N88-16404

Knowledge-Based Simulation*

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ABSTRACT

The complexity of space systems and increased costs for construction and operation make it necessary to both evaluate these systems in advance and to provide crew members with adequate advisory facilities in flight to determine the impact of changes in operational parameters. Currently, it is difficult to provide these facilities because of the need to weigh multiple objectives against one another when making system operation decisions.

Simulation has long been recognized as a useful tool for studying the behavior of complex systems which are conceptually difficult to understand and often mathematically intractable. Unfortunately, there are problems which limit its utility. Factors which influence its use include: the timeliness of results, cost, accuracy, lack of flexibility, and extensive programming requirements. However, combining simulation methodologies with A.I. techniques yields a practical approach to simulation known as knowledge-based simulation. The result is a tool which not only aids in model development but makes specific recommendations based on simulation analysis output.

This paper will describe an architecture for a knowledge-based simulator. The task of scheduling represents an area in which such a tool might be applied. More specifically, scheduling for crew and ground support activities for the shuttle and space station would benefit from the application of knowledge-based simulation. The knowledge-based simulator would allow the crew and support personnel to schedule and reschedule activities in a timely and flexible manner to examine and test possible plans.

INTRODUCTION

"Simulation is the process of designing a model of a real system and conducting experiments with this model for the purpose of either understanding the behavior of the system or of evaluating various strategies (within the limits imposed by a criterion or set of criteria) for the operation of the system" [6]. Systems which are characterized by complexity and task criticality require an accurate model of the system and its operation to allow the exploration and examination of system characteristics and to provide an opportunity for "fine-tuning" the proposed event set prior to execution. In addition, there must be adequate interaction facilities available during simulation execution to determine the impact of changes in important operational parameters. This is especially important when many interacting objectives must be considered in the decision-making process.

An approach to simulation is required that can accurately handle the complexity while retaining flexibility and timeliness. Combining simulation methodologies with knowledge-based techniques and object oriented approaches to modeling facilitates the automation of many of the manual functions associated with simulation; particularly modeling and analysis of results. An important attribute of this approach is the separation of data and procedures. Current simulation

* This work was supported by the McDonnell Douglas Independent Research and Development program.

languages embed data in procedures, thus limiting flexibility. The knowledge-based simulator is accessible interactively to allow the user to dynamically explore possibilities. Simulation becomes a more practical tool for "fine tuning" plans prior to implementation and performing "what if" exploration.

CONVENTIONAL SIMULATION

Simulation, in general, allows observation of a system's behavior through the controlled application of changes to a particular model. Simulators are tools that make it easier for humans to solve problems by providing information which describes the performance of a system under specific conditions. However, the results produced by current simulation techniques must be analyzed by the user. In this sense, conventional simulation systems are essentially descriptive rather than prescriptive tools that provide little insight or guidance to the inexperienced user. Their use can lead to inaccurate system assessments since the evaluation of what occurs in the simulation is the responsibility of the user.

The greatest advantage provided by simulation is that, by working with an idealized model of a system, it is possible to perform evaluations that could not be performed on the real system. Simulations are often used when an analytical solution either doesn't exist or is extremely complex; experimenting with the real system is too expensive, too time-consuming, too disruptive, or even destructive; or the actual system does not yet exist.

Current simulation techniques require the user to perform a manual set of steps. The user defines the model using a simulation language such as SLAMII or GPSS. It is necessary to verify the model prior to simulation. Analysis of the output is performed using operations research techniques and user experience. The user must then formulate conclusions which are justified by the analysis. The manual nature of these approaches results in a number of disadvantages. Constructing the initial model is often costly in terms of both people and computing requirements. Current techniques only address activities which have been explicitly specified in a model which may or may not accurately represent the system. This results in a serious lack of flexibility which is required for representing the dynamic systems. The accuracy and timeliness of both the input and the output data are often questionable when dynamic systems are modeled because of the time required for input and the difficulty in interpreting the output.

KNOWLEDGE-BASED SIMULATION

Knowledge-based techniques provide a basis for the development of a knowledge-based simulation tool to aid decision making in complex systems which cannot be adequately modeled or understood using mathematical techniques. Along with recommendations, knowledge-based simulation is able to provide the rationale to support a proposed action. The fact that the model knowledge, the operation logic, and the control components are separate provides modularity and facilitates the modification or addition of facts and rules which control the system. The use of a knowledge-based approach results in improved flexibility, improved user comprehension and greater accuracy and reliability of recommendations. The knowledge-based simulator has the ability to analyze developments over time, predict the future according to the assumptions implicit in the simulation model, analyze the results according to the rules and facts contained in the knowledge bases, and issue recommendations to the user.

Knowledge-based simulation applies the A.I. techniques of knowledge representation and reasoning to automate and expand the conventional simulation approach. These techniques expedite the development, verification, and modification of the simulation model by supporting direct interaction between the user and the simulation model. In addition, they can be combined with traditional operations research techniques to provide a facility which not only evaluates and explains simulation output but which allows the user to explore alternatives from any point in the simulation. The knowledge-based approach to simulation uses an object-oriented representation of relationships between entities. It provides a more flexible model which is more amenable to change than are models programmed in more traditional simulation languages. [1,2,3,4,5]

ARCHITECTURE

When defining an architecture for a knowledge-based simulator, a number of areas must be addressed. These include the user interface, the model definition/editor, the simulation set-up, the simulation, the simulation analysis, intelligent exploration, and the associated knowledge bases. Figure 1 illustrates the basic components of a knowledge-based simulator.

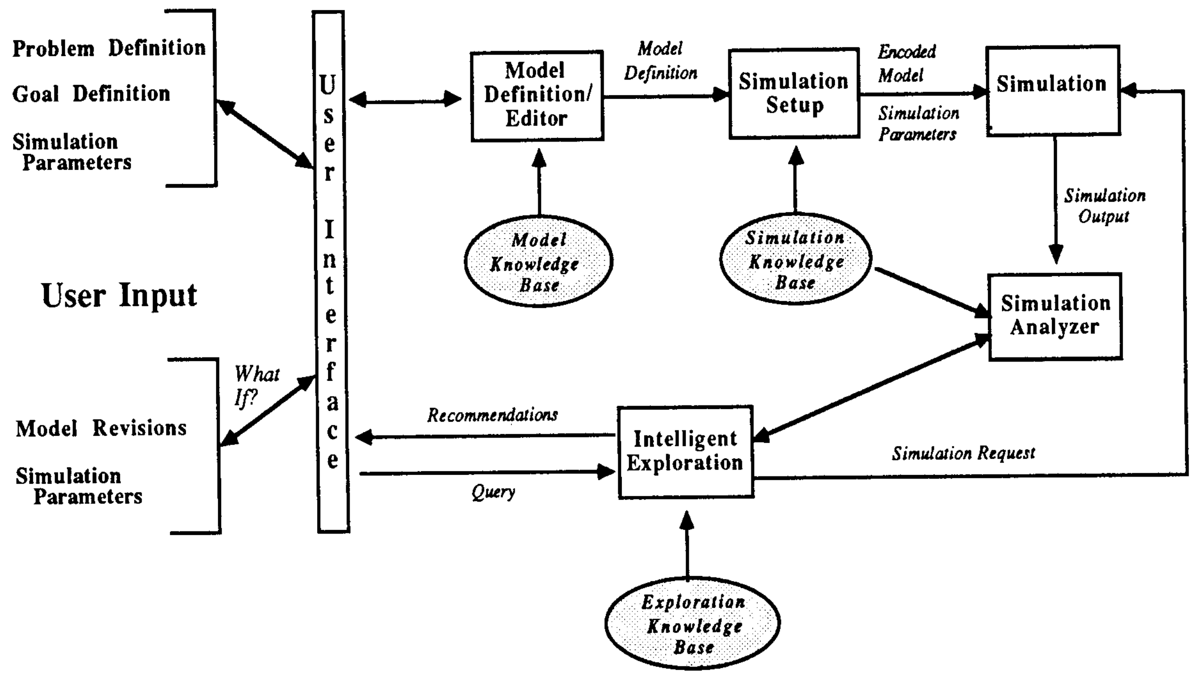

Figure 1. Architecture for a Knowledge-Based Simulator

User Interface

The User Interface is the user's link to the simulation environment. It must support the model building process, the output process, and the simulation evaluation process. When designing a user interface for any program, it is important to consider the user's background, the circumstances in which the program will be used, what inputs are required, what can be automated, what output information is important, and what form the information must take to be most easily understood.

Knowledge-based simulation specifically requires that the user be able to enter a problem description and goal statement as a set of constraints to the system. This input goes to the Model Definition/Editor which synthesizes a model for the simulation. The user also enters Simulation Parameters which include instructions for collecting simulation statistics.

The User Interface must handle the conclusions drawn from simulation analysis and produced by the Intelligent Exploration module. It must allow the user to query the Intelligent Exploration module for an explanation of these Recommendations. These queries may request that the simulation be modified and rerun starting at a specific point.

Model Definition/Editor

The model is synthesized from a combination of user input in the form of a Problem Definition and Goal Definition. The Model Definition/Editor facilitates revisions to the model by making it readily accessible to the user. It is also necessary for the model to be checked for validity, consistency and completeness prior to simulation. The latter is a difficult problem!

The Model Knowledge Base contains operational data such as system states and state transformation logic. This information specifies dynamic values, relationships among time dependent variables whose values change as a result of system operation, and operation procedures which move the system from state to state [1]. In addition, the Model Knowledge Base might include skeleton entities which can be instantiated to specifically identify attributes and behaviors which define the entity [3].

The model itself is composed of declarative objects and relations which match the user's concept of model organization. The model contains rules and facts about the system on both a global and local level. This knowledge defines system components, their attributes, and the environment. The environment definition includes organizational goals, system entities, entity relationships, and operational logic for dynamic interaction.

Simulation Set-up

The Simulation Set-up module takes the model and data collectors specified by the user and produces a set of instructions for the simulator. The output of this module initiates the simulation using the appropriate simulation parameters and instructions.

The setup and subsequent analysis access the Simulation Knowledge Base containing facts and rules pertaining to the simulation. This knowledge base contains procedures for performing the simulation and for evaluating results. A facility must be provided to allow the user to specify an existing procedure or to define new procedures [3]. This knowledge base should be extensible by the user.

Simulation

The simulation will initially be based on a discrete event approach. A clock will be advanced to the current time as significant events occur. Significant events are defined by the model. The simulation will be patterned after the object oriented techniques used in knowledge-based tools such as Simkit from Intellicorp, Inc.

Simulation Analysis

The data resulting from the simulation is analyzed according to a user specified goal. The user can indicate whether conventional operations research techniques or user defined methods should be used. An approach to this analysis begins with the representation of each goal as a set of constraints. Instruments for data collection provide input to the analysis. Following the simulation, each constraint is evaluated using a constraint utility index which could be created at the time the model is synthesized [3]. The effectiveness of a given event set can then be determined by considering the relative importance of each constraint in terms of the event set being evaluated. The output of the analysis is sent to the Intelligent Exploration module for presentation to the user in the form of Recommendations based on the evaluation results.

Intelligent Exploration

A knowledge-based simulator should provide the user with recommendations for further improving simulation and analysis results. The user can then utilize this information to perform further simulations in an exploration or optimization mode.

Graphic interaction allows the user to select objects and explicitly edit their attributes and behaviors. The user should be able to query the states of visible objects, obtain graphical representations of relations among objects, and use the display to explain the behavior of the simulation wherever appropriate. This allows both intelligent explanation and intelligent exploration. Exploration allows the user to selectively modify a simulation, examine options from any point in the simulation, focus attention on selected aspects of the model, perform sensitivity analysis, and ask how particular results might be achieved [5]. To this end, the facility must be able to backtrack to a previous point in the simulation.

It is important that the user have confidence in the recommendations. Therefore, it must be possible to request further explanation. In fact, the primary task of explanation is to convince the user that a model is behaving reasonably and to show how the simulation arrived at a particular result. This can be done graphically or by means of a query.

CONCLUSIONS

Knowledge-based simulation will provide a flexible, interactive environment for the simulation of complex systems. The architecture described takes advantage of both conventional simulation approaches and knowledge-based techniques to define a knowledge-based simulator. This architecture can be extended to a variety of simulation applications.

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