WORKSHOP REPORT

Integration of Problem-Solving Techniques in Agriculture

A. Dale Whittaker and Ronald H. Thieme

Problem-solving techniques such as modeling, simulation, optimization, and network analysis have been used extensively to help agricultural scientists and practitioners understand and control biological systems. By their nature, most of these systems are difficult to quantitatively define. Many of the models and simulations that have been developed lack a user interface which enables people other than the developer to use them. As a result, several scientists are integrating knowledge-based–system (KBS) technology with conventional problem-solving techniques to increase the robustness and usability of their systems.

To investigate the similarities and differences of leading scientists' approaches, a pioneer workshop, supported by the American Association for Artificial Intelligence (AAAI) and the Knowledge Systems Area of the American Society of Agricultural Engineers, was held in San Antonio, Texas, on 10–12 August 1988. Part of the AAAI Applied Workshop Series, the meeting was intended to bring together researchers and practitioners active in applying AI concepts to agricultural problems.

0738-4602/89/$3.50 © 1989 AAAI.

Agriculture is an area of enormous potential for applications involving integrated KBS and conventional technologies. For example, excellent databases are available for information ranging from historical weather data to individual dairy cow records. Complex simulations have been developed to describe phenomena from plant growth to economic systems. Such investments are valuable as knowledge sources for knowledge-based decision making.

The primary goals of the workshop were to (1) assess the state of the art of integrated systems for agriculture, (2) determine factors necessary to advance the state of the art, (3) expose research needs and opportunities for the future, and (4) form an interdisciplinary core of researchers for future communication and collaboration.

The workshop was organized to ensure that these goals were reached. During the first two days, papers were presented by a selected group of participants to set the stage for discussion and help define the state of the art. Presenters had approximately 45 minutes to describe the philosophy of their approach and the implementation details. Several completed systems were on display during discussion and break times. Breaks were scheduled after every other presentation to provide time for informal discussions. It was during these free periods that the most fruitful interaction took place. The third day was devoted to discussing and summarizing the issues raised throughout the workshop and to plan future directions.

Major Themes

The papers were organized according to major topics: database integration, simulation and optimization integration, and certainty in integrated systems. The participants were then divided into discussion groups to identify significant trends, impacts, and opportunities in their areas of expertise. The major themes arising from these discussions follow.

Accessibility for Conventional Applications

Integrating KBSs with simulations, databases, and other conventional applications increases the audience for these applications. Several simulations developed within academic and research organizations have not been used to their potential because they are difficult to apply. Even when such models and simulations are used, the danger exists of their being used inappropriately because of insufficient user knowledge.

In some cases, KBSs have been integrated as intelligent front ends, or data collectors, into applications to (1) remove the burden of syntax and format and (2) apply domain-specific knowledge to request user information expressly required by the integrated application. In other cases, such systems can provide best guesses when the user is unable to provide input.

KBSs have also been used as output filters, or data interpreters. A continuing need exists for the development of such back-end systems for simulations, optimization programs, and

other models. Often, the output of a simulation must be interpreted by an expert. Output filters make these programs usable by providing higher-level inferences without the presence of scarce experts. Used in this way, a KBS can decipher the results of a simulation and apply it to a user-specific situation.

Robust simulations are capable of compactly representing large spheres of knowledge and are valuable resources for knowledge-based decision making. This kind of integration effectively transforms a data generator (the model) into a solution generator by replicating scarce knowledge, that is, by encapsulating the expertise of the model builder or expert user into a KBS. Early research into AI applications in agriculture has shown that this method is feasible for implementing complex models and simulations. It appears that the use of AI to enhance research system deployment is an opportunity for industry involvement.

The integration of traditional decision support models with KBSs also offers a promising methodology for utilizing incomplete and uncertain information to make risk-efficient decisions. Agricultural models, whether experimental or mathematic, provide a better understanding of real-world systems. However, some aspects of the system are always neglected, or some property cannot always be precisely measured. Because of these restrictive assumptions or imprecise measurements, the model results can be interpreted incorrectly. The success of using agricultural models as decision support tools depends on recognizing the effect of a particular inaccuracy on the interpretation of the obtained results.

Interdisciplinary Research and Development

The concept of integrated systems suggests that interdisciplinary research and development (R&D) efforts will take on a primary role. This role can affect how funding is allocated and how research teams are organized.

KBS technology has already highlighted the distinction between finding new knowledge in the agricultural domain and making this knowledge available with new technologies. AI is applicable to both tasks, but research funding is primarily directed toward discovering new knowledge. The use of KBSs as front and back ends seems to be purely as an assistant in delivering conventional applications because it is their task to control input and interpret output. Thus, an important place is being made for the "extension researcher." Such a person would be responsible for applying new technologies to the delivery of existing research products. In order for this place to be made, competitive grants personnel must realize that AI is a basic tool for researchers.

Integrated systems also allow for broader research perspectives. Because better management techniques are required in all fields, not only in agriculture, such research should be widely applicable to other disciplines. Thus, research funding should not be exclusively dedicated to agricultural problems. To be competitive in applying for funding, agricultural researchers must be willing to broaden their scope and work with other disciplines.

Integrated systems can also have a profound impact on the makeup of R&D teams. It appears that researchers in agriculture will increasingly use AI techniques in classical research, as they now use conventional problem-solving techniques such as linear programming and simulation. AI will thus become another tool in the researcher's library of tools as opposed to an end in itself. However, because the primary goal of the agricultural researcher is not to develop such computing practices, increased interdisciplinary work will be necessary between the providers of the application problems (agricultural researchers) and the providers of the computer solutions (KBS researchers). Tools that support concepts such as inferential databases and deeply coupled systems will allow agricultural researchers to focus on agricultural research problems rather than on computer science problems.

An interdisciplinary research effort will also be needed to integrate risk and uncertainty concepts. In addition to agricultural systems and computer programming expertise, at least one member of the interdisciplinary team must have expertise in decision theory. The researchers will need to concentrate on developing formal structures in probability and decision theory that address critical management needs. Research, extension,[1] and industry need to be involved in coupling these formal structures with KBSs. Finally, extension, industry, and the end users must be involved to make the integrated systems deliverable and useful.

Deeper Coupling

Although the orientation has thus far been in applying existing KBS technology to agricultural problems to make solutions deliverable, new basic methods and techniques are evolving, for example, deep reasoning, inferential databases, and qualitative simulation. Researchers will need such technologies to solve problems never before solvable. AI then becomes an enabling technology for researchers rather than purely a delivery tool or an enhancement of current techniques.

The knowledge represented in the knowledge-based portion of integrated systems will become deeply coupled to the algorithmic portion. Truly robust systems will require that the system know not only what input to develop or what model to use but also why. Tools available for researchers developing such systems will become more open, transportable, and robust. These deeply coupled systems will allow much more seamless system operation.

Database integration is a good example of deep coupling. Often, the databases used in agriculture are small and local to a specific user. In other instances, large, potentially multiuser databases are required. Thus, the static "hooks" that most commercial tools now provide are inadequate in many cases. Instead, a dynamic link to the database file providing most of the functionality of the database management program is often required. The trend toward tightly integrated reasoning and database functionalities will assist in this aspect. Industry can find a place in supporting large, multiuser databases.

Rapid advancement has taken place in KBS development shells and languages. Knowledge, information, decision support models, probabilistic methods, and utility concepts can all be integrated. This type of integrated KBS can provide good decision support information, assist in technology transfer, and reduce the potential for errors and oversights.

Many KBS applications in agriculture are taking advantage of such integration. For example, object-oriented programming used in conjunction with rule-based programming is becoming popular. The abstraction, encapsulation, and inheritance mechanisms that characterize such systems are necessary for a number of problems in agriculture and are useful in integrating with conventional applications. Blackboard architectures can be used to unite multiple knowledge sources of different types into a cooperative whole.

Incorporating Risk and Uncertainty

A need exists for integrating KBSs with the incomplete and uncertain information associated with agricultural models. Available knowledge and information such as research findings, experimental data, and mathematical model output are extremely important for making good decisions. However, efficiently managing and utilizing this knowledge and information is becoming increasingly problematic. Furthermore, most of this knowledge and information is uncertain and imprecise. Therefore, the uncertainty features of KBSs will play an important role in selecting risk-efficient decision alternatives.

Probabilistic methods for making decisions are becoming common. The digital computer has made it easy to develop and implement these methods for solving a wide variety of problems. Reliability-based design and statistical quality control are examples. A related trend is the use of utility concepts for making better decisions with uncertain and imprecise data. An action or decision for agricultural systems results in a consequence that depends on the state of nature. This consequence can be measured using utility concepts. Integrating probabilistic methods and utility concepts with KBSs is a key step to providing a useful decision support tool where risk and uncertainty play a major role.

A critical need exists for communicating risk and uncertainty concepts to agricultural researchers, extension agents, and farmers. Recognizing that risk and uncertainty exist allows better decisions to be made with less precise information. KBSs offer a promising technology for coupling risk and uncertainty concepts into an effective delivery tool to address this critical need.

Deployment on NonSpecialized Platforms

The delivery of (tightly) integrated systems was a major concern at this workshop. Although currently available KBS building tools are generally providing broader functionality and increased integration, the majority of them do not allow the extraction of necessary functionalities for delivery. This situation has prompted researchers and practitioners to develop their own tools to provide the requisite functionality without carrying the overhead of sophisticated systems. A common practice seems to be conducting initial R&D using large, full-function hardware-software combinations. The necessary components are then extracted for efficient delivery on the smaller machines to which users are likely to have access.

Summary

Participants unanimously agreed that the format and content of the workshop helped them to assess the state of the art of integrated systems for agriculture and discuss with their peers what future directions are important for R&D. The state of the art is characterized by the use of KBSs to "surround" existing applications, using them as knowledge stores. To advance this state, researchers will be looking toward tools that provide deeper coupling and include risk and uncertainty concepts to address a totally new class of problems in agriculture. Opportunities include increased interdisciplinary R&D for building new tools, analyzing agricultural problems, and deploying final solutions.

Because of the warm reception given this first workshop by the participants, a follow-on workshop is being planned for 1989. For more information, contact Bernard Engel, Agricultural Engineering Department, Purdue University, West Lafayette, IN 47907. For a copy of the proceedings from this workshop, contact A. Dale Whittaker, Department of Agricultural Engineering, Texas A&M University, College Station, TX 77843-2117.

Notes

1. In agriculture, extension is considered an entity, as is industry or research. *Extension* is the component responsible for delivering research products to users.

A. Dale Whittaker is an assistant professor in the Agricultural Engineering Department at Texas A&M University, College Station, TX 77843-2121. He is a charter officer of the Emerging Technologies Division, Knowledge Systems Area of the American Society of Agricultural Engineers and a member of AAAI. Dr. Whittaker served as the chairman of the 1988 AAAI Workshop on Knowledge-Based Systems Integration in Agriculture.

Ronald H. Thieme is a project leader at the Bull HN Information Systems Knowledge Engineering Center, and can be reached at 53 Red Acre Road, Stow, MA 01775. He is chairman of the Knowledge Engineering Committee of the American Society of Agricultural Engineers and a member of AAAI. Dr. Thieme's current interests include applying knowledge-based systems and advanced development environments to real-world situations.