ARTIFICIAL INTELLIGENCE FOR FOREST PEST MANAGEMENT

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ABSTRACT

A broad overview of research on artificial intellegence is developed to identify domains in which developments show greatest potential for application in forest pest management. Expert systems, which are of the greatest immediate potential, are described. Applications of expert systems to solving forest pest management problems are reviewed.

INTRODUCTION

What has become known as the science of artificial intelligence began with a 1956 conjecture that it should be possible to describe every aspect of learning so precisely that a machine could be made to mimic it (Patent 1986). This conjecture has become the "Holy Grail" of artificial intelligence, because it is difficult to define what is meant by intelligence and, despite 33 years of research in this area, no one has produced a machine that can even approach the human mind in its capacity to solve a variety of complex problems. Unlike the situation with the Holy Grail, however, it is possible, theoretically, to know when one has devised a machine that can think by applying the Turing test (Patent 1986). This test consists of trying to distinguish between the answers to questions posed of a person and a "thinking" machine. When it is impossible to distinguish between the two responses, one can conclude that a thinking machine has indeed been produced. Naturally, it might require considerable cleverness on the part of the questioner to trick the machine into revealing its identity. Nevertheless, machines have been built that approach the ability of humans in performing certain "thinking" tasks. A more modest definition of artificial intelligence is "how to make computers do things at which, for the moment, people are better" (Patent 1986). This definition is more convenient and skirts some of the philosophical problems of defining intelligence. By this definition, then, what constitutes artificial intelligence will change as we progress toward the "Holy Grail" of this area of human endeavor.

A major area of artificial intelligence research addresses problems in simulating human perception of language and vision. An inability to integrate the information derived from these sensory modes to produce a reasoned response has interfered with our attaining the ultimate goal of artificial intelligence research. Combined with our inability to effectively program for common sense these inadequacies make it even more difficult to achieve that goal. Part of the problem with language recognition arises from difficulties we have in discerning the rules of natural language, the ambiguity of language as we use it, and the contextual significance of the message. We absorb considerable quantities of information as we mature and can selectively recall the necessary information and process it to produce an appropriate response in most situations. Just how this is to be programmed is, at present, unknown. Similarly, although we are presented with large quantities of information in most scenes, considerable filtering occurs, and we are able to extract the pertinent information from a scene to produce a response. Such processing involves problems that are beyond our abilities to simulate in a machine, not the least of which is the supposition that the machine can be made to "know" what is important.

Despite these problems, some surprises have developed from the study of artificial intelligence. It is possible to simulate the processes by which experienced individuals, often with incomplete information, make decisions about complex systems. These simulations are now known as expert systems and have considerable application in crop management. My objective is to provide a brief description of these systems because of their potential significance to the practice of forest pest management.

EXPERT SYSTEMS

There are several definitions of what constitutes an expert system. A computer program that provides a solution to a problem by simulating the human reasoning process and using a body of knowledge can be called an expert system (Stone et al. 1986) In practice, the problem for which a solution is sought is normally sufficiently complex that it is worthwhile developing an expert system for its solution. Further, there should be a repeated need for these solutions. This typically arises because of changing conditions in either time or space (or both), exactly the situation faced by Canadian forest pest managers confronted with a dynamic system over a large geographic area.

The human reasoning process that is simulated in expert systems often involves the extensive use of heuristics as opposed to the algorithms commonly employed in other computer programs. Whereas an algorithm is a formal procedure guaranteed to produce a correct or optimal solution, the heuristic approach employs simplifications and rules of thumb to provide an acceptable solution (Latin et al. 1987). The expediency of using the heuristic approach is often dictated by the quantity and quality of information available or obtainable for solving the problem in a reasonable time at reasonable cost.

The contrast between algorithmic and heuristic solutions to a problem is best illustrated by comparing the use of Koch's postulates (an algorithm) for the identification of a disease-causing organism to the heuristic approach used in the field diagnosis of the cause of the disease (Latin et al. 1986). For example, the application of Koch's postulates to identifying the organism causing Armillaria root rot would require that

a. the pathogen is associated with all trees showing the symptoms,
b. the pathogen is grown in pure culture,
c. healthy trees can is inoculated with this culture,
d. the inoculated trees develop the symptoms observed in nature, and
e. the pathogen can be re-isolated from the inoculated trees.

This process would require a minimum of several months but would provide the best information concerning the identity of the pathogen. By contrast, field diagnosis of the presence of Armillaria root rot in a stand would depend on finding a combination of symptoms that includes all of the following:

1. dead trees are associated with trees having thin crowns and/or chlorotic foliage,
2. the affected trees occur in vaguely defined pockets or centers, and
3. the characteristic white mycelial fan occurs under the bark of the root collar or roots of recently dead trees.

This process would require at most a few hours (if travel time is required) but would provide information that may be subject to some probability of error.

A further distinction between ordinary computer programs or computer simulations and expert systems is that the former process data whereas knowledge is grist for the latter. Data are observations or facts that are summarized to provide information. Information from one source can be interpreted with respect to that derived from other sources to form knowledge. In the example above, the data obtained from observing conditions 1 through 3 can be summarized for the forest stand and interpreted along with other research results (including those derived from using Koch's postulates) to provide knowledge about the epidemiology of Armillaria root rot in stands. This knowledge can thus be applied to make predictions about the impact of the disease in particular stands.

Expert systems are composed of two essential components and a variety of utilities that enhance their capabilities and versatility. The component that is unique to the application for which the expert system was designed is the knowledge base. This knowledge base is the totality of information derived from human experts who have an understanding of the structure and functioning of the natural system. This knowledge is organized so that it can be addressed and employed efficiently by the expert system. Although there may be several ways to represent the knowledge base, the most common method is to formulate a rule base composed of a series of logical statements, usually in the form of IF...THEN statements. The rule base may include facts, principles, generalities, opinions, and hypothesized relationships. Expert systems can be programed to update the knowledge base in response to information derived from the natural system. This may include changes to the structure of the rules (IF...THEN statements) in addition to adjustments to the parameters of any algorithms that are incorporated into the expert system. Weighing the truth value of opinions and hypothesized relationships and updating these weights may also be used in contributing to updates in the knowledge base. Making changes in the knowledge base in response to experience is analogous to learning; hence the inclusion of expert systems in the field of artificial intelligence research is justified.

Operation of the expert system (which involves checking current information about the natural system against the rules in the knowledge base) is performed by the other essential component of expert systems known as the "inference engine." The inference engine searches the rule base, performs up-dates as required, and provides a solution to the problem at hand. It has been found expedient to isolate the problem-solving logic from the knowledge base because it is not necessary to alter the structure of the inference engine in response to the changing conditions of the natural system, which are reflected as updates to the rule base.

The expert system's solution to the problem may be a decision or a prescription. One of the utilities of the expert system is the reporting facility, which can provide a report on how the solution was derived. The forest manager would be irresponsible if he accepted (but did not check on) a suspect decision, knowing that the expert system contained rules that were based on opinions and hypothesized relationships.

Other utilities may be incorporated in the expert system to automatically provide managers with options for solving their problem. Although not characteristic of expert systems per se, these utilities would include a connection management system to manage the flow of information among the various computers connected to the system, a data-base management system to manage data from other sources, and a user interface to permit the manager to interact with the expert system. A utility that will probably be incorporated in most forest pest management expert systems in Canada will be a geographical information system to provide spatial information required to manage pests whose ranges cover large geographic areas (Coulson et al. 1989).

SYSTEM DEVELOPMENT CONSIDERATIONS

There are four requirements to be considered in the development of expert systems. The first is the availability of human experts conversant with the natural system being examined. These experts should possess the knowledge to adequately describe the functioning of the system. This knowledge need not be perfect and, where understanding of the natural system is deficient, best guesses will suffice to develop a prototype expert system. Sensitivity analyses, future research, and indeed updates by the system itself can be used to fill gaps in the knowledge base. Having identified the experts, the next step is to obtain, organize, and structure the knowledge in a form that can be programmed for the knowledge base. This job is the responsibility of "knowledge engineers." The other two considerations in system development are the choices of software and hardware with which the expert system is to be developed and implemented. Although it is not essential, the programming language used in development of the rule base is often one of the several developed specifically for artificial intelligence applications. Hardware considerations depend on the application, but with the recent increase in power of personal computers this is less of a constraint. Personal computers offer an opportunity for placing expert systems at the disposal of individuals working in locations, such as district offices of large forestry agencies, which are remote from centers of computing.

There are significant developmental constraints. A major concern is the availability of experts to solve the problem at hand. In applications involving biosystematics, for example, experts on particular taxonomic groups may not be trained or available. The second constraint is that the experts, once identified, may not be willing to participate in the project. Other demands for their expertise may preclude their participation. The cost of expert system development is the third major consideration influencing the decision to proceed. An expert system for diagnosing bacterial blood infections involving 200 pathogens took 10-person years to develop, but this involved considerable pioneering work, including the development of a programming language suitable for use in artificial intelligence programing (Patent 1986). Depending on the application, system development in forest pest management may require anywhere from two to eight person-years. Because of this cost the need to develop an expert system to solve a problem has to be carefully assessed. In large forestry concerns, the savings in wood costs, discounted to present net value, resulting from informed decisions on the timely harvest of stands threatened by pests can be used in evaluating the cost of expert system development. Other techniques are available to be used in evaluating the benefits, costs, and need for systems development.

FOREST PEST MANAGEMENT APPLICATIONS

Four major areas in which expert systems can be applied in forest pest management are diagnostics, integrated pest management, training, and technology transfer. The first is a relatively straightforward application of information to be found in insect and disease identification manuals and the experience of knowledgeable individuals who provide this service in their day-to-day activities. The need for this service can be evaluated by the history of requests for diagnostic services of the Forest Insect and Disease Survey (FIDS) of Forestry Canada and the Biosystematics Research Centre of Agriculture Canada in Ottawa. At present, the Northwest Region's FIDS unit handles approximately 2500 such requests annually, but the demand for this service is known to be substantially larger in this region's forestry community. An expert system for forest pest diagnostics could significantly improve the quality and volume of service currently provided to the forestry community of this region. The expert system would not obviate the need for specialists; rather, it would permit a more efficient use of their time to handle less routine identifications.

Integrated pest management applications of expert systems in forestry are at present under development for the hemlock looper in Newfoundland, and there are proposals to develop systems for other forest pests of the mixed-wood forests in the Northwest Region. Significant strides have been made in the development of integrated pest management systems for a variety of forest insects in North America through accelerated research and development programs. These insects include the spruce budworm, western spruce budworm, gypsy moth, mountain pine beetle, western pine beetle, and southern pine beetle. In each case decision-support systems can be easily developed or have been developed, and an expert system is under development for the southern pine beetle (Coulson et al. 1989). The impact of these developments on resource management has not been fully analyzed to date; however, the benefits from expert system development allow application of the methodology to pest management problem solving at different administration levels while ensuring that the needs and problem-solving style of the individual manager are addressed (Coulson et al. 1989). No individual can effectively utilize all pertinent information in solving complex pest management problems in short time intervals or explore several plausible solutions simultaneously. To embed these solutions in an integrated resource management decision process further complicates an already difficult problem. Expert systems present an opportunity to address these concerns. It is believed that the application of expert systems to forest pest management problems will provide the greatest opportunity for Canadian forestry practitioners to manage pests in integrated resource management systems.

Training of personnel, which is a third major application of expert systems, can be accomplished by encouraging individuals to explore expert systems developed to solve particular problems. The expert system accompanied by on-line user manuals, knowledge base documentation, and familiarization or training protocols could be a training tool in itself. Expert systems designed specifically to train people have, of course, been developed. In addition to the expertise of the pest management specialist, the services of a teaching specialist would be required. Because of the variety of products available from an expert system, students could tailor the learning session to their individual needs. The almost immediate response of the system provides a learning situation that would appeal to individuals who wish to explore the system with a clever selection of conditions. In essence, the exercise has the appeal of a game with all the attendant benefits of rapid learning and skill development.

Expert systems also address the need to disseminate research results in a cogent and coherent fashion in a manner accessible and useful to the nonexpert practitioner. Although it is useful to consult the specialist in making decisions, the specialist may not be available. Thus if properly designed, an expert system can be a teaching tool, a means of technology transfer, and an aid to decision making in forest pest management in a decentralized forestry community.

CONCLUSIONS

Managers make decisions about natural systems that are not completely understood (double entendre deliberate). The expert system permits these decisions to be made by mimicking the expert in the use of facts, information, knowledge, and some of the expert's opinions. Unlike the expert, the expert system can assess a large number of possible solutions and select among the best of them in a short period and report the route by which the solution was obtained. The extremely rapid decline in the cost of computing hardware and the relative scarcity of experts will probably combine to spur development of these expert systems for forest pest management applications in integrated resource management systems. These systems will not replace the experts but can be their tools to focus their attention on resource management problems in vital need of research.

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