AI Magazine Volume 11 Number 3 (1990) (© AAAI)

# Knowledge-Based Systems in Agriculture and Natural Resource Management

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■ *The second workshop in two years on the integration of knowledge-based systems with conventional computer techniques in agriculture and natural resource management (NRM) was held 18–19 August 1989 in Detroit, Michigan, in conjunction with the Tenth International Joint Conference on Artificial Intelligence. The workshop drew scientists from the United States and Canada, working in disciplines from engineering to entomology in universities, government, and industry. Twenty-two papers were presented at the workshop, after which participants were asked to discuss several key questions about the development, delivery, and use of knowledge-based systems in solving problems in agriculture and NRM.*

Solving problems in agriculture and natural resource management (NRM) requires an understanding of both biological and economic systems, systems that are characteristically complex and unpredictable. Traditional computer-based approaches to problem solving in these domains—mathematical modeling, simulation, and optimization—have had only limited success. In the early 1980s, researchers began to apply knowledge-based approaches to problems in agriculture and NRM. In recent years, interest has intensified in the integration of knowledge-based approaches with conventional computer methodologies to increase the power, utility, and user friendliness of these systems.

The 1989 workshop was intended to focus on this problem of integration, with the goal of bringing together leading scientists and investigating the similarities and differences in their approaches as well as identifying trends in research over the last few years. This year, 22 papers were presented in the two-day meeting, with each speaker given 20 minutes. Discussion time was generously allotted to allow the participants to spontaneously react to issues raised in the presentations. At the conclusion of the selected papers, the workshop broke into four groups to discuss and summarize the information presented.

The breadth of the background of the workshop's attendees was remarkable. Participants represented universities in 13 U.S. states and two Canadian provinces, two U.S. Department of Agriculture laboratories, Agriculture Canada, two commercial agriculture companies, and one AI workstation-software manufacturer. The disciplines represented included computer science, electrical engineering, agricultural engineering, agricultural economics, agronomy, soil science, entomology, aquaculture, and climatology.

The diversity of the participants was reflected in the wide spectrum of papers presented. Application domains ranged from aquatic weed control to mill process control to expert system evaluation and implementation. The methodologies discussed included simulation, object-oriented programming, knowledge-based interfaces, optical sensing, blackboard systems, and information retrieval. Each of these topics might have supported a workshop in its own right. However, the thread of agriculture held the proceedings together as the group grappled with the unique features of agricultural and NRM applications that demand novel solutions.

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Following the formal presentations, workshop participants were divided into four discussion groups to address the following questions: What aspects of agricultural and NRM problems offer unique challenges to research in knowledge-based systems? What knowledge-based–system approaches seem best suited to agricultural and NRM problems? What is the role of integrated systems? What were the issues raised relating to the delivery and implementation of knowledge-based systems in agriculture and NRM? The groups' findings are summarized in the following sections.

## Challenges for AI Research in Agriculture and Natural Resource Management

Agricultural problems naturally pose certain technical difficulties of interest to AI researchers: There is a technological and psychological problem in that attempts to apply knowledge-based systems in agriculture have often met with resistance. More attention to modeling end users' perceptions and emotions is needed. The fact that NRM affects the general public (through food and water quality, general public health, and the pocketbook) means that political questions might become important to decision making. The distributed nature and loose organization of the agriculture industry poses some practical problems as well. Implementing the technology in a dispersed and computer-poor industry is difficult. Knowledge distribution techniques for agricultural practitioners unfamiliar with computers must use better explanation and combined AI-graphics systems.

Some specific technical issues must be addressed by AI research. The predominance of stochastic elements in agriculture and NRM demands better representations for dealing with processes such as the weather. Spatially referenced data and spatial variability must be incorporated into knowledge-based systems. Time-based reasoning and the representation of coordinated multiagent processes are also needed to address issues of simulation and planning. Finally, because expertise in agriculture and NRM is diffuse and disorganized, AI researchers interested in knowledge acquisition need to address the problems of synthesizing fractionalized expertise.

Conservation agriculture, climate change, environmental degradation, and sustainable low-input farming are major issues in agriculture that tax current AI technologies. In response to these concerns, AI research in agriculture and NRM over the next two years will need to address the theoretical integration of simulation and database technologies with AI technologies. Emphasis will need to shift from the production of shells to the production of AI languages that provide good integration with other tools. If the large-scale problems of farm planning and environmental preservation are to be addressed, control structures appropriate to integrating large, diverse systems must be pursued. Technologies for coordinating multiple experts through multiagent planning must be developed. The transfer of AI technology to "heartland" scientists must take place to put the appropriate AI tools in the hands of scientists most concerned with agricultural problems.

## Knowledge-Based System Technologies and Methods Used or Needed in Agriculture and Natural Resource Management

Rule-based systems still predominate in the knowledge-based systems currently being used and developed in agriculture and NRM. Rules work well at capturing many kinds of agricultural knowledge; however, some kinds of agricultural knowledge require more than just rules. Several presentations at the workshop went beyond purely rule-based systems to talk about multiple experts and deep reasoning. Object-oriented programming is also becoming more common as an overall programming technique in this area, both for simulation and the structuring of knowledge bases. Blackboard systems have begun to be used to integrate knowledge from multiple experts or multiple knowledge sources.

Almost one-third of the presentations dealt with simulation, sometimes embedding knowledge-based components within a classical simulation model, sometimes embedding the simulation within an expert front or back end. These papers involved linking a knowledge-based system to a model built in a language such as C or Fortran. There were also a few examples of intelligent simulation, in which the key issues involved the representation of actors in the simulated system and of spatial data and information.

Many presenters addressed the interface between existing or old algorithms and knowledge-based systems. Some were working on ways to integrate existing algorithmic functions, for example, through embedded expert systems to control simulation models or through blackboard systems. However, others were working to recode old algorithmic knowledge into forms accessible to newer simulation tools and information retrieval systems. There was some consensus that rewriting existing models and algorithms was preferred; however, there was no sign of any generally accepted methodology for accomplishing this recoding.

Tools for representing spatial data are becoming more and more important in agriculture and NRM. Some of the participants felt that geographic information systems (GISs) need to be modified so that maplike representations can easily be integrated into reasoning systems. Other approaches to representing spatial data included object-oriented systems. One presenter discussed the use of object-oriented programming and GIS in simulation.

## The Integration of Knowledge-Based Systems and Conventional Systems

One of the thrusts of the workshop was the integration of conventional and knowledge-based systems. It was quickly apparent that integrated systems are now standard. Although many workshop participants were applying rule-based shells to agricultural problems only a year ago, all participants at this year's meeting were working with hybrid systems of one kind or another. As a result, the term integrated system lost its importance. Thus, workshop discussions tended to focus on other aspects of the participants' research.

Systems can be integrated at different levels. For instance, systems can be coded using different engines—an inference engine and a database manager. Many systems are termed integrated because of this structural characteristic. Other systems can be considered integrated, however, if they merge conceptual problem-solving approaches, for example, using a heuristic front end on a simulation model to choose appropriate functions in a simulation run. Such intellectual or algorithmic integration is independent of coding and represents the philosophy of most of the participants. This view has arisen because agricultural problems are often complex and multifaceted, and thus, different approaches are needed to fit different pieces into the overall puzzle.

This algorithmic integration has primarily surfaced in the last year or so, along with a trend toward embedded systems. The trends are also reflected in the now general use of lower-level tools and languages rather than commercial shells. Also significant was the emergence of embedded systems in which the knowledge-based component is transparent to the user. Perhaps the novelty of knowledge-based systems has worn off, and researchers are using them only where they are appropriate rather than where they can be prominently featured. We seem to be finding more uses for this technology that depend on utility rather than glitter.

## Issues of Delivery and Implementation

Agriculture is a highly distributed industry. Within it are many potential markets for knowledge-based systems. However, the most obvious of these markets, the pool of individual farmers, is also the least likely to own computers or be trained in, or convinced of, their worth. This situation has already contributed to a bottleneck of applications reaching the field, and it continues to be a problem in the development of knowledge-based systems. What computer equipment is in the field also turns over slowly. This inertia slows new system development. One must either develop applications for obsolete machines or deliver applications on equipment that few, if any, farmers and natural resource managers own.

If knowledge-based systems are to become widely used in agriculture and NRM, users must be brought into the development process. The management of plants, crops, orchards, and forests is currently a field-oriented endeavor. For managers to be enticed to use knowledge-based systems, these office-bound systems must be integrated into the existing decision-making structure. Bringing the users into the development and design process will help ensure that the final product will be used and that user interfaces are more responsive to the needs of the end user.

The question of where knowledge-based systems for agriculture and NRM ought to be developed points out another problem. Universities develop software that is free or virtually free to their clientele. Industry is effectively removed from the market because of the competition. However, universities are not set up to market their products or maintain and update them. It would be beneficial to foster cooperative university-industry relations so that the marketing and sales processes could be taken over by industry and so that some sales proceeds could be channeled back to the university-based development team to support updating and maintenance.

To date, virtually all knowledge-based–system development has been conducted by the research arm of land-grant universities. However, these universities also include Cooperative Extension Service personnel and are mandated to transfer the results of research to the field and the public through the extension service. In other areas of research, the extension service assumes the primary responsibility of interacting with the public, farmers, and natural resource managers. Unfortunately, state extension services are generally not equipped to develop or transfer knowledge-based–system technology to the public, and researchers have had to take on the roles of both developer and implementer. Knowledge-based–system development for agriculture and NRM will remain an inefficient process in land-grant universities until the Cooperative Extension Service becomes a true partner in development and implementation.

## Future Directions

Applications of knowledge-based systems in agriculture and NRM have become much more sophisticated over the last two years. This trend will likely continue. We expect to see more uses of the technology that are not immediately service oriented, for example, applications in simulation, control, and research organization. The trend toward basic languages and tools rather than off-the-shelf shells probably reflects the lack of appropriate tools for agricultural problems. If products were developed that addressed spatial and highly variable data, time-dependent processes, and multiple fragmented expertise, they would be used. However, the current commercial promise of agricultural applications is not enough to drive the major AI software vendors to deliver such products.

Over the next few years, we expect to see more field applications of knowledge-based systems. Many will be integrated to some degree with databases, which are needed to account for time-dependent processes and voluminous amounts of information and data. As computers become more commonplace on farms, the market will grow. Currently, the applications are ahead of the capacity of farmers to use them. Therefore, delivery issues will likely dominate the agricultural and NRM AI field in the near future.

## Acknowledgments

We thank Howard Beck, John Roach, Dale Whittaker, and Walter Wolf for their summaries of the four discussion groups.

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