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EXPANDING EXPERTISE BY USE OF AN EXPERT SYSTEM

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ABSTRACT

By constructing an expert system as a research project proceeds it is possible to aid the development of expertise within the research project. This benefit occurs because there is a need for rules in the construction of the system and this motivates the researchers to formalize and relate the rules that researchers are constantly forming. There is also a benefit because each researcher putting his newly formed knowledge into the system makes it available to all other participants in the project.

When the project involves complex scientific phenomena the use of interconnected simple mathematical models is needed to properly express the relations. The ability of the models to represent the values of a field of parameters permits researchers to refer to the individual phenomena within the realm of the model without having to reexpress all the complex relationships the model approximates. The model is still useful even when the rules being input into the expert system involve modifications that must be applied to the model output in particular situations.

1. INTRODUCTION

An axiom of expert system development has been that a human expert must be able to solve a problem before an expert system is feasible. A new application that uses an evolving expert system to test and demonstrate tentative rules as a group of experts develop their understanding is pushing this axiom to the limit.

The present system involves a multiple laboratory project investigating the down-valley winds that develop in larger mountain valleys at night. These winds occur when the air next to the ground cools, becomes more dense, and starts to flow down the valley. One motivation for understanding these winds is the possibility that oil shale processing plants will be located in such areas and these down-valley winds would cause a pooling of the plant pollutants.

This particular project is similar to many atmospheric science research efforts that involve coordinated research by several organizations. The problem involves the complex interactions of the atmosphere with researchers individually investigating their own specialized fields and relating their findings to the overall research problem. This means the techniques being used for the down-valley flows have a fairly wide applicability, and will be discussed in terms of a generalized approach rather than just in terms of this particular project.

The object is to build an expert system using the general knowledge of the researchers as well as what they have learned about the subject being investigated. In trying to express their results in rules suitable for a knowledge based expert system the researchers formalize and express many results that would never appear in project reports. The rules for the expert system may involve a number of if's, and's, and or's which would sound too tentative and uncertain to include in a report or scientific article.

Research often involves observing what occurs and forming a tentative set of rules relating what has occurred to the existing conditions. The data are then analyzed to verify that the tentative rules are valid, but the different researchers usually have different tentative rule sets. It is not enough to observe what has occurred; the object is to conceptualize and categorize the data into a compact set of conclusions.

When there are seemingly conflicting rules, the process of formalizing the rules for the expert system becomes a real asset. After attaching all the required conditions to the rules, the different researchers will often find they have complimentary rather than conflicting rules. When tentative rules disagree over what happens under particular conditions, at least one more condition needs to be attached to the rules. This need for more specific conditions illustrates how rule formulation can expose areas in which there is need for more research.

The use of an expert system with rules provided by researchers in other specialties provides an aid to the individual researcher in understanding his own results. By using the expertise put into the system by other experts, he obtains a wider context for his results. For example, he may know that conditions A and B must be satisfied before he observes result C, but without the expert system he would be unaware that conditions A and B cannot come about when condition D occurs. The system thus expands his result to include the fact that D excludes C.

2. SYSTEM FRAMEWORK

Because of the differences in how the present expert system is to be used, it has to be constructed somewhat differently than the usual inquiry system. It is implemented on a VAX 780 in the FRANZ LISP language. The system also includes a set of mathematical subroutines that are programmed in the C language.

Input to the system is by selecting from a list of conditions that can specify the environment, and this environment determines if a particular result occurs. But the occurrence is actually just be another environmental condition and may also serve as one of the conditions for some other rule. This means that conditions and results are part of a single set. Small differences in the way different researchers would express the environment can be quite important and the use of a menu for the specification of the environment avoids the proliferation of almost equivalent conditions that do not quite match. If a new rule requires a condition that is not available on the menu, the new condition is added to the menu, but only after an effort is made to use the existing menu. The use of a menu also helps remind the researchers of conditions that might otherwise be overlooked.

In operation the system provides a menu and the user selects the desired environmental conditions. The system then uses its rule set and these conditions to determine all other environmental conditions which would be expected to occur as a result of the specified conditions. The most important conditions are output along with an invitation to question the system about the results. The system can relate such things as the ruleleading to a particular result, and with repeated questions the full details about how the result came to be reported can be explored. It is also possible to ask why some particular result does not occur and be given those conditions that would have to exist for that result to be valid.

It is important to distinguish here between conclusions about conditions and the complete set of results available from the system. A mathematical model, which is discussed below, is available for providing numerical values of meteorological conditions at general locations. These values must be requested from the system when they are desired.

There is a second set of rules that are only tentative. This set can be either included or excluded when the system is operated. The rules in this category may have overlapping or conflicting conclusions. Doing comparative runs of the system with different subsets of tentative rules permits the researchers to test their observations against the rules and either verify, extend, or refute the rules.

After a tentative rule is refuted by the use of observational data, the person who provided the rule has the opportunity to further specify the conditions under which it applies. This serves to resolve disputes and to focus the attention of the person providing the rule on possible shortcomings of the rule.

3. MATHEMATICS AND THE EXPERT SYSTEM

In meteorology one uses a combination of mathematics and observations. The scientists make observations that are both quantitative and qualitative, and these lead to conclusions that can be expressed in words. In this sense the rules the meteorologist puts forth are not so different than the rules found in any other expert system. The difference comes in the application of the rules. The qualitative rule that sounds simple may result in greatly altered situations that cannot be stated in a reasonable number of words.

This can be better understood with an example such as the rule "If the surface is covered with trees, the drag coefficient will be large." The wind field at the surface is determined by the relative values of the drag coefficient and other physical parameters. A change in the drag coefficient can change the speed and the direction of the wind, which changes cooling rates and so on down through several other sets of parameters.

In dealing with a situation such as this the expert system builder faces a dilemma because his craft is based on the assumption that experts have the ability to solve problems without starting from first principles. Yet the need to describe the repercussions of something like the example above seem impossible to express without going to the equations that relate drag and meteorological observables.

In spite of this dilemma, there is a halfway ground that the experts use to avoid having to solve partial differential equations in their heads. The meteorologist knows that there is a set of equations which, if properly applied, contain the solution to a problem of this sort. However, the equations require rather precise boundary conditions, a supercomputer to solve, and even after the solution is found it is not possible to discern what the result of altering some particular parameter would be. That result can only be determined by altering the parameter and numerically solving the equations again. The expert avoids this dilemma by using a set of empirical mathematical relations that give reasonable approximations to the full set of dynamical equations.

This same approach is being used to build the expert system. A number of equations are used to approximate interactions among parameters. Examples of this might be the wind down the slopes and the wind down the axis of a valley. Of course there is some interaction of these two winds, but so far it has been possible to use an equation that simply espresses that the sum of the winds down the slope make up the wind down the valley. Moreover, an algebraic equation involving two parameters is assumed for the profile of the wind velocity as a function of altitude. This gives a tremendous compression of information because with the values of two parameters the velocity at every point on the profile can be specified. The system can then be queried about the velocity at any altitude, and it will provide it.

Generally, the relations used have represented some phenomena, not just parameters. The example in the previous paragraph illustrated how a mathematical approximation can be used to specify the phenomena of the wind field. In the same way rather direct equations or models of phenomena like turbulent mixing, radiative cooling, or effects of ground cover are needed to transform the words used by the experts into quantitative relationships.

Most of the equations represented in the models were known before the present project started. They had either been used by experimenters as equations for fitting their data or derived through the use of simplifying assumptions. The greatest effort was in getting the different equations related to each other. This is a continuing effort because new understanding by the researchers often involves interactions between the models.

Having once formed such a framework as a basis for the expert system, it is always possible to add new terms to the equations in the models. Such equations may represent idealizations of the actual situation, or specify what changes in the real situation are brought about by particular conditions. The task of the expert system is to couple these changes into the overall situation through all the relations that involve the altered parameters. Changing one equation has a ripple effect on many other equations. In the same way that it is necessary to cycle through a set of if-then statements until there is a pass when no additional statements are satisfied, it is necessary to cycle through the equations several times for all interactions to come to equilibrium. So far, no problems with hangups due to oscillations in the equations have occurred, but such hangups could occur.

At this point it might be best to restate why the expert system is being built when it sounds as though one can run a mathematical model that calculates the value of all the observable quantities throughout the region of interest. The basic equations are known for the model, but how some quantities should be expressed and the scale of events which are important are not known. The researchers have to examine individual phenonena to learn how the individual events are important in the overall situation. The ability of the expert system to deal with large numbers of relations, to cope with incomplete information, and to serve as a collecting point for relations make it a valuable addition to the research program.

The mathematical models convert words into fields of numbers, but there is a multitude of models that could be used for this conversion. It requires an expert to select the proper model, to provide the needed default parameters for missing information, and to appreciate how valid the model results will be in a particular situation. In the present application, the expert system is being used to combine the developing expertise of experts in several meteorological specialties.

The expert system is being constructed as one way of trying to understand why particular meteorological events occur as well as what events occur. This makes the query system of more than usual importance and requires a distinction between what happens and why it happens. It is often necessary to include what might be called a "because" in the if-then statement. The because gives a physical explanation of the basis of the rule. For example, there might be a rule, "If there is a strong ambient wind at levels above the valley, and if this wind is not in the direction of the valley flow, then the wind down the valley walls will be negligible because of turbulent coupling of momentum." The because clauses have no effect on the system operation but are important in the research mode. They label the empirical rule with the physical concept that underlies the rule.

The because statements can pose a difficulty even though the rule itself is generally accepted because the researchers may differ as to why the rule is valid. One of the researchers will normally be able to use reasoning and data to demonstrate the superiority of his form of the because statement, but until he does there is no harm in including more than one possibility in the because. It might say, "... because of turbulent coupling of momentum, or because of Bernoulli effects." This leaves the question open until someone finds an acceptable solution to the disagreement.

In other cases a rule may be found useful, but there may be no known connection between the parameters involved in the if clause and the then clause. The reason will usually turn out to be some third factor that relates the if and the then clauses. Until this happens, the because statement can state that the connection is not understood. Such a statement presents an open c‾ lenge to the researchers and can be expected to be r ed before much time passes.

4. DISCUSSION

As is often the case, this system is turning out to be quite different than originally conceived. The most interesting and important aspect of this has been the need to introduce a mathematical model into the system. Meteorologists seem to be able to converse about the topics being put into the expert system with almost no mathematics. The difference is that each of the people in the conversation already has a mental image of the phenomenon involved.

The conversations usually discuss the effects of changes in one or two parameters, and this keeps the picture simple enough for everyone to keep their mental image updated. The expert system does not limit itself to one or two parameters: and thus it may not be possible for the user to understand how the expert system result comes about. The use of the mathematical model helps by allowing numerical and graphical information to be presented. The graphical information is especially helpful to the user in transforming his mental image into the system result and vise versa, and that is important in achieving system credibility.

The study of down-valley winds is still in progress and work on the expert system will continue until after the research is complete. At that time the expert system will have abstracted most of the project results. It will have also served the useful purposes of helping the researchers formalize their observational results into definite rules and of improving cross communications between different research specialties. It is also significant that the system will provide a mechanism to preserve the expertise that has been developed in a more complete and usable form than the usual project report. It will also prevent loss of the expertise as the researchers drift into new and different research subjects.