Arguing About Preferences And Decisions*

T.L. van der Weide, F. Dignum, J.-J. Ch. Meyer,
H. Prakken, and G.A.W. Vreeswijk

Universiteit Utrecht
{tweide,dignum,jj,henry,gv}@cs.uu.nl

Abstract. Complex decisions involve many aspects that need to be considered, which complicates determining what decision has the most preferred outcome. Artificial agents may be required to justify and discuss their decisions to others. Designers must communicate their wishes to artificial agents. Research in argumentation theory has examined how agents can argue about what decision is best using goals and values. Decisions can be justified with the goals they achieve, and goals can be justified by the values they promote. Agents may agree on having a value, but disagree about what constitutes that value. In existing work, however, it is not possible to discuss what constitutes a specific value, whether a goal promotes a value, why an agent has a value and why an agent has specific priorities over goals. This paper introduces several argument schemes, formalised in an argumentation system, to overcome these problems. The techniques presented in this paper are inspired by multi attribute decision theory.

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1 Introduction

In complex situations, decisions involve many aspects that need to be considered. These aspects are typically different in nature and therefore difficult to compare. This complicates determining what outcome is the most preferable. Throughout the paper, we will use buying a house as an example, which involves many different aspects. For example, an agent may care about the costs of a house, but also about how fun, comfortable, close to shops, and how beautiful a house is. Artificial agents are expected to act in the designer's or user's best interest. This requires designers or users to communicate their wishes to the agent and the agent to explain and discuss why a certain decision was made. A significant amount of research has been concerned with using argumentation

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theory for decision-making and practical reasoning to determine which decisions are defensible from a given motivation, see for example [7, 2, 1].

A possible argumentation framework for decision-making for this purpose is the one proposed in [1]. Several decision principles are formalised to select the best decision using arguments in favour and against the available decisions. Agents are assumed to have a set of prioritised goals, which are used to construct argument in favour and against decisions. For example, agent α has the goal to live in a house that is downtown and the less important goal to live in a house bigger than $60m^2$. In complex situations it is useful to argue about *what* goals should be pursued. Why have the goal to live downtown and why not in a village? Why is living downtown more important than living in a bigger house? However, justifying and attacking goals is not possible using the framework of [1].

In order to solve this problem, we could use the framework described in [2], where goals can be justified and attacked using the values they promote and demote. People use their values as standards or criteria to guide selection and evaluation of actions [10, 12]. The values of agents reflect their preferences. For example, agent α has the value of fun and of comfort. The goal to live downtown promotes the value of fun and the goal to live in a bigger house promotes the value of comfort. In [2] an argument scheme is proposed for practical reasoning in which goals and actions can be justified and attacked by the values they promote and demote. What constitutes a specific value like fun, comfort, justice, or health often is disputable and therefore it is also disputable whether goals and actions promote values. Namely, another agent may find that living downtown demotes the value of fun because of the noise and lack of parking space. However, in [2] it is not possible to explain or discuss what constitutes a value and consequently it is also not possible to justify or attack that a goal or action promotes or demotes a value.

This paper presents an argumentation approach to discuss what constitutes a specific value and its effects on agent's goals and preferences over outcomes. To argue about decisions, an argumentation system is described in Section 2. Since the subject of argumentation is making decisions, some basic notions of decision theory are also described in Section 2. Next, we propose a model to specify the meaning of values and their relation to preferences in Section 3. This model is based on previous work [15] and inspired by techniques from decision theory to find an appropriate multi-attribute utility function [8, 9]. A value is seen as an aspect over which an agent has preferences and can be decomposed into the aspects it contains. Given the meaning of a value, several argument schemes are proposed in Section 4 to justify that goals promote or demote values. The introduced formalism is demonstrated with an example of buying houses in Section 5. The paper is concluded with some discussion and conclusions.

2 Background

In Section 2.1, an argumentation system is described that will be used to argue about what decision is best. Outcomes describe the effects of decisions and attributes describe properties of outcomes. Attributes of outcomes can be used to describe what constitutes a value and to justify goals. To argue about what decision is best, the notions of outcomes and attributes from decision theory are introduced in our argumentation system in Section 2.2.

2.1 Argumentation

Argument schemes are stereotypical patterns of defeasible reasoning [14]. An argument scheme consists of a set of premises, a conclusion, and is associated to a set of critical questions that can be used to critically evaluate the inference. In later sections, argument schemes are proposed to reason about what decision is best.

We introduce an argumentation system to reason defeasibly and in which argument schemes can be expressed. For the largest part, this argumentation system is based on [5]. We will use both defeasible and strict inference rules. The informal reading of a strict inference rule is that if its antecedent holds, then its conclusion holds without exception. The informal reading of a defeasible inference rule is that if its antecedent holds, then its conclusion tends to hold.

Definition 1 (Argumentation System). *An argumentation system is a tuple $\mathcal{AS} = (\mathcal{L}, \mathcal{R})$ with $\mathcal{L}$ the language of first-order logic and $\mathcal{R}$ a set of strict and defeasible inference rules.*

We will use ϕ and ψ as typical elements of $\mathcal{L}$ and say that ϕ and $\neg\phi$ are each other's complements. In the meta-language, $\sim\phi$ denotes the complement of any formula ϕ, positive or negative. Furthermore, $\rightarrow$ denotes the material implication.

Definition 2 (Strict and defeasible rules). *A strict rule is an expression of the form $s(x_1, \ldots, x_n) : \phi_1, \ldots, \phi_m \Rightarrow \phi$ and a defeasible rule is an expression of the form $d(x_1, \ldots, x_n) : \phi_1, \ldots, \phi_m \rightsquigarrow \phi$, with $m \geq 0$ and $x_1, \ldots, x_n$ all variables in $\phi_1, \ldots, \phi_m, \phi$.*

We call $\phi_1, \ldots, \phi_m$ the antecedent, ϕ the conclusion, and both $s(x_1, \ldots, x_n)$ and $d(x_1, \ldots, x_n)$ the identifier of a rule.

Arguments are inference trees constructed from a knowledge-base $\mathcal{K} \subset \mathcal{L}$. If an argument A was constructed using no defeasible inference rules, then A is called a *strict argument*, otherwise A is called a *defeasible argument*.

Example 1. Let $\mathcal{AS} = (\mathcal{L}, \mathcal{R})$ be an argumentation system such that $\mathcal{L} = \{\phi_1, \phi_2, \phi_3\}$ and $\mathcal{R} = \{s() : \phi_1 \Rightarrow \phi_2; d() : \phi_1, \phi_2 \rightsquigarrow \phi_3\}$. From the knowledge-base $\mathcal{K} = \{\phi_1\}$, we can construct 3 arguments. Argument A_1 has conclusion ϕ_1, no premises, and no last applied inference rule. Argument A_2 is constructed by applying $s()$. Consequently, A_2 has premise A_1, conclusion ϕ_2, and last applied inference rule $s()$. Argument A_3 can then be constructed using $d()$ and has premises A_1 and A_2, conclusion ϕ_3, and last applied rule $d()$. Arguments A_1 and

A_2 are strict arguments and argument A_3 is a defeasible argument. A_3 can be visualised as follows:

$$\dfrac{\phi_1 \quad \dfrac{\phi_1}{\phi_2}\, s()}{\phi_3}\, d()$$

All arguments can be attacked by rebutting one of their premises. Defeasible arguments can also be attacked by attacking the application of a defeasible rule. For example, let $d(c_1, \ldots, c_n) : \phi_1, \ldots, \phi_m \rightsquigarrow \phi$ be a defeasible inference rule that was applied in argument A. We can attack A in three ways: by rebutting a premise of A, by rebutting A's conclusion, and by undercutting a defeasible inference rule that was applied in A. The application of a defeasible inference rule can be undercut when there is an exception to the rule. An argument concluding $\sim d(c_1, \ldots, c_n)$ undercuts A.

Following [4], argument schemes are formalised as defeasible inference rules. Critical questions point to counterarguments that either rebut the scheme's premises or undercut the scheme. In Section 3.4, we show how to determine what conclusions are justified given a set of arguments.

2.2 Outcomes And Attributes

The notion of *outcomes* is one of the main notions in decision theory [8, 11] and is used to represent the possible consequences of an agent's decisions. The set Ω of possible outcomes should distinguish all consequences that matter to the agent and are possibly affected by its actions. Agents have preferences over outcomes and decision theory postulates that a rational agent should make the decision that leads to the most preferred expected outcome.

The notion of *attribute* is used to denote a feature, characteristic or property of an outcome. For example, when buying a house, relevant attributes could be price, neighbourhood in which it is located, size, or type of house. An attribute has a domain of 'attribute-values' outcomes can have. Every outcome has exactly one attribute-value of each attribute. It cannot be that an outcome has two attribute-values of the same attribute.

Example 2 (Buying a house). There are 2 houses on the market and buying one of them results in one of the two outcomes $\Omega = \{\omega_1, \omega_2\}$. Consider the attributes 'price', 'size', 'neighbourhood', and whether there is a garden. Price is expressed in dollar and size in m^2. The neighbourhood can either be 'downtown' or 'suburb' and 'yes' represents there is a garden and 'no' that there is not.

Outcome ω_1 has the following attribute-values: price is 150.000, size is 50, neighbourhood is 'suburb' and garden is 'yes'. On the other, outcome ω_2's price is 200.000, size is also 50, neighbourhood is 'downtown' and garden is 'no'.

Each attribute is a term in $\mathcal{L}$ and we use $\mathcal{A}$ to denote the set containing all attributes. If x is an attribute, we will also say x-values instead of the attribute values of attribute x. We define several functions concerning attributes and outcomes.

– The function $\mathsf{domain}(x)$ returns a set of attribute-values that the attribute x can have. For example, let attribute nbhd denote the neighbourhood of a house, then $\mathsf{domain}(\mathsf{nbhd}) = \{\mathsf{downtown}, \mathsf{suburb}\}$ or for the attribute price, $\mathsf{domain}(\mathsf{price}) = \mathbb{R}^+$.
– For each attribute x, the function $\overline{x} : \Omega \rightarrow \mathsf{domain}(x)$ gives the attribute-value of the given outcome for the attribute x. For example, $\overline{price}(\omega_1) = 150.000$.

Example 3. Suppose that $\Omega = \{\omega_1, \omega_2\}$ is true, x is an attribute and $\mathsf{domain}(x) = \{1, 2, 3\}$. In that case, the function $\overline{x}$ returns the following: $\overline{x}(\omega_1) = 3$ and $\overline{x}(\omega_2) = 1$.

3 Justification Of Preferences Over Outcomes

Preferences can be expressed in terms of outcomes, e.g. outcome A is preferred to outcome B. The more aspects are involved, the more difficult it becomes to directly express preferences over outcomes. Luckily, it is also natural to express preferences in terms of attributes of outcomes. For example, maximising the attribute profit is preferred. From such statements, preferences over outcomes can be justified, e.g. outcome A is preferred to outcome B because the A's profit is higher. Typically, outcomes have many attributes, yet agents care only about a subset. What set of attributes an agent cares about determines the preferences over outcomes. Using argumentation, agents can discuss why certain attributes should and others should not be used.

Justification for a preference statement like "agent α prefers living downtown to living in a suburb", is useful to better understand α's preferences. Namely, α could argue that the centrality of a house positively influences the amount of fun of a house and that α wants to maximise fun. If it is better understood why α prefers something, then one could disagree (centrality is not fun because it is very noisy) and give alternatives perspectives (living near nature is also fun and do you not also care about quietness).

In complex situations, the preferences of agents depend on multiple attributes. By decomposing an agent's preferences into the different aspects it involves, the number of attributes an aspect depends on becomes smaller. By recursively decomposing preferences, we will arrive at aspects that depend on a single attribute. For example, an agent α decomposes its preferences concerning houses into the aspects costs and comfort. The perspective of costs is determined by the attribute acquisition price. Comfort however, depends on multiple aspects. Therefore, comfort is decomposed into location and size. Location is then connected to the attribute neighbourhood and size to the surface area of the house. One may argue that α forgets that other aspects also influence costs, e.g. maintenance, taxes, heating costs, and so on. On the other hand, another agent may decompose comfort differently. For example, for agent β comfort is influenced by the closeness to highway and whether there is central heating.

In Section 3.1 we will introduce *perspectives* to represent preferences and aspects of preferences, after which we introduce perspectives on attribute values in Section 3.2. In Section 3.3 we introduce influence between perspective to denote that one perspective is an aspect of another. Finally in Section 3.4, we slightly adapt Value-based Argumentation Frameworks, see [3], to determine what conclusions are justified to make.

3.1 Perspectives

An ordering over outcomes can represent an agent's preferences. In that case, if an outcome is higher in the order, the agent prefers that outcome. Similarly, outcomes can be ordered according to some criterion. For example, outcomes can be ordered by how fun they are, or how fair they are. To talk about these different orderings, we introduce the notion of *perspective*. With buying houses, an outcome may be better than another from the perspective of costs, worse from the perspective of its centrality, indifferent from the perspective of comfort, and perhaps incomparable from the perspective of fun.

Definition 3 (Perspective). *A perspective p is associated with a preorder, $\leq_p$ over outcomes Ω. The set $\mathcal{P}$ denotes the set of all perspectives.*

In other words, a perspective p is associated to a binary relation $\leq_p \subseteq \Omega \times \Omega$ that is transitive and reflexive. If $\omega_1 \leq_p \omega_2$ is true, we say that ω_2 is weakly preferred to ω_1 from perspective p. Strong preference from perspective p is denoted as $\omega_1 <_p \omega_2$ and stands for $\omega_1 \leq_p \omega_2$ and $\omega_2 \not\leq_p \omega_1$. Equivalence from perspective p is denoted as $\omega_1 \approx_p \omega_2$ and stands for $\omega_1 \leq_p \omega_2$ and $\omega_2 \leq_p \omega_1$.

Each agent α is associated with a perspective $\hat{\alpha}$ representing α's preferences over outcomes. If $\omega_1 <_{\hat{\alpha}} \omega_2$ is true, then we either say that ω_2 is preferred to ω_1 from agent α's perspective, or we say that α prefers ω_2 to ω_1. Since perspectives are the main notion in this paper, $\hat{\alpha}$ is abbreviated to α, so that α denotes a perspective.

Not only the preferences of agents can be represented with perspectives, we will also use perspectives to represent aspects of outcomes and the values of agents. For example, the value of 'safety' is represented with a perspective that orders outcomes according to how safe they are or the aspect of comfort is represented with a perspective that orders outcomes by the amount of comfort.

Example 4. Agent α wants to buy a new house and wants to minimise costs, maximise fun and maximise comfort. In Figure 1a, we sketch how the preferences of agent α can be decomposed and how attributes of outcomes can be assigned. Costs are determined by the attribute acquisition price. Fun is influenced by the centrality of the house, i.e. the more central the neighbourhood, the more fun it is. Comfort is influenced by how quiet it is and the size of the house. Again, the attribute neighbourhood is ordered but now by how quiet the neighbourhood is. The size is determined by the surface area of the house.

Agent β just won the lottery and does not care about costs. To β fun is being close to nature, which is completely different from α's idea about fun. Also, because β has a car and α does not, β cares about whether there is enough parking space in the area. Figure 1b sketches the decomposition of β's preferences.

(a) α's preferences (b) β's preferences

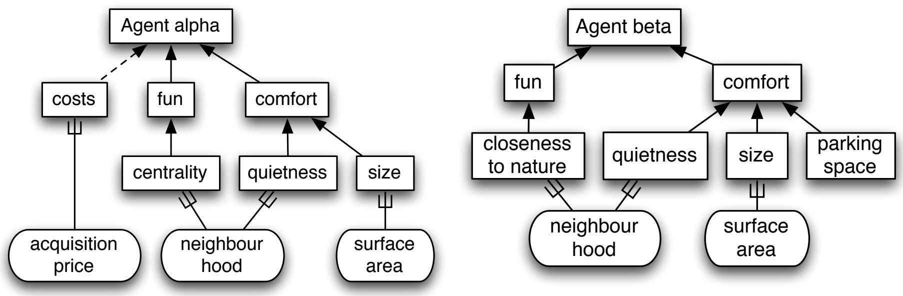

Fig. 1: Different Perspectives Using Different Attributes

3.2 Attributes Determine Perspectives

Attributes can be used to determine how outcomes should be ordered from a perspective. For example, if you want to order houses from the perspective of size, then the attribute 'surface area of the house' is an appropriate attribute. In that case, if house A has a higher surface area than house B, then A is preferred to B from the perspective of size. To use an attribute x to determine a perspective, x's attribute values need to be ordered.

Definition 4 (Attribute Perspective). *An* attribute perspective p_x *is a perspective that is associated with a partial preorder* $\preceq^p_x$ *over the domain of attribute* x*.*

Note that there can be different attribute perspectives on the same attribute.

Example 5. Let the attribute nbhd denote the neighbourhood of the house with $\mathsf{domain}(\mathsf{nbhd}) = \{\mathsf{dwntwn}, \mathsf{vllg}, \mathsf{sbrb}\}$. Furthermore, let $\mathsf{social}_{\mathsf{nbhd}}$ and $\mathsf{quiet}_{\mathsf{nbhd}}$ be attribute perspectives denoting the sociableness and the quietness of the neighbourhood respectively. The different neighbourhoods are preferred from each attribute perspective as follows:

$$\mathsf{sbrb} \prec^{\mathsf{social}}_{\mathsf{nbhd}} \mathsf{vllg} \prec^{\mathsf{social}}_{\mathsf{nbhd}} \mathsf{dwntwn} \qquad\qquad \mathsf{dwntwn} \prec^{\mathsf{quiet}}_{\mathsf{nbhd}} \mathsf{sbrb} \prec^{\mathsf{quiet}}_{\mathsf{nbhd}} \mathsf{vllg}$$

If an attribute value is preferred to another attribute value from p_x, then outcomes with the preferred attribute value are be preferred from p_x. This order between outcomes from an attribute perspective p_x can be inferred with the following strict inference rule.

$$s_{ap}(p_x, \omega_1, \omega_2) : \overline{x}(\omega_1) \prec^p_x \overline{x}(\omega_2) \Rightarrow \omega_1 <_{p_x} \omega_2$$

Example 6. Consider the attributes and attributes perspectives from the previous example. Let there be two outcomes ω_1 and ω_2 such that $\overline{\mathsf{nbhd}}(\omega_1) = \mathsf{dwntwn}$

and $\overline{\mathsf{nbhd}}(\omega_2) = \mathsf{vllg}$. To determine the order between ω_1 from perspective $\mathsf{social_{nbhd}}$ and from perspective $\mathsf{quiet_{nbhd}}$, the following two arguments can be constructed.

$$\frac{\overline{\mathsf{nbhd}}(\omega_2) \prec^{\mathsf{social}}_{\mathsf{nbhd}} \overline{\mathsf{nbhd}}(\omega_1)}{\omega_2 <_{\mathsf{social_{nbhd}}} \omega_1}\ s_{ap} \qquad \frac{\overline{\mathsf{nbhd}}(\omega_1) \prec^{\mathsf{quiet}}_{\mathsf{nbhd}} \overline{\mathsf{nbhd}}(\omega_2)}{\omega_1 <_{\mathsf{quiet_{nbhd}}} \omega_2}\ s_{ap}$$

3.3 Influence Between Perspectives

Some perspectives involve different aspects such that not one attribute can be assigned. For example, the perspective comfort of a house may involve size, location, the type of heating, and so on. In general, the more abstract a perspective is, the more aspects it has. Furthermore, the more abstract a perspective, the more disputable it may be. Thus it becomes important to specify all the different aspects so that one can communicate clearly.

By decomposing an abstract perspective into several more concrete perspectives, one makes explicit what an abstract perspective means and makes it easier to assign attributes to. For example, although α may not be able to express its preferences over houses, α does want to minimise costs, maximise comfort, and maximise fun. These perspectives may be decomposed further, e.g. fun means maximising the centrality of the house, until an attribute can be assigned.

To decompose a perspective into other perspectives, we introduce two relations between perspectives in $\mathcal{L}$ to denote 'influence' between perspectives:

- the binary relation $\uparrow \subseteq \mathcal{P} \times \mathcal{P}$ is written as $p \uparrow q$ and denotes that perspective p *positively influences* perspective q.
- the binary relation $\downarrow \subseteq \mathcal{P} \times \mathcal{P}$ is written as $p \downarrow q$ and denotes that perspective p *negatively influences* perspective q.

If perspective p positively influences perspective q, then outcomes that are better from perspective p tend to be better from perspective q. In other words, if an outcome is better from p and p positively influences q, then this is a reason to believe that the outcome is better from q. For example, the size of a house positively influences the comfort of the house, i.e. the more size, the more comfort.

The following argument scheme reasons with influence: *outcome ω_2 is preferred to ω_1 from p and p positively influences q, therefore ω_2 is preferred to ω_1 from q*. In other words, if a perspective p positively influences perspective q, then an outcome being preferred from p is a reason to believe that that outcome is also preferred from q. We formalise this argument scheme with the following defeasible inference rule:

$$d_{<,\uparrow}(p, q, \omega_1, \omega_2) : \omega_1 <_p \omega_2, p \uparrow q \rightsquigarrow \omega_1 <_q \omega_2$$

The argument scheme to propagate negative influence is similar, except that if a perspective p negatively influences perspective q, then outcomes that are better from perspective p tend to be worse from perspective q. For example, costs negatively influences agent α's preferences, i.e. the more costs, the less preferable for α. This argument scheme is formalised with the following defeasible inference rule:

$$d_{<,\downarrow}(p, q, \omega_1, \omega_2) : \omega_1 <_p \omega_2, p \downarrow q \rightsquigarrow \omega_2 <_q \omega_1$$

Using these inference rules, arguments can be constructed to justify preferences over outcomes using both positive influence and negative influence between perspectives.

Example 7. Agent α wants to buy a new house and to minimise costs, i.e. $\mathsf{costs} \downarrow \alpha$ is true. There are two outcomes, ω_1 and ω_2, such that the acquisition price, denoted attribute acq, of ω_1 is \$200k and of ω_2 \$150k. The acquisition price of a house positively influences the costs, so $\mathsf{costs_{acq}} \uparrow \mathsf{costs}$ is true.

$$\cfrac{\mathsf{costs} \downarrow \alpha \qquad \cfrac{\mathsf{costs_{acq}} \uparrow \mathsf{costs} \qquad \cfrac{\overline{\mathsf{acq}}(\omega_2) \prec^{\mathsf{costs}}_{\mathsf{acq}} \overline{\mathsf{acq}}(\omega_1)}{\omega_2 <_{\mathsf{costs_{acq}}} \omega_1}\, s_{ap}}{\omega_2 <_{\mathsf{costs}} \omega_1}\, d_{<,\uparrow}}{\omega_1 <_\alpha \omega_2}\, d_{<,\downarrow}$$

The relation $\uparrow$ is irreflexive and transitive, meaning that $p \uparrow p$ is never true and that if $p \uparrow q$ and $q \uparrow r$ are true, then $p \uparrow r$ is true. If $p \uparrow p$ would be true and for any two outcomes $\omega_1 <_p \omega_2$ is true, then we can defeasibly infer that $\omega_1 <_p \omega_2$ is true using inference rule $d_{<,\uparrow}$. Such an argument concludes one of its premises, which is useless. Furthermore, if $p \uparrow p$ can be true, then this may cause infinite loops in implementations. For this reason, the relation $\uparrow$ is irreflexive.

The relation $\uparrow$ should be transitive. Firstly, this is intuitive. For example, let the location of a house positively influence the fun of that house and let the fun of a house positively influence agent α's preferences. Then we can also say that the location of a house positively influences α's preferences. Secondly, this leads to inferences we could already infer. Namely, if $p \uparrow q$, $q \uparrow r$ and $\omega_1 <_p \omega_2$ are true, then we can defeasibly infer that $\omega_1 <_q \omega_2$ is true. Similarly, $\omega_1 <_r \omega_2$ can be defeasibly inferred from $q \uparrow r$ and $\omega_1 <_q \omega_2$. If $\uparrow$ is transitive, then $p \uparrow r$ is also true. From $p \uparrow r$ and $\omega_1 <_p \omega_2$ we can defeasibly infer that $\omega_1 <_r \omega_2$ is true.

The relation $\downarrow$ is irreflexive and antitransitive, meaning that $p \downarrow p$ is not allowed and that if $p \downarrow q$ and $q \downarrow r$ are true, then $p \downarrow r$ is not true. If for some perspective p it would be true that $p \downarrow p$ and for any two outcomes $\omega_1 <_p \omega_2$ is true, then the following argument A can be constructed.

$$A = \cfrac{p \downarrow p \quad \omega_1 <_p \omega_2}{\omega_2 <_p \omega_1}\, d_{<,\downarrow}$$

The conclusion of A conflicts with A's premise $\omega_1 <_p \omega_2$. Consequently, A attacks itself. Allowing $p \downarrow p$ to be true adds nothing useful and can only result in contradictions. Therefore, the relation $\downarrow$ is irreflexive.

The relation $\downarrow$ should be antitransitive. Firstly, this is intuitive. For example, the amount of discount on a house negatively influences the costs of that house (the more discount the less costs) and the costs of a house negatively influences agent α's preferences. Then we can also say that the amount of discount does not negatively influence α's preferences. Secondly, if $\downarrow$ could be transitive, then this could lead to false inferences. Let $p \downarrow q$, $q \downarrow r$ and $\omega_1 <_p \omega_2$ be true. From $p \downarrow q$ and $\omega_1 <_p \omega_2$ we can infer that $\omega_2 <_q \omega_1$ is true and from $\omega_2 <_q \omega_1$ and $q \downarrow r$ we can infer that $\omega_1 <_r \omega_2$ is true. If $p \downarrow r$ would be true, then we could infer that $\omega_2 <_r \omega_1$ is true, which conflicts with $\omega_1 <_r \omega_2$.

3.4 Argumentation Framework

Argumentation Frameworks (AF) were introduced by [6] and provide a formal means to determine what arguments are justified given a set of arguments and a set of attack relations between them. In [3], Value-based Argumentation Frameworks (VAF), an extension of AFs, were introduced.

Our definition of a Perspective-based Argumentation Framework (PerspAF) is largely based on the definition of a VAF (because of space limitations, we refer the reader to [3] for details of VAFs).

Definition 5. *A PerspAF is defined by a tuple* $\langle \mathsf{Args}, R, \mathcal{P}, \eta \rangle$*, where* Args *is the set of all arguments, R the attack relations between arguments,* $\mathcal{P} = \{p_1, p_2, \ldots, p_k\}$ *a set of k perspectives, and* $\eta : \mathsf{Args} \rightarrow 2^{\mathcal{P}}$ *a mapping that associates a set of perspectives with each argument in* Args*. A total ordering* $\trianglelefteq_\alpha$ *of* $\mathcal{P}$ *is associated to each agent* α *for a PerspAF* $\langle \mathsf{Args}, R, \mathcal{P}, \eta \rangle$*.*

In PerspAFs, arguments may use multiple perspectives, whereas arguments can only use a single value in VAFs. To determine whether an attack between argument A and B is successful, only the perspectives are used that A and B do not use both.

The following concepts are related to PerspAFs and are identical to the concepts of VAFs except for when an argument defeats or successfully attacks another argument for a specific audience. Let $\langle \mathsf{Args}, R, \mathcal{P}, \eta \rangle$ be a PerspAF and α an agent.

- argument A α-*defeats* argument B if $(A, B) \in R$ and if there is no perspective $p \in \eta(B) \setminus \eta(A)$ such that $q \lhd_\alpha p$ for each $q \in \eta(A) \setminus \eta(B)$.
- argument A is α-acceptable to the set of arguments $S \subseteq \mathsf{Args}$ if: for every $B \in \mathsf{Args}$ that successfully α-attacks A, there is some $C \in S$ that successfully α-attacks B
- a set $S \subseteq \mathsf{Args}$ is α-conflict-free if: for each $\langle A, B \rangle \in S \times S$, either $\langle A, B \rangle \notin R$ or $\eta(A) \lhd_\alpha \eta(B)$
- a set $S \subseteq X$ is α-admissible if: S is α-conflict-free and every $A \in S$ is α-acceptable to S
- a set is a preferred extension for α if it is maximal α-admissible set

Example 8. Let $\mathcal{P} = \{\mathsf{fun}, \mathsf{comfort}, \alpha\}$ and let audience α order these perspectives as follows: $\mathsf{comfort} \lhd_\alpha \mathsf{fun} \lhd_\alpha \alpha$. Consider the following two arguments:

$$A_f = \frac{\mathsf{fun} \uparrow \alpha \quad \omega_1 <_{\mathsf{fun}} \omega_2}{\omega_1 <_\alpha \omega_2} \qquad A_c = \frac{\mathsf{fun} \uparrow \alpha \quad \omega_2 <_{\mathsf{comfort}} \omega_1}{\omega_2 <_\alpha \omega_1}$$

Let $\langle H(\{A_f, A_c\}, R), \mathcal{P}, \eta\rangle$ be a PerspAF. The conclusions of both arguments conflict, and thus they attack each other and $R = \{(A_f, A_c), (A_c, A_f)\}$. Since argument A_f uses the perspectives α and fun, $\eta(A_f) = \{\alpha, \mathsf{fun}\}$. Similarly, $\eta(A_c) = \{\alpha, \mathsf{comfort}\}$. Consequently, $\eta(A_f) \setminus \eta(A_c) = \{\mathsf{fun}\}$ and $\eta(A_c) \setminus \eta(A_f) = \{\mathsf{comfort}\}$.

Argument A_c does not α-defeat A_f because A_f uses the perspective fun, not used by A_c, and fun is preferred to $\mathsf{comfort}$. On the other hand, argument A_f α-defeats A_c because $(A_f, A_c) \in R$ and there is no perspective used by A_c that is both not used in A_f and is preferred to every perspective in A_f not used in A_c. The set $\{A_f\}$ is the preferred extension for α.

4 Justification Of Goals

In this section, we propose how an agent α can justify having a goal given α's preferences. In [13], Simon views goals as threshold aspiration levels that signal satisfactory of utility. A goal thus does not have to be optimal. Following [16], we see goals as expressions of the desirability of attribute values of a single attribute signaling that these attribute values are 'satisfactory'. For example, an agent may have the goal to live in a house that is located downtown. This expresses that the attribute value 'downtown' of the attribute 'location' is satisfactory to that agent. Another attribute value, e.g. 'suburb', does not achieve that goal and is thus not satisfactory.

The predicate $\mathsf{goal}(\alpha, x, G)$ is introduced in $\mathcal{L}$ and denotes that agent α should have the goal to achieve an outcome that has an x-value in $G \subset \mathsf{domain}(x)$. If agent α has the goal to achieve an x-value in G (i.e. $\mathsf{goal}(\alpha, x, G)$ is true) and outcome ω_1 has an x-value in G, i.e. $\overline{x}(\omega_1) \in G$ is true, then we say that goal $\mathsf{goal}(\alpha, x, G)$ is achieved in outcome ω_1. Consequently, a subset of Ω achieves a goal and the other outcomes in Ω do not achieve that goal.

4.1 Justification Is Subjective

What justification for a goal an agent accepts, depends on the type of agent. For example, a very ambitious but realistic agent only accepts goals that aim for the best achievable x-value, whereas a less ambitious agent may accept goals that just improves the current situation or does better than doing nothing. Another agent may set its standard on a value that is realistic and challenging, i.e. not too easy and not too difficult.

We introduce two argument schemes to distinguish between satisficing goals and optimising goals. The following argument scheme justifies the goal to achieve an x-value that is the best possible. The basis for this justification is that agents should aim to achieve their maximal potential.

> *Agent α wants to maximise attribute x-values from perspective p_x,*
> *v is most preferred x-value from p_x that is achievable,*
> *therefore, α pursues the goal to achieve x-values of v or better from p_x*

If the predicates $\max(\alpha, p_x, v)$ and $\min(\alpha, p_x, v)$ denote that v is the maximal / minimal x-value from p_x that α can achieve, then the optimistic goal argument scheme can be modelled with the following defeasible inference rules:

$$d_{\mathsf{optm},\uparrow}(\alpha, p_x, v) : p_x \uparrow \alpha, \max(\alpha, v, p_x) \rightsquigarrow \mathsf{goal}(\alpha, x, \{g \in \mathsf{domain}(x) \mid v \preceq^p_x g\})$$
$$d_{\mathsf{optm},\downarrow}(\alpha, p_x, v) : p_x \downarrow \alpha, \min(\alpha, v, p_x) \rightsquigarrow \mathsf{goal}(\alpha, x, \{g \in \mathsf{domain}(x) \mid g \preceq^p_x v\})$$

A possible undercutter of the optimistic argument scheme is that achieving the goal is too unlikely. Therefore, the agent should adopt the goal to achieve an easier x-value. Another undercutter would be that achieving v is too costly and that α does not care that much about p_x.

The following argument scheme justifies a goal in a satisficing manner. This scheme's underlying motivation is that agents should adopt goals that achieve outcomes that are satisfactory rather than the best outcome.

Agent α wants to maximise attribute x-values from perspective p_x,
v is a satisfactory and achievable x-value for α,
therefore, α pursues the goal to achieve x-values of v or better from p_x

A possible undercutter for the satisficing argument scheme is that it is too easy and that the agent should adopt a more challenging goal. Another undercutter could be that the perspective p_x is important to α and therefore α should set a higher goal.

Let the predicate $\mathsf{satisf}(\alpha, x, v)$ denote that x-value v is satisfactory for agent α. Then this argument scheme can be modelled with the following defeasible inference rule.

$$d_{\mathsf{satisf},\uparrow}(\alpha, p_x, v) : p_x \uparrow \alpha, \mathsf{satisf}(\alpha, x, v) \rightsquigarrow \mathsf{goal}(\alpha, x, \{g \in \mathsf{domain}(x) \mid v \preceq^p_x g\})$$
$$d_{\mathsf{satisf},\downarrow}(\alpha, p_x, v) : p_x \downarrow \alpha, \mathsf{satisf}(\alpha, x, v) \rightsquigarrow \mathsf{goal}(\alpha, x, \{g \in \mathsf{domain}(x) \mid g \preceq^p_x v\})$$

This only solves part of the problem because how can an agent justify that an attribute value is satisfactory? We can think of several justifications of a satisfaction level: anything better than the current situation is satisfactory, it is better than some standard action such as 'do nothing', it is better than what other agents achieve, or the agent is obliged to achieve at least v. This is however still an open issue that is left for future work.

4.2 Priorities Of Goals

In our PerspAFs, agents have a total ordering over perspectives that represents what perspective they find most important. This information can be used to give goals priorities. Namely, if α has goal G because of perspective p_x and goal H because of perspective q_y and α finds p_x more important than q_y, i.e. $q_y \lhd_\alpha p_x$, then goal H is more important to α.

Goals are created using an attribute perspective that influences an agent. For the same attribute perspective, optimistic goals are stricter than satisficer goals since they do not include satisfactory attribute values upon which the agent can improve. For this reason, achieving an optimistic goal should have a higher priority than achieving a satisficer goal for the same attribute perspective.

5 Buying A House

Agent α, who lives in a suburb, recently got a raise in income and wants to buy a new house to live in. The broker shows two houses that are for sale, one in a village and one downtown, represented with outcomes ω_v and ω_d respectively. Of course, α has the possibility not to buy a new house and stay in its current house. This is represented with outcome ω_0. Consequently, $\Omega = \{\omega_0, \omega_d, \omega_v\}$. Except for its own house, α is unfamiliar with these houses and can therefore not express whether it prefers one of the new houses to its own house.

The broker includes the following attributes of each house: the neighbourhood, the size, and the acquisition price. The attribute nbhd denotes the neighbourhood of the house and $\mathsf{domain}(\mathsf{nbhd}) = \{\mathsf{dwntwn}, \mathsf{sbrb}, \mathsf{vllg}\}$. The attribute area denotes how big the house is in square meters. Consequently, $\mathsf{domain}(\mathsf{area}) = \mathbb{R}^+$. The attribute acq denotes the price of the acquisition of the house and $\mathsf{domain}(\mathsf{acq}) = \mathbb{R}^+$. The set of all attributes is the following: $\mathcal{A} = \{\mathsf{nbhd}, \mathsf{area}, \mathsf{acq}\}$. The attribute values for each outcome can be found in Table 1.

Table 1: Attribute Values Of Outcomes

Attribute	Domain	ω_0	ω_d	ω_v
nbhd	{dwntwn, sbrb, vllg}	sbrb	dwntwn	vllg
area	$\mathbb{R}^+$ in m^2	60	50	100
acq	$\mathbb{R}^+$ in \$1000	0	220	190

5.1 Decomposing Perspectives

Agent α starts reasoning about its preferences over Ω by expressing what aspects it finds important. Namely, α wants to minimise costs, maximise fun and maximise comfort. By doing so, α's perspective is decomposed into other perspectives that are more concrete. Because α wants to minimise costs, the perspective costs negatively influences the perspective of α, i.e. $\mathsf{costs}\downarrow\alpha$ is true. Also, α wants to maximise fun and comfort, so $\mathsf{fun}\uparrow\alpha$ and $\mathsf{comfort}\uparrow\alpha$ are true.

Agent α figures that the acquisition price attribute is appropriate to determine the perspective of costs such that the higher the acquisition price, the higher the costs. The attribute perspective $\mathsf{costs}_{\mathsf{acq}}$ prefers an acq-value if it is higher. Therefore, $\mathsf{costs}_{\mathsf{acq}}\uparrow\mathsf{costs}$ is true.

For α fun means having people around him. The centrality of a house positively influences fun since α is more likely to out for dinner or drinks with his friends. Therefore, α decomposes the perspective fun into the perspective of the centrality of the neighbourhood, denoted with the attribute perspective $\mathsf{cntrl}_{\mathsf{nbhd}}$ on the attribute nbhd. Consequently, $\mathsf{cntrl}_{\mathsf{nbhd}}\uparrow\mathsf{fun}$ is true.

There is however no attribute that α finds adequate to determine the perspective of comfort. Therefore, comfort is decomposed into the quietness around the house and its size. Size is measured by the attribute perspective $\mathsf{size}_{\mathsf{area}}$ that orders the attribute area (denoting the surface area in m^2) according to size. The attribute perspective $\mathsf{quiet}_{\mathsf{nbhd}}$ orders neighbourhoods by their quietness. Both attributes positively influence comfort, i.e. $\mathsf{size}_{\mathsf{area}} \uparrow \mathsf{comfort}$ and $\mathsf{quiet}_{\mathsf{nbhd}} \uparrow \mathsf{comfort}$ are true.

The attribute perspectives $\mathsf{cntrl}_{\mathsf{nbhd}}$ and $\mathsf{quiet}_{\mathsf{nbhd}}$ both order the attribute values of the attribute 'neighbourhood' and are as follows:

$$\mathsf{sbrb} \prec^{\mathsf{cntrl}}_{\mathsf{nbhd}} \mathsf{vllg} \prec^{\mathsf{cntrl}}_{\mathsf{nbhd}} \mathsf{dwntwn} \qquad\qquad \mathsf{dwntwn} \prec^{\mathsf{quiet}}_{\mathsf{nbhd}} \mathsf{sbrb} \prec^{\mathsf{quiet}}_{\mathsf{nbhd}} \mathsf{vllg}$$

5.2 Arguments About Preference

Now, α starts constructing arguments concerning its preferences over houses. The following argument concludes that α should prefer staying in its house, outcome ω_0, to buying the house downtown, ω_d, because the costs of not buying are lower.

$$A_{\mathsf{costs}} = \cfrac{\mathsf{costs} \downarrow \alpha \qquad \cfrac{\overline{\mathsf{acq}}(\omega_0) \prec^{\mathsf{costs}}_{\mathsf{acq}} \overline{\mathsf{acq}}(\omega_d)}{\omega_0 <_{\mathsf{costs}_{\mathsf{acq}}} \omega_d}\ s_{ap}}{\omega_d <_\alpha \omega_0}\ d_{\downarrow,<}$$

However, the following argument concludes that α should prefer ω_d, which conflicts with A_{costs}'s conclusion, because ω_d is more fun since it is located in a more central neighbourhood.

$$A_{\mathsf{fun}} = \cfrac{\mathsf{fun} \uparrow \alpha \qquad \cfrac{\mathsf{cntrl}_{\mathsf{nbhd}} \uparrow \mathsf{fun} \qquad \cfrac{\overline{\mathsf{nbhd}}(\omega_0) \prec^{\mathsf{cntrl}}_{\mathsf{nbhd}} \overline{\mathsf{nbhd}}(\omega_d)}{\omega_0 <_{\mathsf{cntrl}_{\mathsf{nbhd}}} \omega_d}\ s_{ap}}{\omega_0 <_{\mathsf{fun}} \omega_d}\ d_{\uparrow,<}}{\omega_0 <_\alpha \omega_d}\ d_{\uparrow,<}$$

Agent α keeps thinking and comes up with the following argument that concludes that its current house is actually more comfortable since it is in a neighbourhood that is more quiet.

$$A_{\mathsf{comfort}} = \cfrac{\mathsf{comfort} \uparrow \alpha \qquad \cfrac{\mathsf{quiet}_{\mathsf{nbhd}} \uparrow \mathsf{comfort} \qquad \cfrac{\overline{\mathsf{nbhd}}(\omega_d) \prec^{\mathsf{quiet}}_{\mathsf{nbhd}} \overline{\mathsf{nbhd}}(\omega_0)}{\omega_d <_{\mathsf{quiet}_{\mathsf{nbhd}}} \omega_0}\ s_{ap}}{\omega_d <_{\mathsf{comfort}} \omega_0}\ d_{\uparrow,<}}{\omega_d <_\alpha \omega_0}\ d_{\uparrow,<}$$

Given these three arguments, we want to determine what conclusions are justified. For this we construct the PerspAF $\langle H(\mathsf{Args}, R), \mathcal{P}, \eta\rangle$, with:

$$\begin{aligned}
\mathsf{Args} &= \{A_{\mathsf{costs}}, A_{\mathsf{fun}}, A_{\mathsf{comfort}}\}\\
R &= \{(A_{\mathsf{costs}}, A_{\mathsf{fun}}), (A_{\mathsf{fun}}, A_{\mathsf{costs}}), (A_{\mathsf{comfort}}, A_{\mathsf{fun}}), (A_{\mathsf{fun}}, A_{\mathsf{comfort}})\}\\
\mathcal{P} &= \{\alpha, \mathsf{fun}, \mathsf{comfort}, \mathsf{costs}, \mathsf{quiet}_{\mathsf{nbhd}}, \mathsf{cntrl}_{\mathsf{nbhd}}, \mathsf{costs}_{\mathsf{acq}}, \mathsf{size}_{\mathsf{area}}\}
\end{aligned}$$

and function η, that maps an argument to the perspectives it contains, is as follows.

$$\eta(A_{\mathsf{costs}}) = \{\alpha, \mathsf{costs}, \mathsf{costs}_{\mathsf{acq}}\}$$
$$\eta(A_{\mathsf{fun}}) = \{\alpha, \mathsf{fun}, \mathsf{cntrl}_{\mathsf{nbhd}}\}$$
$$\eta(A_{\mathsf{comfort}}) = \{\alpha, \mathsf{comfort}, \mathsf{quiet}_{\mathsf{nbhd}}\}$$

Let α find fun more important than comfort and costs more important than fun, i.e. $\mathsf{comfort} \lhd_\alpha \mathsf{fun}$ and $\mathsf{fun} \lhd_\alpha \mathsf{costs}$ are true. Then A_{fun} α-defeats A_{comfort} and A_{costs} α-defeats A_{fun}. Then the set $\{A_{\mathsf{comfort}}, A_{\mathsf{costs}}\}$ is the preferred extension, so the conclusion that α prefers staying in its current house to buying a house downtown is justified.

5.3 Goals

If α will also visit other brokers and thus considers more houses, it can be computationally efficient for α to generate a number of goals that can easily be checked when evaluating a new house. Given a number of goals, evaluating an outcome involves checking whether its attribute values are in the goals. If no goals are used, then evaluating an outcome involves constructing arguments for all relevant perspectives to check whether it is better than some other outcome(s).

The current house of α is $60m^2$, i.e. $\overline{\mathsf{area}}(\omega_0) = 60$, and α finds this size satisfactory. Since α does not feel very strongly about the size of its house, α uses the satisfycing argument scheme to justify the following goal.

$$\frac{\mathsf{size}_{\mathsf{area}} \uparrow \alpha \quad \mathsf{satisf}(\alpha, \mathsf{area}, 60)}{\mathsf{goal}(\alpha, \mathsf{area}, \{g \in \mathsf{domain}(\mathsf{area}) \mid g \geq 60\})}\ d_{\mathsf{satisf}}$$

With its new job, α can maximally lend 200 thousand dollar for the acquisition of a house and therefore α sets its aspiration level for the acquisition on 200. Given this information, α justifies having the following goal:

$$\frac{\mathsf{costs}_{\mathsf{acq}} \downarrow \alpha \quad \mathsf{satisf}(\alpha, \mathsf{acq}, 200)}{\mathsf{goal}(\alpha, \mathsf{acq}, \{g \in \mathsf{domain}(\mathsf{acq}) \mid g \leq 200\})}\ d_{\mathsf{satisf}}$$

The current house of α is in a suburb and α wants to maximise neighbourhood with respect to both centrality and quietness, i.e. $\mathsf{cntrl}_{\mathsf{nbhd}} \uparrow \alpha$ and $\mathsf{quiet}_{\mathsf{nbhd}} \uparrow \alpha$ are true. Agent α cares a lot about the centrality of its house and less about its quietness. Therefore, α uses the optimising argument scheme to justify its goal to live downtown:

$$\frac{\mathsf{cntrl}_{\mathsf{nbhd}} \uparrow \alpha \quad \max(\alpha, \mathsf{dwntwn}, \mathsf{cntrl}_{\mathsf{nbhd}})}{\mathsf{goal}(\alpha, \mathsf{nbhd}, \{\mathsf{dwntwn}\})}\ d_{\mathsf{optim}}$$

About the quietness α cares less and therefore uses the satisfycing argument scheme:

$$\frac{\mathsf{quiet}_{\mathsf{nbhd}} \uparrow \alpha \quad \mathsf{satisf}(\alpha, \mathsf{nbhd}, \mathsf{sbrb})}{\mathsf{goal}(\alpha, \mathsf{nbhd}, \{\mathsf{sbrb}, \mathsf{vllg}\})}$$

It is impossible for α to achieve both goals. However, α finds costs more important than fun and fun more important than comfort. Consequently, α finds the goal to live downtown more important than the goal to live in a quiet suburb.

6 Discussion

6.1 Outcomes Compared To States

In [3, 2], states are used to reason about decisions over actions, rather than outcomes. A state is a truth assignment to a set of propositions. In a state r, an agent can perform an action a, which results in another state s. If the agent performs a, there is a state transition from state r to state s.

In decision theory, making a decision results in an outcome. Outcomes represent all possible consequences of a decision. Outcomes can represent the state resulting from the action performed, effects in the far future, how pleasant the action was, and possibly the history of all preceding states. An outcome is thus a more general notion than a state, because outcomes can contain all information in states and even more.

6.2 Values Versus Perspectives

In [2], there is a valuation function δ that takes a state transition and a value and returns whether that state transition either promotes, demotes, or is neutral towards that value. More specifically, $\delta : S \times S \times V \to \{+, -, 0\}$ with S the set of states and V the set of values. Note that a state transition either promotes, demotes, or is neutral towards a value resembles Simon's simple valuation function, which values an outcome either as 'satisfactory', 'indifferent' or 'unsatisfactory'.

The valuation function must be specified for all state transitions and all values, which can become time consuming when the number of states or values increases. Namely, if there are n states and m values, then the valuation function must be specified for $m \cdot n^2$ different inputs. Furthermore, if two agents disagree about whether a state transition is promotes a value, e.g. whether performing an action promotes the value of fun, then they can only explain that that is the outcome of their valuation function. Since values typically are abstract, it is important to explain and discuss what a value means. This is not possible in the approach of [2].

In our approach, a value is represented with a perspective, which is associated with an ordering over outcomes. A perspective can be decomposed into other perspectives and a perspective can be associated with an attribute of outcomes. This allows agents to explain and argue why a transition or goal promotes one of their values. For example, an agent can explain that its value of 'fun' means maximising spending time with friends and minimising time at work. whereas another agent can then explain that to him fun means spending time in nature and accomplishing things at work.

Furthermore, decomposing an abstract perspective into more specific perspectives for which an ordering is more easy to specify, makes it less demanding to specify whether a transition promotes, demotes or is neutral towards a value.

If a perspective p represents a value, then its associated ordering $\leq_p$ can be used to the define the valuation function δ for p in the following way

$$\delta(q_1, q_2, v) = \begin{cases} + & \text{if } q_1 <_v q_2 \\ - & \text{if } q_2 <_v q_1 \\ 0 & \text{if } q_1 \equiv_v q_2 \end{cases}$$

If $\leq_v$ is a total order, i.e. no elements are incomparable, then δ is a normal function, otherwise δ is a partial function.

7 Conclusion

In this paper we have proposed several argument schemes to argue about what decision is best for an agent based on its preferences over outcomes. An agent's preferences are expressed in terms of values and goals and we propose a model to represent what a value means and how it affects an agent's preferences. If the meaning of a value is clear, goals can be justified or attacked by arguing that they promote or demote a value.

We represent values as perspectives over outcomes. By recursively decomposing the different aspects of a perspective into other perspectives until they are decomposed in attribute perspectives, the meaning of a perspective and thus a value is made explicit. In this way, an agent can explain what a value exactly means to him, which allows other agents to argue that some aspect is wrong or forgotten or that the wrong attribute is used. Agents can justify pursuing a goal using the perspectives that are important to an agent and the attributes that are associated to those perspectives. We have discussed a satisficing and a optimistic argument scheme to justify a goal. Furthermore, priorities between goals can be justified using the priorities agents have over perspectives.

In future work, the relation between values and goals may be explored further. Different agent types and different situations may lead to pursuing different goals. An optimistic goal may be undercut by stating that it is too hard to achieve, but when is a goal too hard to achieve? Moreover, how can an agent justify that an attribute value is satisfactory and how is that influenced by circumstances?

When an agent finds costs more important than the centrality of the neighbourhood, and a house in a suburb is \$1 cheaper than a house downtown, then the costs argument is stronger than the centrality argument. By extending the formalism in this paper with 'distances' between attribute values, such weird results might be solved.

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