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Decision Making in Complex Systems

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Individuals, organizations, and governments are often expected to make decisions of far-reaching consequences. Judgment and decision-making capabilities are important facets of human intelligence. Systematic studies of these topics have commenced only in the 1960s. Simultaneous developments in computer hardware and software and in fields such as artificial intelligence have given impetus to the study of human decision making from descriptive, normative, and prescriptive points of view. Real-world decision problems are often unstructured and difficult to formulate. There are multiple objectives, distributed decision makers and difficulties in acquiring different types of knowledge needed for problem solving. Human knowledge is often available in natural language with its inherent ambiguity and vagueness. While a human being has only "bounded rationality," his intuition and common sense enable him to make good decisions in using qualitative nonnumerical information in narrow domains of expertise such as medical diagnosis. He has to be supported by decision aids when confronted with situations in complex systems. In this paper, we briefly review decision making in complex systems from the point of view of intelligent decision support systems, which applications to the project management task.

KEY WORDS: complex systems; decision making; decision support; artificial intelligence; intelligent systems.

1. INTRODUCTION

Decision making is an all-pervading activity. Individuals have to make decisions often in their lives, and similarly firms and governments have to make decisions continuously. While some decisions seem simple or trivial, certain others seem to have far-reaching consequences. Some decisions are of the one-shot types, while others involve a sequence of actions influenced by feedback of results from earlier decisions. Some decisions seem ad hoc, while others appear to have been made after consideration of all the available knowledge of the problem. It is, therefore, necessary to understand the underlying reasoning process before

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studying decision making. At the outset, it is important to note that agents (individuals or firms) make decisions to achieve some goals following an evolutionary and causally motivated reasoning process.

The term decision making is used to refer to a range of intelligent activities including making a judgment based on reason, selecting a preferred option based on deliberation, and assessing a rapidly evolving situation to choose quickly a course of action.

There appears to be a difference of opinion about the ability of human beings to make sound decisions. Recent developments in artificial intelligence (AI) in computer science have led to the evolution of expert systems and knowledge-based systems in a variety of domains such as medicine, finance, law, and engineering. In these systems, conscious effort is made to elicit the decision-making behavior of a human expert. A human being's expertise in a narrow domain is captured in terms of "If . . . Then . . ." rules in the system's knowledge base characterizing his "Situation–Action" behavior. This shows that human experts are believed to be capable of making sound decisions in situations such as medical diagnosis or engineering design which are narrow domains of human specialization.

The systematic (normative) approach to decision making involves the following steps:

- recognizing a decision problem,
- understanding and modeling the system and its environment,
- recognizing the decision maker (DM),
- recognizing the DM's objectives and preferences,
- analyzing the constraints,
- developing the alternatives, and
- choosing among the alternatives.

2. STUDIES IN JUDGMENT AND DECISION MAKING

Systematic studies on judgment and decision making commenced in 1960s (Arkes and Hammond, 1986). These problems can be studied from several perspectives. The decision maker (DM) may be a human being, a computing machine, or an ideal agent. The approach and emphasis vary depending on whether the problem is studied in a school of engineering, medicine, management, or law. Topics of problem solving, mental imagery, memory, thinking, language, learning, and behavior belong to the realm of psychology. Psychology is also concerned with the nature of human judgment and decision-making processes emphasizing the types of errors people make in complex decision situations and suggesting ways of overcoming these shortcomings. Computers and

AI have provided the credible metaphor of "human information processing" in the mind machine. Statistics, particularly, Bayesian statistics, has provided a wide range of general techniques for optimal decision making under uncertainty with various assumptions. AI has always stressed the computational aspects of decision making. Expert systems inspired by AI are concerned with knowledge acquisition and reasoning. Philosophy looks at normative theories of human rationality (Simon, 1986). In operational research and management science, mathematical models of judgment and decision analysis have been considered. Computer systems evolved from data processing machines to management information systems and intelligent decision support systems employing knowledge engineering. Decision-making models were studied in the context of business, economic, and military settings and these models have been evaluated with respect to their ability to represent the human decision-making process (DMP) and the underlying rationality of human beings. The research efforts were mainly along three main streams.

- *Descriptive:* Using models and theories to describe and explain human decision-making behavior by studying human beliefs and preferences as they are.
- *Normative:* Using axioms to make optimal decisions and to study the logic of decision making and nature of rationality, attempting to suggest how good decisions ought to be made.
- *Prescriptive:* Developing techniques and aids for supporting and improving human decision making.

The knowledge is often imprecise and the DMP is only approximate, as several questions are to be answered:

- how to obtain knowledge about utilities;
- how to elicit, represent, and present several types of knowledge;
- how to generate and present the alternatives; and
- how to carry out the DMP.

3. DECISION MAKING IN COMPLEX SYSTEMS

Studies in decision making range from normative models of decision analysis and optimal decision making (suggesting how decisions ought to be made) to descriptive models of naturalistic decision making (studying how humans actually make decisions). There appears to be considerable divergence between the theoretically optimal strategies and the behavior observed in practice. It is, therefore, generally accepted that rational decision making is problematic in complex systems.

Human decision makers are generally reluctant to make important decisions in complex situations and resort to actions such as

- procrastination;
- endless pursuit of better information;
- reliance on habit or tradition;
- deferring the decision to aids when there is no particular reason to think that they can do better; and
- converting the decision problem to alternative (possibly simpler) paradigms such as optimization, classification, planning, assignment, etc.

This probably explains the development of a large number of aids for decision making ranging from consultants and system analysts to intelligent decision support systems (IDSS). The role of an IDSS in a complex system is shown in Fig. 1. This may be called the prescriptive approach wherein techniques and aids are supporting and improving human decision making are devel-

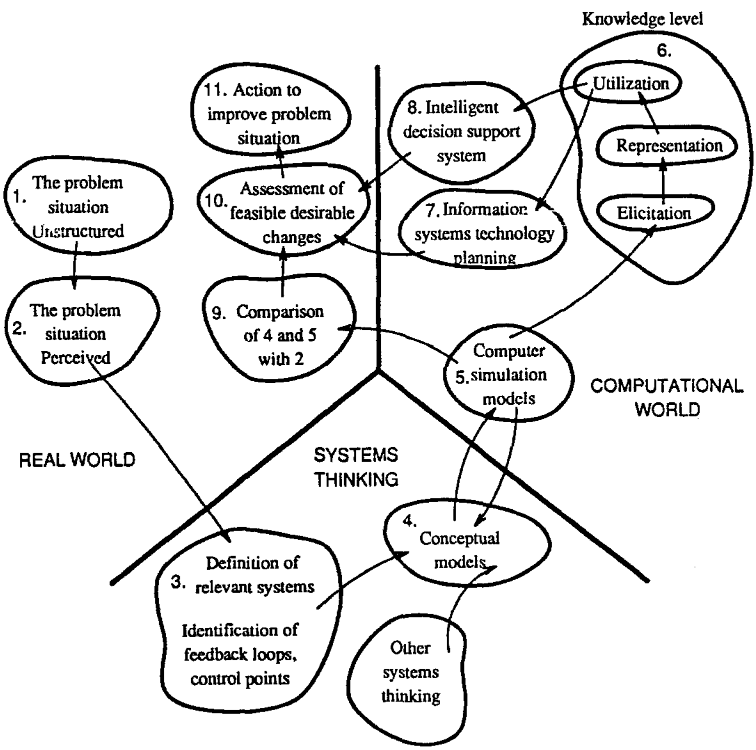

Fig. 1. The role of an IDSS in a complex system.

oped by utilizing the human being's strengths and compensating for his biases and weaknesses.

Decision making in complex systems is difficult because of

- interconnected systems,
- multiple objectives and constraints,
- dynamics,
- modeling issues,
- imprecise goals and constraints,
- uncertainties in the environment,
- the counterintuitive nature of solutions,
- multiple decision makers, and
- incomplete sharing of information among DMs.

In this paper, we present the recent developments in decision making in complex systems from the point of view of IDSS. We illustrate this with our recent work on IDSS development for project management (Noronha, 1993).

4. INTELLIGENT DECISION SUPPORT SYSTEMS (IDSS)

IDSS are interactive computer-based systems that use data, expert knowledge, and models for aiding organizational decision makers in semistructured problems incorporating problem-solving techniques of AI. IDSS draw inspiration from decision analysis and decision theory, artificial intelligence, knowledge-based systems, systems engineering, and cognitive engineering.

The ultimate goal of IDSS is to help a decision maker (DM) "to find the most preferred solution for his/her decision problem." When there are multiple criteria, there is no method that would enable the DM to compare all possible solutions at the moment of final choice. There is a need for implicit or explicit assumptions regarding the DM's preference structure. There is a need to understand the notion of rationality of the DM and also focus on the DM's actual behavior (behavioral realism).

4.1. Decision Analysis

Decision analysis involves a priori decomposition of the decision process into its components before the decision is made. Decomposition is often achieved by the construction of a decision tree. The DM should know the following.

- What are the courses of action open to the DM?
- What are the possible consequences of each of the actions?
- What is the likelihood of each scenario?
- What is the worth of each consequent event of each scenario to the DM?

In reality, the decision tree is only an all-pervasive root metaphor, which makes it natural to speak of *the moment of choice* to a DM *faced with several well-defined alternatives* portraying branches emanating from a single point in the tree. The problem of developing systematically a set of valid alternative courses of action has been neglected in the decision theory. It is also difficult for the DM to estimate the probabilities and utilities in a real-world situation. The usual paradigm of maximizing a subjective expected utility criterion is neat and utopian. The real world is complex and the situation is characterized by continually changing environment, ill-defined goals, ambiguous utilities, and high time pressure. The decision process is to be represented carefully.

4.2. The Decision Process

Just as in other management problems such as planning and scheduling, even in decision making we can define a spectrum of problems defined over worlds characterized by (Noronha and Sarma, 1991)

- decision problems in known deterministic worlds,
- decision problems in benign real worlds, and
- decision problems in hostile real worlds.

The first category of decision problems may easily be transformed into optimization problems and planning problem in artificial intelligence. The second category of decision problems are those encountered in radar, communications and medical diagnosis such as hypothesis testing, signal detection, or pattern recognition/classification problems. The third category are those occurring in games and other distributed AI situations. There are multiple decision makers guided by multiple objectives, multiple world views, and fuzzy goals and constraints. When the DM recognizes the need to make a decision, he constructs a model of the world based upon his perception and understanding of it at that time instant.

4.3. Artificial Intelligence

Artificial intelligence aims to build intelligent systems. On the one hand, it studies logic and reasoning in general problem solving, and on the other it recognizes the importance of domain specific knowledge in solving decision problems in diverse spheres of human endeavor. The emphasis in expert systems has been on acquisition and representation of knowledge elicited from domain experts.

4.4. Knowledge-Based Systems

Artificial intelligence research during the last two decades has shifted away from domain independent techniques such as heuristic search in favor of reliance on knowledge specific to the target domain. This led to the birth of knowledge engineering and the early knowledge-based systems were expert systems, where the emphasis is on acquisition of knowledge from human experts and its representation and storage in the knowledge base of the system. IDSS philosophy differs somewhat from that of expert systems and the emphasis is on amplifying a DM's capabilities, utilizing his strengths while compensating his weaknesses.

4.5. IDSS Design Goals

There are many goals that must be achieved by any IDSS implementation.

- IDSS should support problem formulation. It should allow the DM to formulate the originally ill-defined problem on an incremental and evolutionary basis.
- It should accept diverse types of knowledge which the DM can readily provide and attempt to use it to the maximum extent possible. Ability to provide qualitative and fuzzy reasoning are appropriate here.
- The human should dominate the decision-making process, unlike an autonomous expert system.

5. IDSS FOR PROJECT MANAGEMENT

Project management is a real-world problem that provides adequate richness for exploring development of an IDSS. The decision-making tasks involved in such an IDSS are the following.

1. Ground Work: Project feasibility study
   - Should the project be accepted?
2. Project planning
   - What are the project objectives?
   - How do you decompose a project into a set of activities?
   - What are the alternative ways of carrying a project?
   - How do you estimate the required durations and other resource requirements?
   - How do you identify the milestones and set deadlines?
3. Project Scheduling
   - How do you achieve optimal scheduling?
   - What is the impact of resource constraints on project scheduling?

4. Project Monitoring
   - How do you decide on slippage?
   - How do you decide on rescheduling or termination?
5. Project Replanning
   - What are the issues relating to project replanning?

Noronha (1993) proposes some novel tools for developing an IDSS for this problem. His problem-solving methodology may be outlined as follows.

1. Develop a graphical model called a project influence graph (PIG)
2. Qualitative model development
3. Numerical model development
4. Subjective model development
5. Sensitivity analysis
6. Operations planning
7. Simulation and Scheduling

5.1. Project Influence Graph (PIG)

The classical planning tool in project management is the PERT chart which represents an activity precedence graph. While PERT is useful in scheduling and control, it does not aid decision making. The Project Influence Graph (PIG) is a powerful new tool for intelligent decision support in planning, scheduling, and project management applications. The PIG represents the project at multiple levels of hierarchy. At the top level, it is an influence diagram with decision nodes and value nodes. As one goes down to lower levels, the decision nodes branch out to multiple activity charts coupled by and/or graphs.

The project planning phase involves key decisions regarding synthesis of goals and objectives with constraints, resource allocation, and critical timing decisions. The project influence graph systematically captures the planning process at several levels and conveniently depicts the evolution of the final PERT chart for project scheduling. The PIG is thus an ideal front end user interface tool for an IDSS for project planning and management. The PIG exhibits strategic focus at the top level and operational details as needed at lower levels.

5.2. Model Development

Real-world uncertainties may be handled via qualitative reasoning in the PIG using a combination of probabilistic and fuzzy reasoning as needed. A well-developed PIG can be used for midcourse corrections and for implementing contingency plans if the schedules slip from the original plan. Models such as petri nets can be derived from the PIG and may be used for simulation studies and answering questions such as "the probability of missing a deadline."

6. CONCLUSIONS

This paper briefly outlines decision making in complex systems. The role of IDSS is emphasized along with the use of artificial intelligence techniques to help people to make good decisions and to train them in the decision making process.

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