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Source: *Vegetatio*, Vol. 69, No. 1/3, Theory and Models in Vegetation Science (Apr. 30, 1987),
pp. 115-121
Published by: Springer
Stable URL: http://www.jstor.org/stable/20038108
Accessed: 23/09/2014 15:22

The role of expert systems in vegetation science

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Abstract

An area of artificial intelligence known as experts systems (or knowledge-based systems) is being applied in many areas of science, technology and commerce. It is likely that the techniques will have an impact on vegetation science and ecology in general. This paper discusses some of those impacts and concludes that the main effects will be in areas of applied ecology especially where ecological expertise is needed either quickly (e.g. disaster management) or across a wide range of ecological disciplines (e.g. land management decisions). Expert systems will provide ecologists with valuable tools for managing data and interacting with other fields of expertise. The impact of expert systems on ecological theory will depend on the degree to which 'deep knowledge' (i.e. knowledge based on first principles rather than on more empirical rules) is used in formulating knowledge bases.

Introduction

In the early 1980's the Japanese Ministry of Trade and Industry announced that it was supporting a wide ranging programme to develop the hardware and software resources for a 'fifth generation' of computers. This triggered a major increase in effort in an area of artificial intelligence known as expert systems as many other nations announced similar efforts. The impact that expert systems are likely to have on society – including all fields of science – over the next decade or so have been discussed by many authors (Weizenbaum, 1976; Feigenbaum & McCorduck, 1983; Duda & Shortcliffe, 1983; Lenat, 1984; Shannon *et al.*, 1985; Waterman, 1986). Here, I discuss some aspects of the application of expert systems (or knowledge-based systems as many prefer to call them) to ecology and especially that part of ecology that is involved in the prediction of the consequences of our actions in managing our environment.

What is an expert system?

There is a plethora of material describing expert systems in both the serious and popular scientific press and thus I will not attempt to review this material here. An expert system is a computer program capable of holding an apparently intelligent conversation with the user. It asks questions and the order of the questions changes with the responses given. Based on the knowledge held by the system and the answers to the questions, the system eventually states or validates a conclusion or decision and is able to explain how and why it reached this conclusion. Or more concisely it is a computer program designed to behave like professional experts.

An expert system can make use of a set of heuristic rules (i.e. 'rules of thumb') rather than a purely quantitative data base. It can be written in any of the common computer languages, despite some claims that that 'real' expert systems are written in LISP, PROLOG or a language similarly obscure to biologists. The program has two main components: a knowledge base, which is a series of often empiri-

cal rules or relationships, and an inference engine, which is code that is able to interact with the user and link the user's input to the knowledge base in order to answer some of the users' questions. There are advantages when writing expert systems in using a declarative (also called non-procedural) language such as PROLOG rather than an imperative (or procedural) language such as FORTRAN. Whereas in an imperative language the user must specify the steps to be taken in solving a problem (the algorithm), in a declarative language the user specifies only a description of the problem to be solved. The language itself provides the methodology to examine its data base and attempts to derive a solution. The main limitation in the development of declarative languages has been that they are slow to execute, but this is being overcome by advances in both computer software and hardware.

The major difference between an expert system and a process model, typical of the IBP programme and numerous other programmes, is best shown by example. Figures 1 & 2 show two versions of a section of a model of the damage to trees by fire in a forest community. The first describes the impact in strictly quantitative functions (i.e. a process model), while the second describes the same features in a mixture of quantitative and qualitative rules (production rules) more typical of a knowledge based system

In the process model knowledge about the system is encoded as mathematical formulae. The derivation of these formulae often require data that are difficult to obtain, or else 'guesstimates', which give the equations a false appearance of accuracy. In expert systems the knowledge is encoded as rules. There is usually some loss of accuracy, although more and more rules can be added to overcome this. However, the potential loss of accuracy

Fig. 1. A section of a process model of tree damage and mortality.

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bark-thickness = FUNC1 (species)
bark-damage = FUNC2 (species, time-since-fire)
bark-remaining = bark-thickness − bark damage
effective-intensity = SEASONAL-EFFECT (season) * intensity
heating-effect = effective-intensity * FUNC3 (bark-remaining)
kill (species) = FUNC4.1 (heating-effect, species)
basal-sprout (species) = FUNC4.2 (heating-effect, species)
stem-sprout (species) = FUNC 4.3 (heating effect, species)
no-effect (species) = 1.0 − kill (species) − basal-sprout (species) − stem-sprout (species)
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Fig. 2. Some production rules for tree damage and mortality

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IF species is (Eucalyptus delegatensis OR E. fastigiata)
    THEN species-type is sensitive

IF intensity is no-scorch
    THEN no-effect

IF intensity is (crown-fire OR full-scorch) AND
  species-type is sensitive
    THEN all-killed

IF intensity is (crown-fire OR full-scorch) AND
  species-type is NOT (sensitive) AND
  EITHER (
  season is dry AND
    EITHER (
      dbh < limit
      THEN stem-sprout is uncommon
              basal-sprout is common
              killed is rare)
  OR
  dbh > = limit
      THEN stem-sprout is very − common
              basal-sprout is uncommon
              killed is practically-none )
  )
OR (
  season is wet AND
    EITHER (
      dbh < limit
      THEN stem-sprout is common
              basal-sprout is common
              killed is practically-none )
  OR      (
  dbh > = limit
      THEN stem-sprout is very − common
              basal-sprout is rare
              killed is practically-none )
  )
IF previous-fire > 4 years-ago AND
  EITHER    (
    species is E. pauciflora       THEN limit is 35-cm
  OR
    species is E. dives            THEN limit is 20-cm
  OR
    species is E. dalrympleana  THEN limit is 15-cm
  OR
    etc.
          )
IF previous-fire < = 4-years-ago AND
              etc.
```

is a problem only when we truly do know the system well enough the make precise predictions.

In the knowledge based model the biological system is described in terms of a series of production rules (i.e. IF situation true THEN this applies) and facts (e.g. the species *Eucalyptus delegatensis* is of

the sensitive species type). Proponents of expert systems argue that a knowledge based system more realistically mimics the human expert's use of knowledge. The example in Fig. 2 is not written in a particular language, but demonstrates one of the advantages of the declarative languages such as PROLOG in that the order of inclusion of rules is flexible — for example, the term 'limit' can be used in a rule which comes before the other rules which supply other essential information about limit. This makes it easy to update and modify such models.

When to use an expert system.

Table 1 shows a summary of the situations suitable for the application of expert systems (Forsyth, 1984). Do they apply to ecological work?

Diagnostic — Many ecological problems require that an item be classified or a choice be made between options. This is especially true in applied ecology where the question asked is often, 'which of a series of actions should be taken?' For example, should I conduct a prescribed burn in spring or autumn; should I burn today or not?

No established theory — I suspect that this is possibly an erroneous contrast, but nevertheless most ecologists would agree that much of ecology lacks a firmly established theory.

Data noisy and incomplete — No comment is needed.

Domain well bounded — This could be a problem in ecological applications because the domain under consideration when tackling ecological problems is usually very broad. Thus, expert systems will be able to provide advice on only small sections of wider problems. However, one of the long term goals of those working with expert systems is to link expert systems of different domains (e.g. Pereira *et al.*, 1984).

Human expertise scarce — This is true although unemployed postgraduates may disagree. However, many managers are making day-by-day decisions concerning ecological problems without the access

Table 1. A checklist of when to use knowledge based systems (based on Forsyth, 1984).

Suitable	Unsuitable
Diagnostic	Calculative
No established theory	Well established formulae
Data are noisy	Facts known precisely
Domain of knowledge well bounded	Domain not well bounded
Human expertise scarce and in demand	Expertise readily available

to ecological expertise which may be of assistance to them.

...and in demand — This is the real problem. Consultant ecologists are still relatively rare professionals and several factors are involved. First, many ecological problems do not require consultancy, but rather research. Thus the ecologists are called upon largely to provide data rather than to provide recommendations on decision making. That is, ecological expertise is too scarce in many situations for the consultancy role to have developed. Secondly, many managers consider themselves to be well acquainted with the numerous aspects of solving a land management problem and, thus, consider consulting a range of ecological specialists to be unnecessary. It is possible that expert systems may be developed to cover many of the specialist areas, thus making them more readily available to decision makers without the lengthy and expensive process of face to face consultation. These expert systems should be able to warn decision makers when more direct consultation is advisable.

Applications of knowledge based methodology in ecology have been limited largely to diagnostic problems. Starfield & Bleloch (1983) outlined an expert system to advise on prescribed burning. Noble (1985) has described an expert system that assists users to run a model which incorporates the vital attribute scheme (Noble & Slatyer, 1980) to predict vegetation change. Davis *et al.* (in press) have developed a knowledge based model which predicts aspects of fire intensity in tropical woodlands in northern Australia. This program forms part of a larger study to develop knowledge based systems to assist in the management of Kakadu National Park (Davis *et al.*, 1985; Walker *et al.*, 1985).

What will expert systems contribute to ecology?

I have already alluded to some of the impact that I think that the development of expert systems technology may have on ecology as a profession, but here I want to ask what might expert systems contribute to our understanding of ecological principles.

Expert systems may or may not contribute to ecological theory. If expert systems are used only to bring together a number of ecological rules-of-thumb and to package them in a way more readily available to a user then ecological understanding will advance very little. If, however, in our attempt to formulate the knowledge bases, we are forced to re-think the nature of ecological relationships then expert systems may have some impact. This is the basis of the debate about the role of 'deep' versus 'surface' knowledge in expert systems.

Deep versus surface knowledge

Most expert systems use rules with the form:

IF pattern THEN action

For example,

IF it is spring THEN don't burn

This sort of rule represents the surface knowledge of expertise in prescribed burning. The rule carries no insight into the processes that link the pattern 'it is spring' with the action 'don't burn'. It may be derived from simple empirical knowledge (i.e. experience) gathered over centuries.

The definition of deep knowledge is somewhat hazy but it is often described by example such as, deep knowledge includes the first principles to which a human expert will need to resort in order to solve difficult problems or to provide a creditable explanation of particular advice. More explicitly, deep knowledge often involves the use of rules of the form:

IF pattern-A & action THEN pattern-B will follow

For example,

IF spring foliage of species X is present & you burn THEN plant reserves will be depleted

IF it is spring & you deplete reserves of X

THEN summer growth will be poor

IF summer growth of X is poor THEN mortality increases

IF mortality of X increases & X is a desirable species THEN this is an unwanted result

IF result is unwanted THEN don't burn

The advantages of having deep knowledge built into the data base are several. If users are confronted by the rule

IF it is spring THEN don't burn

and they ask why, then the expert system can reply only

Don't burn in spring
BECAUSE it is spring

whereas with the deep knowledge rules the reply would be along the lines of

Don't burn in spring
BECAUSE it leads to an unwanted result
BECAUSE it leads to increased mortality of a desirable species
BECAUSE there has been poor summer growth
BECAUSE plant reserves were depleted in spring

Some users will then demand to know why poor summer growth leads to high mortality or why burning in spring depletes plant reserves, but there has to be a cut off point in any consultative system.

There is dispute among the expert systems' circles as to whether simple surface knowledge is sufficient to build useful expert systems. Most expert systems that have reached the production stage so far have been a collection of surface rules with a few additional rules to guide the inference engine of the expert system in efficiently consulting these rules. Chandrasekaran & Mittal (1983) have argued that, in medical diagnosis systems at least, it is not necessary to resort to deep knowledge to produce effective expert systems. Attarwala & Basden (1985) also discuss this topic in terms of causality and model detail based on their experiences in developing expert systems for corrosion control in industrial plants and tend to favour the use of deep knowledge.

The deep knowledge system will often allow

more generality in an expert system. For example, if we want to change a goal from that of protecting a species to eradicating it, then in the surface knowledge system we would have to change many of the rules relating to that species, whereas in the deep knowledge system we may need to change only the goal to be achieved, e.g. from achieving low summer mortality to achieving high mortality.

Deep knowledge will also provide more opportunities for interactions in ecological knowledge bases that combine several domains of expertise. For example, the above set of rules may interact with a set of rules in a domain dealing with the dynamics of a granivore. These rules may include:

If summer growth of X is poor THEN seed set is poor

IF seed set of X is poor THEN reproductive success of bird species Y is poor, etc.

Thus the two domains i.e. the impact of prescribed burning and the success of granivores are linked at this deeper level of knowledge.

If commercial pressure or simplistic expert systems engineering leads to ecological expert systems containing only surface knowledge then there is little possibility of a gain to ecological theory (as opposed to the practice of applied ecology). If we are forced to rethink and clearly state the inter-relationships between ecological processes in order to link them in a way that can provide advice (i.e. prediction) there is more to be gained.

Other impacts of expert systems

Starfield & Bleloch (1983), in the first paper on the application of expert system to ecology, suggested educational and communication advantages in building expert systems. These points are similar to the advantages listed for process modelling in the lead up to the IBP programme. Similarly, the claim that if expert systems theory forces ecologists to re-think ecological relationships then this will be of some benefit, is close to some of the early claims about process modelling — i.e. even if the models don't work we will still learn by building them.

It is sometimes argued that expert systems must be built by a new and special class of scientists known as knowledge engineers (Weiss & Kulikowski, 1984; Davis *et al.,* in press). Thus we

have the equivalent to the 'synthesizers' of the IBP programme. At present the number of ecologists with skills appropriate to developing application packages based on expert systems are few and the tools crude. However, I doubt if this will remain the case as improved shells (software packages for developing expert systems) become available — a view supported by some of the expert systems workers themselves (e.g. Basden, 1983).

An aspect of expert systems technology that will have an impact on all professions that deal with large amounts of information, is their application to data base design. Commercial pressures are likely to lead to the development of relational data bases which use expert systems techniques to deduce additional connections between elements of the data base and to interact via a natural language interface. Like statistics, scuba tanks and word processors, these data bases will have an impact in the ecologist's ability to retrieve — and, hopefully, use — ecological information. Pereira *et al.* (1984) have begun a project in Portugal to develop a data base for environmental biophysical resource evaluation. In this they aim to bring the expertise of several disciplines, such as geology, hydrology, botany, zoology and microclimatology together in one expert system and to make this available to decision makers.

Another aspect of expert systems theory deals with systems that assist in the laborious tasks of interrogating experts and systematically organizing their knowledge. There are two broadly different approaches here. One is to aid the user in setting up the knowledge base. This involves assessing new rules againt those already in the knowledge base and warning of inconsistencies and incompleteness (e.g. omitting to tell the system facts that are so obvious to the expert that they are easily overlooked, such as that trees are usually much taller than grasses). TEIRESIAS is an example of such software (Davis & Lenat, 1982). The other approach is to provide the system with many case histories and algorithms for deducing, and even inducing, additional rules (e.g. Quinlan, 1983 for end games in chess). Most success in this area appears to be in diagnostic situations, e.g. an expert system to diagnose diseases of soy-bean (Michalski & Chilausky, 1980; Sammut, 1985). This learning approach is likely to have only limited application in ecology since we rarely have the large number of consistent

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case histories to work with. However, relatively inexpensive software packages that implement some aspects of computer induction (e.g. 'EXPERT-EASE', & 'RULEMASTER; Waterman, 1986) are available for microcomputers and this may encourage ecologists to experiment with them (see McLaren, 1985 for an application of EXPERT-EASE).

Expert systems can also be used in training people. There have been some promising packages developed in this area but the subject falls outside this paper. However, the benefits to the ecological community of an expert system that guides the user through the complexities of experimental design, or of multivariate data analysis, should not be underestimated.

Discussion

Expert systems will have a major impact on applied ecology. Probably the most spectacular, and immediately challenging, problems will be in those aspects of environmental impact analysis dealing with disaster management. In these circumstances — e.g. wildfires or noxious spills — ecological information is needed quickly, it must be based on knowledge already held (i.e. there is no time for research), human experts may be unavailable and several domains of expertise may be involved. A high proportion of the first efforts to apply expert systems to ecology deal with aspects of fire management (Starfield & Bleloch, 1983; Davis et al. in press; Noble, 1985).

As applications increase, practitioners in the expert systems field will attempt to link the knowledge bases from disparate areas of ecology thus leading their more theoretically oriented colleagues to consider more carefully the unifying concepts of ecology. This claim was made for process modelling in its early days, but process modelling is a relatively restrictive tool. The necessity to quantify ecological knowledge was an insurmountable hurdle in many cases — or at least a useful and often valid excuse for not trying to achieve those unifying concepts. Expert systems don't carry the quantification restriction. They ask only that we can express our ideas in concise, logical rules.

References

Attarwala, F T. & Basden, A., 1985. A methodology for constructing expert systems. R&D management 15: 141–149.

Basden, A., 1983. On the application of expert systems. Int. J. Man-Machine Studies 19: 461–477.

Chandrasekaran, B. & Mittal, S., 1983. Deep versus compiled knowledge approaches to diagnostic problem solving. Int. J. Man-Machine Studies 19: 425–436.

Davis, J. R., Hoare, J. R. L. & Nanninga, P. M., 1985. The GEO-KAK fire behaviour and fire effects Expert System. In: J. Walker, J. R. Davis & A. M. Gill (eds), Towards an expert system for fire management at Kakadu National Park. CSIRO Div. Water and Land Resources Tech. Mem. 85/2. pp. 153–169. CSIRO, Canberra.

Davis, J. R., Hoare, J. R. L. & Nanninga, P. M., in press. Developing a fire management expert system for Kakadu National Park, Australia. J. Envir. Management.

Davis, R. & Lenat, D. B., 1982. Knowledge-based systems in artificial intelligence. McGraw-Hill, New York.

Duda, R. O. & Shortcliffe, E. H., 1983. Expert systems research. Science 220: 261–268.

Feigenbaum, E. A. & McCorduck, P., 1983. The fifth generation: artificial intelligence and Japan's computer challenge to the world. Michael Joseph, London.

Forsyth, R., 1984. The architecture of expert systems. In: R. Forsyth (ed.), Expert systems: principles and case studies. pp. 9–17. Chapman & Hall, London.

Lenat, D. B., 1984. Computer software for intelligent systems. Sci. Amer. 251: 152–160.

McLaren, R., 1985. Knowledge acquisition by computer induction. R&D Management 15: 159–166.

Michalski, R. S. & Chilausky, R. L., 1980. Knowledge acquisition by encoding expert rules versus inductive learning from examples: An experiment utilizing plant pathology. Int. J. Man-Machine Studies 12: 63–87.

Noble, I. R., 1985. Fire effects, vital attributes and expert systems. In: J. Walker, J. R. Davis & A. M. Gill (eds), Towards an expert system for fire management at Kakadu National Park. CSIRO Div. Water and Land Resources Tech. Mem. 85/2. pp. 96–103. CSIRO, Canberra.

Noble, I. R. & Slatyer, R. O., 1980. The use of vital attributes to predict successional changes in plant communities subject to recurrent disturbances. Vegetatio 43: 5–21.

Pereira, L. M., Oliveira, E. & Sabatier, P., 1984. Expert evaluation in logic of environmental resources through natural language. In: A. Elithorn & R. Banjeri (eds), Artificial and human intelligence. pp. 309–311. Elsevier Science Publishers.

Quinlan, J. R., 1983. Learning efficient classification procedures and their application to chess end games. In: R. S. Michalski, J. G. Carbonelli & T. M. Mitchell (eds), Machine learning. pp. 463–480. Tioga Press, Palo Alto.

Sammut, C. A., 1985. Concept development for expert system knowledge bases. Aust. Computer J. 17: 49–55.

Shannon, R. E., Mayer, R. & Adelsberger, H. H., 1985. Expert systems and simulation. Simulation 44: 275–284.

Starfield A. M. & Bleloch A. L., 1983. Expert systems: An approach to problems in ecological management that are difficult to quantify. J. Envir. Management 16: 261–268.

Walker, J., Davis, J. R. & Gill A. M. (eds), 1985. Towards an expert system for fire management at Kakadu National Park. CSIRO Div. Water and Land Resources Tech. Mem. 85/2. CSIRO, Canberra.

Waterman, D. A., 1986. A guide to expert systems. Addison-Wesley. Reading Massachusetts.

Weiss, S. M. & Kulikowski, C. A. 1984. A practical guide to designing expert systems. Chapman & Hall, London.

Weizenbaum, J., 1976. Computer power and human reason. W. H. Freeman & Co. New York.