Automation

INTERPRETIVE PROCESSING/EXPERT SYSTEMS: AN INITIATIVE IN WEATHER DATA ANALYSIS AND FORECASTING

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ABSTRACT

Interpretive processing is a computer interactive procedure that enhances the abilities of the weather forecaster to decide on a forecast. The procedure makes it easier to draw conclusions from the meteorological analysis of observational data, forcasting techniques, and past forecast experience available when deciding on a forecast. This article provides some concepts for the application of Artificial Intelligence (AI)/expert systems technology to interpretive processing. Expert/knowledge-based systems exhibit a three-fold benefit for weather forecasting. They are: (1) providing improved data analysis and decision-making support due to enhanced consistency and thoroughness; (2) supporting training of new forecasters; (3) supporting skill maintenance for experienced forecasters, especially with regard to their action in infrequently occuring/unfamiliar situations.

The use of expert systems would help ensure that the best forecast knowledge is available to the forecaster on duty. The AI/expert systems concepts would be applied as part of the effort toward further automation in NWS field operations and, within the scope of interpretive processing, to implement a forecasting system management aid and empirical procedure found useful in deciding on a forecast.

1. INTRODUCTION

A Department of Commerce goal is the restructuring of the National Weather Service by 1990 to provide more timely and accurate forecasts with improved cost-effectiveness. In keeping with this goal, the NWS is working on further developments in the automation of field operations. Related to this, the agency has initiated an effort in Interpretive Processing. Interpretive processing is defined as a computer interactive procedure that enhances the abilities of the weather forecaster to decide on a forecast. The procedure makes it easier to draw conclusions from the meteorological analysis of observational data, forecasting techniques, and past forecaster experience available when deciding on a forecast. This report provides some concepts for the application of Artificial Intelligence (AI)/expert systems technology to Interpretive Processing, especially with respect to the possibility of enhancing the contribution of forecaster past experience. The thrust of this initiative would be two-fold: (a) to formalize the capture of empirical knowledge/procedures used by field personnel and, (b) to develop an information management support system, a "weather information processing executive." This executive would orchestrate the interaction and use of various prediction models and national guidance, would provide for an increased degree of automation of the surveillance (met watch function) and provide "guidance" to the forecaster with respect to things that he should do, such as to issue watches and warnings.

The possible value of Interpretive Processing in the next generation of automation in NWS field operations is suggested by the following observations about CSIS (Centralized Storm Information System) : (3)

> "Having a computer to help organize the forecaster's work, remind him of the status of his forecast products, and keep him up to date in a rapidly changing weather situation has proven invaluable in dealing with wide spread severe storm outbreaks."

Seemingly, this statement could apply to other weather forecasting environments as well.

The Interpretive Processing (and AI/expert systems) thrust is in recognition of the need in the next few years to support the assimilation of the significantly greater amounts of data that will be required for higher resolution (mesoscale forecasting). This is the principal attribute of the next generation of automation for the NWS field offices.

"Artificial Intelligence" may be defined as "A subfield of computer science concerned with the concepts and methods of symbolic inference by a computer and the symbolic representation of the knowledge to be used in making inferences. A computer can be made to behave in ways that humans recognize as 'intelligent' behavior in each other."(4) Perhaps more usefully, AI can be defined in terms of its applications to the more specific engineering goal of "...the development of computer programs that can solve problems normally thought to require human intelligence."(5)

"Expert systems" can be defined as "...problem-solving computer programs that can reach a level of performance comparable to that of a human expert in some specialized problem domain."(6) Often, the term "knowledge based system" is employed as more or less the equivalent of "expert system". Perhaps, as suggested in reference 5, a differentiation can be made between the two, to wit:

> "...a knowledge-based system is an AI program whose performance depends more on the explicit presence of a large body of knowledge than on the possession of ingenious computational procedures; by expert system we mean a knowledge-based system whose performance is intended to rival that of human experts."

Some of the basic concepts of expert systems have already been applied in weather forecasting, especially of severe weather by the National Weather Service and Air Weather Service, U.S. Air Force (7,8,9,10). These applications were not formally "expert" or "knowledge-based" systems, but they did address the important objective of capturing the experience and judgement of senior forecasters for use by those with less experience. They also served another objective, to help to fuse the knowledge and experience of several experts. The fusion process is a difficult one. It is similar to the forecaster's obtaining the consensus of his peers about his weather hypothesis before formalizing it into a forecast. Recently, as part of the initial NWS development activity on Interpretive Processing systems, an experimental algorithm (11,12) that exhibits learning behavior has been devised to predict the "likelihood" or "possibility" that a severe thunderstorm will occur. The algorithm has been programmed in the BASIC language, suitable for use on a personal computer.

The development of AI/expert systems algorithms for weather information processing and forecast generation support will have the potential to enhance the basic meteorological science itself by forcing codification of relevant procedures, thought processes, etc. in a precise, thorough, and consistent manner. Also, when available on-line to the forecasting community, such algorithms should enhance the skills of the forecaster through the process Cook has termed "interactive judgment" (1). He defines it as "...a procedure for helping decision makers to understand the basis of their judgments and to improve the quality of their decisions...". That is, the forecaster may learn <u>from</u> the algorithm (provided it exhibits a sufficient capability to "explain" its "line of reasoning" or provide a "trace") <u>and</u> the algorithm can be modified, based on inputs from the forecaster or, possibly, by monitoring his actions. This concept epitomizes a computer interactive system.

It appears that expert/knowledge-based systems exhibit considerable potential benefit for weather forecasting. The benefit should be three-fold:

(1) to provide improved data analysis and decision-making support due to enhanced consistency and thoroughness;

(2) to support training of new forecasters;

(3) to support skill maintenance for experienced forecasters, especially with regard to their actions in infrequently occurring/unfamiliar situations.

The use of expert systems would help ensure that the best forecast knowledge is available to the forecaster on duty. This knowledge would be derived from "experts" in the appropriate forecasting areas. The knowledge incorporated into the system would be the result of fusing the inputs from the set of "experts." The acquisition of such a knowledge base including its systematization (to assure internal consistencies, etc.) is perhaps the most difficult aspect of constructing an expert system; also, it is the most expensive.

Weather forecasting may be considered as a decision-making task. Information processing methodologies being developed for medical diagnosis, such as expert systems and AI, hold promise for application to the problem of weather forecasting. Indeed, Allen has noted that "A number of similarities between weather forecasting and medical diagnosis become evident when each is considered as a decision task." He also has observed that "...in both tasks the decision maker is faced with information of varying degrees of significance...both tasks involve a selective gathering of data from prodigious data sources". (14) Weather forecasting also exhibits structural similarities to military tactical command, control, and communications (C^3) systems. C^3 systems must handle an ever increasing volume of data provided by new sensors. Like the weather forecaster, the C^3 system user is in a situation in which "...this new sensing capability must be matched by an ability to filter, discriminate, correlate, and fuse the information...(presented to him)". (15)

In both cases, the problem is one of information reduction. We construct new types of systematic procedures to make conclusions and support decision-making, based on observed data, but without requiring the "bandwidth" of the human information channel to increase corresponding to the amount of new information available. Thus, a major objective of the NWS's effort in Interpretive Processing is to provide an "executive function" or "information management support system." It would provide process management assistance to the forecaster to orchestrate the interaction and use of numerical models, guidance, and AI/expert/heuristic /knowledge-based systems. It would also provide aid to the forecaster in sequencing his activities such as issuing watches and warnings, etc.

As part of its program to realize the Commerce Department goal of more timely and accurate weather forecasts, the Weather Service recognizes the need in the next few years to support the assimilation of the significantly greater amount of data that will be required for higher resolution (mesoscale) forecasting. This greater amount of data will have to be processed without any significant increase in manpower. This means that an increase in productivity is inherently an objective of the Interpretive Processing initiative. Further, the goal of enhanced forecasting accuracy is commensurate with the goal of achieving a higher quality of forecasts. The goals of higher productivity in the forecast development process and higher quality in the resultant forecast products should be achievable in the next-generation NWS field automation effort through the use of Interpretive Processing techniques.

2. CONCISE SUMMARY OF EXPERT/KNOWLEDGE-BASED SYSTEMS

This section briefly summarizes the principal features and some desirable capabilities of knowledge-based systems and outlines their potential usefulness to the National Weather Service.

An expert/knowledge-based system captures the problem solving expertise of a field of endeavor (or more customarily, a well-bounded portion thereof) and uses it as a computer-based consultant that can provide intelligent assistance to a practitioner in that field. The basis for such a system is obtaining knowledge from an "expert", in recognition that an expert's high level of performance is due to: special knowledge, judgment, and experience. "Knowledge" is to be distinguished from "information"; "knowledge" is information that has been processed, reduced, and otherwise has been gleaned of the elements that are significant for the task at hand. As Feigenbaum and McCorduck (ref. 4, p. 75) have noted:

> "The power of the expert systems comes from the knowledge they contain. That knowledge is, at present, stored in the heads of human experts, and getting it out - what AI researchers call the knowledge acquisition problem - is the biggest bottleneck that the knowledge engineers currently face."

Obtaining "knowledge" to build into an expert system is difficult for at least two significant reasons: (1) often a person is not cognizant of the thought processes - or the chains of reasoning that he employs to reach a conclusion; (2) often there is not one specialist whose expertise either spans the entire problem of interest or with whom other acknowledged experts agree exactly as to the nature of the parameters describing the process of concern.

An expert system has three principal structural components (see Figure 1) (4): an input/output system, an inference system, and a knowledge base. The knowledge base contains "facts", such as from a textbook, and "heuristic knowledge", which is the knowledge of good practice or of making a good guess. The inference subsystem, often constructed with "IF-THEN" rules, draws conclusions based on data produced via the input/output subsystem plus data provided via the knowledge base. The input/output subsystem provides the means for the user to communicate with the expert system. A weather information processing system can also employ other types of inputs from automated sources, such as from weather instruments or the LFM (Limited Fine Mesh) model.

The success of an expert system is based upon being able to describe the chains of reasoning the human expert employs in diagnosis or situation assessment and then deciding upon an action (such as issuing a warning) or making a judgment (such as a forecast for precipitation). The knowledge base and the inference subsystem (see Figure 1), working in cooperation, duplicate the results of the chains of reasoning. The inference subsystem essentially asks questions of the environment (or portions thereof which are being evaluated) via the input/output subsystem. Often, a sequence of IF-THEN rules has been used as the basis for this mechanism; alternative implementations have been employed as well. The knowledge base can be organized in a number of ways; one is through the use of "scripts" (16) (a term developed by Professor Roger Schank of Yale). A script contains general situational information. It is important to note that the inference subsystem and the knowledge base are often not implemented as individual entities, but rather are frequently effected together as one logical unit.

The design of the input-output system is key to the utility of an expert system. The term "user friendly" is often used to denote the idea that the (computer-based) system should be: easy for the user to communicate with (ideally in a language very similar to that which he employs when communicating with his peers, or in another "familiar" format, such as a graphical one), should guide him in its use; and should be resistant to erroneous actions by the user. Learning to use computers has been found difficult by many in various applications; the user wants to concentrate on the information he is exchanging with the computer (system) and not on the mechanism of its transfer. The designers of an expert system must be especially sensitive to this fact, especially with respect to the older prospective user and/or persons whose function is primarily mangerial. Indeed:

> "Of course, most users don't need to know how to program. They just need the right software package. But when they don't understand how a computer works, they don't know why they do certain things and the steps needed to operate the machine seem almost magical." (17)

Work is being done to facilitate the use of computers by those who are not trained to communicate with computers in their (assembly) language. (18) One approach is to use graphics to structure say, the development of an invoice from various basic data elements. Such an approach could be used to develop the knowledge base and the inference subsystem for an expert system. Indeed, the General Electric Company has developed a tool for "knowledge management", called GETREE, that may be useful for this purpose. (19) The developer can use it to develop an inference tree structure which can be employed, subsequently, in an operational environment to relate symptoms back to causes.

A key requirement for an expert system to be really useful is that it be "adaptive" to the user. It should be responsive to the aptitude of the individual user (such as has been suggested for computerized testing in which the system picks the next suitable question based on previous questions and answers (20). The adaptive capability means that the system would offer a greater degree of decision making support if the user is relatively inexperienced then if he is experienced. It should recognize the unique data usage habits of each user. For example, even if radar and satellite imagery as well as surface sensors are available to him, a given forecaster might choose to use just the radar. Another point is that while menu-driven systems may be useful, the sophisticated user should not be required to go down through an elaborate "tree" to get to the function he wants. The input-output subsystem should be able to be adaptive to the user in this regard. One can envision its being able to learn by experience, perhaps in simulated situations, by dealing with the various forecasters with whom it would have to interact.

The "adaptive" concept might be extended from the input-output subsystem to the expert system overall, especially in performing the function(s) of an information management support system or "weather information executive" (see "Introduction" section). The proposition here is that the system should be able to improve its performance with experience, and the more it is used, the easier its use should become. It should be designed such that when a situation "similar" to one previously encountered is found, it will be able to "know what to do" or at least, be able to give better advice to the forecaster. This concept is similar to that of "The Programmable-Compiler" (21) in which a compiler would be organized to enable programmers "...to add new instructions and macro instructions to the language (they use) according to their individual needs."

Expert/knowledge-based systems offer two principal categories of benefits. First, they provide the potential to codify expertise available in the experience of one person or a small set of people and make it available to a larger set of people for their use. This is especially valuable for a decision capability designed to deal with unusual situations, say the occurrence of a hurricane in Idaho. This codification of expert opinion also might support a reduction in the variability of forecaster performance. The second area of benefits of expert knowledge-based systems is that they provide the potential to enhance the applied science (e.g., meteorology) itself by forcing codification of rules of thumb, procedures that have been found by experience to be useful, etc. This codification would be in a precise, thorough, and consistent manner. Thus, expert knowledge such that "strong 500-mb vorticity advection" is often found to be associated with the occurrence of a severe storm (22), would be converted into numerical values that could be processed such that the "possibility" of occurrence of a storm could be stated in a meaningful way, that is consistent from storm episode to storm episode (11). This is the approach used in the IF-THEN rule structure for "MYCIN", a program that can diagnose infectious diseases and recommend treatment. (6) Use of an expert system that has the option of automatic learning (such as described in references 11 and 12) could be used to develop a relationship between independent and dependent variables that is consistent even if obtaining a set of variable values sufficient for training purposes (such as establishment of regression coefficients) would take a prohibitively long period of time.

The utility to the National Weather Service of the use of expert/knowledge-based systems is thought to be three-fold. First, they would provide an improved data analysis capability and enhanced support of decision making. Second, they could be used to support the training of new (inexperienced forecasters) as well as of forecasters who are changing assignments (say, from tropical hurricanes to severe thunderstorm forecasting). Third, they could be used to support the maintenance of the capability of experienced forecasters. This would be especially valuable for infrequently occurring situations, which is where any one forecaster's own relevant experience may be minimal.

AI/expert systems can provide a number of advantages when instituted properly in appropriate information processing applications. They can codify expertise that is statable using "linguistic variables" (23) such as "good", "weak", "moderate", "strong", etc., which are basically opinions about cause-effect relationships. An expert system can combine the expertise of many persons such that, in principle at least, it can perform better on the average, than say any one of them, on a problem of defined scope. Also, this codified expertise is available for application in an infrequently found situation when the human expert(s) upon whose knowledge it is based is (are) not available at that time/location. The expert system will provide a greater degree of consistency in decision-making than people often do because the system will follow the same logical paths reliably and won't forget. These systems can maximize the powerful capabilities of computer use, which are principally computational speed and memory.

3. EXISTING APPLICATION OF EXPERT SYSTEM CONCEPTS IN WEATHER FORECASTING

Some of the basic concepts of expert systems have already been applied in weather forecasting, especially of severe weather by the National Weather Service and the Air Weather Service, U.S. Air Force. These applications were not formally "expert" or knowledge-based systems, but they did address the important objective of capturing the experience and judgement of senior forecasters for use by those with less experience to help ensure that the best forecast knowledge was available to the forecaster on duty. They also attempted to deal with the need to fuse the knowledge of different experts to perhaps more completely cover the field of interest jointly than any one very experienced person could, individually.

The earlier expert systems applications covered in this section were manually implemented rules of thumb found to apply to particular types of situations of interest. While they appear to have been developed without formal cognizance of A.I./expert systems concepts, they, none the less, employ the basic concept of an expert system. They use explicit rules for evaluating data to make a decision -- in the case of the weather application, to diagnose certain indicator variables and make a forecast of certain aspects of the weather. Another basic attribute of A.I./expert systems that the weather forecasting applications exhibit is that the importance, and hence, the weights ascribed to each of the variables, are chosen based on the results of "internal processing" of the data by the system designer(s). Several of these earlier "expert" systems are described below.

Miller (25) and subsequently Crisp (7) of the U.S. Air Force, Air Force Global Weather Central at Offutt Air Force Base, developed material on analysis and severe storm forecasting procedures. Some of the parameters Miller presents were employed by Gaffney and Racer (11,12) in their proposed A.I./expert system for the development of severe storm forecasting "advisories." Note, one shouldn't say "forecast"; the expert system is a tool to be used by the forecaster who actually develops the forecast. In the development of the "advisory", each of the parameters or variables is scored from the set of alternative values; "weak", "moderate", and "strong". Miller mentally combines these parameter evaluations. A modern A.I. system would combine them "mechanically", according to some rules(s) implemented on a computer. When assessing the parameters, Miller uses language equivalent to Zadeh's "possibility" (26) (or the equivalent "confidence factors" of the "Mycin" medical diagnosis program (6)). For example, with respect to a tornado at Topeka, Kansas, he states "...nearly all of the parameters favor the development of severe weather." This language provides a "possibilistic measure" (a la Zadeh) as it clearly reflects an assessment of the "degree of compatibility" of the parameters (values) with the phenomenon of interest (the potential storm). Crisp's work formalizes that of Miller, putting it more in terms of explicit rules for the guidance of personnel unfamiliar with severe weather forecasting. Indeed, he states that his work "...is a formal, detailed, step-by-step guide to the practical aspects of severe weather forecasting."

Miller and Maddox (8) described a heuristic procedure that provides a "severe weather threat index" (SWEAT), developed in the Air Force. They note it and another index (SPOT) are "...found to be valuable forecaster aids, especially so in an environment where individual forecaster retentivity is short and where the range of individual forecaster experience is very large." The comments about retentivity and experience are more applicable to the military services than to the National Weather Service. Thus, the focus of SWEAT and SPOT is seen to be strongly in accord with the principal objectives of "interpretive processing."

The basic steps used in the preparation of a Convective Outlook (AC) used by personnel of the NWS National Severe Storms Forecast Center (9) include a "severe weather checklist" of 10 parameters which are evaluated as a group using "IF-THEN" rules to determine the "possibility" of a storm. A person inexperienced in severe storm forecasting would probably use the "checklist" explicitly. An experienced person would use it implicitly, having essentially acquired the requisite expertise through repeated application. In the case of an experienced person, the "checklist" provides him a degree of what might be termed "synthetic expertise" that he would otherwise have had to acquire through on-the-job training (OTJ). Of course, there are many other elements of his work that the forecaster has to acquire via OJT. However, the availability of the checklist and related procedures for its application may speed up the training process and thus it could enhance the value of the new forecaster's contribution to forecasting operations.

A "diagnostic" procedure has been developed at the NWS National Hurricane Center for evaluating numerical guidance materials. (10) Its principal element is a "decision ladder" that "...supplies a systematic means of formalizing prediction experience which in turn can be used to develop more effective prediction models." This is noted to be in keeping with the observation that "...the emphasis at the National Hurricane Center is presently being placed on the development of diagnostic procedures and tools, first to identify the frailties of each numerical prediction and second to enable the heuristic reasoning of the forecaster to be applied systematically to a decision ladder from which an effective forecast judgment can be reached with minimum subjectivity." These comments capture the principal thrusts of Interpretive Processing which are to formalize the capture and use of empirical procedures and experience and to provide for an information management support system that would be implemented using decision ladders to aid in the systematization of weather forecasting analysis and decision making.

Another procedure, developed by Gustin (27) aids in forecasting minimum temperatures. Still another, developed by personnel of the Air Weather Service, U.S. Air Force, provides a simple way to forecast whether precipitation will be rain only, rain and snow mixed, or snow only (in the winter only!).

The several "expert systems" considered in this section share a goal, to systematize and make explicit certain procedures that are either "in the heads" of experienced people or found (perhaps "buried") in some book of procedures, and perhaps, not easily accessible there. They also represent the result of fusion of various contributors' points of view.

4. PRINCIPAL CHARACTERISTICS OF THE FORECASTING PROCESS/OPPORTUNITIES FOR IMPROVEMENT

This section characterizes weather forecasting in general as a decision-making task and more particularly in terms of the functions the forecaster "typically" performs. The forecasting process is also compared to medical diagnosis and the military command-control function, which