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 comparisons suggest a potentially high degree of applicability of Interpretive Processing or forecaster decision aids. These computer situation analysis techniques are being applied increasingly in both of these fields.

Weather forecasting is a decision-making task. (14) When considering the potential application of AI/expert systems technology, one will find this point of view to be more instructive than thinking of it only as "...an application of meteorological physics and mathematics." (14) Forecasting is structurally analogous to medical diagnosis. Allen observes that "A number of similarities between weather forecasting and medical diagnosis become evident when each is considered as a decision task." (14) In both cases, the decision maker (doctor or weather forecaster) uses selectively gathered data having varying degrees of reliability and significance to reach the best possible judgment in the least time possible. Basically, in each case, the decision maker does a situation assessment (or diagnosis) and then decides upon an action. The medical practitioner evaluates the likely disease or problem prognosis and then selects a treatment; the forecaster assesses the likely evolution of the weather system he is currently following and issues a warning, a watch, and/or takes another appropriate action based on his "situation assessment."

The weather forecasting process is analogous to a military command and control system which may be defined as "...a technological, procedural, and organizational extension of the sensing, processing, and communication capabilities of the military commanders whose decisions it supports." (15) The development of a weather forecast is a creative act just like that of a military commander who selects a course of action. The need to process greater amounts of data produced by various sensors and to make sense out of that material faces the weather forecasting community as it moves to support higher resolution (mesoscale) forecasting. The military commander finds himself in a similar situation. The volume of information that military staffs must handle has increased very significantly since the World War II era, but accomodating this information by further expansion of staff is thought not to be the appropriate solution. Indeed, "...The only escape from this incompatible situation lies in the extensive application of automation, primarily computers - a "man-machine" system is (better) than "man" alone or "machine" alone." (15)

Wohl has noted (15), with respect to aiding military force commanders, that an analysis of (and development of requirements for support of) "...force management decisions and decision aids must include an analysis of the decision process itself." He summarizes the decision process of the military commander with the "commander's catechism":

- o Where am I? (Situation)
- o Where is the enemy?
- o What is he doing?
- o How can he hurt me most?
- o What have I got to thwart him?
- o How can I do him in?
- o Am I in balance? Movements in order? Reserves? Logistics?
- o How long will it take me to...?
- o How long will it take him to...?
- o How will it look in an hour? Six hours?
- o What is the most important thing to do right now?
- o How do I get it done?

An attempt was made to develop an analogous precis of the weather forecaster's decision making process. The result is a "weather forecaster's catechism":

- o What is the present weather situation?
- o What is the recent weather situation?
- o What are the weather factors that will most affect my particular forecasting responsibility?
- o What is my weather hypothesis?
- o How does it compare with existent guidance, forecast, and data?
- o Do I have a consensus of my peers?
- o What is the forecast?
- o What particular parameters do I forecast?
- o Whom do I notify?
- o Is my forecast still valid?

This set of questions is the result of a limited attempt to write down a generalization of "what the forecaster does." In the operational situation, the answers to these questions could then prompt an action according to the sequence, "SINCE (the answer to the question), THEN (the appropriate action)." This could be the procedural basis for the information management support system, or "weather information processing executive" mentioned in the "Introduction" section. Observe how this SINCE-THEN structure (suggested by I. Randy Racer of the NWS Office of Meteorology) initiates an <u>action</u> and complements and naturally follows the IF-THEN situation in the inference subsystem (see Figure 1) of the expert system, which provides for a situational analysis.

The development of "the weather forecaster's catechism" was illustrative of the difficulty of developing a knowledge base for an expert system. Several meteorologists were consulted in the formation of the catechism; they could not completely agree. On the positive side, asking some meteorologists "what they do" seems to be useful, perhaps especially to themselves, in trying to aid their own understanding of why they do something and thence offering them the opportunity to infer appropriate changes, such as for better management of their time. Much more analysis of Weather Service forecasting procedures will have to be done before an operational "Interpretive Processing System" can be constructed (see section on Plan).

The forecasting process has a number of characteristics that make it a good candidate for the application of AI/expert systems technology involved in the implementation of an Interpretive Processing system. The weather forecaster uses a variety of types of information obtained from a number of sensors, from national guidance, and from experience (usually his own, but on occasion, the amalgamation of others' as well). This information has various degrees of: availability, reliability, significance, and level of abstraction. The forecasting process involves the integration of guidance, local data, experience and judgment. It has been observed that (28):

> "Each forecaster uses a variety of guidance material, often different than that used by his co-workers. This material ranges from observational data and initial analyses to computer prepared products, subjective techniques and empirical rules."
>
> "In general, the process used by the forecaster in any one of these work centers involves the use of automated computer guidance, manually-prepared guidance products, and forecast procedures tempered with rules proven over years of use."

The forecasting process is driven by: time (there is a schedule for certain types of forecasts, for example); weather events (the presence of a certain weather pattern can be the impetus for certain actions, such as the issuance of a watch or a warning), or by forecasting products themselves (a given product may naturally follow another). Weather forecasting deals both explicitly and implicitly with complex physical relationships. The explicit relationships include both physical laws, such as the gas law, and functional ones, such as derived from a lot of empirical data, using regression equations or other such mathematical techniques.

The opportunity exists to enhance forecaster performance; Interpretive Processing" is directed to that end. There are fundamental limitations in the ability of people to process information; fortunately, they correspond to the strong points of a computer system. These limitations are: imperfect and often biased long-term recall; short-term recall of only a few (4-7) items; relatively slow information processing rate; and the operation serially on logical or algebraic information. People exhibit inconsistency in making judgments. This applies to a given person at different times when provided the same information as well as two (or more) people when simultaneously provided the same information.

Some investigation has indicated that there is a fair degree of variability in an individual forecaster's performance (as indicated by various skill scores) from time to time as well as among a set of forecasters. A major objective of Interpretive Processing is to reduce this variance, by aiding the individual forecaster to be more consistent as well as to narrow the range of performance among the set of forecasters. Figure 2 depicts the variability of performance currently experienced for various skill measures and the desired (reduced) range of variability. We believe that interpretive processing can contribute substantially to such reduction by making the timely application of consistent processing possible where many of the rules that define the nature of that processing can, in fact, be inferred from the performance of forecasters.

The application of the "best" organizational experience to the forecasting situation at hand is frequently not possible because the forecaster who has the most relevant experience is not present. The "best" experience, typically, is scattered throughout the organization; a major objective of the Interpretive Processing initiative is to codify such "experience" and make it available to all the forecasters who might be able to use it. As Dr. Samuel Johnson said: "Knowledge is of two kinds. We know a subject ourselves, or we know where we can find information upon it."

The potential exists to improve forecaster performance through the reduction of various types of errors. Errors are introduced by a number of processes, including the misjudgement of the probabilities of occurrence of certain events that can influence the evolution of a weather system, the influence of desiring to avoid a penalty, and non-uniform (over the relevant population of forecasters) of decision-risk preferences.

Undoubtedly, a forecaster's inability to implement all of the algorithms that are relevant to his current weather data analysis/forecasting problem can have a negative impact on his performance. An important operational concept of interpretive processing is that the forecaster would have a wider range of algorithms available to him than only those with which he is necessarily personally familiar (typically those to whose development he has contributed). The interpretive processing function would provide for the forecaster to "call up" application programs that are relevant to his requirements, which would include heuristic or "rules of thumb" capabilities as well as appropriate numerical models. This information access capability might be implemented using a tool such as the "User Specialty Language" system which "...was created to provide users with a tool for accessing and analyzing data without having to become expert in electronic data processing. It was assumed, however, that the user would be a professional knowledgeable in his field, not the casual user..." (24)

The Interpretive Processing capability will address another area of forecaster activity that has limited his performance, the difficulty of melding change indicator surveillance (the met watch function) with his other duties, both of a scientific and an administrative nature. Change indicator surveillance (looking for value changes or rates of change) is a very important function but one that might, in principle at least, be better done by a computer system than by a person because it involves routine, repetitive, and often algorithmically simple operations. That may not be the case when the change indicators are more in the nature of a change in a pattern (such as the movement of a front) that a person is better able to discern than a machine (at least using currently practicable information processing technology). Allen recognizes the possibility of "...using man's fast efficient visual pattern and motion recognition ability as a source of input for forecasting systems based on statistical relationships." (14) Perhaps, this gets at the essence of the interpretive processing concept, a symbiotic relationship of person (weather information processing professional) and computer system in which each focuses his (its) attention on those portions of the weather forecast in which his (its) capabilities are most efficiently applied. Such a fusion of labor between man and machine is the basis for productivity and (often) quality increases of great interest currently.

5. THE METEOROLOGICAL FORECAST PROCESS AND INTERPRETIVE PROCESSING

This section describes the "overall" meteorological forecast process and the places where interpretive processing can be incorporated into it.

The meteorological forecast process is composed of two principal functions; forecast and surveillance. The forecast process covers the development of weather forecasts and various products; the surveillance process, or met watch, involves monitoring of the values or rates of change of various meteorological variables (and weather system "patterns" that are derivable from them) that could indicate that a new forecast should be issued, or other action should be taken.

Figure 3 presents a simplified view of the weather forecast process as a sequence of operations: collection of data and information, the assimilation of this material, the analysis of the associated elements, the formulation of various forecasts and products, and the dissemination of these materials to the public and to other weather information processing functions.

Interpretive processing can be applied to these functions in two ways. First, Interpretive Processing includes a weather information processing executive which would provide management assistance to the forecaster in handling the assimilation, analysis, and formulation functions. Thus, it would "suggest" an ordered process of activities to the forecaster, and would support him in orchestrating the interaction and use of various "application programs" for the processing of meteorological data, as well as guidance, and would support the fusion of data from different sources (e.g., satellite and radar imagery). Second, Interpretive Processing would be involved in the assimilation and analysis functions as expert/knowledge-based and empirical/heuristic models, implemented as application programs.

Figures 4 and 5 present the surveillance and forecast processes, respectively, as "closed loop" systems. The surveillance process or met watch (see Figure 4) checks for the continuing validity of forecasts. Basically, it includes the taking of new observations, periodically (or as appropriate to their last observed values or rates of change) and comparing these figures with thresholds or ranges. Departure from the ranges or exceeding the thresholds triggers the process of developing a new (or revised) forecast (see Figure 5 for the process flow). The surveillance process is an excellent application for an increased level of automation. Many similar processes have been automated as parts of industrial process control systems.

Figure 5 represents the overall flow of the process of developing forecasts and products. The collection function includes the gathering of (current) observational data as well as stored data as appropriate. Further, it includes the insertion of forecaster past experience. Also, the collection function includes the insertion of national guidance and the running of local numerical models. The collected data goes to the assimilation and analysis processes which are effected in part by purely human efforts, in part by purely machine effort, and in part by human/machine interaction. A basic objective of future NWS automation efforts is to have the human and human/machine interactive components assume a much greater proportion of the assimilation and analysis processes than in current forecast process configurations. As noted by Allen (14), future forecasting systems should recognize that man's "...visual information processing capability is superb" and that they could be applied in making judgments about patterns of data in "...novel frames - such as humidity/stability space." The PROFS (Prototype Regional Observing and Forecasting Service) effort at the NOAA Environmental Research Laboratories is exploring the use of improved human/machine interactive capabilities, including the overlaying of displays from different sensors; the results of this effort should be applicable to the establishment of an interpretive processing capability.

The assimilation/analysis functions might require more data to be useful in making a decision and/or raising the level of confidence in a decision already made; the "request new information" block in Figure 5 represents this function. If the appropriate forecast decisions can be made, then the process progresses to the formulation function (not shown in Figure 5). Please note that the functions depicted in Figure 5 are represented in the box labeled "develop working forecast" in Figure 4.

6. TOWARD AN INTERPRETIVE PROCESSING SYSTEM

This section provides some of the philosophy of structuring an Interpretive Processing system and suggests that the CSIS has already prototyped some of the aspects of the future Interpretive Processing capability, especially with respect to its functions as a "weather information processing executive."

The basic element of an Interpretive Processing AI/expert system will be a decision tree. It will be the vehicle to codify procedures, alternative analyses, sequences of operations to be undertaken under certain prescribed circumstances, etc. A "decision tree" is a diagrammatic structure such that:

> "The whole array of possible sequences of decisions can be very conveniently represented by (a)...branchlike figure...(The) nodes of the decision tree represent points at which decisions must be made. The alternative actions being considered at a given node are represented by straight lines emanating from the node which are referred to as branches of the tree".(29)

Decision trees have been employed by businessmen (30,31) to aid in the assessment of what actions to take (such as whether to drill an oil well at a particular spot, or not), when there is risk, due to uncertainties in the information made available as well as uncertainties in the outcome, even given that a certain action <u>is</u> taken.

The decision tree approach to codifying decisions and choice sequences in a logical manner can be used as a means to make risk-taking attitudes among different decision makers (weather forecasters) more consistent. Preference theory (31,32) addresses this objective. It also deals with the business decision makers - and <u>could</u> deal with weather "decision makers" or forecasters who work in an organization that has a top management group - "that wants decision makers down the line to have a better common understanding of a desired corporate attitude toward risk taking" - "... And in the absence of a clearly stated policy, it is unlikely that decisions made by managers at various levels will adequately reflect the desired corporate attitude." (31)

The decision tree approach to documentation of current decision making patterns would support the NWS objectives of forecasters making more consistent decisions under more nearly commonly agreed upon risk preferences.

The decision tree structure to implement Interpretive Processing will probably be developed from two different logical structures, "IF-THEN" and "SINCE-THEN." The first would be employed in the diagnosis of the weather situation. The second would be employed to cause an action, such as issuing a watch or a warning in response to that diagnosis. It could also cause an action in response to a clock signal ("IF 1400 HRS, THEN ISSUE FORECAST TYPE A").

An example of an "IF-THEN" structure for weather information processing may be found in reference 11, in which 13 variables representing aspects of a weather situation are considered in making a diagnosis of the possibility of a severe storm. The "IF-THEN" structure is a two-tier one; the first relates to defining the severity of each variable and the second combines these values into an assessment of the possibility that a severe storm will occur.

Defining the value of the "700-mb Dry Intrusion", one of the 13 variables cited in reference 11, would occur according to the following sequence:

IF	"no data available" OR "weak 700 mb winds"
THEN	"variable value" = "weak"
IF	winds ranging from "dry" to "moist" intrude AND "angle of intrusion" rotation 40° AND "wind speed" 15kt.
THEN	"variable value" = "moderate"
IF	winds intrude AND "angle of intrusion" rotation 40° AND "wind speed" 25 kt
THEN	"variable value" = "strong"
IF	"variable value" = "weak"
THEN	x_9: = .15
IF	"variable value" = "moderate"
THEN	x_9: = .65
IF	"variable value" = "strong"
THEN	x_9: = .95

(where x_9 is the numerical value for this varible)

The second tier of "IF-THEN" decision rules for the severe storm case could include a structure such as:

IF	variable 1 = "weak", or
IF	variable 2 = "weak", or
IF	variable 3 = "weak", or
IF	variable 10= "weak"
THEN	"severe storm not likely"
THEN	F = .15

(where F is the numerical value for the severe storm advisory).

The Interpretive Processing capability will have to be able to accommodate the processing of patterns such as found on a weather map. This is clearly more difficult, if it is to be done automatically or almost entirely so with perhaps a bit of manual assistance for process initiation in final judgments, than is applying a sequence of questions to single dimensional meteorological variables such as temperature. Reference 11 provides several examples of such "pattern" variables, one (x_7) is the "850 mb temp. ridge location", which is defined with respect to its position, "east", "over", or "west" of the "moist axis".

Taniguchi et al. (33) describe a system for retrieving weather charts that involves "...knowledge-based picture understanding of weather charts" that could be a prototype for a "weather pattern analyses" that might be incorporated into an interpretive processing capability. Taniguchi's approach is similar to that used for various other pattern recognition systems that use feature extractors that try to detect the occurrence of various standard features in the pattern. A concept for the recognition of handwritten capital letters seems to be particularly relevant here. Kickert and Koppelaar (34) describe a system wherein a letter is defined as consisting of a sequence of "line" and "curve" segments. Pattern recognition of a letter consists of recognizing first each element and the degree to which it is "curved" or "straight" ("flat" or "vertical" or at some angle with respect to the horizontal of the writing surface) and second, the degree to which the proper sequence (for a given letter) of such segments is present. Kickert and Koppelaar use fuzzy set concepts as a theoretical support for this approach. They state that "in this method the rather dubious assumptions about underlying probability density functions of handwriting are avoided. Moreover, the concept of vagueness seems to be a more appealing and convincing way of describing the variability in letters than the concept of probability." They also observe that "obviously any assumption about a particular parametrical probability density function would be highly dubious here. A nonparametric classification procedure, not assuming any particular function , would surely have a better empirical basis." This approach to handprinted letter recognition thus is based on the notion that the (fuzzy membership) assignment of the terms "curved" etc. to a line segment is a heuristic choice. This approach could be applied to display real time segments on a weather chart.

The CSIS may be regarded as a prototype for various aspects of interpretive processing. It was developed in recognition that "...the meteorologist's inability to associate with the real-time data is a signigicant barrier to the improvement of short-term forecasts and warnings." (3) The availability of CSIS at the NSSFC has resulted in an increase in forecaster productivity because it performs a prototype of the "process management assistance" function of interpretive processing as it helps to organize the forecaster's work, reminds him of the status of his forcast products, and keeps him up to date in a rapidly changing weather situation (3). Also, CSIS performs in the "process management assistance" role, and thereby increases productivity as "the system ingests the data, files it, processes it, and displays routine products without manual intervention. The data is ready at the forecaster's convenience."(3) Reference 3 further observes that "The scheduler function of CSIS which allows automatic ingestion of data and processing of products has proven invaluable in CSIS. Over half the programs executed on CSIS are initiated automatically by the scheduler."

7. CONCLUDING OBSERVATIONS

The emerging technology of artificial intelligence/expert systems appears quite promising for application to Interpretive Processing. Interpretive processing is computer interactive procedures that enhance the ability of the forecaster to decide on a forecast. The AI/expert systems concepts would be applied as part of the effort toward further automation in NWS field and National Center operations. A higher level of automation is necessary due to the requirement to handle the significantly greater amounts of data expected to require processing in the future, especially for mesoscale forecasting, without corresponding manpower increases. Another need is to reduce the variability of forecaster performance observed. Interpretive Processing will address these needs for productivity improvement and quality enhancement.

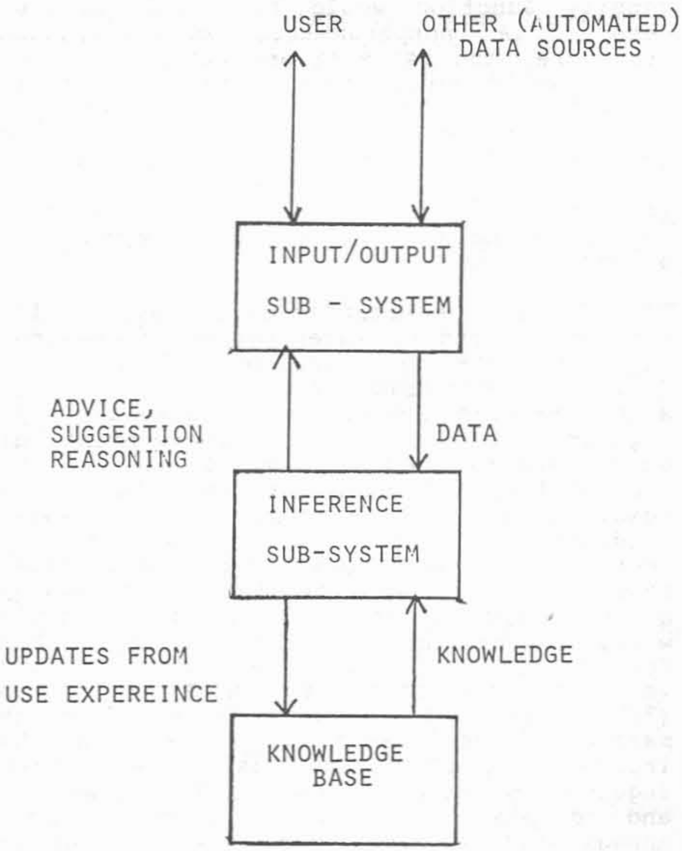

Figure 1. Structure of an expert system

The AI/expert systems technology will be applied within the scope of Interpretive Processing to implement a forecasting system management aid and heuristic procedures found useful in deciding on a forecast. The premier effort in introducing this technology will be in actually writing down current NWS forecaster decision procedures that will be automated to a certain degree as well. Also, one must specify the flows of the decision procedures that are likely to be required to support new capabilities not currently implemented as part of field or national center operations (such as expanded mesoscale coverage). The introduction of AI/expert systems concepts into the weather service is more recognition that the best forecasting procedures and experience can be applied systematically on an agency-wide basis than it is application of fundamentally new capabilities.

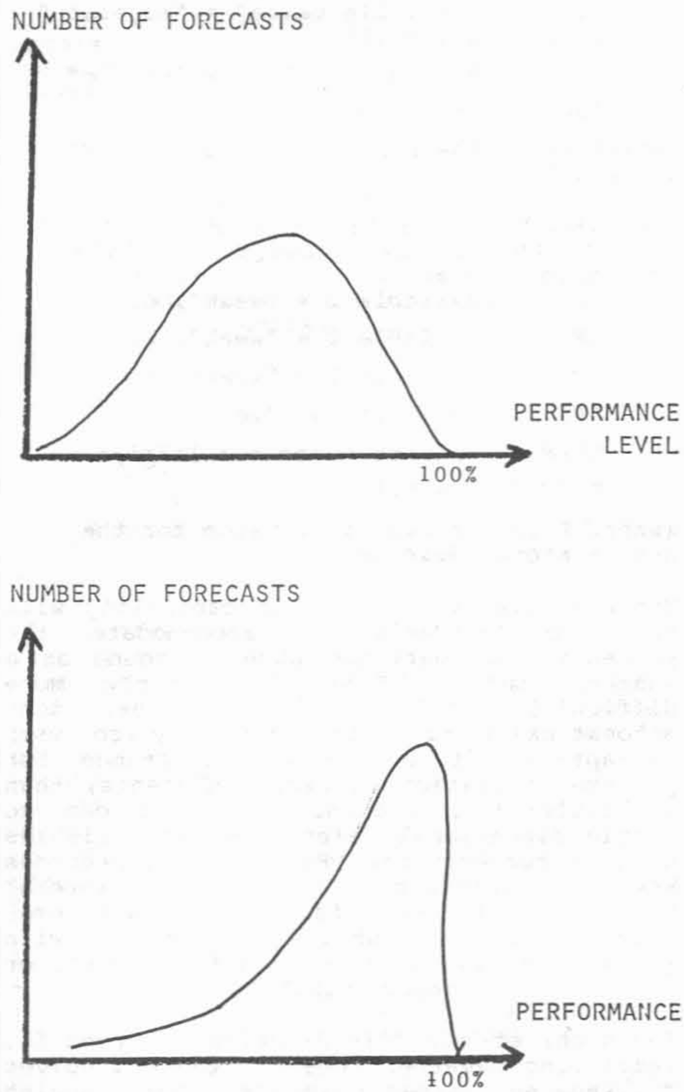

Figure 2 - Potential for forecaster performance level improvement/reduction in variability

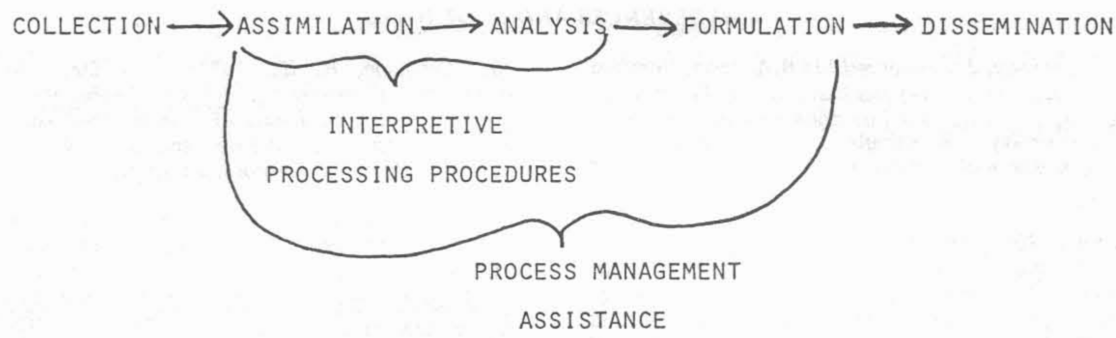

Figure 3. - Application of interpretive processing to the weather forecast process

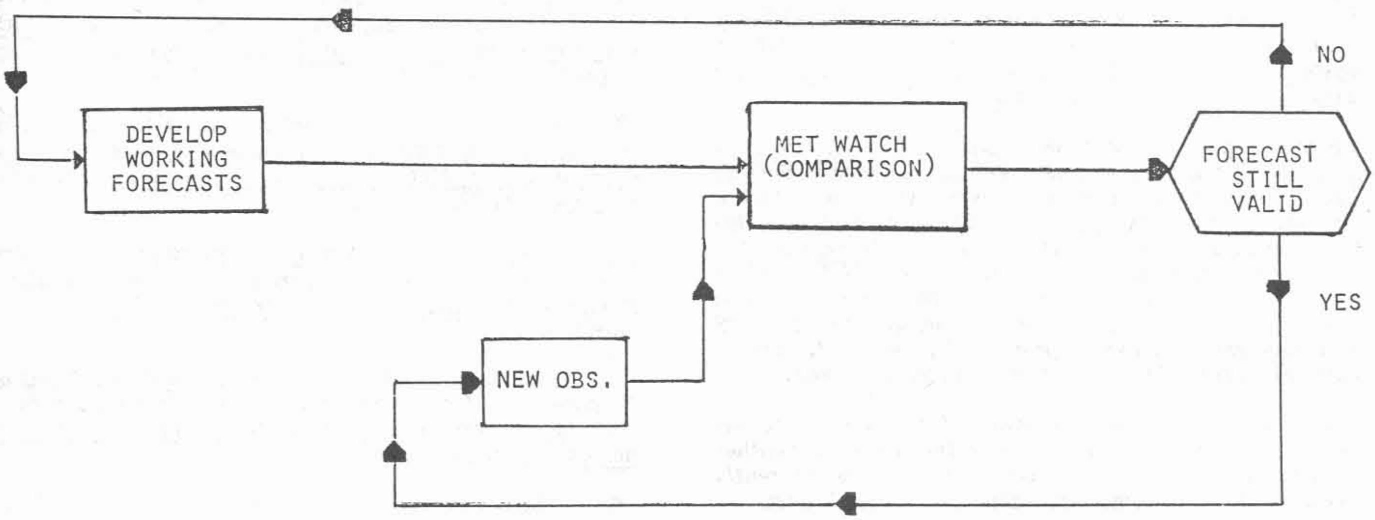

Figure 4. - Surveillance process - met watch for continuing validity of forecasts

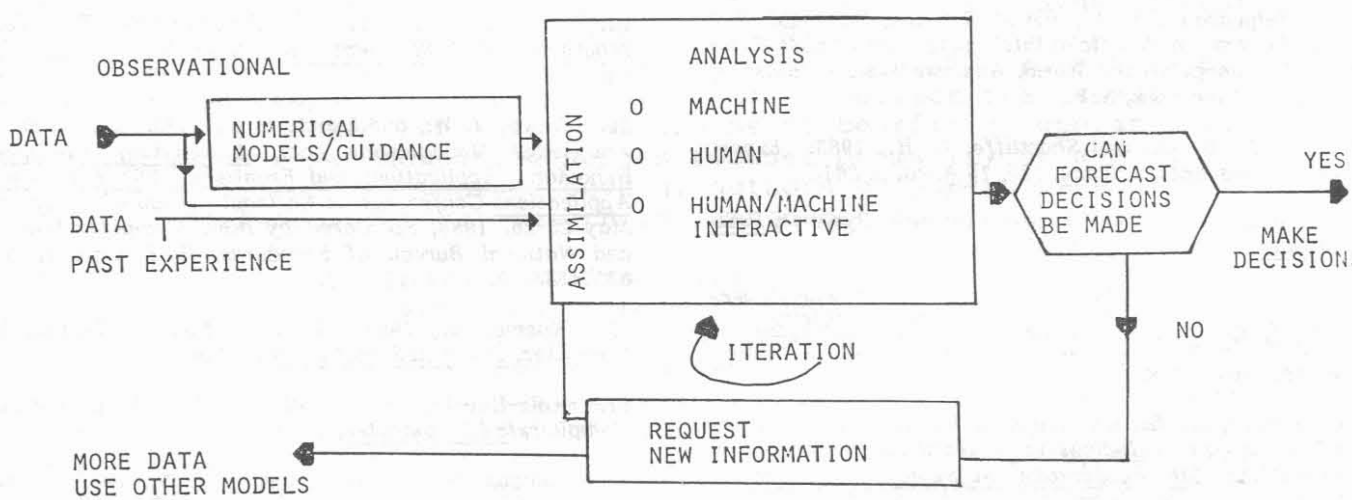

Figure 5. - Intrepretive processing executive forecast process - develop forecasts/products

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