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Cognitive support methods for multi-criteria expert decision making

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Abstract

In this paper, written for the session on multi-criteria decision analysis of the EURO XV–INFORMS XXXIV International Conference (Barcelona, July 1997), we present different cognitive methods for supporting an expert decision maker in her/his daily decision practice. The first part of the paper deals with the construction of a cognitive artifact of the decision problem. The second part discusses the main methodological components of our approach and the final part introduces some possible approaches as candidates for an ecological validation.

Keywords: Multi-criteria decision making; Cognitive decision support; Man–machine cooperation; Human centered processes

1. Introductory context delimitation

The cognitive approach to multi-criteria decision aid that we propose may be seen as a first step in the direction of intelligent support of Man/Machine cooperation with the goal of uncovering and enhancing first – the formal representation of the decision problem and secondly – possibly satisfactory problem-solving strategies. In this sense, our approach works towards a communicative clarification, where the two involved systems, the artificial formal decision system and the human expert decision maker work on a common understanding of the problem and search for satisfactory problem-solving strategies.

1.1. Solving by resolving

We limit our considerations to decision problems of an intrinsically repetitive nature such as regular planning and scheduling problems, or on-line production control problems. Such problems occur quite naturally in everyday industry, administration or business practice. In these decision contexts, actual human decision-makers often possess satisfactory problem-solving strategies gradually acquired during past decision experiences through a more or less formal "learning-by-doing" process.

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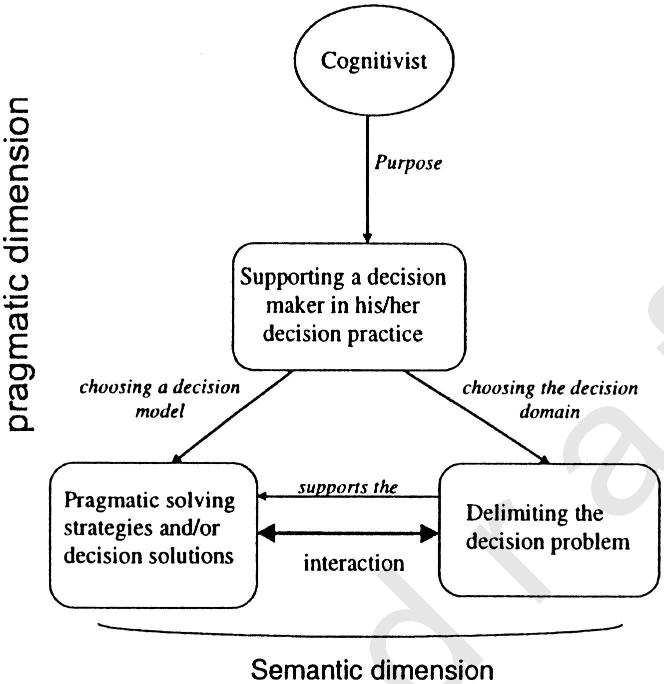

Fig. 1. How to support a decision maker.

When observing such natural human decision expertise, we will make a careful distinction between the observable "embodied" decision extension, i.e. the actually observed on-site decision practice, and the possibly communicated conscious decision intention, i.e. the strategic discourse the decision maker utters to explain, legitimate or comment on his decision practice. [1]

1.2. Supporting the decision maker

It is imperative to point out that our approach does not intend to replace the actual human decision maker by an artificial formal decision system as is usually the objective in classic operational research and/or artificial intelligence, but instead we try to uncover and enhance the existing decision practice by supporting the decision maker in his/her attempt to formalize his/her decision intention (see Fig. 1). [2]

To do so, we rely on a behaviourist approach, gathering the effectively observable decision acts with their respective consequences. From this decision history, we try to induce "cognitive problem-solving strategies" the decision maker might have used to reach his/her decision acts.

2. Constructing a cognitive artifact of the decision problem

Our operational purpose is to construct a formal model or representation of the decision

[1] "... Un expert incarne normalement son savoir-faire, ses actes naissent des inclinations spécifiques que sa disposition intelligente produit en réponse à des situations spécifiques. ... L'individu véritablement expert, peut ..., si c'est nécessaire, reconstituer sa [compétence cognitive] et apporter une justification. Il peut rationaliser ses actes a posterio, ou du moins peut s'y essayer sans difficulté. ... ", *F.J. Varela, Quel savoir pour l'éthique* [16].

[2] The design of the figure is inspired by the work of Gerd Gigerenzer concerning modelling and measurement in psychology ([6]).

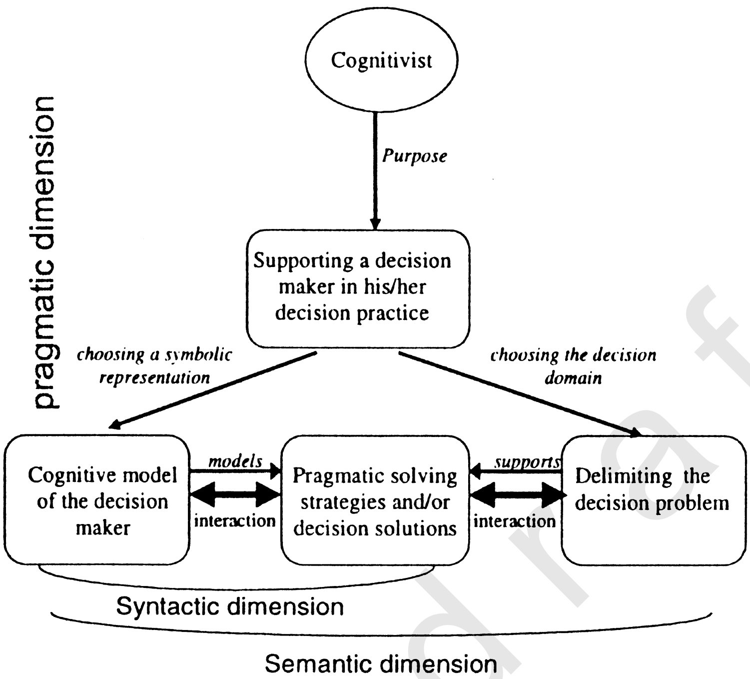

Fig. 2. Cognitive modelling of the decision problem.

problem and of corresponding solving strategies by symbolic coding and application of inductive and algebraic closure operations (see Fig. 2).

2.1. Communicative dimension

This formal model may be seen as an artifact [3] to be used as discussion support in order to simulate, evaluate and compare observed and declared decision extensions with declared decision intentions. It is important to stress on the one hand the essentially communicative purpose of this artifact. It is mainly used to communicate between actors around the decision problem: to define the problem and to formalize possible solving strategies. On the other hand, this artifact consists essentially in a symbolic linguistic construction generally based on elementary first order predicate logic calculus.

2.2. Necessary symbolic coding

The importance of this symbolic production derives from the fact that it effectively only instantiates the actual expert decision maker. [4] In our practical implementation we use, for operational purposes, a sub-model of this logic, given by the constraint logic programming languages, more directly suited for immediately computable logical

[3] In the French community, the term *artifact* has a negative connotation. Here this term is to be taken in a positive sense as is common in the Anglo-Saxon community, and it denotes a formal construction supposed to enhance the cognitive abilities of a person.

[4] "... On peut dire que ce que nous appelons "je", nous-mêmes, naît des capacités linguistiques récursives de l'homme et de sa capacité unique d'autodescription et de narration. ... la fonction langagière est elle aussi une capacité modulaire qui cohabite avec toutes les autres choses que nous sommes sur le plan cognitif. Nous pouvons concevoir notre sentiment d'un "je" personnel comme le récit interprétatif continuel de certains aspects des activités parallèles dans notre vie quotidienne. ...", *F.J. Varela, Quel savoir pour l'éthique* ([16]).

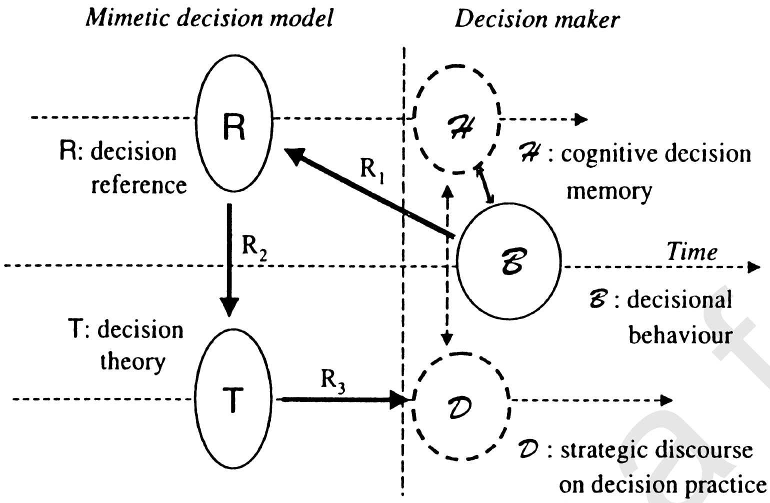

Fig. 3. Describing the decision practice.

specifications. Indeed, concurrent propagation as operationally implemented with the help of these systems allows an efficient study and simulation of such decision expertise.

To understand the operational difficulty of such constructions, [5] we consider a threefold problem: – first, how to describe the empirically observable decision practice under extensional form, – in a second step, how to extract by logic induction from this formal historic description a possible decision intension, i.e. a set of decision strategies or rules apparently underlying the decision extension, – in a third step, how to reflect this decision intension towards the decision maker (see relations R_1, R_2 and R_3 in Fig. 3).

3. Implementing a mimetic decision model

> "Le temps devient temps humain dans la mesure où il est articulé sur un mode narratif, et que le récit atteint sa signification plénière quand il devient une condition de l'existence temporelle" *Paul Ricœur, Temps et Récit* ([13])

Installing a formal engine between the human decision maker and the information return from the daily decision practice involves creating a mimetic formal model of the decision expertise shown by the operator in his real practical activity (see Fig. 3).

Implementation of such a formal model passes through three *mimetic* [6] steps:

[5] "Le Systéme Sémantique Global précède théoriquement ses réalisations textuelles mais pratiquement il ne peut être construit, appliqué et partiellement postulé que dans les moments concrets où l'on se dispose à interpréter une portion textuelle donnée. Les textes sont le résultat d'un jeu d'unités sémantiques préétablies dans le champ virtuel de la sémiosis illimité, mais le processus de sémiosis illimité ne peut être réduit à ses descriptions partielles que lorsqu'on a affaire à un texte donné ou à un groupe de textes. Même les "scénarios" hypercodés sont [...] le résultat d'une circulation intertextuelle précédente. La société réussit à enregistrer une information encyclopédique seulement parce que celle-ci a été fournie par des textes antérieurs. Encyclopédie et Thesaurus sont le distillat (sous forme de macropropositions) d'autres textes. Cette circularité ne doit pas décourager une recherche rigoureuse: le seul problème est d'établir des procédures précises pour rendre compte de cette circularité", *Umberto Eco, Lector in Fabula* ([5]).

[6] The idea of distinguishing three mimetic steps in the historical (re)construction of a decision practice is based on the corresponding work of P. Ricœur, Temps et récit ([13]).

1. a *symbolic coding* (arrow R_1) capturing the semiotics of the decision process description, i.e. installing a symbolic universe of discourse allowing formal expression (from a syntactic point of view) of the behaviour of the decision maker. This construction gives rise to what we denote the exemplary decision *reference* or *extension*;
2. a *configuration* step (arrow R_2) capturing or computing the cognitive strategies giving an insight into the decision maker's behaviour. We denote this construction as the decision *theory* or *intension*;
3. and a most important last step (arrow R_3) installing the *reflective mirror* towards the decision maker in order to create a hermeneutic circle needed to validate and to make evolve positively the mimetic decision model. This is achieved by confronting the mimetic model, i.e. a given decision reference and theory with the corresponding strategic discourse on the corresponding decision practice.

Trying to collect data on a given decision practice necessarily involves capturing physical measurements and/or qualitative assessments from the empirical context in which the decision practice takes place. For instance, in the COMAPS project (see [4]), the involvement of a human expert controller allows us to rely on his expertise to gather all relevant figures and data for describing the control practice. Without this symbolic representation, no decision practice is assessable and no behavioural and discourse data may be collected and represented.

Table 1
Example of hypothetical control practice $\mathscr{B}$

	X_1	X_2	X_c
1	65	64	23
2	61	61	20
3	61	60	20
4	60	60	20
5	61	61	20
6	60	62	21
7	64	64	24
8	60	59	20
9	62	64	21

3.1. Encoding the decision behaviour

Let us illustrate this step with the help of the following simple decision problem from a hypothetical production control expertise. We consider two production process state parameters, X_1 and X_2, taking rational values in interval $[40, 70]$, associated with a tunable control parameter X_c taking integer values around 20. This control parameter is used to maintain both process state parameters between values 60 and 61.

Let us now consider in Table 1 a hypothetical control practice [7]. From this observed control practice we can construct the actual underlying control decision actions in the light of their supposed informational support. This construction leads to a given decision extension, the so-called *decision reference R*. In our simplified example here we may assume, that the informational support of the decision maker consists of the control parameters X_1 and X_2, associated with their first differences from date $t-1$ to t, formally denoted as $\Delta_t^{t-1}(X_1)$ and $\Delta_t^{t-1}(X_2)$ respectively, and the tunable process control variable X_c. The effective control decision action is encoded as first difference $\Delta_{t+1}^{t}(X_c)$ of control parameter X_c from time t to $t+1$. We may furthermore assess a threefold quality judgment ($Y = \{ok-, ok, ko+\}$) which is based on the resulting process state parameters X_1 and X_2 at time $t+1$. Here we assume that they must be both together confined to the interval $[60, 61]$. In Table 2 we have included all these observations.

3.2. Configuring the decision story

From this set of qualified control decisions, we can construct inductively the apparently underlying control strategies. In general this problem is a NP-hard computational job and astonishingly, expert human decision makers generally show good or satisfactory practical performance. In

[7] This example is taken from the Circuit Foil S.A. cooper sheet production control problem described in the COMAPS project ([4]).

Table 2
Hypothetical decision reference R

t	X_1	$\Delta_t^{t-1}(X_1)$	X_2	$\Delta_t^{t-1}(X_2)$	X_c	$\Delta_{t+1}^{t}(X_c)$	Y
1	65	0	64	0	23	−3	*ok*
2	61	−4	61	−3	20	0	*ok*
3	61	0	60	−1	20	0	*ok*
4	60	−1	60	0	20	0	*ok*
5	61	+1	61	+1	20	+1	*ko+*
6	60	−1	62	+1	21	+3	*ko+*
7	64	+3	64	+2	24	−4	*ko−*
8	60	−4	59	−5	20	+1	*ko+*
9	62	+2	64	+5	21	−1	*ko+*

order to be able to support and eventually enhance this performance, we must understand the apparently underlying decision strategies. Here, we obtain for instance some apparent control rules as shown in Table 3 below.

But it is not sufficient to exhibit such possible control strategies computed on the basis of the decision reference. We must also reflect these results towards the decision maker.

3.3. Installing a validating dialogue

It is easy to detect that the level of parameters X_1 and X_2 is positively related to the level of the control variable X_c. What the control reference reveals here is that a typical 'expert' control decision action for a *well functioning process* is to *do nothing* ($\Delta_{t+1}^{t}(X_c) = 0$ for situations t_2, t_3 and t_4) and to *considerably decrease* the control parameter ($\Delta_{t+1}^{t}(X_c) = -3$) if the process state parameters are *definitely too high* as in situation t_1 for instance. But it also reveals a *typical* (or *expert*) control error as illustrated by the control situation t_6, where the shown control decision action is clearly going into the wrong direction (see Table 2 above). Indeed, let us again compute the same kind of control theory this time for the *ko+* qualified control situations. A closer look at the rules emerging from Table 3 above reveals that two different cases may characterize such an erroneous control practice. First, the normal case where, with already too high process state parameters, we continue to raise the control variable (cf Table 2 above: situations t_6, t_5 and t_8). But also a more subtle case appears where, being confronted to seriously high process parameters, the proposed reduction of the control parameter is insufficient to bring back the process state parameters to their normal confined interval (cf situation t_9 for instance).

Table 3
Some apparent control rules

Combinations	Values	Decision	Quality
X_2, X_1	[60, 60], [60, 61]	0	*ok*
X_2, X_1	[64, 65]	−3	*ok*
X_2, X_1	[62, 60]	3	*ko+*
X_2, X_1	[64, 62]	−1	*ko+*

This brief example clearly shows that the reflection of these apparent decision rules towards the decision maker is of tremendous importance.

3.4. The hermeneutic circle

> "Ce n'est pas par le discours ou le $\lambda o \gamma o \sigma$ extérieur que l'homme se distingue de l'animal, car certains animaux sont tout à fait capables de proférer des signes et des sons. Ce qui nous nous caractérise en propre, c'est uniquement le fait qu'une réflexion intérieure puisse précéder la voix. Cette réflexivité nous met à même de soupeser les points de vue qui s'offrent à nous et de les mettre à une distance critique", *Jean Grondin, L'universalité de l'herméneutique* ([7]).

Indeed, this is the specific difference we want to make between traditional OR and AI approaches and ours. From theoretical considerations we know that the inductive configuring step, from which emerges some intensional decision representation, is computationally NP-hard in general, which leaves us from an operational point of view with only heuristic approaches. Now, traditional methods try to adapt the communicative dialogue to the validation of this necessarily heuristic part of the decision support. On the contrary, we try to put the human decision maker effectively in the loop, in the sense that he/she is an essential element of validation of the cognitive artifact. A consequence is the resulting natural multidimensional or multi-criteria representation of the decision problem. To represent the solving strategies, we rely on the well formalized psychological model described in the moving basis heuristic paradigm ([2,1]).

However, from a cognitive psychological viewpoint, it is important to realize that the intentional discourse concerning a given decision expertise will generally produce two different typical descriptions of the underlying decision expertise.

On the one hand, speaking of the decision extension, typical occurrences or representatives in the sense of prototypes (Rosch [14]) will be evoked. On the other hand, concerning the intensional side, the intentional discourse will produce typical properties, family resemblances ([15]) or promising aspect combinations ([2]) which characterize given satisfactory decision acts.

These cognitive biases, resulting from common underlying cognitive mechanisms such as dominance structures and anchoring phenomena, fragmentation of the discourse and uncheckable inductive closures, will produce a natural divergence between these two evocations. There will be a small set of prototypes opposed to a small set of abusively generalized intensional sentences.

Repetitive confrontation of both these representations with an actually observable decision practice will generally lead to a convergence of the decision problem formulation and resolution into a consistent and stable symbolic formulation.

Section 4 reviews some attempts to ecologically validate this methodology.

4. Ecological validation of the cognitive support approach

Our methodological approach mainly tends to support the decision maker either by uncovering and expressing his/her intentional multi-criteria decision discourse, and/or by supporting the decision maker in reducing the cognitive biases naturally occurring in this discourse.

To do so, we briefly present four different methods:

1. un-supervised computing of a decision intension by simply exploiting a historically observed decision extension (Wang [17]);
2. cooperative supervised computing of a decision intension by interacting with the decision maker ([8]);
3. supporting the intentional discourse by repetitive application of intensional and extensional hermeneutics ([3]);
4. supporting the cooperation between human and artificial (machine based) decision experts (COMAPS approach [4]).

4.1. Computing the decision expertise

This approach is close to classic machine learning techniques such as decision trees and rule extraction approaches. The main difference between these approaches and ours lies in the fact that the algorithmic development is driven by a cognitive psychological model of the decision maker, the ‘Moving Basis Heuristic’ proposed by Barthélemy and Mullet [1]. Theoretical requirements are that the decision maker supports a stable and consistent symbolic representation of the decision problem, a fact we denote as ‘*Galoisian*’, and that a historic set of observed decision situations is provided. The decision concerns non cyclic categorical judgments based on multiple aspects from discrete ordinal attributes. A first implementation of the approach is discussed by Wang [17] with an application concerning the observation of 14 clinical psychologists with respect to their usual pedagogical orientations and recommendations. A second implementation, mixing sub-symbolic with symbolic elements, has been realized by Kant [10], leading to the Categ_ART neural net tool. [8] The underlying basic assumption is again a ‘Galoisian’ decision maker concerning categorical judgments based on aspects from discrete ordinal attributes.

[8] Kant himself motivates his tool as a psycho-mimetic approach.

4.2. Cooperative decision expertise extraction

A second case is given by an interactive refinement of the previous approach leading first to the ASCLEPUIS tool as proposed by Guillet [9] which has been applied to an industrial experiment discussed in [8]. A second experience was conducted by Lenca [11] and led to the construction of the APACHE tool with a corresponding application in banking [11]. Again, similar theoretical requirements are presupposed such as a 'Galoisian' decision maker with respect to categorical judgments based on multiple aspects from discrete ordinal scales. [9]

4.3. Supporting the expert's discourse on decision practice

Parallel to the above-mentioned experiments, a third validation experiment concerned the cognitive study of a complex production scheduling problem in the wire drawing industry ([3]). In this context a basic theoretical assumption was that the decision maker is *asymptotically* '*Galoisian*' in the sense that practical application of the method should enable the decision maker to construct and finally support a more or less stable and consistent symbolic representation of the decision problem. No restrictions are put on the kind of decisions and aspects. A detailed description of this experiment may be found in Pichon's thesis [12].

4.4. Supporting the cooperation between human and artificial (machine based) decision experts

Finally, all the preceding approaches have been combined in a common cognitive framework to support the development of the COMAPS tool [4]. Here no restrictions are put on the kinds of aspects (nominal, ordinal or numeric attributes are possible). The decision maker is supposed to be *locally and asymptotically* '*Galoisian*' in the time dimension, in the sense that the symbolic (formal) representation of the decision problem may freely follow the naturally given evolution of the real decision practice and nevertheless, at a given local time point, may be adequately formalized.

[9] It is noticeable that this industrial application represents the motivation for the COMAPS project definition.

5. Concluding remarks

Our cognitive approach to multi-criteria decision aid may be seen as a first step in the direction of intelligent support of man/machine cooperation in the sense that our artificial decision system (the machine) is not intended to replace the actual decision maker in the decision making process, but more subtly serves to uncover and enhance the formal representation of the decision problem and possibly satisfactory solving strategies. In this sense the approach works towards a communicative clarification, where the two involved systems, the artificial formal decision system and the human expert decision maker, work on a common understanding of the problem and good solving strategies.

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