An argumentation-based approach to multiple criteria decision

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Abstract. The paper presents a first tentative work that investigates the interest and the questions raised by the introduction of argumentation capabilities in multiple criteria decision-making. Emphasizing the positive and the negative aspects of possible choices, by means of arguments in favor or against them is valuable to the user of a decision-support system. In agreement with the symbolic character of arguments, the proposed approach remains qualitative in nature and uses a bipolar scale for the assessment of criteria. The paper formalises a multicriteria decision problem within a logical argumentation system. An illustrative example is provided. Various decision principles are considered, whose psychological validity is assessed by an experimental study.

Keywords: Argumentation; multiple-criteria decision, qualitative scales.

1 Introduction

Humans use arguments for supporting claims e.g. [5] or decisions. Indeed, they explain past choices or evaluate potential choices by means of arguments. Each potential choice has usually pros and cons of various strengths. Adopting such an approach in a decision support system would have some obvious benefits. On one hand, not only would the user be provided with a “good” choice, but also with the reasons underlying this recommendation, in a format that is easy to grasp. On the other hand, argumentation-based decision making is more akin with the way humans deliberate and finally make a choice. Indeed, the idea of basing decisions on arguments pro and cons is very old and was already somewhat formally stated by Benjamin Franklin [10] more than two hundreds years ago.

Until recently, there has been almost no attempt at formalizing this idea if we except works by Fox and Parsons [9], Fox and Das [8], Bonnet and Geffner [3] and by Amgoud and Prade [2] in decision under uncertainty. This paper focuses on multiple criteria decision making. In what follows, for each criterion, one assumes that we have a *bipolar univariate* ordered scale which enables us to distinguish between *positive values* (giving birth to *arguments pro* a choice

x) and *negative values* (giving birth to *arguments cons a choice* x). Such a scale has a neutral point, or more generally a neutral area that separates positive and negative values. The lower bound of the scale stands for total dissatisfaction and the upper bound for total satisfaction; the closer to the upper bound the value of criterion c_i for choice x is, the stronger the value of c_i is an *argument in favor of* x; the closer to the lower bound the value of criterion c_i for choice x is, the stronger the value of c_i is an *argument against* x.

In this paper, we propose an argumentation-based framework in which arguments provide the pros and cons of decisions are built from knowledge bases, which may be pervaded with uncertainty. Moreover, the arguments may not have equal forces and this make it possible to compare pairs of arguments. The force of an argument is evaluated in terms of three components: its certainty degree, the importance of the criterion to which it refers, and the (dis)satisfaction level of this criterion. Finally, decisions can be compared, using different principles, on the basis of the strength of their relevant arguments (pros or cons).

The paper is organized as follows. Section 2 states a general framework for argumentation-based decision, and various decision principles. This framework is then instantiated in section 3. Lastly, section 4 reports on the psychological validity of these decision principles.

2 A general framework for multiple criteria decision

Solving a decision problem amounts to defining a pre-ordering, usually a complete one, on a set $\mathcal{X}$ of possible choices (or decisions), on the basis of the different consequences of each decision. Argumentation can be used for defining such a pre-ordering. The basic idea is to construct arguments in favor of and against each decision, to evaluate such arguments, and finally to apply some principle for comparing the decisions on the basis of the arguments and their quality or strengths. Thus, an argumentation-based decision process can be decomposed into the following steps:

1. Constructing arguments in *favor* of /*against* each decision in $\mathcal{X}$.
2. Evaluating the strength of each argument.
3. Comparing decisions on the basis of their arguments.
4. Defining a pre-ordering on $\mathcal{X}$.

2.1 Basic definitions

Formally, an argumentation-based decision framework is defined as follows:

Definition 1 (Argumentation-based decision framework). *An* argumentation-based decision framework *is a tuple* $<\mathcal{X}, \mathcal{A}, \succeq, \lhd_{Princ}>$ *where:*

- $\mathcal{X}$ *is a set of all possible decisions.*
- $\mathcal{A}$ *is a set of arguments.*
- $\succeq$ *is a (partial or complete) pre-ordering on* $\mathcal{A}$*.*

– $\triangleleft_{Princ}$ *(for principle for comparing decisions), defines a (partial or complete) pre-ordering on* $\mathcal{X}$*, defined on the basis of arguments.*

The output *of the framework is a (complete or partial) pre-ordering* $\triangleleft_{Princ}$*, on* $\mathcal{X}$*.* $x_1 \triangleleft_{Princ} x_2$ *means that the decision* x_1 *is* at least as preferred as *the decision* x_2 *w.r.t. the* principle *Princ.*

Notation: Let A, B be two arguments of $\mathcal{A}$. If $\succeq$ is a pre-order, then $A \succeq B$ means that A is at least as 'strong' as B.
$\succ$ and $\approx$ will denote respectively the strict ordering and the relation of equivalence associated with the preference between arguments. Hence, $A \succ B$ means that A is strictly preferred to B. $A \approx B$ means that A is preferred to B and B is preferred to A.

Different definitions of $\succeq$ or different definitions of $\triangleleft_{Princ}$ may lead to different decision frameworks which may not return the same results.

Each decision may have arguments in its favor, and arguments against it. An argument in favor of a decision represents the good consequences of that decision. In a multiple criteria context, this will represent the criteria which are positively satisfied. On the contrary, an argument against a decision may highlight the criteria which are insufficiently satisfied. Thus, in what follows, we define two functions which return for a given set of arguments and a given decision, all the arguments in favor of that decision and all the arguments against it.

Definition 2 (Arguments pros/cons). *Let* $x \in \mathcal{X}$*.*

– $Arg_P(x)$ *= the set of arguments in* $\mathcal{A}$ *which are in favor of* x*.*
– $Arg_C(x)$ *= the set of arguments in* $\mathcal{A}$ *which are against* x*.*

2.2 Some principles for comparing decisions

At the core of our framework is the use of a principle that allows for an argument-based comparison of decisions. Below we present some intuitive principles *Princ*, whose psychological validity is discussed in section 4. A simple principle consists in counting the arguments in favor of each decision. The idea is to prefer the decision which has more supporting arguments.

Definition 3 (Counting arguments pros: CAP). *Let* $<\mathcal{X}, \mathcal{A}, \succeq, \triangleleft_{CAP}>$ *be an argumentation based decision framework, and Let* $x_1, x_2 \in \mathcal{X}$*.*
$x_1 \triangleleft_{CAP} x_2$ *w.r.t CAP iff* $|Arg_P(x_1)| > |Arg_P(x_2)|$*, where* $|B|$ *denotes the cardinality of a given set B.*

Likewise, one can also compare the decisions on the basis of the number of arguments against them. A decision which has less arguments against it will be preferred.

Definition 4 (Counting arguments cons: CAC). *Let* $<\mathcal{X}, \mathcal{A}, \succeq, \triangleleft_{CAC}>$ *be an argumentation based decision framework, and Let* $x_1, x_2 \in \mathcal{X}$*.*
$x_1 \triangleleft_{CAC} x_2$ *w.r.t CAC iff* $|Arg_C(x_1)| < |Arg_C(x_2)|$*.*

Definitions 3 and 4 do not take into account the strengths of the arguments. In what follows, we propose two principles based on the preference relation between the arguments. The first one, that we call the *promotion focus* principle (Prom), takes into account only the supporting arguments (i.e. the arguments PRO a decision), and prefers a decision which has at least one supporting argument which is preferred to (or stronger than) any supporting argument of the other decision. Formally:

Definition 5 (Promotion focus). *Let* $<\mathcal{X}, \mathcal{A}, \succeq, \triangleleft_{Prom}>$ *be an argumentation-based decision framework, and Let* $x_1, x_2 \in \mathcal{X}$.
$x_1 \triangleleft_{Prom} x_2$ *w.r.t Prom iff* $\exists\ A \in Arg_P(x_1)$ *such that* $\forall\ B \in Arg_P(x_2)$, $A \succ B$.

Note that the above relation may be found too restrictive, since when the strongest arguments in favor of x_1 and x_2 have equivalent strengths (in the sense of $\approx$), x_1 and x_2 cannot be compared. Clearly, this could be refined in various ways by counting arguments of equal strength.

The second principle, that we call the *prevention focus* principle (Prev), considers only the arguments against decisions when comparing two decisions. With such a principle, a decision will be preferred when all its cons are weaker than at least one argument against the other decision. Formally:

Definition 6 (Prevention focus). *Let* $<\mathcal{X}, \mathcal{A}, \succeq, \triangleleft_{Prev}>$ *be an argumentation based decision framework, and Let* $x_1, x_2 \in \mathcal{X}$.
$x_1 \triangleleft_{Prev} x_2$ *w.r.t Prev iff* $\exists\ B \in Arg_C(x_2)$ *such that* $\forall\ A \in Arg_C(x_1)$, $B \succ A$.

Obviously, this is but a sample of the many principles that we may consider. Human deciders may actually use more complicated principles, such as for instance the following one. First, divide the set of all (positive or negative) arguments into strong and weak ones. Then consider only the strong ones if any, and apply the Prevention focus principle. In absence of any strong argument, apply the Promotion focus principle. This combines risk-aversion in the realm of extreme consequences, with risk-tolerance in the realm of mild consequences.

3 A specification of the general framework

In this section, we give some definitions of what might be an argument in favor of a decision, an argument against a decision, of the strengths of arguments, and of the preference relations between arguments. We will show also that our framework capture different multiple criteria decision rules.

3.1 Basic concepts

In what follows, $\mathcal{L}$ denotes a propositional language, $\vdash$ stands for classical inference, and $\equiv$ stands for logical equivalence. The decision maker is supposed to be equipped with three bases built from $\mathcal{L}$:

1. a *knowledge* base $\mathcal{K}$ gathering the available information about the world.
2. a base $\mathcal{C}$ containing the different *criteria*.
3. a base $\mathcal{G}$ of *preferences* (expressed in terms of goals to be reached).

Beliefs in $\mathcal{K}$ may be more or less certain. In the multiple criteria context, this opens the possibility of having uncertainty on the (dis)satisfaction of the criteria. Such a base is supposed to be equipped with a total preordering $\geq$.

$$a \geq b \text{ iff } a \text{ is at least as certain as } b.$$

For encoding it, we use the set of integers $\{0, 1, \ldots, n\}$ as a linearly ordered scale, where n stands for the highest *level of certainty* and '0' corresponds to the complete lack of information. This means that the base $\mathcal{K}$ is partitioned and stratified into $\mathcal{K}_1, \ldots, \mathcal{K}_n$ ($\mathcal{K} = \mathcal{K}_1 \cup \ldots \cup \mathcal{K}_n$) such that formulas in $\mathcal{K}_i$ have the same certainty level and are more certain than formulas in $\mathcal{K}_j$ where j < i. Moreover, $\mathcal{K}_0$ is not considered since it gathers formulas which are completely not certain.

Similarly, criteria in $\mathcal{C}$ may not have equal importance. The base $\mathcal{C}$ is then also partitioned and stratified into $\mathcal{C}_1, \ldots, \mathcal{C}_n$ ($\mathcal{C} = \mathcal{C}_1 \cup \ldots \cup \mathcal{C}_n$) such that all criteria in $\mathcal{C}_i$ have the same *importance level* and are more important than criteria in $\mathcal{C}_j$ where j < i. Moreover, $\mathcal{C}_0$ is not considered since it gathers formulas which are completely not important, and which are not at all criteria.

Each criterion can be translated into a set of consequences, which may not be equally satisfactory. Thus, the consequences are associated with the satisfaction level of the corresponding criterion. The criteria may be satisfied either in a positive way (if the satisfaction degree is higher than the neutral point of the considered scale) or in a negative way (if the satisfaction degree is lower than the neutral point of the considered scale). For instance, consider the criterion "closeness to the sea" for a house to let for vacations. If the distance is less than 1 km, the user may be fully satisfied, moderately satisfied if it's between 1 and 2 km, slightly dissatisfied if it is between 2 and 3 km, and completely dissatisfied if it is more than 3km from the sea. Thus, the set of consequences will be partitioned into two subsets: a set of *positive "goals"* $\mathcal{G}^+$ and a set of *negative* ones $\mathcal{G}^-$.

Since the goals may not be equally satisfactory, the base $\mathcal{G}^+$ (resp. $\mathcal{G}^-$) is also supposed to be stratified into $\mathcal{G}^+ = \mathcal{G}_1^+ \cup \ldots \cup \mathcal{G}_n^+$ (resp. $\mathcal{G}^- = \mathcal{G}_1^- \cup \ldots \cup \mathcal{G}_n^-$) where goals in $\mathcal{G}_i^+$ (resp. $\mathcal{G}_i^-$) correspond to the same level of (dis)satisfaction and are more important than goals in $\mathcal{G}_j^+$ (resp. $\mathcal{G}_j^-$) where j < i. Note that some $\mathcal{G}_i$'s may be empty if there is no goal corresponding to this level of importance. For the sake of simplicity, in all our examples, we only specify the strata which are not empty. In the above example, taking n = 2, we have $\mathcal{G}_2^+ = \{dist < 1km\}$, $\mathcal{G}_1^+ = \{1 \leq dist < 2km\}$, $\mathcal{G}_1^- = \{2 \leq dist \leq 3km\}$ and $\mathcal{G}_2^- = \{3 < dist\}$.

A goal g_i^j is associated to a criterion c_i by a propositional formula of the form $g_i^j \rightarrow c_i$ meaning just that the goal g_i^j refers to the evaluation of criterion c_i. Such formulas will be added to $\mathcal{K}_n$. More generally, one may think of goals involving several criteria, e.g. dist ¡ 1km or price $\leq$ 500.

3.2 Arguments pros and cons

An argument *supporting* a decision takes the form of an *explanation*. The idea is that a decision has some justification if it leads to the satisfaction of some criteria, taking into account the knowledge. Formally:

Definition 7 (Argument). *An* argument *is a 4-tuple* $A = <S, x, g, c>$ *s.t. 1)* $x \in \mathcal{X}$*, 2)* $c \in \mathcal{C}$*, 3)* $S \subseteq \mathcal{K}$*, 4)* S^x *is consistent, 5)* $S^x \vdash g$*, 6)* $g \rightarrow c \in \mathcal{K}_n$*, and 7)S is minimal (for set inclusion) among the sets S satisfying the above conditions.*
S is the support *of the argument, x is the* conclusion *of the argument, c is the criterion which is evaluated for x and g represents the way in which c is satisfied by x.* S^x *is the set S adding the information that x takes place.*
$\mathcal{A}$ *gathers all the arguments which can be built from the bases* $\mathcal{K}$, $\mathcal{X}$ *and* $\mathcal{C}$*.*

Let's now define the two functions which return the arguments in favor and the arguments against a decision. Intuitively, an argument is in favor of a given decision if that decision satisfies positively a criterion. In other terms, it satisfies goals in $\mathcal{G}^+$. Formally:

Definition 8 (Arguments pros). *Let* $x \in \mathcal{X}$*.*

$$Arg_P(x) = \{A =< S, x, g, c > \in \mathcal{A} \mid \exists j \in \{0, 1, \ldots, n\} \text{ and } g \in \mathcal{G}_j^+\}.$$

$Sat(A) = j$ *is a function which returns the* satisfaction *degree of the criterion c by the decision x.*

An argument is against a decision if the decision satisfies insufficiently a given criterion. In other terms, it satisfies goals in $\mathcal{G}^-$. Formally:

Definition 9 (Arguments cons). *Let* $x \in \mathcal{X}$*.*

$$Arg_C(x) = \{A =< S, x, g, c > \in \mathcal{A} \mid \exists j \in \{0, 1, \ldots, n\} \text{ and } g \in \mathcal{G}_j^-\}.$$

$Dis(A) = j$ *is a function which returns the* dissatisfaction *degree of the criterion c by the decision x.*

3.3 The strengths of arguments

In [1], it has been argued that arguments may have forces of various strengths. These forces allow an agent to compare different arguments in order to select the 'best' ones, and consequently to select the best decisions.

Generally, the force of an argument can rely on the beliefs from which it is constructed. In our work, the beliefs may be more or less certain. This allows us to attach a *certainty level* to each argument. This certainty level corresponds to

the smallest number of a stratum met by the support of that argument.
Moreover, the criteria may not have equal importance also. Since a criterion may be satisfied with different grades, the corresponding goals may have (as already explained) different (dis)satisfaction degree.
Thus, the the force of an argument depends on three components: the *certainty level* of the argument, the *importance* degree of the criterion, and the *(dis)satisfaction* degree of that criterion. Formally:

Definition 10 (Force of an argument). *Let* $A = \langle S, x, g, c \rangle$ *be an argument. The* force *of an argument A is a triple* $Force(A) = \langle \alpha, \beta, \lambda \rangle$ *such that:*

$\alpha = min\{j \mid 1 \leq j \leq n \text{ such that } S_j \neq \emptyset\}$, *where* S_j *denotes* $S \cap \mathcal{K}_j$.
$\beta = i$ *such that* $c \in \mathcal{C}_i$.
$\lambda = Sat(A)$ *if* $A \in Arg_P(x)$, *and* $\lambda = Dis(A)$ *if* $A \in Arg_C(x)$.

3.4 Preference relations between arguments

An argumentation system should balance the levels of satisfaction of the criteria with their relative importance. Indeed, for instance, a criterion c_i highly satisfied by x is not a strong argument in favor of x if c_i has little importance. Conversely, a poorly satisfied criterion for x is a strong argument against x only if the criterion is really important. Moreover, in case of uncertain criteria evaluation, one may have to discount arguments based on such evaluation. This is quite similar with the situation in argument-based decision under uncertainty [2]. In other terms, the force of an argument represents to what extent the decision will satisfy the most important criteria.

This suggests the use of a *conjunctive* combination of the certainty level, the satisfaction / dissatisfaction degree and the importance of the criterion. This requires the commensurateness of the three scales.

Definition 11 (Conjunctive combination). *Let A, B be two arguments with* $Force(A) = \langle \alpha, \beta, \lambda \rangle$ *and* $Force(B) = \langle \alpha', \beta', \lambda' \rangle$.
$A \succ B$ *iff* $min(\alpha, \beta, \lambda) > min(\alpha', \beta', \lambda')$.

Example 1 *Assume the following scale* $\{0, 1, 2, 3, 4, 5\}$. *Let us consider two arguments A and B whose forces are respectively* $(\alpha, \beta, \lambda) = (5, 3, 2)$ *and* $(\alpha', \beta', \lambda') = (5, 1, 5)$. *In this case the argument A is* preferred *to B since* $min(5, 3, 2) = 2$, *whereas* $min(5, 1, 5) = 1$.

However, a simple conjunctive combination is open to discussion, since it gives an equal weight to the certainty level, the satisfaction/dissatisfaction degree of the criteria and to the importance of the criteria. Indeed, one may prefer an argument that satisfies for sure an important criteria even rather poorly, than an argument which satisfies very well a non-important criterion but with a weak certainty level. This suggests the following preference relation:

Definition 12 (Semi conjunctive combination). *Let A, B be two arguments with* $Force(A) = \langle \alpha, \beta, \lambda \rangle$ *and* $Force(B) = \langle \alpha', \beta', \lambda' \rangle$. $A \succ B$ *iff*

– $\alpha \geq \alpha$',
– *min*(β, λ) > *min*(β', λ').

This definition gives priority to the certainty of the information, but is less discriminating than the previous one.
The above approach assumes the commensurateness of two or three scales, namely the certainty scale, the importance scale, and the weighting scale. This requirement is questionable in principle. If this hypothesis is not made, one can still define a relation between arguments as follows:

Definition 13 (Strict combination). *Let A, B be two arguments with* $Force(A)$ = <α, β, λ> *and* $Force(B)$ = <α', β', λ'>. $A \succ B$ *iff:*

– $\alpha \geq \alpha'$, *or*
– $\alpha = \alpha'$ *and* $\beta > \beta'$ *or,*
– $\alpha = \alpha'$ *and* $\beta = \beta'$ *and* $\lambda > \lambda'$.

3.5 Retrieving classical multiple criteria aggregations

In this section we assume that information in the base $\mathcal{K}$ is fully certain.
A simple approach in multiple criteria decision making amounts to evaluate each x in $\mathcal{X}$ from a set $\mathcal{C}$ of m different criteria c_i with $i = 1, \ldots, m$. For each c_i, x is then evaluated by an estimate $c_i(x)$, belonging to the evaluation scale used for c_i. Let 0 denotes the neutral point of the scale, supposed here to be bipolar univariate.

When all criteria have the same level of importance, counting positive or negative arguments obviously corresponds to the respective use of the following evaluation functions for comparing decisions

$$\sum_i c'_i(x) \quad or \quad \sum_i c''_i(x)$$

where $c'_i(x) = 1$ if $c_i(x) > 0$ and $c'_i(x) = 0$ if $c_i(x) < 0$, and $c''_i(x) = 0$ if $c_i(x) > 0$ and $c''_i(x) = 1$ if $c_i(x) < 0$.

Proposition 1. *Let* $<\mathcal{X}, \mathcal{A}, \succeq, \lhd_{CAP}>$ *be an argumentation-based system. Let* $x_1, x_2 \in \mathcal{X}$.
When $\mathcal{C} = \mathcal{C}_n$, $x_1 \lhd_{CAP} x_2$ *iff* $\sum_i c'_i(x_1) \geq \sum_i c'_i(x_2)$.

Proposition 2. *Let* $<\mathcal{X}, \mathcal{A}, \succeq, \lhd_{CAC}>$ *be an argumentation-based system. Let* $x_1, x_2 \in \mathcal{X}$.
When $\mathcal{C} = \mathcal{C}_n$, $x_1 \lhd_{CAC} x_2$ *iff* $\sum_i c''_i(x_1) \leq \sum_i c''_i(x_2)$.

When all criteria have the same level of importance, the promotion focus principle amounts to use $max_i\ c'_i(x)$ with $c'_i(x) = c_i(x)$ if $c_i(x) > 0$ and $c'_i(x) = 0$ if $c_i(x) < 0$ as an evaluation function for comparing decisions.

Proposition 3. *Let* $<\mathcal{X}, \mathcal{A}$, *Conjunctive combination,* $\lhd_{Prom}>$ *be an argumentation-based system. Let* $x_1, x_2 \in \mathcal{X}$.
When $\mathcal{C} = \mathcal{C}_n$, $x_1 \lhd_{Prom} x_2$ *iff* $max_i\ c'_i(x_1) \geq max_i\ c'_i(x_2)$.

The prevention focus principle amounts to use $min_i\ c''_i(x)$ with $c''_i(x) = 0$ if $c_i(x) > 0$ and $c''_i(x) = -c_i(x)$ if $c_i(x) < 0$.

Proposition 4. *Let* $<\mathcal{X}, \mathcal{A}$*, Conjunctive combination,* $\lhd_{Prev}>$ *be an argumentation-based system. Let* $x_1,\ x_2 \in \mathcal{X}$*.*
When $\mathcal{C} = \mathcal{C}_n$*,* $x_1 \lhd_{Prev} x_2$ *iff* $min_i\ c''_i(x_1) \leq min_i\ c''_i(x_2)$*.*

When each criterion $c_i(x)$ is associated with a level of importance w_i ranging on the positive part of the criteria scale, the above $c'_i(x)$ is changed into $min(c'_i(x), w_i)$ in the promotion case.

Proposition 5. *Let* $<\mathcal{X}, \mathcal{A}$*, Conjunctive combination,* $\lhd_{Prom}>$ *be an argumentation-based system. Let* $x_1,\ x_2 \in \mathcal{X}$*.*
$x_1 \lhd_{Prom} x_2$ *iff* $max_i\ min(c'_i(x_1), w_i) \geq max_i\ min(c'_i(x_2), w_i)$*.*

Similar proposition holds for the prevention focus principle. Thus, weighted disjunctions and conjunctions [7] are retrieved.

3.6 Example: Choosing a medical prescription

Imagine we have a set $\mathcal{C}$ of 4 criteria for choosing a medical prescription: Availability (c_1), Reasonableness of the price (c_2), Efficiency (c_3), and Acceptability for the patient (c_4). We suppose that c_1, c_3 are more important than c_2, c_4. Thus, $\mathcal{C} = \mathcal{C}_2 \cup \mathcal{C}_1$ with $\mathcal{C}_2 = \{c_1, c_3\}$, $\mathcal{C}_1 = \{c_2, c_4\}$.

These criteria are valued on the same qualitative bipolar univariate scale $\{-2, -1, 0, 1, 2\}$ with neutral point 0. From a cognitive psychology point of view, this corresponds to the distinction often made by humans between what is strongly positive, weakly positive, neutral, weakly negative, or strongly negative. Each criterion c_i is associated with a set of 4 goals g_i^j where $j = 2, 1, -1, -2$ denotes the fact of reaching levels $2, 1, -1, -2$ respectively. This gives birth to the following goals bases:
$\mathcal{G}^+ = \mathcal{G}_2^+ \cup \mathcal{G}_1^+$ with $\mathcal{G}_2^+ = \{e(x, c_1) = 2, e(x, c_2) = 2, e(x, c_3) = 2, e(x, c_4) = 2\}$, $\mathcal{G}_1^+ = \{e(x, c_1) = 1, e(x, c_2) = 1, e(x, c_3) = 1, e(x, c_4) = 1\}$. $\mathcal{G}^- = \mathcal{G}_2^- \cup \mathcal{G}_1^-$ with $\mathcal{G}_2^- = \{e(x, c_1) = -2, e(x, c_2) = -2, e(x, c_3) = -2, e(x, c_4) = -2\}$, $\mathcal{G}_1^- = \{e(x, c_1) = -1, e(x, c_2) = -1, e(x, c_3) = -1, e(x, c_4) = -1\}$.

Let $\mathcal{X} = \{x_1, x_2\}$ be a set of two potential decisions regarding the prescription of drugs. Suppose that the three alternatives, x_1 and x_2 receive the following evaluation vectors:

- $e(x_1) = (-1, 1, 2, 0)$,
- $e(x_2) = (1, -1, 1, 1)$,

where the ith component of the vector corresponds to the value of the ith criterion. This is encoded in $\mathcal{K}$. All the information in $\mathcal{K}$ are assumed to be fully certain.
$\mathcal{K} = \{e(x_1, c_1) = -1,\ e(x_1, c_2) = 1,\ e(x_1, c_3) = 2,\ e(x_1, c_4) = 0,\ e(x_2, c_1) = 1,\ e(x_2, c_2) = -1,\ e(x_2, c_3) = 1,\ e(x_2, c_4) = 1,\ (e(x, c) = y) \rightarrow c\}$. Note that the last formula in $\mathcal{K}$ is universally quantified.

Let's now define the pros and cons each decision.
$A_1 = \langle \{e(x_1, c_2) = 1\}, x_1, e(x_1, c_2) = 1, c_2 \rangle$
$A_2 = \langle \{e(x_1, c_3) = 2\}, x_1, e(x_1, c_3) = 2, c_3 \rangle$
$A_3 = \langle \{e(x_1, c_1) = -1\}, x_1, e(x_1, c_1) = -1, c_1 \rangle$
$A_4 = \langle \{e(x_1, c_4) = 0\}, x_1, e(x_1, c_4) = 0, c_4 \rangle$
$A_5 = \langle \{e(x_2, c_1) = 1\}, x_2, e(x_2, c_1) = 1, c_1 \rangle$
$A_6 = \langle \{e(x_2, c_2) = -1\}, x_2, e(x_2, c_2) = -1, c_2 \rangle$
$A_7 = \langle \{e(x_2, c_3) = 1\}, x_2, e(x_2, c_3) = 1, c_3 \rangle$
$A_8 = \langle \{e(x_2, c_4) = 1\}, x_2, e(x_2, c_4) = 1, c_4 \rangle$

$Arg_P(x_1) = \{A_1, A_2\}$, $Arg_C(x_1) = \{A_3\}$,
$Arg_P(x_2) = \{A_5, A_7, A_8\}$, $Arg_C(x_2) = \{A_6\}$.
If we consider an argumentation system in which decisions are compared w.r.t the CAP principle, then $x_2 \lhd x_1$. However, if a CAC principle is used, the two decisions are indifferent.
Now let's consider an argumentation system in which a conjunctive combination criterion is used to compare arguments and the Prom principle is used to compare decisions. In that case, only arguments pros are considered.
$Force(A_1) = (2, 1, 1)$, $Force(A_2) = (2, 2, 2)$, $Force(A_5) = (2, 2, 1)$, $Force(A_7) = (2, 2, 1)$, $Force(A_8) = (2, 1, 1)$. It is clear that $A_2 \succ A_5$, A_7, A_8. Thus, x_1 is preferred to x_2.
In the case of the Prev principle, only arguments against the decisions are considered, namely A_3 and A_6. Note that $Force(A_3) = (2, 2, 1)$ and $Force(A_6) = (2, 1, 1)$. The two decisions are then indifferent using the conjunctive combination. The leximin refinement of the minimum in the conjunctive combination rule leads to prefer A_3 to A_6. Consequently, according to Prev principle x_2 will be preferred to x_1.

This example shows that various Princ may lead to different decisions in case of alternatives hard to separate.

4 Psychological validity of argumentation-based decision principles

Bonnefon, Glasspool, McCloy, and Yule [4] have conducted an experimental test of the psychological validity of the counting and Prom/Prev principles for argumentation-based decision. They presented 138 participants with 1 to 3 arguments in favor of some action, alongside with 1 to 3 arguments against the action, and recorded both the decision (take the action, not take the action, impossible to decide) and the confidence with which it was made. Since the decision situation was simplified in that sense that the choice was between taking a given action or not (plus the possibility of remaining undecided), counting arguments pro and counting arguments con predicted similar decisions (because, e.g., an argument for taking the action was also an argument against not taking it). Likewise, and for the same reason, the Prom and Prev principles predicted similar decisions.

The originality of the design was in the way arguments were tailored participant by participant so that the counting principle on the one hand and the Prom and Prev principles on the other hand made different predictions with respect to the participant's decision: During a first experimental phase, participants rated the force of 16 arguments for or against various decisions; a computer program then built online the decision problems that were to be presented in the second experimental phase (i.e., the decision phase proper). For example, the program looked for a set of 1 argument pro and 3 arguments con such that the argument pro was preferred to any of the 3 arguments con. With such a problem, a counting principle would predict the participant to take the action, but a Prom/Prev principle would predict the participant not to take the action.

Overall, 828 decisions were recorded, of which 21% were correctly predicted by the counting principle, and 55% by the Prom/Prev principle. Quite strikingly, the counting principle performed significantly below chance level (33%). The 55% hit rate of the Prom/Prev principle is far more satisfactory, its main problem being its inability to predict decisions made in situations that featured only one argument pro and one argument con, of comparable forces. The measure of the confidence with which decisions were made yielded another interesting result: The decisions that matched the predictions of the Prom/Prev principles were made with higher confidence than the decisions that did not, in a statistically significant way. This last result suggests that the Prom/Prev principle has indeed some degree of psychological validity, as the decisions that conflict with its predictions come with a feeling of doubt, as if they were judged atypical to some extent.

The dataset also allowed for the test of the refined decision principle introduced at the end of section 2.2. This principle fared well regarding both hit rate and confidence attached to the decision. The overall hit rate was 64%, a significant improvement over the 55% hit rate of the Prom/Prev principles. Moreover, the confidence attached to the decisions predicted by the refined principle was much higher (with a mean difference of more than two points on a 5-point scale) than the confidence in decisions it did not predict.

5 Conclusion

Some may wonder why bother about argumentation-based decision in multiple criteria decision problems, since the aggregation functions that can be mimicked in an argumentation-based approach would remain much simpler than sophisticated aggregation functions such as a general Choquet integral. There are several reasons however, for studying argumentation-based multiple criteria decision. A first one is related to the fact that in some problems criteria are intrinsically qualitative, or even if they are numerical in nature they are qualitatively perceived (as in the above example of the criterion 'being close to the sea'), and then it is useful to develop models which are close to the way people deal with decision problems. Moreover, it is also nice to notice that the argumentation-based approach provides a unified setting where inference, or decision under uncertainty can be handled as well. Besides, the logical setting of argumentation-based decision enables to have the values of consequences of possible decisions assessed through a non trivial inference process (in contrast with the above example) from various pieces of knowledge, possibly pervaded with uncertainty, or even partly inconsistent.

The paper has sketched a general method which enables us to *compute* and *justify* preferred decision choices. We have shown that it is possible to design a logical machinery which directly manipulates arguments with their strengths and returns preferred decisions from them.

The approach can be extended in various directions. It is important to study other decision principles which involve the strengths of arguments, and to compare the corresponding decision systems to classical multiple criteria aggregation processes. These principles should be also empirically validated through experimental tests. Moreover, this study can be related to another research trend, illustrated by a companion paper [6], on the axiomatization of particular qualitative decision principles in bipolar settings. Another extension of this work consists of allowing for inconsistent knowledge or goal bases.

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