j$). Hence we need to show for all j, r, $\{d_k\} \vdash d_k$ withstands (with help) attacks from $\{Nd_k g_j, NX_j^{rk}\} \vdash Nd^k$. For fixed j, r, $\{d_k\} \vdash d_k$ withstands attacks from $\{Nd_k g_j, NX_j^{rk}\} \vdash Nd^k$ if $\{Nd_k g_j, NX_j^{rk}\} \vdash Nd^k$ does not withstand attacks towards it. Because NX_j^{rk} is an assumption, if there is an argument `Arg` for a contrary of NX_j^{rk}, and `Arg` is not attacked, then $\{Nd_k g_j, NX_j^{rk}\} \vdash Nd^k$ is counterattacked and $\{d_k\} \vdash d_k$ is admissible. We show such `Arg` exists when d_k is most-preferred.

For all $d_r \in \mathtt{D}, r \neq k$, for $g_j \in \mathtt{G}$ there are two possibilities:

1. it is the case that $g_j \notin \gamma(d_k)$ and $g_j \in \gamma(d_r)$; and
2. it is not the case that $g_j \notin \gamma(d_k)$ and $g_j \in \gamma(d_r)$, i.e., one of the following three sub-cases holds:
   (a) $g_j \notin \gamma(d_k)$ and $g_j \notin \gamma(d_r)$,
   (b) $g_j \in \gamma(d_k)$ and $g_j \in \gamma(d_r)$,
   (c) $g_j \in \gamma(d_k)$ and $g_j \notin \gamma(d_r)$.

In case 1, since d_k is most-preferred, by Definition 4, there exists $g_t \in \mathtt{G} \backslash \{g_j\}$, such that

$$(1)\ g_t > g_j \text{ in } \mathtt{P},\ (2)\ g_t \in \gamma(d_k), \text{ and } (3)\ g_t \notin \gamma(d_r).$$

(i) Since $g_t > g_j$ in $\mathtt{P}$, there is $Pg_t g_j \leftarrow$ in $\mathcal{R}$. (ii) Since $g_t \in \gamma(d_k)$, there is a "proof" for $d_k g_t$, i.e., $\{\} \vdash d_k g_t$ is an argument. (iii) Since $g_t \notin \gamma(d_r)$, there is no argument for $d_r g_t$, hence $Nd_r g_t$ is not attacked (the contrary of $Nd_r g_t$ is $d_r g_t$). Jointly, (i)(ii)(iii), show that there is an argument for X_j^{rk} (by rule $X_j^{rk} \leftarrow d_k g_t, Nd_r g_t, Pg_t g_j$): $\{Nd_r g_t\} \vdash X_j^{rk}$ and this is not attacked. Since the contrary of NX_j^{rk} is X_j^{rk}, $\{Nd_k g_j, NX_j^{rk}\} \vdash Nd^k$ cannot withstand the attack from $\{Nd_r g_t\} \vdash X_j^{rk}$.

In case 2(a), $g_j \notin \gamma(d_r)$, hence there is no attribute $a_i \in \mathtt{A}$ such that d_r has a_i and g_j is fulfilled by a_i. Hence $d_r a_i \leftarrow \notin \mathcal{R}$ or $g_j a_i \leftarrow \notin \mathcal{R}$, or both. Therefore there is no way to "prove" $d_r g_j$ and hence such g_j cannot be used to construct the argument for Nd^k (the only rule with head Nd^k is $Nd^k \leftarrow d_r g_j, Nd_k g_j, NX_j^{rk}$). So no attacks against d_k can be formed in this case.

In case 2(b) and 2(c), $g_j \in \gamma(d_k)$, hence there is $a_i \in \mathtt{A}$ such that d_k has a_i and g_j is fulfilled by a_i. Therefore $\{\} \vdash d_k g_j$ is an argument. Since there is no assumption in the support of $\{\} \vdash d_k g_j$, $\{Nd_k g_j, NX_j^{rk}\} \vdash Nd^k$ cannot withstand the attack from $\{\} \vdash d_k g_j$ (the contrary of $Nd_k g_j$ is $d_k g_j$).

In case 1 or 2, either $\{Nd_k g_j, NX_j^{rk}\} \vdash Nd^k$ is not an attacking argument or cannot withstand attacks towards it. Hence $\{d_k\} \vdash d_k$ withstands attacks from $\{Nd_k g_j, NX_j^{rk}\} \vdash Nd^k$.

It is easy to see $\{\{d_k\} \vdash d_k\} \cup \Delta$ is conflict-free, as follows. Δ includes all arguments defending $\{d_k\} \vdash d_k$, since attackers of $\{d_k\} \vdash d_k$ are of the form $\{Nd_k g_j, NX_j^{rk}\} \vdash Nd^k$ for $r \neq k$, $\mathtt{Arg} \in \Delta$ are either of the form $\{\} \vdash d_k g_j$ or $\{Nd_r g_t\} \vdash X_j^{rk}$, for $r \neq k, j \neq t$. Therefore, assumptions and claims in Δ are of the forms $Nd_r g_t$ and $d_k g_j, X_j^{rk}$, respectively. Since $d_k g_j, X_j^{rk}$ are not contraries of $Nd_r g_t$ for $r \neq k, j \neq t$, Δ is conflict-free. Similarly, $\{\{d_k\} \vdash d_k\} \cup \Delta$ is conflict-free.

Since $\{d_k\} \vdash d_k$ is an argument and, with help from a conflict-free set of arguments, withstands all attacks towards it, $\{d_k\} \vdash d_k$ belongs to an admissible set of arguments.

(**Part II.**) We show: if $\{d_k\} \vdash d_k$ belongs to an admissible set of arguments, then d_k is most-preferred. To show d_k is most-preferred, we need to show for all $d_r \in \mathtt{D} \setminus \{d_k\}$, the following holds:

$\star$ for all $g_j \in \mathtt{G}$, if $g_j \notin \gamma(d_k)$ and $g_j \in \gamma(d_r)$, then there exists $g_t \in \mathtt{G}$ such that: (1) $g_t > g_j$ in $\mathtt{P}$, (2) $g_t \in \gamma(d_k)$, and (3) $g_t \notin \gamma(d_r)$.

Since $\{d_k\} \vdash d_k$ belongs to an admissible set, $\{d_k\} \vdash d_k \cup \Delta$, we know:

1. $\{d_k\} \vdash d_k$ is an argument;
2. with help of Δ, $\{d_k\} \vdash d_k$ withstands all attacks towards it.

Since arguments attacking $\{d_k\} \vdash d_k$ are of the form $\{Nd_k g_j, NX_j^{rk}\} \vdash Nd^k$ (the contrary of d_k is Nd^k and the only rule with head Nd^k is $Nd^k \leftarrow d_r g_j, Nd_k g_j, NX_j^{rk}$), $\{d_k\} \vdash d_k$ withstanding the attack from $\{Nd_k g_j, NX_j^{rk}\} \vdash Nd^k$ means that one of the following three conditions holds:

1. there is no argument for Nd^k for some j, r, i.e., there is no way to "prove" $d_r g_j$, i.e., there is no argument with claim $d_r g_j$ due to the absence of $a_i \in \mathtt{A}$, hence either $d_r a_i \leftarrow \notin \mathcal{R}$ or $g_j a_i \leftarrow \notin \mathcal{R}$. This means $g_j \notin \gamma(d_r)$. Therefore part of the antecedent of $\star$, $g_j \in \gamma(d_r)$, is false and $\star$ holds for g_j, d_r;
2. there is an argument `Arg` for the contrary of $Nd_k g_j$ and `Arg` withstands all attacks towards it with help from Δ. Since $\mathcal{C}(Nd_k g_j) = \{d_k g_j\}$, having an argument with claim $d_k g_j$ means d_k meets g_j, i.e., $g_j \in \gamma(d_k)$. Therefore the other part of the antecedent of $\star$, $g_j \notin \gamma(d_k)$, is false and $\star$ holds;
3. there is an argument `Arg` for the contrary of NX_j^{rk} and `Arg` withstands all attacks towards it. Since $\mathcal{C}(NX_j^{rk}) = \{X_j^{rk}\}$ and $X_j^{rk} \leftarrow d_k g_t, Nd_r g_t, Pg_t g_j$, having `Arg` with claim X_j^{rk} and `Arg` withstanding all of attacks towards it means:
   (a) there is an argument for $d_k g_t$;
   (b) $\{Nd_r g_t\} \vdash Nd_r g_t$ withstands all attacks towards it;
   (c) there is an argument for $Pg_t g_j$.

3(a) implies d_k meets g_t, hence $g_t \in \gamma(d_k)$; 3(b) implies d_r does not meet g_t, hence $g_t \notin \gamma(d_r)$; 3(c) implies $g_t > g_j$ in $\mathtt{P}$. Jointly, 3(a) 3(b) and 3(c) imply $\star$.

As $\star$ holds for all cases 1, 2, and 3, and there are no other cases, d_k is most-preferred.

4 Preferences over Combined Goals

Preferences can be expressed over combined goals. For instance it may be that g_1 is preferred to both g_2 and g_3, but g_2 and g_3 together are more preferred than g_1. To model preferences over combined goals, we redefine the preferences $\mathtt{P}$ as a partial order over sets of goals, and denote it by $\mathtt{P}^{\mathtt{s}}$.

To save space, we do not repeat Definition 1 but use $\langle \mathtt{D}, \mathtt{A}, \mathtt{G}, \mathtt{DA}, \mathtt{GA}, \mathtt{P^s} \rangle$ to denote an extended decision framework with preferences defined over sets of goals ($2^{\mathtt{G}}$). Note that the new definition is a generalisation of the earlier one as $\mathtt{P}$ are $\mathtt{P^s}$ over singletons. We leave Definition 3 unchanged.

To ease the presentation, we define the notion of *comparable goal set* (*comparable set* in short) as follows:

Definition 6. *Given edf* $= \langle \mathtt{D}, \mathtt{A}, \mathtt{G}, \mathtt{DA}, \mathtt{GA}, \mathtt{P^s} \rangle$, *we let the* comparable goal set, $\mathtt{S}$, *(in edf) be such that:* $\mathtt{S} \subseteq 2^{\mathtt{G}}$, *and*

– *for every* $s \in \mathtt{S}$, *there is an* $s' \in \mathtt{S}, s \neq s'$, *such that either* $s < s' \in \mathtt{P^s}$ *or* $s' < s \in \mathtt{P^s}$*;*
– *for every* $s \in 2^{\mathtt{G}} \setminus \mathtt{S}$, *there is no* $s' \in 2^{\mathtt{G}}$, *such that* $s < s' \in \mathtt{P^s}$ *or* $s' < s \in \mathtt{P^s}$.

Example 5. Let $\mathtt{G}$ be $\{g_1, g_2, g_3, g_4, g_5\}$, let $\mathtt{P^s}$ be:

$$\{g_1\} > \{g_2\} > \{g_4, g_5\} > \{g_3\} > \{g_4\} > \{g_5\}.$$

Then the comparable goal set is: $\{\{g_1\}, \{g_2\}, \{g_3\}, \{g_4\}, \{g_5\}, \{g_4, g_5\}\}$.

We redefine Definition 4 to incorporate the change from $\mathtt{P}$ to $\mathtt{P^s}$, as follows.

Definition 7. *A* most-preferred-set extended decision function $\psi^E \in \Psi^E$ *is such that given an extended decision framework edf* $= \langle \mathtt{D}, \mathtt{A}, \mathtt{G}, \mathtt{DA}, \mathtt{GA}, \mathtt{P^s} \rangle$, *let* $\mathtt{S}$ *be the comparable set in edf, for every* $d \in \mathtt{D}$, $d \in \psi^E(edf)$ *if and only if the following holds for all* $d' \in \mathtt{D} \setminus \{d\}$*:*

– *for all* $s \in \mathtt{S}$, *if* $s \not\subseteq \gamma(d)$ *and* $s \subseteq \gamma(d')$, *then there exists* $s' \in \mathtt{S}$, *such that:*
  - $s' > s \in \mathtt{P^s}$,
  - $s' \subseteq \gamma(d)$, *and*
  - $s' \not\subseteq \gamma(d')$.

We say d is a most-preferred-set *(in edf). We refer to a generic most-preferred-set decision function as* ψ^E_s.

Intuitively, Definition 7 is Definition 4 with goals replaced by comparable sets. An informal reading of Definition 7 is: to select a decision d, we check against all other d' to ensure that: for any comparable set of goals s, if d' meets s but d does not, then there exists some s' more preferred than s such that s' is met by d but not d'.

We modify Example 3 to illustrate Definition 7 as follows.

Example 6. As in Example 3, $\gamma(d_1) = \{g_2, g_4, g_5\}$, and $\gamma(g_2) = \{g_2, g_3\}$. Unlike Example 3, we let $\mathtt{P^s}$ be the one shown in Example 5. Though g_3 is more preferred than g_4 and g_5 individually, g_4 and g_5 together are more preferred than g_3. It is trivial to see d_1 is more preferred than d_2 as d_1 meets both g_4 and g_5 whereas d_2 does not. Hence, d_1 is a most-preferred-set decision.

Similar to Definition 5, ABA can be used to compute most-preferred-set decisions. We give the corresponding ABA framework as follows.

Definition 8. *Given an extended decision framework edf* $= \langle \mathtt{D}, \mathtt{A}, \mathtt{G}, \mathtt{DA}, \mathtt{GA}, \mathtt{P^s} \rangle$, *let* $\mathtt{S} = \{s_1, \ldots, s_w\}$ *be the comparable set in edf, the* most-preferred-set ABA framework corresponds to *edf is* $AF = \langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \mathcal{C} \rangle$, *where:*

- $\mathcal{R}$ *is such that:*
  for all k, j *and* i *with* $1 \leqslant k \leqslant n$, $1 \leqslant j \leqslant m$, $1 \leqslant i \leqslant l$:
  - *if* $\mathtt{DA}_{k,i} = 1$ *then* $d_k a_i \leftarrow \in \mathcal{R}$;
  - *if* $\mathtt{GA}_{j,i} = 1$ *then* $g_j a_i \leftarrow \in \mathcal{R}$;
  - $d_k g_j \leftarrow d_k a_i, g_j a_i \in \mathcal{R}$;

  for all k *with* $1 \leqslant k \leqslant n$, *all* $s_p \in \mathtt{S}$, *let* $s_p = \{g'_1, g'_2, \ldots, g'_r\}$
  - $d_k s_p \leftarrow d_k g'_1, d_k g'_2, \ldots, d_k g'_r \in \mathcal{R}$;

  for all $s_1, s_2 \in \mathtt{S}$, *if* $s_1 > s_2 \in \mathtt{P^s}$, *then* $P s_1 s_2 \leftarrow \in \mathcal{R}$;
  for all k, r *with* $1 \leqslant k \leqslant n$, $1 \leqslant r \leqslant n$, $k \neq r$, $1 \leqslant j \leqslant w$:
  $Nd^k \leftarrow d_r s_j, N d_k s_j, N X_j^{rk} \in \mathcal{R}$.
  for all k, r, j, t *with* $1 \leqslant k \leqslant n$, $1 \leqslant r \leqslant n$, $k \neq r$, $1 \leqslant j \leqslant w$, $1 \leqslant t \leqslant w$, $j \neq t$: $X_j^{rk} \leftarrow d_k s_t, N d_r s_t, P s_t s_j \in \mathcal{R}$;
  that is all the rules in $\mathcal{R}$.
- $\mathcal{A}$ *is such that:*
  if $1 \leqslant k \leqslant n$, $d_k \in \mathcal{A}$;
  for all k, r, j *with* $1 \leqslant k \leqslant n$, $1 \leqslant r \leqslant n$, $k \neq r$, $1 \leqslant j \leqslant w$: $N X_j^{rk} \in \mathcal{A}$;
  for all k, j *with* $1 \leqslant k \leqslant n$, $1 \leqslant j \leqslant w$: $N d_k s_j \in \mathcal{A}$;
  that is all the assumptions.
- $\mathcal{C}$ *is such that:*
  for all k *with* $1 \leqslant k \leqslant n$, $\mathcal{C}(d_k) = \{Nd^k\}$;
  for all k, r, j *with* $1 \leqslant k \leqslant n$, $1 \leqslant r \leqslant n$, $k \neq r$, $1 \leqslant j \leqslant w$: $\mathcal{C}(N X_j^{rk}) = \{X_j^{rk}\}$;
  for all k, j *with* $1 \leqslant k \leqslant n$, $1 \leqslant j \leqslant w$: $\mathcal{C}(N d_k s_j) = \{d_k s_j\}$.

Definition 8 is given in the same spirit as Definition 5. Instead of checking every individual goal being fulfilled by a decision ($d_k g_j$), using the rule $d_k g_j \leftarrow d_k a_i, g_j a_i$, Definition 8 checks sets of goals $d_k s_j$ fulfilled by a decision using two rules: $d_k s_p \leftarrow d_k g'_1, d_k g'_2, \ldots, d_k g'_r$ and $d_k g_j \leftarrow d_k a_i, g_j a_i$. Hence, a decision meeting a comparable set is the decision meeting all goals in the comparable set. We illustrate this new notion of ABA framework corresponding to extended decision framework with preferences over sets of goals in the next section.

As in Theorem 1, selected decisions are arguments in admissible extensions:

Theorem 2. *Given an extended decision framework edf* $= \langle \mathtt{D}, \mathtt{A}, \mathtt{G}, \mathtt{DA}, \mathtt{GA}, \mathtt{P^s} \rangle$, *let* $AF = \langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \mathcal{C} \rangle$ *be the most-preferred-set ABA framework corresponding to edf. Then, for all* $d \in \mathtt{D}$, $d \in \psi_s^E(edf)$ *if and only if the argument* $\{d\} \vdash d$ *belongs to an admissible set in AF.*

The proof of Theorem 2 is very similar to that of Theorem 1. The difference is that a decision meeting a goal is replaced by a decision meeting a comparable sets ($d_k g_j \leftarrow d_k a_i, g_j a_i$ is replaced by $d_k s_p \leftarrow d_k g'_1, d_k g'_2, \ldots, d_k g'_r$). The structure of the proof remains unchanged and the conclusion holds.

5 Selecting Medical Literature as Decision Making

In medical research, one sometimes faces the problem of choosing which medical studies to base a diagnosis on, for a given patient. We view this as a decision making problem and show how our techniques can be used to solve it.

For this case study, we have identified 11 randomised clinical trials on the treatment of brain metastases. The decisions of our model are choices to use a given paper in a diagnosis—they can therefore be represented by names or IDs for the papers themselves. The Arm IDs and PMID Numbers of these literature are given in Table 3. Each literature contains a two-arm trial. We extract a list of representing trial design criteria and patient characteristics from these papers. These criteria and characteristics are considered *attributes* (A) of decisions.

The relations between papers and trial criteria / characteristics are given in Table 4 (DA). Here, a "1" in row k column i should be interpreted as the trial reported in paper p_k has criterion / characteristics i. A blank means the corresponding criterion / characteristics is either not reported or not met by the particular paper. For instance, the first row should be read as: the trial reported in paper p_1 included patients over 18 years old, those with 1 or many brain metastases, with performance status either 0 or 1, and more than 60 percent of the patient sample population included in this trial had primary lung cancer.

id	**ArmID**	**PMID Number**
1	Ayoma Jama 2006	16757720
2	Graham IJROBP 2010	19836153
3	Chang Lancet 2009	1980120
4	Langley ClinOnc 2013	23211715
5	Kocher JCO 2011	21041710
6	Patchell NEJM 1990	2405271
7	Patchell Jama	9809728
8	Mintz Cancer 1996	8839553
9	VechtAnn Neurol 1993	8498838
10	Andrews Lancet 2004	15158627
11	Kondziolka IJROBP 1999	10487566

Table 3. 11 medical studies on brain metastases.

Since the aim is to find medical papers for a particular patient, we view properties of the given patient as goals (G). In this setting, "good" decisions are medical papers that better match with the particular patient's properties. We present relations between patient's properties and trial characteristics in Table 5 (GA). "1"s in the table represent trial characteristics meeting patient properties. Blanks means otherwise. For instance, the sample patient shown in Table 5 has four properties: being 64 years old, has three metastases, has a performance status 2, and has lung cancer.

We first let the preference (P) be:

	> 18	$1m$	$2m$	$> 2m$	ECD	$PS\ 0,1$	$PS\ 2$	$PS\ 3,4$	$Lung > .6$	$Breast > .6$
p_1	1	1	1	1		1			1	
p_2					1	1	1			
p_3	1	1	1	1		1	1			
p_4	1	1	1	1					1	
p_5	1	1	1	1	1					
p_6	1	1				1				
p_7	1	1				1			1	
p_8		1				1	1	1		
p_9	1	1				1	1			
p_{10}	1	1	1	1	1	1			1	
p_{11}			1	1		1				

Table 4. Paper / Trial Characteristics (DA)

	> 18	$1m$	$2m$	$> 2m$	ECD	$PS\ 0,1$	$PS\ 2$	$PS\ 3,4$	$Lung > .6$	$Breast > .6$
$Age64$	1									
$3met$				1						
$PS\ 2$							1			
$Lung$									1	

Table 5. Patient Properties / Trial Characteristics (GA)

$$3mets > Lung > PS2 > Age.$$

Here, the preference order states that: the number of metastases is more important than where the main cancer comes from than the performance status than the age of the patient. Thus, we form an extended decision framework $edf = \langle \mathtt{D}, \mathtt{A}, \mathtt{G}, \mathtt{DA}, \mathtt{GA}, \mathtt{P} \rangle$ with decisions $\mathtt{D} = \{p_1, \ldots, p_{11}\}$, attributes $\mathtt{A} = \{> 18, 1m, 2m, > 2m, ECD, PS\ 0,1, PS\ 2, PS\ 3,4, Lung > .6, Breast > .6\}$, and goals $\mathtt{G} = \{Age64, 3\ met, PS\ 2, Lung\}$, GA, DA, and P are given above.

We omit the ABA framework, AF, corresponding to this extended decision framework. We use `proxdd`[6] to compute the admissible arguments. There, we see that $\{p_{10}\} \vdash p_{10}$ is in an admissible extension in AF, as illustration in Figure 2.

To illustrate preferences over sets of goals, we let $\mathtt{P}^{\mathtt{s}}$ be:

$$\{PS2, Age\} > \{3mets\} > \{Lung\} > \{PS2\} > \{Age\}.$$

The comparable goal set is: $\{\{PS2, Age\}, \{3mets\}, \{Lung\}, \{PS2\}, \{Age\}\}$. We insert new rules such as:

- $p1SPS2age \leftarrow p1PS2, p1Age$
- $p1S3mets \leftarrow p13mets$

and so on in the corresponding ABA framework (read as: $p1$ meets the comparable goal set $\{PS2, age\}$ if $p1$ meets $PS2$ and $p1$ meets Age; $p1$ meets the

[6] http://www.doc.ic.ac.uk/~rac101/proarg/

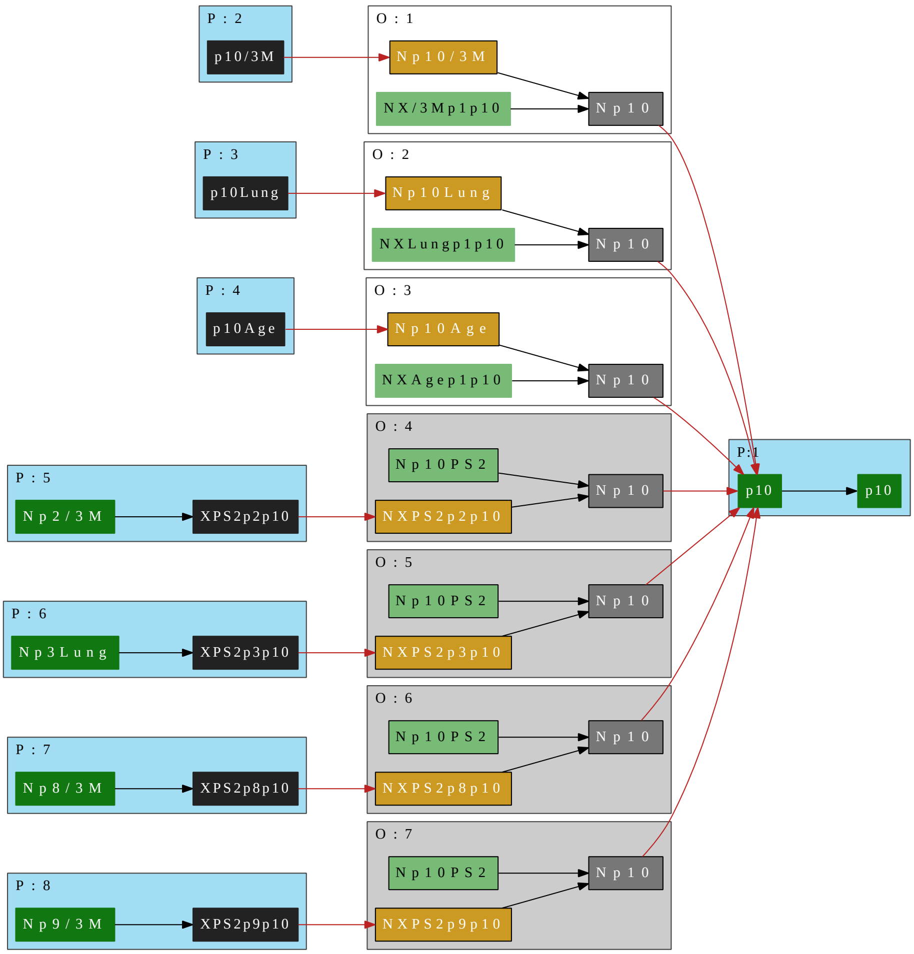

Fig. 2. Graphical illustration of p_{10} being a most-preferred decision. Note that this figure omits opponent arguments which have been counter-attacked by proponent arguments shown in this graph. **Right / Root:** p_{10} is a good paper. **Middle / Opponents:** (attacking the root) p_{10} is not good as it does not meet the *3 metastases* goal and it is not the case that p_{10} meeting some more important goal than *3 metastases*. (O:1) p_{10} is not good as it does not meet the *main cancer from lung* goal and it is not the case that p_{10} meeting some more important goal than *main cancer from lung*. (O:2) Etc. **Left / Support:** (attacking the middle ones) p_{10} meets the *3 metastases* goal (P:2). p_{10} meets the *main cancer from lung* goal (P:3), etc.

comparable goal set $\{3mets\}$ if $p1$ meets $3mets$, etc.). A graphical illustration of p_3 being a most-preferred-set decision is given in Table 3.

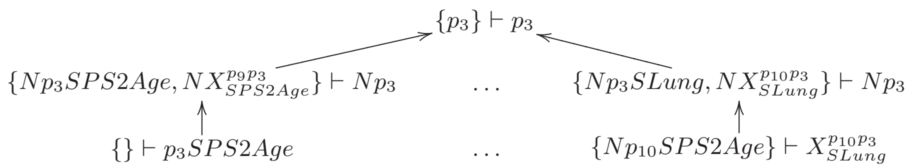

Fig. 3. Graphical illustration of p_3 being a most-preferred-set decision. Note that this figure only shows a small part a debate graph. A reading is follows. **Root:** p_3 is a good paper. **Middle Left:** (attacking the root) p_3 is not good as it does not meet the comparable set $\{PS2, age\}$ and it is not the case that p_3 meeting some more important comparable set than $\{PS2, age\}$. **Bottom Left:** (attacking the middle left) p_3 meets $\{PS2, age\}$. **Middle Right:** (attacking the root) p_3 is not good as it does not meets $\{Lung\}$ and it is not the case that p_3 meeting some more preferred comparable set than p_{10} meeting $Lung$. **Bottom Right:** (attacking the middle right) p_3 meets $\{PS2, age\}$ whereas p_10 does not, and $\{PS2, age\}$ is more preferred than $\{Lung\}$.

6 Related Work

Matt et.al. [9] present an ABA based decision making model. Our work differs from theirs in that we study decision making with preference over goals and sets of goals whereas they focus on decision making without preferences.

Dung et al. [4] present an argumentation-based approach to contract negotiation. Part of that work can be viewed as argumentation-based decision-making with preferences. The main differences are: (1) we give formal definition of decision making frameworks whereas they do not; (2) we study preference over a set of goals whereas they do not; (3) we make explicit connections between 'good' decisions and 'acceptable' arguments whereas they do not.

Fan and Toni [6] present a model of argumentation-based decision-making. Compare to that work, this paper gives a more thorough look at decision making with preferences over goals by examining preferences over individual goals and sets of goals whereas that work has not. Moreover, this work uses a real world example, medical paper selection, as the case study, whereas [6] has not.

Amgoud and Prade [1] present a formal model for making decisions using abstract argumentation. Our work differs from theirs as: (1) they use abstract argumentation whereas we use ABA; (2) they use a pair-wise comparison between decisions to select the "winning" decision whereas we use an unified process to map extended decision frameworks into ABA and then compute admissible arguments.

7 Conclusion

We present an argumentation based decision making model that supports preferences. In our model, we represent knowledge related to decision making in extended decision frameworks in the forms of decisions, attributes, goals and preferences over (sets of) goals. We define extended decision functions to select "good" decisions. We then map both decision frameworks and decision functions into ABA frameworks. In this way, computing selected decisions becomes computing admissible arguments. We obtain sound and complete results such as selected decisions are claims of admissible arguments and vice versa. A benefit of our approach is that it gives an argumentative justification to the selected decisions while computing it. A natural extension of our approach is incorporating defeasibility into our approach to model a form of uncertainty. Comparing with many work in multi-criteria decision making [11], our approach gives a finer granularity in reasoning as not only decisions and goals are considered but also attributes and preferences.

We apply our decision making model to clinical trial selection: given properties of a patient, we select papers that are most relevant to this patient, from a set of papers. We view papers as decisions, trial criteria and characteristics as attributes, patient properties as goals. Hence, "good" decisions are papers best match with patient properties. We show our model gives satisfactory results. Also since our decision model is generic, we can apply it in many other domains. For example, we plan to apply the developed decision making model to select the most suitable treatment for a patient in future.

Although the argumentation frameworks generated are large in comparison with the decision frameworks, the generation is typically quick, and all queries we investigated were answered by `proxdd` in less than 0.05 seconds. Future work will investigate the complexity and performance evaluation more thoroughly; should the generation of ABA frameworks be found to be expensive, we will look at the possibility of 'lazy' generation, producing relevant inference rules in $\mathcal{R}$ on the fly, as query answering needs them.

Other future directions include studying decision-making with other form of knowledge representation, studying decision-making with conditional preference [2], and studying decision-making in the context of multiple agents sharing potentially conflicting knowledge and preferences.

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