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► **To cite this version:**

Jean-Pierre Barthélemy, Gilles Coppin, Philippe Lenca. Cognitive approach to decision making and practical tools. 9th IFAC symposium on automated systems based on human skill and knowledge, 22-24 mai, Nancy, France, May 2006, Nancy, France. 10.3182/20060522-3-FR-2904.00020 . hal-02124110

HAL Id: hal-02124110

<https://hal.science/hal-02124110>

Submitted on 5 Jul 2022

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COGNITIVE APPROACH TO DECISION MAKING AND PRACTICAL TOOLS

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Abstract: Since the 70's decision making is understood as the issue of a process. Among some complementary approaches the search for a dominance structure (Montgomery, 1983) has been implemented, under the name of the Moving Basis Heuristic, MBH, (Barthélemy and Mullet, 1986). The MBH allows to compute the final states of a decision process and to extract some possible decision rules. In a first part we review some evidence about decision making as information processing and describe the MBH. In the second we shall discuss induced tools of rules extraction. Last we discuss about the updating a rules base. The first part will be anchored within cognitive psychology. The two others will refer to real practical applications (banking, industrial process control).

Keywords: decision making, cognitive tools, rules extraction

INTRODUCTION

This paper, devoted to decision making, articulates two main dimensions: the analysis of the processes involved by decision issues, and applications in professional settings.

The concerned decision makers are assumed to be experts in their fields. Decision making is concerned with static or evolutive situations. In the first case the parameters of the decision problem are fixed. In the second case, the parameters evolve in time and the decision at time $t + 1$ is not necessarily taken on the same basis than the decision at time t .

In a first section we shall briefly present some cognitive approaches to decision making. A main paradigm is to see decision making as the issue of an information processing. The second section is devoted to the static case. Its main purpose is the extraction of decision rules. It involves mathematical tools like poset theory. The third section discusses evolutive situations.

1. SOME EVIDENCE ABOUT DECISION MAKING AS INFORMATION PROCESSING IN A MULTI-ATTRIBUTE SETTING

1.1 *Decision and decision makers*

Decision making involves two main types of tasks: choice and judgment. In a choice task, the alternatives are compared, the ones to the others, in a judgmental task a label has to be attached on each alternative. A choice task needs, at least, two alternatives. Only one suffices to perform a judgmental task.

Several types of decision makers (DM in the sequel) are usually considered: naive, novice, expert, professional of decision making (i.e. statistician and/or operation researcher, ...). In this paper we shall focus on experts. An expert DM is familiar with the tasks he/she has to perform. He/she knows how to structure what a naive subject would consider as amorphous. An expert is someone who can make sense out of chaos (Shanteau, 1988). An expert is also able to convince his/her

colleagues and as well as his/her hierarchy. All of them agree to acknowledge his/her great experience. A main characteristic of expertise is the low amount of the information processed to perform a decision (while a novice uses an overcrowded amount of information, an expert one uses what is just enough but relevant). Obviously such a phenomenon is balanced by the high quality and the appropriateness of the used information. This characteristic is confirmed by studies about memory in cognitive psychology (Lindsay and Norman, 1980). The expert will process information in his/her short term working memory, but with strategies compiled in his/her long term memory.

1.2 Decision making as information processing

From 18th century decision making has been much concerned by *decision under uncertainty*. It involved two main features:

- (1) a behaviorist approach: regularities between associations of responses (decision issues, R) and stimuli (decision problems, S) allow to design a probabilistic model $p([f(S)] = R)$.
- (2) a rather mathematically sophisticated modeling, utility theory, stochastic choice theory games theory...

Decision under uncertainty involves choice tasks, where a DM has to choose an action, among several, without knowing what will be the issue of such a choice. It has been strongly related to the so-called *rationality principle*, which assumes that:

- The DM is able to generate, exhaustively, all the alternatives and their issues, involved in a given decision situation;
- He/she is able to assign to each issue an attractiveness value (utility function);
- He/she is able to perform a global balance (which integrates all the attractiveness values), in order to evaluate the global attractiveness (utility) of each alternative;
- Finally, he/she chooses the alternative(s) offering an optimal balance.

Fully formalized by (Von Neumann and Morgenstern, 1944), following the Allais paradoxes, the rationality principle has been questioned by many researchers. The notion of heuristics and the work of Simon about decision in administration, propose some alternatives to the rationality principle, like *limited rationality*, *satisfaction principle*, ... (Simon, 1957). The rationality of a DM is bounded by his/her mental representations of the problem. Thus optimizations become local and can concern features like the pleasure to perform a task, cognitive effort, the risk appeal...

The Simon *satisfaction principle* postulates that, due to a limited time, the DM in a selection task will choose the first alternative (in the order where he/she examine them) that fulfills a few relevant criteria. The notion of *cognitive effort* leads to another principle: a DM will not use more cognitive effort than what is strictly needed to perform the task (Occam's razor). Thus he/she will limit his/her effort at what is strictly needed to reach a confidence level. More generally, and more recently, it has been observed (Payne *et al.*, 1988) that, facing a drastic limitation in time he/she will be less compensatory in his/her use of attributes and prefer a few information on some alternatives rather than to manage global evaluations of each of them.

Other paradigms are depth-first and breadth-first searches. Imagine that alternatives are evaluated on several attributes. Such a situation can be represented by a *decision matrix*, whose rows correspond to alternatives and columns to attributes. A *depth-first strategy* (intra dimensional) assumes that the DM focuses on attributes, select them (according to a preference order, often called a lexicography) and then examine the alternatives. On the opposite a *breadth-first* (inter dimensional) strategy assumes that a DM focuses first on alternatives and evaluate them on relevant attributes.

A breadth-first search can be required when the information related with two alternatives is not available at the same time –this could be the case for a judgmental task–(Montgomery and Svenson, 1976). Moreover, such a strategy does not assume that all the alternatives are described by the same collection of attributes.

The struggle between “intra” and “inter” appeared to be more or less meaningless. A number of experimental studies have shown noticeable differences according to the subjects.

It has been observed that the proportion of the searched attribute values decreases when the number of alternatives increases. Moreover the growth of the number of attributes favor this growth, more than the growth of the number of alternatives. These results advocate an intra-attributes strategy. It has been shown that in stressed conditions (diversions, urgency, background noise), a DM tends to eliminate first alternatives with low attribute values. Thus stress tends to favor inter dimensional strategies (Payne, 1976).

Indeed, the inter vs. intra dilemma leads to the observation that decision strategies can be sequentially used, with different levels of importance according to the subjects, the tasks and the environment. For details and references see (Mullet, 1984).

To summary, three main features rise out:

- The more complex is the decision problem, the more an intra-dimensional strategy is used;
- The more the environment is constraining, the more an inter-dimensional strategy is used;
- The subjects prefer composite strategies to strategies who would be purely inter or intra.

1.3 The psychology of decision, toward information processing models

1.3.1. Generalities As discussed above, decision making can be viewed as the outcome of an information process. Several kinds of processes have been studied. Among them: heuristics, like representativity or availability (Kahneman *et al.*, 1982), articulation of elementary strategies (Svenson, 1979), decision making as problem solving (Huber, 1986) and as a search for a dominance structure (Montgomery, 1983).

The three points discussed in 1.3.2 imply that each attribute induces an *attractiveness scale* (e.g. an alternative *a* is more attractive than an alternative *b* on a given attribute, (Montgomery and Svenson, 1976)).

1.3.2. Elementary strategies Elementary strategies account for the notion of bounded rationality: they integrate the ingredients of rationality described in 1.2, they are linked to mental representations of the DM and they involve a few amount of information.

There is a strong relationship between the strategies used by a DM and his/her mental representation of a decision problem. Such a representation depends on:

- The structure of the attractiveness scales: numerical scales, ordinal scales, semi-ordinal scales, bipartite scales, difference scales. The “qualitative” evaluation of an alternative on a scale is usually called an “aspect”.
- The comparability of the attractiveness scales associated with the attributes (*commensurable* or not).
- The existence, or not, of a preference order between attributes (usually called a *lexicographic* order).

We shall illustrate the notion of elementary strategies by three examples. For a comprehensive study of elementary strategies the reader is referred to (Montgomery and Svenson, 1976) and (Barthélemy and Lapébie, 1995). For an easier description, we shall assume that the attractiveness scales are numerically encoded.

- (a) Semi-ordinal scales (a difference threshold is associated with each attribute), no commensurability (the attributes are not pairwise comparable) and lexicography (there is a preference order between attributes): *Lexicographic rule*. The attributes are ranked into a lexicographic order. If *a* is more attractive than *b* on the first attribute, then *a* is chosen. Otherwise the second attribute is examined and the same strategy apply, and so on.
- (b) Semi-ordinal scales, no commensurability and no lexicography: *Dominance rule*. The chosen alternative is more attractive than the other on at least one attribute and not less attractive on the others.
- (c) Difference scales, commensurability, no lexicography: *The greatest difference in attractiveness rule*. The chosen alternative maximises the difference of the encoded aspects over all the attributes.

1.3.3. Decision making as problem solving According to (Huber, 1986) a decision process may be analysed as a problem solving process. Common points are :

- An initial situation understood by the DM;
- An understandable goal to reach;
- No acquaintance of the track to follow from the initial situation to the goal, but some knowledge about it.

In that spirit, Huber has introduced some elementary operators (a mirror to elementary strategy ?) that account for a “logical” description of a decision process. To facilitate the understanding, let provide three examples of elementary operators among some others: EVAL evaluates an alternative on one attribute, EQ tests the “equivalence” of two alternatives on one attribute and DED is a production rule like “if condition then action”.

1.3.4. Decision making as the search for a dominance structure This approach has been strongly supported by Montgomery in several papers (e.g., 1983). The basic idea is that among the many possible strategies, the dominance rule is used as a major one. Obviously it will not spontaneously apply. Hence, the decision process will reduce essentially to the search for a representation of the problem (in terms of considered attributes, attractiveness scales and thresholds) where one (or more) alternatives dominates the others (in the sense of a dominance rule).

A given dominance structure will depend on the decision situation. The same DM may uses several structures according to the problem he/she faces. Moreover if he/she is an expert, we can assume that his/her dominance structures are stabilized.

1.3.5. *The Moving Basis Heuristics as a way to compute dominance structures* The MBH (Barthélemy and Mullet, 1986) and (Barthélemy and Mullet, 1992) allows to compute dominance structures. We shall present it in the framework of selection tasks (this will be the experimental paradigm of section 2, extended to a judgmental task in section 3). Summarizing various evidences described above, the MBH accounts for four contradictory arguments:

- parsimony: due to his/her short-term memory capacities (in term of storage there is no intermediate storage in a long-term memory, and limited computational abilities) the DM manipulates a short amount of aspects implied into a dominance structure. This principle runs in favor of lexicographic rules.
- reliability/warrantability: the considered sets of aspects can be large (in quantity and/or quality) enough, in order to justify, individually and/or socially the decision issues. Sets of considered aspects have to be meaningful, thus this principle may imply conjunctions of several aspects.
- decidability/flexibility: the DM has to choose. By appropriate changes into dominance structures until a decision is reached as a relatively short notice he/she will examine several possible dominance structures in a flexible way.
- preference: performing a decision task the DM shows his/her preferences among the attributes.

Some points arise from the preceding discussion: decision rules are composite rules. They induce lexicographically ordered simple rules of the form “if condition then decision” disjunctively written. The “if condition” (i.e. a conjunctive rule) involves a limited set of attributes and thresholds on it.

2. INDUCED TOOLS FOR RULES EXTRACTION

2.1 Problem

In this section we shall restrict to a selection/elimination task. A given alternative a of a world A is either selected or rejected. Then this defines the categorization problem with 2 separated clusters: the world of alternatives A is clustered in 2 separated sets, the “accepted” alternatives and the “rejected” alternatives. Be able to explain DM’s strategies is equivalent to learn the border between the two categories.

2.2 Methodology

2.2.1. *Formalization* An alternative a in A is described by p attributes X_i , $1 \leq i \leq p$, inducing an ordinal attractiveness scale for each attribute according to DM’s preferences.

Each attribute X_i has $c_i + 1$ values belonging to a domain V_i and is represented by a linear order $P_i = \{0 \leq 1 \leq \dots \leq c_i\}$. The alternative a has a natural representation in a p -dimensional space $P = P_1 \times \dots \times P_p$. The set P is the direct product of the p linear orders P_i and an alternative a in A is represented by a element $x = (x_1, \dots, x_p)$ of P .

We assume a monotonicity property: when an alternative is selected (respectively rejected), then every alternative that has better (respectively worse) values on all the attributes is selected (respectively rejected). As a consequence, the rules of a DM may be viewed as minimal conjunctive requirements. To learn decision rules is equivalent to learn minimal chosen alternatives (Pichon *et al.*, 1994). The alternatives must be assigned to the category C_1 (selected alternatives) or to C_2 (rejected alternatives) (eventually we can maintain a non choice category).

The monotonicity principle is translated in P with the following “propagation” rules ($\forall x, x' \in P$, $x' \geq x \Leftrightarrow i = 0, \dots, p$, $x_i \geq x_i$) and thus P is divided in two hierarchical parts C_1 and C_2 . For $x \in P$:

- if $x \in C_1$ then $\forall x' \in P$, $x' \geq x \Rightarrow x' \in C_1$
- if $x \in C_2$ then $\forall x' \in P$, $x' \leq x \Rightarrow x' \in C_2$

2.2.2. *Learning methodology* Computing the set of minimal elements of C_1 is equivalent to seeking for antichain i.e. a subset of pairwise incomparable elements of P (Pichon *et al.*, 1994).

To achieve this goal, we have designed an efficient and interactive algorithm which extracts rules used by the DM with a few number of questions in order to save DM’s cognitive efforts and used time: the APACHE tool. It is briefly described (for mean features, see (Lenca, 1995b) and (Lenca, 1997)). APACHE starts from an initial “learning” space L_0 . It could be the entire poset P , but some irrelevant elements, without realistic existence in the real world A , can be eliminated from P . At the step i with the set of uncategorized alternatives L_i , the algorithm involves three main procedures (while we do not reach a halt criteria):

Procedure 1: compute an uncategorized alternative a_i in L_i

Procedure 2: propose a_i to DM and read the DM decision d_i (accept or reject)

Procedure 3: propagate the pair (a_i, d_i) with the monotonicity principle in the learning space L_i to produce L_{i+1}

The algorithm generates interactively a questionnaire Q (Q is a list of uncategorized alternatives a_i , for $i = 1, \dots, q$, where q is the length of the questionnaire) to submit to the DM. Then a crucial point is to minimize the length of the questionnaire.

To achieve this goal the different alternatives a_i are dynamically generated (procedure 1). This is to say that a_i only depends of the set of uncategorized alternatives at the preceding step. And a_i is designed in order to minimize the set of uncategorized alternatives after procedure 2 (read DM decision d_i) and procedure 3 (propagate a_i and d_i in the current learning space L_i to produce the next learning space L_{i+1}):

- if d_i is: “select”, then mark as “selected” the alternatives better than a_i in L_i .
- if d_i is: “eliminate” then, mark as “eliminated” the alternatives worst than a_i in L_i .

This algorithm is heuristic and greedy. In order to tend to optimize the number of questions we have maximized, at each step, the number of marked alternatives. Procedure 1 computes a_i by the following optimization rule:

$$\max_{a_i \in L_i} [\min(|\{x \in L_i, x \geq a_i\}|, |\{x \in L_i, x \leq a_i\}|)]$$

This is a kind of maximin strategy that allows us to minimize the decision maker’s worst answer in terms of questionnaire’s length.

2.2.3. Applications APACHE has been used for financial decision making: know how customers accept or refuse saving plans (Lenca, 1995a), (Lenca, 1995b), as well as in microfinance within a multi-expert framework (Kala Kamdjoug *et al.*, 2005). The rules extracted from our cognitive hypothesis have been validated.

3. UPDATING A RULE BASIS FOR INDUSTRIAL PROCESSES CONTROL

3.1 Problem

Industrial processes involve more and more quality tools. Modern devices for quality control involve the two following points: a quality control tool has to be non intrusive and it must also guarantee the quality of the global production. Other challenges are to maintain and enhance experts’ know-how, and to transmit and capitalise experiences.

To each industrial process is associated a life cycle:

- A learning phase: the operator comes from the “novice” state to the “expert” state.
- A maintenance phase: the expert operator applies his/her know-how and adapts the process control,
- A re-initialisation phase (breaking/revision phase): the structural changes are so important that a simple adaptation is not enough.

As the last phase is generally expensive and intrusive (the process must stop), it is clearly useful to expand the maintenance phase. This leads us to manage the evolutions of both the process and its operator(s), and especially the gaps that could arise between them.

In the spirit of section 2 we shall assume that the operator decision behaviour can be represented by a set of rules. Thus two questions arise: are these rules relevant for the current state of the process, and in case of a negative answer, how to help the operator to update them?

The first question covers three cases:

- Case 1.1: appearance of new situations not covered by the previously computed rules.
- Case 1.2: contradiction between the operator’s decisions and the decisions predicted by the current rules.
- Case 1.3: strong evolutions of the process in such a way that a part of previously computed rules can not apply.

The second question covers two cases:

- Case 2.1: the rule basis can be automatically updated (e.g. in case 1.1 the new rules can be just inserted in the basis).
- Case 2.2: the intervention of the operator is requested to examine the contradictions. When this intervention is unsuccessful it may be needed to enter in the re-initialisation phase.

3.2 Methodology

3.2.1. Process description and modeling We are concerned by control situations that can be represented by a sequence of parameters together with a label accounting for a decision (Le Saux *et al.*, 2002; Barthélemy *et al.*, 2002).

As in section 2.1 rules are of “if then” types. But we shall consider here possible priorities (if rules R and R' can apply to the same case then R is used, this account with preferences between attributes). The “if” part involves domain values of a few number attributes. Hence with each label the “then” part is associated a set of rules.

3.2.2. *Updating* To transform a landscape of rules, we use elementary operations, e.g. creation of new rules (case 1.1) to deal with new incoming raw data that are not covered by any existing rule, splitting one existing rule in two, extending the interval values involved in a rule in order to adapt to new incoming data, or detecting new priority levels amongst existing rules (case 1.2). Case 1.3 may imply a complete re-initialisation phase and a new extraction of rules from the updated data set (Müller and Wiederhold, 2002). These operations are used hierarchically in order to account for the cognitive principles involved in the MBH (e.g. decrease the number of attributes involved in the “if” part of a rule -parsimony- or increase them -reliability-, or create new rules, etc.). For details about these elementary operations the reader is referred to (Le Saux *et al.*, 2002).

4. CONCLUSIONS

This paper is concerned with cognitive approaches in decision making. In order to make them operational, we have designed a mathematical modeling followed by algorithmic devices. Among several applications we have discussed two of them, induced tools for rules extraction and the updating the rule basis dedicated to quality control for industrial processes.

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