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Supporting the identification and structuring of decision problems using knowledge-based exploratory analysis

Suranjan De
Santa Clara University, sde@scuacc.scu.edu

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Suranjan De
Department of Decision and Information Sciences
Leavey School of Business and Administration
Santa Clara University
Santa Clara, CA 95053
E-mail: sde@scuacc.scu.edu

Introduction

This paper presents the principles underlying our ongoing efforts to develop a knowledge-based exploratory analysis system (KEAS) which supports decision problem structuring (DPS) through an interactive process of consultation between a decision maker (DM) and a KEAS. This research is an outgrowth of the author's earlier experience in developing and using a decision support system to support decision making in a real world situation [1]. In our earlier work, the DSS (consisting of a database, a model base, and a user interface) was helpful in supporting the decision maker's efforts once the decision maker was able to articulate the exact nature of the decision problem that must be solved. However, our experience suggests that the DSS was lacking in its ability to support the decision maker's efforts at recognizing the precise nature of the decision problem; this issue has been referred to as problem recognition [3] and issue formulation [6] in the DSS literature. More specifically, we found that:

(i) a DM has difficulty specifying

- a set of relevant objectives at the outset,
- attributes to measure objectives before DMs know the characteristics of the system that best meets their objectives at an appropriate level, and
- constraints before DMs know the consequence of imposing these constraints.

(ii) a DM seeks *insights* during the problem solving process,

(iii) a DM gains insights by

- conducting analyses of interest to them,
- applying their own substantial knowledge about the application domain, and
- using the problem-solving knowledge of expert analysts

(iv) at the outset, a DM may not have a detailed plan for accomplishing a task; they conduct one or more analyses and then decide what to do next.

The underlying premise of this paper is that a DM may not always be able to precisely define a decision problem at the outset; we refer to such decision problems as ill-structured. A decision situation may be ill-structured because of the DM's inability to completely specify its decision elements and measures to quantify them; this may result, for example, from the DM's need to resolve complex issues resulting from conflicting objectives. We believe that, in an ill-structured decision situation, a KEAS must allow the DM to explore interactively the ramifications of achieving a specified set of objectives or selecting from a specified set of alternatives; such exploratory analyses may result in a deeper understanding of what can and cannot be achieved in a decision situation. We believe that a DM can attempt to better structure the problem through a careful examination of various issues pertaining to the decision situation, aided by supporting analyses provided by the KEAS.

In general, an exploratory analysis is the generation of computational results that a DM may seek to examine. We believe that, through a systematic examination of results of such analyses, a DM develops insights into the nature of a decision problem and a better understanding of what can and cannot be achieved. Hence, the KEAS is designed to facilitate a process-oriented approach that assists a DM in arriving at a complete specification of the decision problem through a cognitive process of learning, understanding, and assessment. This specification includes the identification of decision elements (e.g., objectives, alternatives, and evaluation criteria) that characterize a decision situation and of specifying the DM's expectations in dealing with that situation. We refer to the process of arriving at a specification of the decision problem as decision problem structuring (DPS). The KEAS is designed to support DPS; once a decision problem has been structured, established DSS methodologies can be applied to arrive at a decision.

Overview of the KEAS

We define DPS as consisting of the following activities: (i) identification and structuring of objectives of the DM, (ii) specification of attributes to measure the achievement of objectives and, possibly, to measure potential consequences, (iii) creation of a set of alternatives to be explored, and (iv) specification of evaluation criteria in the form of a preference structure or a value function to evaluate those alternatives. Since a DM may be unable to perform all of these activities until he/she understands the decision problem better, we advocate an incremental approach to DPS in which a DM may gain insights into the nature of the decision problem through a series of exploratory analyses.

We propose three key concepts that must underlie the development of a KEAS. The first key concept is the use of "expectation failure" as a guiding principle in conducting exploratory analyses. We assume that a DM approaches a decision problem with a set of beliefs and desires regarding various aspects of the decision situation; we capture these beliefs and desires in the KEAS as the DM's "expectations". Moreover, the DM must be able to provide some description of the decision problem structure, even if it is tentative and incomplete. The decision problem structure forms the context or decision frame in which exploratory analyses are conducted. If the DM's expectations are not met, a

phenomenon we refer to as "expectation failure," the KEAS assists the DM in revising previously stated expectations and the decision problem structure. Hence, a DM's problem understanding is viewed as an evolutionary process in which the DM systematically revises expectations and the decision problem structure as a result of insights gained through exploratory analyses. The KEAS supports the DM's cognitive process through a systematic evaluation of expectation failures; the generated decision problem structure is, in effect, a by-product of this consultative process.

The second key concept is the use of a knowledge base to support exploratory analysis. The knowledge base captures the decision problem structure and the DM's expectations regarding its structural elements, which together represent the DM's "cognitive schemata" [2]. We propose a methodology for the initial creation and subsequent revision of a knowledge base during a consultation; a revised knowledge base reflects the evolution in the DM's understanding of the decision problem, gained primarily through an evaluation of expectation failures. A DM's evolution in problem understanding can be captured through an incremental process of constructing and reconstructing a knowledge base. Hence, our approach to a knowledge-based exploratory analysis is based on the use of expectation failures to guide exploratory analyses of interest to a DM and the concurrent manipulation of a knowledge base to reflect the DM's incremental learning that occurs during such analyses.

The third key concept is the use of an explanation mechanism within a KEAS. Since exploratory analysis is guided by the DM's stated expectations, we believe that an explanation of their failure can provide additional insights. An explanation ought to be more than just a trace of the problem solving process that led to an explanation failure, a strategy that is widely used in expert system explanations. A satisfactory explanation of an expectation failure in a DPS context must consist of additional supportive arguments drawn from the knowledge base that reinforce the results obtained during exploratory analyses. Moreover, it must explain the options for further analysis in view of an expectation failure.

The KEAS effectively uses these concepts to provide insights into a decision situation faced by a DM. A key aspect of this feature is the exploitation of the linkage among the key elements that drive exploratory analysis: a DM's expectations regarding the decision situation, themes (objectives, alternatives etc.) that characterize the decision situation, and plans to conduct exploratory analysis. In other words, an expectation failure is identified when there is an assessment of a failure in the linkage among the DM's proclaimed expectations, themes, and plans; the key to a DM's understanding of a decision situation is the KEAS's ability to explain the failure in the expectations-themes-plan chain. The enhanced understanding that results can be captured by modifying appropriate structural elements in the knowledge base (and thereby in the decision problem structure).

Supporting Exploratory Analysis using the KEAS

We have identified three types of knowledge that are required to support exploratory analysis First, the knowledge base must capture concepts (which we collectively call *themes*) that guide the analysis process and against which results of exploratory analyses must be evaluated. Themes that are useful in DPS include the DM's objectives, attributes to measure the achievement of objectives, alternatives to achieve the DM's objectives, and the DM's preference structure that can be used to evaluate selected alternatives during exploratory analyses [4,5]. The notion of themes is not new to decision analysts; however, it has not been widely used as part of an interactive, computer-based DSS to support DPS.

Second, the knowledge base must capture the DM's expectations associated with these themes. An expectation is the representation of the beliefs, desires, or principles of the DM regarding a specific aspect of a decision situation. An expectation associated with a structural element (such as an objective or an attribute of an objective) can be encoded in the knowledge base as part of that structural element. The segment of the knowledge base that captures themes and expectations is essentially a collection of such structural elements; we refer to this knowledge base segment as a *thematic structure* (TS).

Finally, the knowledge base must capture knowledge of tasks required to conduct exploratory analyses of interest to the DM; such knowledge is captured in a segment of the knowledge base called *planning structure* (PS). Hence, the knowledge base in a KEAS (which we refer to as consultation knowledge base or CKB) consists of two distinct components, TS and PS.

Exploratory analysis is guided by knowledge of the DM's themes and her expectations associated with these themes. It may begin with a statement, possibly incomplete, of the DM's themes and expectations. The results of an analysis show whether the expectations of the DM underlying the analysis have been met. If there is a deviation from the DM's stated expectations, a KEAS must assist the DM in revising her expectations and the themes that are captured in the decision problem structure. Through a series of such analyses (and evaluations of associated expectation failures), the DM may gain a better understanding of the decision problem; a better understanding, in turn, leads to a more accurate specification of the decision problem. The results of this improved understanding can be captured by revising the knowledge base. The exploratory analysis process is complete when the DM is satisfied with the generated decision problem structure. Hence, exploratory analysis facilitates the generation of a decision problem structure that accurately reflects the DM's values.

The overall consultation procedure that uses CKB is summarized below.

Step 1. Specify contextual knowledge.

Step 2. Specify an analysis that must be performed. Specify the reason for interest in this analysis.

Step 3. Perform analysis identified in Step 2.

Step 4. Assess the results of analyses generated in Step 3. If satisfied with the results, go to Step 6. If not satisfied, identify expectation failure(s).

Step 5. Generate plausible explanation(s) of expectation failure(s).

Step 6. Revise knowledge base as a result of explanation generated in Step 5. For additional analyses, go to Step 1.

Step 7. If satisfied with the decision problem structure, stop. Otherwise, go to Step 1.

Design and Implementation Issues

A prototype of the proposed KEAS is currently being developed using Symantec C++ on a Macintosh 6100/66 computer. We hope to report on these efforts in the future.

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