Paper submitted to **Workshop on Coupling Symbolic and Numerical Computing in Expert Systems**, Boeing Computer Services AI Center, Bellevue, Washington, August 27-29, 1985.

SOME PERSPECTIVES ON KNOWLEDGE ENGINEERING FOR EXPERT SYSTEMS AND SIMULATION

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Abstract: Simulation and expert systems (ESs) are both computer-based technologies for the support of human knowledge processes. Current ESs use superficial rules to encode expertise and do not have access to the deeper causal models used in simulation. Attempts are being made to combine the two technologies. This paper presents a number of perspectives on the problems of doing this, including a theoretical framework for knowledge engineering that is adequate to encompass both.

INTRODUCTION

Simulation has been one of the most significant applications of computing systems since the early development of the digital computer. It is particularly important in control, decision support, and in aiding human knowledge processes by allowing theories and ideas to be tested in operational form. In recent years there has been an explosion of interest in another type of aid to human knowledge processes, with applications in control and decision support, **expert systems** which provide one person with interactive access to another person's skills encoded in a computer in some way.

At first sight this new technology seems quite remote from that of simulation. ESs encode the processes of the human mind, knowledge representation and inference. Most simulation applications are concerned with physical variables that seem far more concrete, and certainly better understood, than the concepts of "knowledge" and "reasoning". There also appears to be a confrontation of paradigms involved:

(a) the classical approach to designing a system solving some problem is to identify the problem in detail, model it mathematically, and then develop an algorithm for its solution either analytically or through simulation;
(b) the ES approach is to assume that the problem is not identifiable in detail but that heuristic solutions to it exist and are exemplified in the skills of experts who are known to be able to solve it, and to model the behavior of the expert in order to develop an algorithm.

This is a substantial shift in problem solving techniques that represents a fundamental change in scientific paradigms. The success of ES technology in solving previously intractable problems in industrial control, medicine, geology, and so on, has created widespread interest in the technology and acceptance of the new paradigm. It has many significant immediate applications. However, there are many links between the technologies of simulation and those of ESs, and possibilities for even more significant applications if the two can be blended effectively together.

This paper considers three significant relationships between simulation and ESs:

(i) that an ES can be considered as the simulation of the mind of a person whereas most simulation is that of the physical world - these can be seen as complementary developments of computing to provide new **media** to support the knowledge, decision and control processes of people;

(ii) that ESs and simulations can be combined in decision support systems and the varied interplay possible between people, simulated experts, simulations and the real world can be used to design new forms of system with enhanced capabilities;

(iii) that a hierarchical model of knowledge and action can provide a framework encompassing both simulation and ESs, and clarify the relationships between them.

As a remark in passing, we note that it is generally assumed that "later is better" and hence that the new logic-based ES technology is an advance beyond the older numeric-based simulation technology. An alternative way of viewing the history of computing is to note that until the 1970s computers were more expensive than people, but that now the situation has reversed. The cost-effective applications of computers in the early years were in significant tasks that people perform badly such as large-scale numeric computation and large-scale information storage and retrieval. Only now does it make sense to begin to substitute computers for people in tasks that people do relatively well such as decision under uncertainty and management. Inference-rule-based ES technology is in many ways simpler than numeric data processing. However, it has not been cost-effective to apply it in the past.

These last remarks are intended to suggest that we should beware assuming that past-generation simulation techniques should be incorporated as modules in present-generation ESs. What we need is a broader systems concept that encompasses both and recognizes the strengths and weaknesses of both technologies.

EXPERT SYSTEMS ANS SIMULATION AS MEDIA FOR COMMUNICATION

Simulation and ESs may be seen as providing **complementary** approaches to providing aids to the person in coping with the world. Simulation provides models of the world which can be used to test ideas before they are tried in the real world. ESs provide models of people which can be used to discuss ideas before they are tried in the real world. This distinction is one that predates computers and occurs in human knowledge acquisition and the media to support it. We may gain

knowledge of the world by direct action or by conversation with others as shown in Fig. 1 (Gaines & Shaw 1985a).

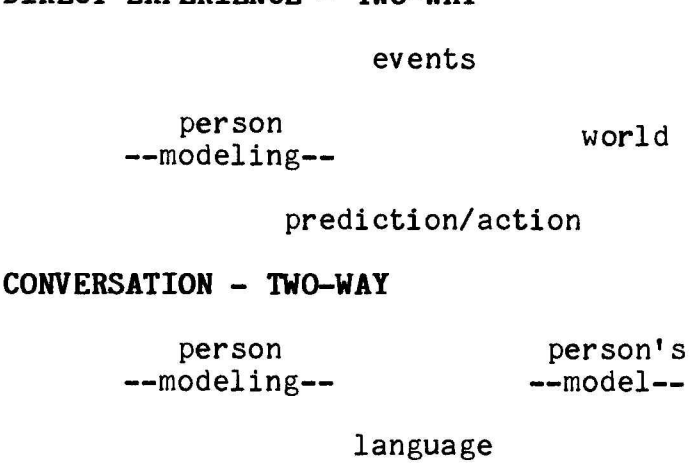

Fig. 1 Two modes of human knowledge acquisition

As shown in Fig. 2, representational media such as photographs and television provide an alternative channel for experience of the world. Symbolic media such as letters and books provide an alternative channel for conversation about the world.

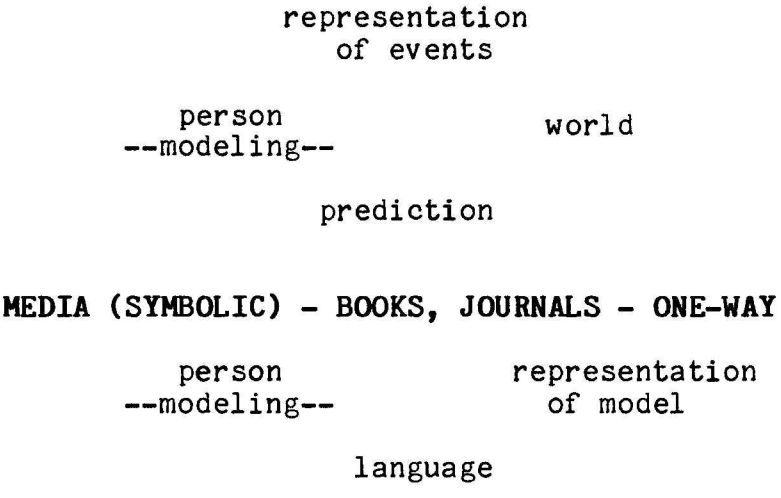

Fig. 2 Two modes of operation of media

A major disadvantage of past media has been that they are one-way. We can experience remote events through television but cannot interact with them. We can access the thoughts of an absent person through his writing but cannot discuss them with him. As shown in Fig. 3, computing can be regarded as a providing a new medium which is two-way and hence interactive (Gaines & Shaw 1984b). Simulation corresponds to mediating direct experience of the world. Expert systems correspond to mediating conversations with people.

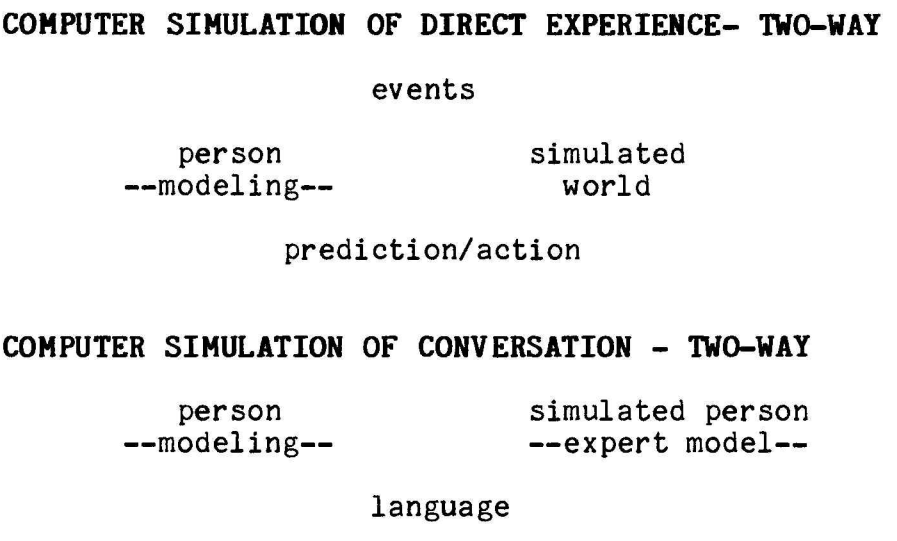

Fig. 3 Computing in the evolution of media: an interactive medium for encoding simulated worlds and people

However, once we view simulation and ES in this way, and when we realize the capability of ES to acquire knowledge both from people and through experience, it is apparent that the two complementary uses of computers shown in Fig. 3 may be combined in a variety of ways. Figure 4 shows a system in which simulation and ES provide mutually supportive capabilities to a person in a decision support system that might well be termed a computer-based **prosthetic brain.**

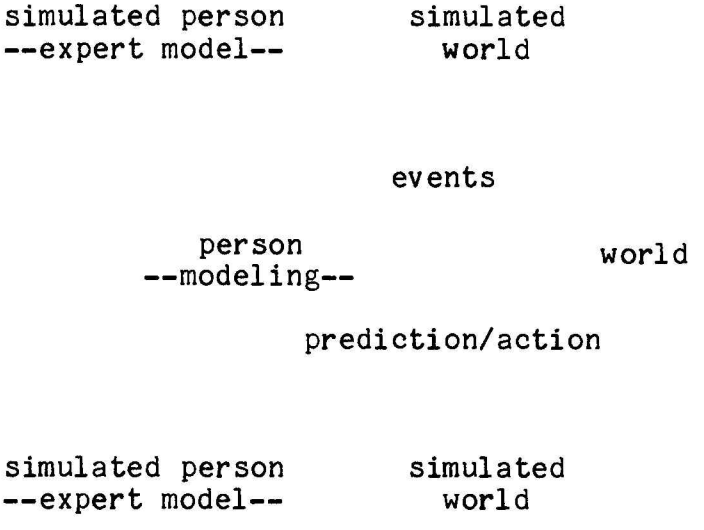

Fig. 4 Combination of simulation of the world and simulation of the expertise of people in a decision support system

In this example, the person interacts with the world. He may test predictions and actions in simulated worlds. He may ask advice from simulated experts. He may turn control over to simulated experts. The

simulated experts may use the simulated worlds as part of their knowledge processing. The simulated experts may have access to real-world experience for knowledge acquisition. The simulated worlds may be updated from real-world experience, by the person or by simulated experts.

This example shows that many combinations of simulation and ES technologies are possible. We may expect future system designs to draw on both and that the power gained through the optimal combination of these technologies will be much greater than the sum of each used separately.

A SYSTEMIC FRAMEWORK FOR EXPERT SYSTEMS AND SIMULATION

The analysis of the previous section corresponds to one view of the relation between ES and simulation currently, that they are complementary decision-support technologies that can be usefully combined. In this section, we give a deeper systemic analysis of the relation between the two technologies that allows it to be analysed mathematically and psychologically. In particular, we are concerned with the nature of **surface** and **deep** expertise as one dimension and with the nature of **linguistic inference** and **mathematical modeling** as another dimension. Current ES may be seen as employing superficial reasoning using imprecise linguistic rules, whereas classical simulation is concerned with deep causal models using precise mathematics. Is there any framework in which all these considerations are related?

META SYSTEMS
relations between relations below

STRUCTURE SYSTEM
relations between models below

GENERATIVE SYSTEM
models that generate data below

DATA SYSTEM
observations in terms of distinctions below

SOURCE SYSTEM
distinctions made

EVENTS **PREDICTION/ACTION**

Fig. 5 Epistemological hierarchy of a personal scientist

In our previous studies of knowledge engineering for ESs not involving simulation we have found it useful to model the processes of knowledge representation and acquisition in terms of the hierarchy shown in Figure 5 (Gaines & Shaw 1981a, 1984a,c, 1985b). Klir (1976) developed

this hierarchy for work on symbolic modeling systems and Gaines (1977) has shown that it forms a basis for general knowledge acquisition algorithms. The loop from events through distinctions up through the modeling hierarchy and then down again to predictions and actions characterizes what Shaw (1980) has termed the **personal scientist.** The upper levels of modeling are totally dependent on the system of distinctions, or personal constructs, used to express experience through the source system. It is this that led us to the use of computer-based construct elicitation techniques as a methodology for knowledge engineering (Gaines & Shaw 1981b, Shaw 1982, 1984, Shaw & Gaines 1983, 1984a,b) that has proved very successful in practice (Boose 1984).

In this paper we want to place emphasis on the upper levels of the hierarchy in order to analyse the relations between ES and simulation. The levels of the hierarchy are the results of distinctions that we make. Thus the source system is distinguished as those distinctions that the particular personal scientist makes; it is a distinction about distinctions defining the construct system of an individual. The data system is distinguished as those distinctions that have been made about a particular event; again a distinction about distinctions defining an event. The generative system is distinguished as a set of distinctions that also defines an event; these are model-generated rather than event-generated. It is the match between the model-generated and event-generated distinctions that determines the degree of approximation of the model to the world; this is a distinction about distinctions among distinctions that defines goodness of fit. A knowledge schema results from distinctions about distinctions at each level in the hierarchy.

This hierarchy and its terminology were developed in the context of mathematical modeling theory. We have given a psychological interpretation also in which the distinctions made are **personal constructs,** the data system is that of **experiences,** the generative system is that of **mental models,** and so on. For the purposes of the present discussion it is sufficient to note that: any purposive system may be represented in terms of this hierarchy; that a variety of support structures exist for each level of the hierarchy, language, mathematics, valuations, and so on; and that feedback may occur at any level between information flowing up the hierarchy and action flowing down it.

What we shall argue is that: one dimension of the distinction between ESs and simulation is that current ESs are concerned with feedback at the data system level whereas current simulation is concerned with feedback at the generative system level; another dimension is that current ESs use linguistic reasoning to support their operation whereas current simulation uses mathematical reasoning to support their operation. We shall further argue that none of these differences are fundamental: that ESs can encompass all levels of the hierarchy and that simulation can operate in linguistic terms. In particular: work on naive physics (Gentner & Stevens 1983) shows the use of linguistic models as a basis for ESs at the generative level; linguistic models have also been used succesfully in simulations (Wenstop 1981); linguistic rule-based systems have also been used successfully in

process control for dynamic systems (Mamdani & Assilian 1981). These are isolated examples to date but illustrate the principles on which future ES developments may be based.

CONCLUSIONS

Simulation and expert systems are complementary techniques for using computers to support human knowledge processing. Attention is focused on ES currently because they are a recent development involving a change in paradigm that has proved effective in industrial applications. There are many benefits to be gained from the application of ESs to problems where the classical approach of modeling the problem and computing an optimum solution is not possible and where, instead, it is possible to generate a solution by modeling a person solving the problem. This allows the automation of tasks that were previously beyond computer implementation because of our lack of in-depth understanding of the processes involved. However, there are even greater benefits to be gained through combination of simulation and ES techniques in integrated systems, and we may expect the focus of attention to shift to such possibilities as ES technology becomes better understood and more readily available. There already exist systemic frameworks for this integration and some examples of the possibilities.

ACKNOWLEDGEMENTS

Financial assistance for this work has been made available by the National Sciences and Engineering Research Council of Canada.

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