Freedom of Choice and Creativity in Multicriteria Decision Making

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Abstract. This paper presents new approaches to formulating and solving complex real-life decision-making problems, making use of the creativity concept. We assume that the decision-making process is embedded in the system of views and mutual relations between the decision-makers and their surrounding environment, so that creativity, as defined formally in Sec. 2, could play a primary role in the decision-making process. We will investigate multicriteria decision problems, where the decision-maker is unable to fully follow decision-making rules resulting from a standard mathematical formulation of multicriteria optimization problem. This is either due to external conditions (such as the need to make a quick decision, loss of data, or lack of data processing capabilities) or when the decision-maker can manifest creativity related to the hidden internal states of the decision-making process. We will provide a formal definition of freedom of choice (FOC), specifying three levels of FOC for multicriteria decision-making (MCDM) problems. Then we will point out that creativity in decision-making can be explained within the framework of autonomous and free decisions, and that decision-making freedom is a necessary prerequisite for creativity. The methods presented here can be applied to analyzing human decision-making processes and conditions allowing the expression of creativity as well as to designing pathways leading to creative decision-making in artificial autonomous decision systems (AADS). The applications of the latter include visual information retrieval, financial decision-making with feature identification, intelligent recommenders, to name just a few.

Keywords: Multicriteria decision-making, freedom of choice, creativity, artificial autonomous decision systems, reference sets.

1 Preliminaries

The aim of this paper is to provide the fundamentals for intelligent, autonomous and flexible embedded applications that can govern independent systems or engage in interactions with humans and artificial intelligent systems. We will directly address the cognitive aspects of such systems, focusing on new approaches to human-computer interaction. Although neither purely normative, nor purely descriptive decision

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theory is used, both are merged in intelligent intention-understanding (and –reconstructing) systems based on modeling the cognitive phenomena of human decision-making. The results presented here should constitute the first steps towards designing a prototype generator for such systems as well as specialized systems derived from the generator. These systems would be tailored to specific applications, including visual preference processing and *decision pilots,* a subclass of recommenders that provide rankings and implement constraints but not the final choice.

Throughout this paper we will refer to decision problems that can be modeled as a multicriteria optimization problem

$$(F: U \rightarrow E) \rightarrow \min(P) \tag{1}$$

with a set of selection rules S, by definition

$$S \subset \{s: 2^{F(U)} \times K \rightarrow 2^U: \forall V \subset U, \omega \in K\ s(F(V), \omega) \subset P(U,F))\}, \tag{2}$$

where U is the set of admissible decisions, the function $F=(F_1,\ldots,F_N)$ is a vector criterion, E is an ordered space with a partial order P, which is constructed from individual preferences concerning the values of F_i, $i=1,\ldots,N$ and some additional conditions imposed on the values of F. Each selection rule S maps the known evaluation with F of a subset V of U and an external knowledge state $\omega \in K$ into the subset of potential best-compromise decisions in V with respect to ω, which – to conform with (1) - are elements of the set of *Pareto optimal* (or *non-dominated)* decisions $P(U,F)$.

Most often, $E=\mathbb{R}^N$, P is defined by a closed and convex cone, selection rules are applied sequentially to single elements of $F(U)$, and K is a set of relations contained in the expert knowledge of the decision-maker or consultant. For instance, K may contain information concerning the constraints to be imposed on trade-off coefficients between criteria F_i. In order to enable the theory presented in this paper to be applied to artificial decision systems, we will examine the possibility of retrieving criteria from the environment using feature identification and retrieval methods, cf. e.g. [5],[7],[8]. We will also assume that the external knowledge and decision selection rules use trade-off and direct information simultaneously, the latter given in form of reference sets [10],[12], anticipated consequences [9],[14] and the history of previous choices.

When studying the theoretical background of intelligent intention-understanding systems, regarded as a class of cognitive decision support systems, we encountered a problem – the limited ability of artificial systems to make creative decisions. Creativity, in its common-sense meaning, was possible only up to a specific extent and constrained by superordinated (human) system objectives. This problem led in turn (cf. [13]) to the definition of the principles of *freedom of choice (FOC),* which we will now formulate in a more formal form as

Definition 1. *Freedom of choice of the 1st order* in problem (1)-(2) is the ability to choose an optimal solution from a given set of admissible alternatives with respect to a set of selected optimality criteria that are specified explicitly. *Freedom of choice of the 2nd order* allows the decision-maker to relax the constraints [11], or – more generally - to embed the initial set of admissible decisions into a superset. Finally, *freedom of choice of the 3rd order* is the power to select one's criteria of choice in the feature space of real-life objects, which are the subjects of the decision maker's final choice.

The criteria considered when defining FOC may be accompanied by external preferences and decision-support procedures, which can also be a subject to choice in some circumstances. Based on the above notions, in the next section we will define creativity as the ability to act within a knowledge-based variable decision model with information inflow. Note that the essence of the notion of *autonomy* is to *have the ability to make decisions.*

The above types of freedom of choice will be attributed to the *primal decision-makers*, which is a basic notion. Their features, actions, relations and interactions between them can be modeled by an ontology. The basic class of this ontology can be extended by adding *secondary decision-makers*, who will be given the ability to learn from their past decision experience and by *supervisors*, who can assign a level of FOC and creativity to other decision-makers. In this paper we will consider a situation where the ability to transfer freedom of choice is restricted to artificial autonomous systems, such as embedded intelligent systems for autonomous vehicles, research robots etc.

The behavior of decision makers when solving multicriteria decision-making (MCDM) problems can be properly explained by fundamental research on neural and psychological decision-making mechanisms, including creativity and additional cognitive phenomena. In Sec. 3 we will show that the use of direct preference information such as reference sets together with feature detection procedures can allow for an automatic formulation of criteria of choice, which – in turn – gives artificial autonomous systems second-order freedom of choice. The greatest freedom can be explored in common multicriteria decision problems, which can be interpreted as multi-step games with nature, the latter implementing an unknown, non-feedback strategy. The solution methods of extended MCDM problems, including cognitive phenomena models, depend strongly on the application area. Therefore different mathematical models will be applied depending on the different mental processes that are behind the solutions of decision problems in different areas. This may happen even if the multicriteria optimization problem formulations are of the same kind, yet the additional preference structures differ considerably. The investigation of these companion circumstances can allow us to assign appropriate MCDM models and methods to different classes of complex decision problems, which is one of the key issues in MCDM.

Furthermore, in Sec.4 we will discuss the problems related to the design of intelligent and creative decision support engines capable of understanding the implicit preferences in real-life human decision problems by reconstructing and disclosing the latent intentions of the decision makers. We will show that to achieve this, computer-based artificial decision systems must possess the ability to search and select criteria of choice, i.e. to have third-order freedom of choice. Such capability has never before been given to artificial systems in an unrestricted form, and numerous authors, from professional foresight to sci-fi writers, have warned about intelligent artificial beings able to make and implement a decision. In Sec. 4 we will also strive to discuss the question as to whether decision support systems (DSS) should possess freedom of choice and creativity and to what extent such systems should use cognitive principles to understand the intentions of human beings. The above-mentioned high-level artificial systems will be endowed with freedom of choice and cognitive skills such as the ability to search, understand, classify and select information, in particular audiovisual streams.

As a field of application, we will point out the multicriteria decision-making problems related to gathering, filtering and selecting images on the web using pattern discovery, recognition and classification, as well as cognitive decision theory methods [8]. The main real-life applications will be systems able to represent, analyze and interpret human behavior. Another specific application field of artificial systems able to follow cognitive decision-making mechanisms is embedded systems. In the latter, human decision makers lacking the ability to make a decision can be assisted in part or even replaced by an artificial system capable of making and implementing decisions. In addition, the above framework will allow us to create new DSS architectures and model the interactive decision processes.

2 Main Problems and Ideas Related to Creative Decision Making

Although creative decision making should be regarded as one of the highest-level cognitive functions of the human mind, its relation to other branches of cognitive science is sometimes unclear. There are four main reasons for this:

- The fragmented partial nature of research on eliciting and modeling human preferences, where psychometric research and the prevailing theoretical studies on multicriteria decision analysis are not fully consistent, and the decision support systems are often designed without paying enough attention to real-life human decision making mechanisms.
- The tendency to restrict the modeling of human decisions to cases where the decision maker is either able to formulate criteria of choice or able to explicitly define the set of admissible alternatives. What follows is a mathematical programming or gaming problem, and subsequent efforts are focused on solving it, without taking into account cognitive phenomena like quickly changing preferences, an extension/contraction of the decision scope resulting from different cognitive processes, replacement of consequence modeling by a single score called a utility or value function.
- The lack of adequate decision models for complex system behavior when the information underlying the decision making has a graphical form. In such situations, autonomous systems are usually restricted to performing pre-defined tasks, according to their clearly defined hierarchy of goals (like an unmanned vehicle's task to reach certain a destination with a load at minimum cost or time, avoiding obstacles and other vehicles)
- The vivid debate concerning the existence of the human decision maker's utility functions, which has been the subject of numerous studies over past decades and has re-directed the interest of researchers to questions other than creativity issues.

This is why insufficient emphasis has been put on researching creative mechanisms of decision-making processes so far (a noteworthy exception is [4]).

As mentioned in the previous section, we will relate the creativity that can be shown when solving the decision problem (1)-(2) to the ability to vary the decision model. In this way, a new decision admitted is better than any optimal or best-compromise decision under the previous model, subject to new quality criteria, however. A necessary condition to modify the problem is the ability to adapt the decision-making process according to external information inflow.

Thus, we can formulate the following:

Definition 2. A *creative extension* of problem (1)-(2) will be defined as a morphism $\varphi=(\varphi_1,\varphi_2,\varphi_3,\varphi_4)$ transforming the set of admissible alternatives U, the vector criterion F, the preference structure P, and the set of decision rules S into a new problem

$$(\varphi_1(F):\varphi_2(U)\rightarrow E_1)\rightarrow min(\varphi_3(P)) \tag{3}$$

with the new set of decision rules S_1 induced by $\varphi_4(K)$, i.e. if $s_1\in S_1$ then

$$s_1:2^{\varphi_1(F)(\varphi_2(U))}\times\varphi_4(K)\rightarrow 2^{\varphi_2(U)} \tag{4}$$

A sequence of creative extensions $\varphi_{(1)}\rightarrow\varphi_{(2)}\rightarrow\ldots\rightarrow\varphi_{(n)}$ such that the output problem of the morphism $\varphi_{(k-1)}$ *is an input problem for* $\varphi_{(k)}$ *, for* $k=2,\ldots,n,$ will be called the *creative decision process.*

A scheme representing the creative process that allows one to extend a multicriteria decision problem while taking into account the above situations is presented in Fig.1.

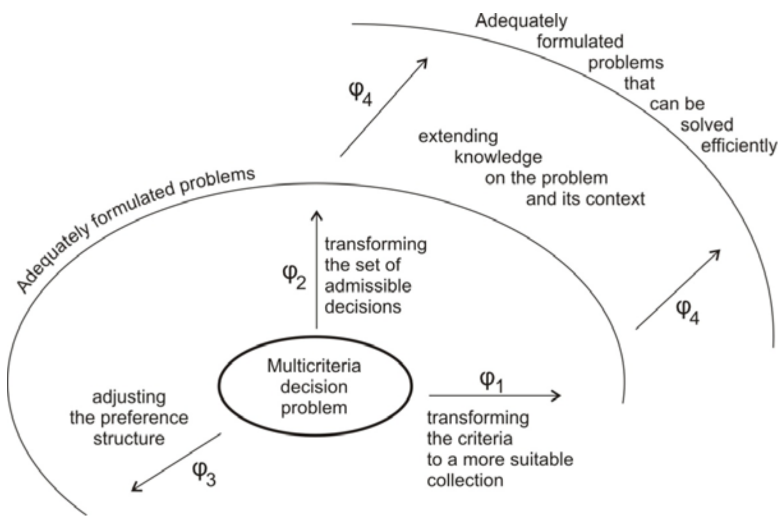

Fig. 1. A scheme of the creative analysis of an MCDM problem

Problem-solving approaches that explore the above-defined creativity concept and lead to a more penetrative analysis of decision problems have already been published [9], [10]. These include:

- The problem of replacing the search for a single best-compromise decision by selecting a subset of admissible decisions that is evaluated by new aggregate criteria such as the average values of original criteria calculated on a subset;

- Considering the problem in a temporal context, taking into account a.o. the choice of an optimal time to make the decision (or announce it), the variable values of attributes that characterize decision alternatives, the possibility of replacing a decision made by another choice etc.;
- Creative elimination of redundant objectives and elements of a preference structure performing an analysis of the previous decision maker's choices and using essential feature-detection algorithms;
- The replacement of a single utility value by a multi-level model of the consequences of a decision made, which can lead to an anticipatory analysis of the problem;
- Creative exploration of the set of decision rules, taking into account cognitive aspects of the decision-maker's behavior.

We will refer to the above-mentioned examples of creative problem extensions in the next sections of this paper. Moreover, creativity can contribute to overcoming the following drawbacks of general approaches to multicriteria problem solving, decision models and support systems:

- Decision support systems are often confused with data storage, retrieval and visualization systems. This corresponds to the first basic problem of decision-making, i.e. decisions made under uncertainty and lack of information. The awareness of the second kind of decision-making problem, i.e. problems where the decision maker's preference structure is non-compatible with the data available or must be elicited, is considerably lower. The knowledge of cognitive decision-making mechanisms that can increase the efficiency and adequacy of this class of decision support systems is even lower.
- There exist a variety of so-called interactive decision-making algorithms (cf. [6]), where the plausibility of information required during the dialogue procedures is not checked, and its further processing does not guarantee final success in form of a convergence to a satisfying compromise decision. Mathematical convergence conditions need not be compatible with the cognitive process of decision making, do not take into account discoveries other than the identification of the next candidate for a compromise solution, and even a simple 'change of mind' by the decision maker during the formal procedure can result in a 'convergence disaster'.
- Contemporary DSS are rarely individualized, and their ability to learn based on previous choices is restricted to new instances of the same problem, if at all.

In spite of the above-mentioned drawbacks, the appearance of computer-aided decision support has contributed to a remarkable change in the practice as well as the philosophy of decision making. The traditional value and role played by the intuition and experience of the decision maker remain relevant, but they should be accompanied by an interactive computer-aided process consisting of

- systematic analysis of available data
- data acquisition and representation.

This should be followed by formulating or re-formulating a mathematical model of the particular decision situation with a representation of knowledge about the preference structure.

While it is difficult to judge the effectiveness of a formal model at this stage, the degree of decision maker satisfaction with the decisions generated using the data and mathematical model can provide information on the model quality. The final phase of the decision process may involve heuristic and non-formalized stages in which initial expectations, intuition, and experience are confronted with the results of machine analysis.

It is commonly accepted that the decisions made should either be optimal, sub-optimal, or compromise. This assumption requires a set of optimality criteria to be defined for each admissible alternative. The notion of optimality has passed an instructive evolution aimed at reaching a higher-level of FOC: from the global minimum of a scalar objective function (usually no freedom of choice), through the notion of a vector minimum in partially ordered criteria space (allowing a choice from among non-comparable non-dominated solutions), to the idea of the extended optimum, as considered in subset selection or dynamical extension problems [10]. According to (3)-(4), these belong to creative decision problem extensions and to the identification of search criteria in a cognitive process [8], the latter leading to third order FOC.

An approach to embedding creativity into decision analysis and support can be based on several key principles:

- the idea of excluding any loss of information about the decision to be made, even inconsistent and contradictory information, which should first be judged as to whether it touches upon the same objects and time instances; pre-defined verification rules can turn out unsatisfactory, which creates a playground for creativity to cope with additional information acquisition and consistency checking
- most decisions should be considered in an *open information space*, i.e. a situation in which the inflow of information in real-time is relevant to the decision making; here, creativity can manifest in the appropriate exploration of this information.

The first principle is based on the following three underlying assumptions, which originate from real-life experience:

- first, we assume that all information available should be applied to the decision process as soon as possible (pre-classification or elimination should be used only exceptionally)
- second, it is assumed that mutually inconsistent or contradictory information received from the decision-maker should be treated as a result of a cognitive process; using a reconstruction of the latter, it should be re-defined or aggregated, but not neglected during the decision-making process
- third, we assume that reference sets and bicriteria trade-offs are the most suitable tools to sufficiently describe many real-life preference structures.

With the usual approach used in interactive decision support, partial information is used there to generate a decision and further information is processed only if the solution was not generated to the decision maker's satisfaction. The final decision depends on the subjective sequence in which the additional information was processed. Moreover, such procedures prolong the decision-making process unnecessarily, and may lead to a loopy inconsistent process, since the convergence conditions for interactive procedures are usually based on overoptimistic assumptions concerning human rationality. Despite the above disadvantages, the success of this philosophy may be explained by the well-known paradigm which states that even an incorrect decision is sometimes better than no decision. In addition, some decision makers, especially those acting as managers or politicians, need an alibi or some kind of decision support to justify a voluntarily or randomly chosen decision.

The first assumption implies that the above approach should be replaced by more complete and thorough analysis of data available.

The second assumption implies the need to understand the human cognitive process that accompanies the decision making. Incorrect or inconsistent statements are often caused by the shortcomings of human perception of decision object features. Instead of forcing the DSS users to give another reply, an intelligent DSS should trace the replies, find and indicate the possible source of inconsistencies using a cognitive perception model [1]. For instance, as a cognitive and temporal extension of the well-known AHP method [2], we propose a procedure which measures the user's reply time in pairwise comparison queries, then relates it to the reliability of scores entered using the observation that the faster the reply is generated, the higher the probability of getting an extremal value of the scale. Another example of using cognitive models to improve well-established interactive procedures is to replace the presentation of one element at a time (classical multicriteria interactive methods) or two elements at a time (pairwise-comparison-based methods) to the user, by presenting arbitrary sets of alternatives at one time and using different types of questions that may be easier to answer, depending on the perception profile of this particular user.

The third assumption refers to the *bicriteria trade-off hypothesis* [13], which states that irrespective of how many criteria are used to make a decision, human decision-makers intuitively try to group them into two aggregated groups and then solve them as a bicriteria problem. This hypothesis, which has recently received new justification coming from brain research, will be further investigated. In particular, one should attempt to find the factors that influence the sequence of aggregation, relating them to feature perception and selection processes.

The second principle mentioned above is based on manifold evidence from experiments performed with web information sources. For instance, when using price comparison engines and recommenders to support goods selection in e-commerce systems, the availability of price offers was changing in time lapses comparable with those needed to make a decision, so no classical optimization problem could be formulated (cf. experiments with air ticket availability [1] and electronic auctions). Apart from internet-based search, similar effects can be observed in personnel or apartment choice, where optimal stopping-based approaches have been applied. The expected rising information flows on the internet will accelerate this process, and create the need for more adequate decision support, using cognitive process modeling.

The notion of creativity proposed here allows us to extend the interactive problem solving process to interactive problem formulation and data acquisition. Thus the problem statement and solution processes are combined in one interactive procedure with several levels of interaction. We expect that this novelty will become a standard in future decision support systems, and its first successful implementation will decide its dominance of the intelligent recommender market.

3 Multicriteria Decision Problem Formulation by Autonomous Systems Based on Reference Sets and Feature Selection

A further extension of common decision analysis approaches that can be attributed to creativity is based on finding relevant features of objects using so-called reference sets. As the features of objects to be chosen can be regarded as pre-criteria, the detection of features by an artificial autonomous decision system (AADS) can allow an automatic formulation of criteria of choice. This can, in turn, give artificial autonomous systems second and higher order freedom of choice. With this approach, the decision maker is able to formulate and process several classes of relevant reference values. However, its scope of subjective handling is restricted, thus the FOC is also restricted.

The foundations of feature subset selection have been given e.g. in [7]. Referring to the reference set approach in multicriteria analysis [12], it should be noted that presenting typical representatives of each class is a common approach in classification procedures. Further steps involve finding characteristic features of such representatives [5]. An intrinsic part of this procedure is learning the relevance of features, the preferences, and, finally, the relevance of objects described by the features. For classification purposes, this approach is often called 'learning from examples'. The approach presented here differs from that used for classification and recognition in the instrumental role of 'cut-off' points used during the procedure: the reference points which form reference sets need not be elements of the database to be researched, and, with the exception of status quo solutions (class A_2 defined later on), do not even need to exist. The essential information is the preference relationship between the elements indicated by the user, who defines the reference points. The examples point out how such a relation acts, then the retrieval algorithm learns how the preferences can be expressed by comparing individual features, and applies them to select alternatives automatically.

Reference sets as defined in the theory of MCDM [12] constitute a tool originally designed to support portfolio selection and design decisions. They are defined as sets of characteristic points in the criteria space with similar levels of utility. There are four basic types of reference sets:

- A_0 – boundaries of optimality – upper (in the case of criteria maximization) boundaries of an area where optimization of criteria makes sense
- A_1 – *target points* –optimization goals
- A_2 – *status quo solutions* – existing solutions which should be improved in the optimization process or lower boundaries of the set of satisfactory solutions
- A_3 – *anti-ideal point* – solutions to avoid.

These set types can be further split into subclasses. All, or only a few, classes of reference sets may occur in a decision problem, while the consistency of problem formulation imposes a number of conditions to be fulfilled by the reference sets. In the context of making a compromise choice, the reference sets can be interpreted as follows [8]:

- A_0 is defined by a set of queries provided by the decision-maker. We assume that the goal of the decision-making process is to find a solution, which is most similar to one of his queries. When no such query can be provided then $A_0=\varnothing$,

- A_1 is a set of criteria reference values ranked by the decision-maker as *most relevant*,
- A_2 is a set of points in the criteria space ranked by the decision-maker as *relevant*,
- A_3 is a set of points in the criteria space ranked by the user as *irrelevant*.

In addition, we can define elements of set A_4 as points ranked by the user as *anti-relevant*, i.e. characterized by attribute values opposite to those sought after. We assume that explicit user preferences constitute the primary background information. We also assume that the criteria can be constructed gradually using the preference information elicited during the interactive search process. Thus, even the number of relevance criteria cannot be assumed to be known a priori as various classes of potential solutions may be characterized by different sets of features and coefficients. The usual application of reference sets is an interactive decision process, where the originally specified targets (set A_1) converge to more realistic, yet acceptable values, the status-quo solutions are updated during the procedure to include newly acquired information about the results of similar choice problems, and so can vary the other classes of reference sets. A scheme of selecting a decision when different classes of direct information about the values of criteria have been defined as reference sets is presented in Fig.2 below.

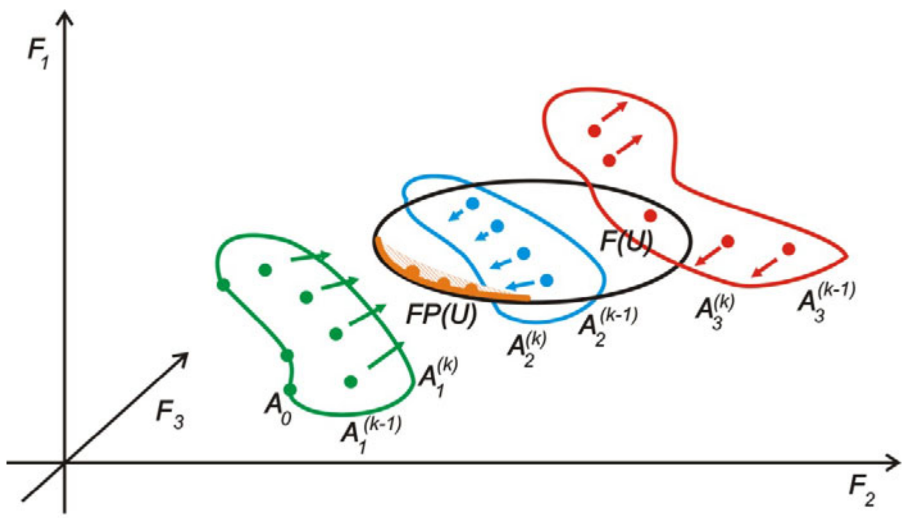

Fig. 2. An example of reference sets used for selecting a compromise solution of a multicriteria decision problem. Arrows denote the update directions during an interactive procedure.

The experiments made on image databases [8] illustrate the considerable potential of the above approaches, which can increase the feasibility and efficiency of Internet-wide graphical recommenders, bringing them to the level of creativity.

Thus a major improvement of Content-Based Information Retrieval (CBIR) can be achieved by a combined application of classification methods and multicriteria preference elicitation. This research direction promises further progress, with the main targets being:

- an optimal man-machine interface when designing a query and providing feedback information
- optimized navigation in the feature space and adaptive feature space contraction/expansion.

An autonomous Internet search engine based on reference sets, with a number of pre-defined high-level features incorporated is now being implemented [8] to allow a reliable efficiency assessment of the proposed method for this type of application. Its performance will depend on the quality of high-level feature extraction, on the elaboration of a reliable feature extraction algorithm, and on the design of an adaptive decision-making engine, which is, in itself, one of the most challenging problems of creative decision making related to information retrieval.

4 The Design of Creative Decision Support Procedures

The implementation of the reference set method outlined in the previous section can be designed as a user-friendly decision support system allowing users to consider different classes of reference sets, criteria-space constraints, and trade-offs in one model. In addition, it can easily incorporate the decision freedom features, such as changing the set of criteria (FOC-level 3), variable constraint set (FOC-level 2), freedom to choose from a set of nondominated points by selecting an appropriate compromise solution selection method (FOC-level 1). Taking into account the creativity as it has been defined by (3)-(4), one can conclude that the FOC of an appropriate level implies the ability of the decision-maker to apply the corresponding components of the creativity morphism $(\varphi_1,\ldots,\varphi_4)$. In real-life DSS applications that would be capable to support creativity in multicriteria decision problem solving, one would require that such systems can support problem formulation as well as its solution within an integrated process. In addition, smart and *creative* acquisition of additional information that can facilitate problem solving should be supported.

The scope of potential applications of this methodology has not been a priori restricted, and it should provide well-suited decision support for a large class of underlying multicriteria decision problems. For instance, specialized decision support procedures can be designed for solving industrial robot diagnostics, financial decision making and planning, or group decision and negotiation problems. Social decision processes can be modeled in a similar way as the decisions made in controlled discrete event systems [10].

Besides its impact on real-life-oriented decision support methodology, the notion of creativity can contribute to the solution of several unresolved theoretical problems, such as the estimation of the value function in image retrieval decision-making problems and the simultaneous analysis of additional preference information given in form of multiple classes of reference points and trade-off constraints [10],[12].

Based on theoretical background provided in [9],[10],[11],[14] one can propose a scheme of such creative decision support system that integrates multicriteria problem re-formulation, enables its embedding in more general problems, allows for additional information acquisition during the decision-making process and takes into account the temporal aspects of decision-making. A graphical scheme is shown in Fig. 3.

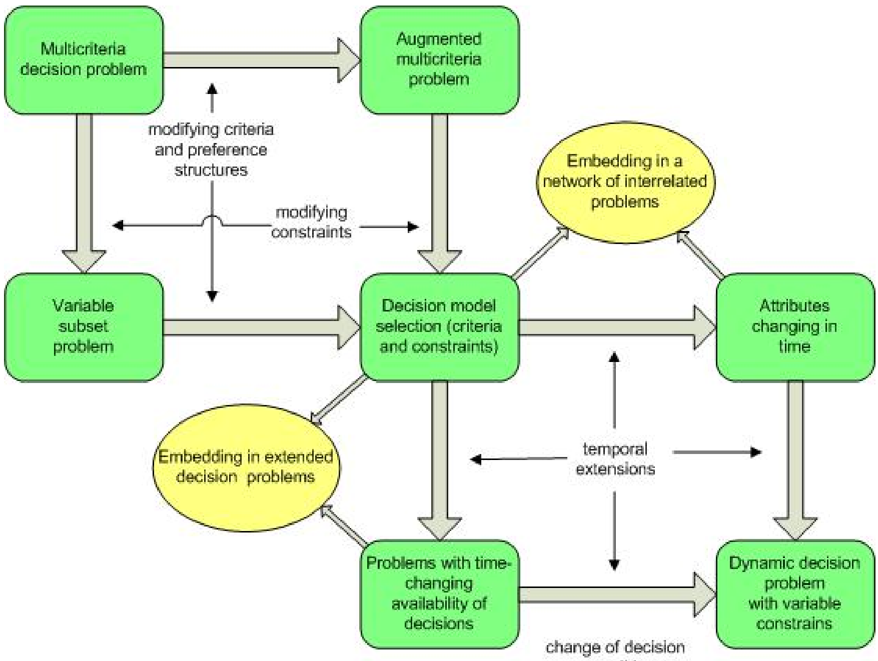

Fig. 3. A scheme of multicriteria decision problem formulation that can be supported by a creative decision support system

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The common principles of computer decision support tools can be listed as follows:

- Irrespective of how advanced mathematical methods are used to process the underlying information, the sophisticated decision support procedures should not be visible to the decision-maker (*mathematical ignorance assumption*)
- It is impossible to avoid checking the consistency of information supplied by the decision maker, including the preference statements. If necessary, they can be redefined in the background so that the consistency conditions are fulfilled.

Nervous, tired or irrational decision makers will supply responses that can lead to chaotically generated dominant alternatives, so that the conditions for terminating the decision-making process were never fulfilled. Nevertheless, in many situations the same nervous or tired decision makers may urgently need a quick and efficient decision aid. To cope with such situations, decision support systems for common use, such as recommenders, should feature an autonomous mechanism (*automatic decision pilot*) that makes it possible to either defer the decision or make a *cautious decision* autonomously. The latter should be understood as the selection of an alternative which conforms maximally to a decision made previously by this system's user and to the individual cognitive decision model.

Having formulated a decision problem, the computer-aided decision support should require no specialized computer or mathematical knowledge. The use of additional preference information in form of reference sets and bicriteria trade-offs to choose a compromise decision, supplemented by extensive visualization and guideline procedures, will allow the system to provide the resulting compromise decision in annotated graphical form. External experts may only provide assistance to apply more penetrative consequence analysis techniques or to retrieve missing data. When artificial systems are given second or third-order FOC it should be noted that formulating the optimization problem with a preference modeling mechanism is just a part of the overall problem formulation, where the representations of external knowledge [3] and the models of objects to be chosen can be more sophisticated than the decision problem itself. However, attempts to construct automatic models of control systems exist [10], so further research on this problem will follow.

5 Final Remarks and Conclusions

Intelligent autonomous systems, such as forthcoming cognitive online recommenders constitute a new market and social challenge. Their implementation horizon, from the current stage of development, product search and price comparison machines, seems to be on the same level as the expected starting point of implementing new classes of creative DSS outlined in this paper that can create a new market trend. Similar expectations can be formulated as regards graphical and hybrid search engines as well as cooperating mobile robots, clinical support systems and other medical and healthcare applications.

New decision-making concepts and methods which will be developed and covered in further research will make it possible to design intelligent mobile artificial systems that will mainly act autonomously, make discoveries, anticipate the consequences of a decision made (cf. [9], [15]) and enhance the quality of interaction with, possibly remote, humans. As robot decision making will be strongly based on robot vision, merging visual information processing with creative decision support procedures is indispensable. The specific applications of creative robot decision making include mobile space, volcano, and submarine research robots, fire and flood rescue robots, etc. One potential application of the latter class of systems is a decision pilot able to act autonomously where there is a lack of human guidance, as in a flood emergency situation.

The development of computer-aided DSS to date has assumed that users behave in a rational, idealistic way, possessing only limited capacity to check consistency and correct choice. In contrast, the class of intelligent and creative DSS presented here will be able to act autonomously when necessary. Coupled with scene understanding capabilities, when embedded in a mobile system, they will be able to select targets and paths leading to them based on different images compared and analyzed with multicriteria optimization algorithms.

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