Chapter 4

# Advanced Computer Technology

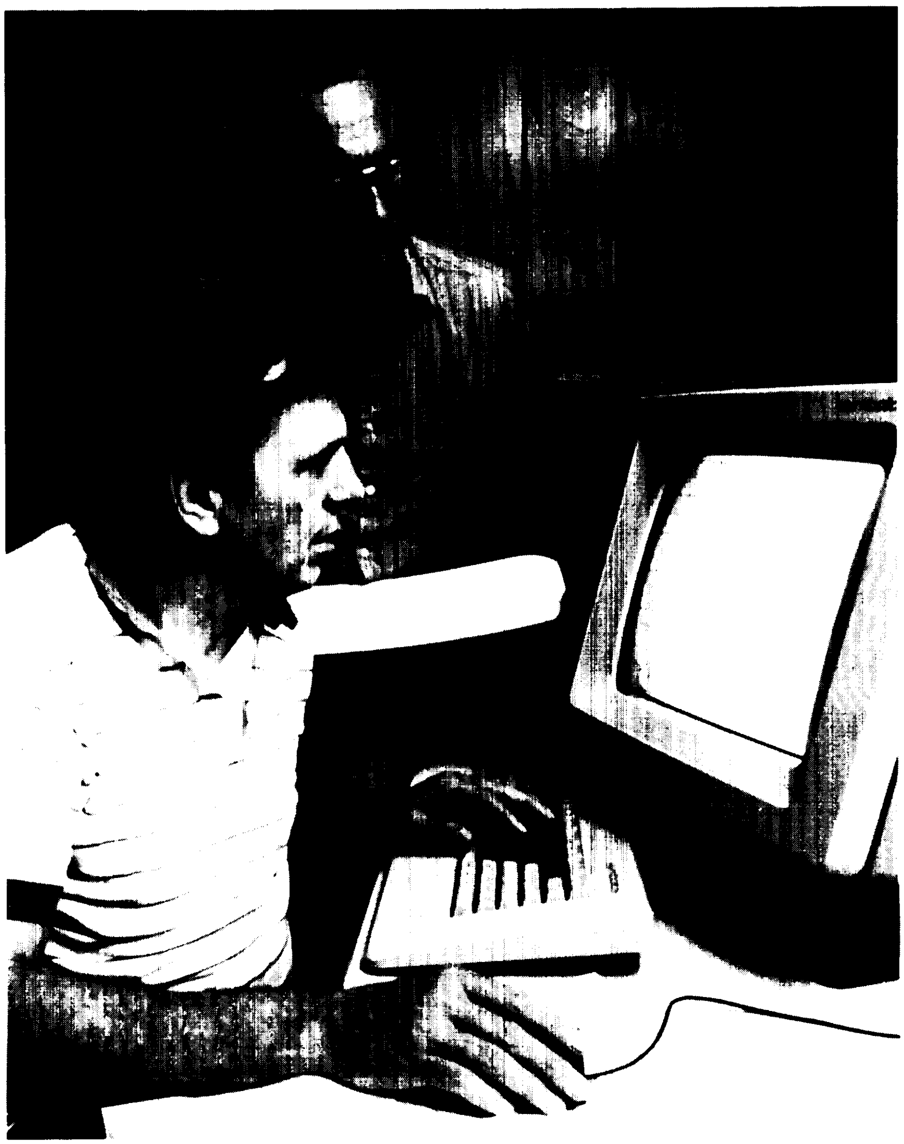

*Photo credit: U.S. Department of Agriculture, Agricultural Research Service*

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## INTRODUCTION

Since the industrial revolution, agricultural systems have intensified, and agricultural productivity has significantly increased along with farm size. Labor-saving devices on farms have increased output per worker several-fold. and advances in understanding and application of biological principles have significantly boosted agricultural yields. With greater production per acre and animal, however, farm management becomes correspondingly more challenging and complex. In general, methods for making management decisions have failed to meet this challenge. As a result, many decisions are ‘‘ uninformed” and many agricultural systems poorly managed.

The application of advanced computer technologies to agricultural management can help remedy this situation. improved access to information will allow farmers to more effectively monitor progress toward optimal performance. Computer technologies of potential use to agricultural managers are advancing at a tremendous rate. The performance of computers has increased several-fold with each new generation of computer chip (figures 4-1 and 4-2). In the last decade. microcomputers have evolved from 64-kilobyte machines with a 320-kilobyte floppy drive to machines with several megabytes of memory and several hundred megabytes of permanent storage; such machines approach the performance of mainframe computers (25 , 54) and can store massive amounts of information.

Advances are also occurring in software technologies, allowing improved utilization of stored information. Decision support systems, for example, provide enterprise-specific, expert recommendations to decisionmakers. Several other types of information technologies allow for rapid access to the latest information.

These advances will provide the tools to improve farm management. For example. close monitoring of” animal performance will allow early detection of diseases and can help reduce stress in animals. Overall, advanced computer technologies can provide managers with the ability to systematically determine the best decision rather than arrive at decisions in an ad hoc fashion. Optimal decisionmaking requires a holistic view of a farm enterprise, factors that affect it, and the probable consequences of management decisions. Thus, a farmer deciding whether to plant a specific crop on a specific field should weigh the profitability of the crop as well as overall farm needs (i. e., nutrition requirements if it is an animal enterprise). The decision will impact land sustainability and the need to use certain pesticides and herbicides or other pest-control methodologies. Computer technologies, by providing the capability of taking these multiple factors into account, can help producers arrive at the best possible decisions and management strategies.

The quality of management, in turn, will influence productivity as well as the future impact of some biotechnologies. For example, the response of milk cows to bST is directly related to management. Poorly managed dairy herds have a lower response to bST than well-managed herds (figure 4-3).

## SPECIFIC COMPUTER TECHNOLOGIES

Computer technology is changing at an unprecedented rate on three different fronts, causing a "three-dimensional" information revolution. Rapid advancements in traditional database and computational programs: in symbolic computing and artificial intelligence: and in systems that improve access to information constitute the three dimensions of the information revolution.

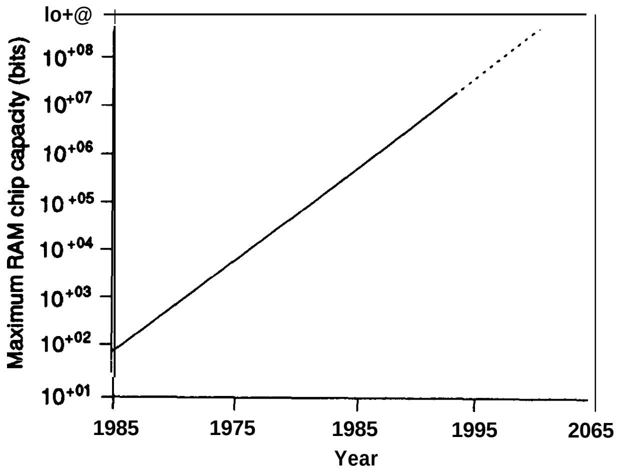
### *Knowledge-Based Systems*

Traditional database and computational programs, which are largely numeric and follow established algorithms. are invaluable resources, but they cannot easily deal with symbolic data or mimic an expert's reasoning process. The so-called knowledge-based systems in the category of symbolic computing and artificial intelligence have these capabilities. American agriculture is just now beginning to capitalize on these resources.

Essentially, knowledge-based systems present expert knowledge in a form that can be used to solve problems. In addition to expert knowledge, such systems require situation-specific databases. For systems that operate in real-time, sensors may play an important part in collecting data for knowledge-based systems (40). General uses of knowledge-based systems include:

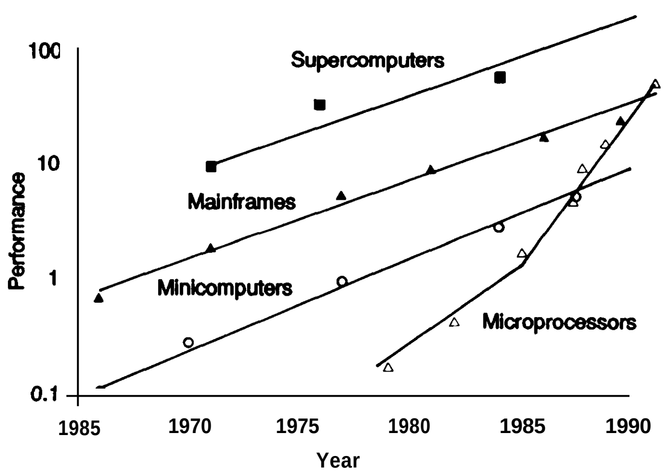
1. recommending solutions for problems (e. g., diagnosis),
2. monitoring the status of a system to determine significant deviations (i. e.. management-by-exception). and

**Figure 4-l—Trends in Semiconductor RAM Density**



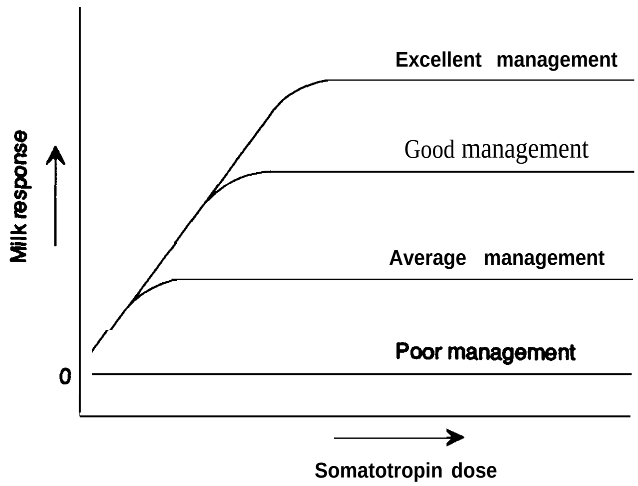

SOURCE: J L Hennessy and N P Jouppi, Computer Technology and Architecture: An Evolving Interaction, ' *IEEE Computer* September:18. 1991

**Figure 4-2—Trends in Microprocessor and 'Mainframe CPU Performance Growth**



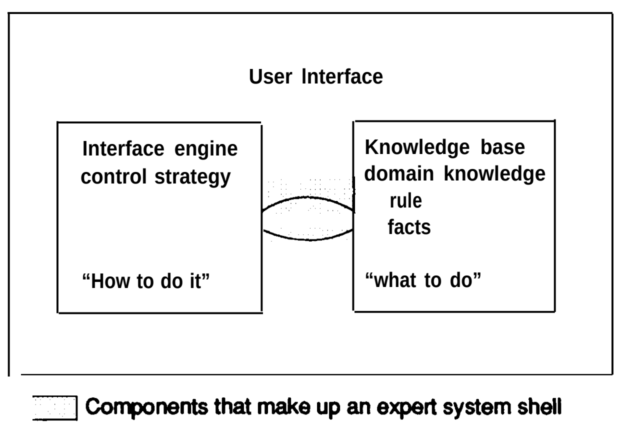

SOURCE: J L. Hennessy and N.P. **Jouppi, "Computer** Technology and Architecture: **An Evolving Interaction, "** *IEEE Computer* **September:18, 1991**

**Figure 4-3—Effect of Quality of Management on Milk Response of Dairy Cows Receiving bST**




SOURCE: D.E. Bauman, "Bovine Somatotropin: The Cornell Experience." Proceedings of the National Invitational Workshop on Bovine Somatotropin, USDA Extension Service, Washington, DC, pp. 46–56.

**Figure 4-4—Structure of an Expert System**




SOURCE: Office of Technology Assessment, 1992

3. forecasting the behavior of a system (i. e.. simulation).

### Expert Systems

Expert systems are the most popular knowledge-based technology in agriculture. The main benefit of expert systems is that they emphasize knowledge acquisition. not programming.

Expert systems are distinguished by a unique structure that separates ''What to do' from ''How to do it' (figure 4-4). The knowledge base tells the program what to do. It contains the expertise for solving the problem without the control structure found in traditional programs. The second component of an expert system is an ''inference engine' that, in effect, shows the program how to do the task at hand. The inference engine contains the control strategy that determines how to combine domain knowledge to solve the problem.

Domain knowledge can be represented in the knowledge base in several different forms, the most common of which is rules (e. g., "If the leaves are brown, then apply insecticide X' see box 4-A). Rules correspond closely to the natural reasoning of experts, are modular, and are easy to maintain. As a result. expert systems are easy to develop and to support. The knowledge in an expert system tends to be symbolic instead of numeric. This feature allows rules to be "heuristic" in nature, akin to "rules-of-thumb. " When exact algorithms do not exist, the rules represent the expert's best guess (94).

Another interesting feature of expert systems is their capability of incorporating uncertainty into rules. For example, the rule "If the leaves are brown, then apply insecticide X; 0.3' means that there is a 30-percent certainty or confidence in the conclusion. Strategies have been developed for combining the uncertainty of rules to give a confidence value for each recommendation (7, 76). Therefore, the expert system is able to make recommendations even when the circumstances of the problem are uncertain. This ability mimics the reasoning of an expert. Expert systems have the added capability of explaining the reasoning used to derive a solution (see box 4-B), much as an expert might. The explanation is a map of the rules chained together by the inference engine ( 102).

**Box 4-A—An Example Rule for an Expert System**

IF

- you are willing to speculate for higher prices AND
- the price trend is up AND
- the basis trend is weakening AND
- the basis trend is not expected to reverse soon AND
- the timing is harvest AND
- the type of available storage is farm OR
- the type of available storage is commercial AND
- you need downside price insurance AND
- Storage revenues are greater than storage costs,

THEN

- forward contract your grain and buy call options.

SOURCE: R.H. Thieme et al., "Expert System Techniques Applied to Grain Marketing Analysis," *Computers and Electronics in Agriculture* 1:299, 1987.

Because expert systems separate the inference engine and knowledge base, it is easy to remove the knowledge from the expert system. leaving a shell that can be reused in other applications. The shell contains the inference engine, user interface. and other domain-independent modules. The first expert system shell was EMYCIN, which resulted when the knowledge base was removed from MYCIN, an expert system that diagnosed human blood diseases (89). Expert system shells have become saleable products, and several are commercially available for use in agriculture ( 14).

There are numerous examples of expert system applications in agriculture. These systems have tended to be diagnostic systems for addressing relatively narrow problems. Large-scale, broad-based expert systems have not been developed in agriculture. The following overview of agricultural expert systems includes systems developed for business decisions. animal production, and crop production.

***Farm and Area-Wide Management—effective de-***cisions regarding the planning, organization, and control of a farm enterprise are essential to agriculture. The legislative, economic, and environmental demands placed on farmers and government agencies that implement agricultural policy create a need for tools that help make sound farm-level and regional policy decisions in agriculture. Tools that help with agricultural problems at a watershed or farm will become increasingly important in the future. This will involve integration of expert systems with geographic information systems, area-wide monitoring systems (78 ), and remote sensing.

The financial difficulties of the 1980s vividly document the cost of poor decisionmaking in the business sector. However, a major obstacle impedes the adoption of expert systems in making business decisions. Business decisions. unlike production decisions, are generally in-

**Box 4-B—An Example of an Explanation Provided by an Expert System**

I conclude that the patient has dreaded lurgy caused by bug-eyed germs with a certainty factor of .76.

**WHY:**

I concluded that the patient's dreaded lurgy was caused by bug-eyed germs because tight abdomen (E3) and acid saliva (E4) indicate swelling of the spleen (E), which taken together with yellowish skin cast (D) provide evidence (CF = .76) that bug-eyed germs are the cause of the dreaded lurgy.

SOURCE: M. Van Horn, *Understanding Expert Systems,* Bantam Books. New York, NY, 1986.

fluenced by values, goals, and risk attitudes. Thus, two experts with the same knowledge and expertise may select different courses of actions (91).

Only a small number of expert system applications is available for farm decisionmaking. Most existing expert systems in this area relate to design, planning, and control. Unfortunately, such functions are considered relatively unimportant by farm managers. Expert systems dealing with data acquisition and interpretation, prediction, and monitoring have not been developed. This may indicate that expert system development efforts are focusing on applications not in the area of greatest need for farm managers (91),

Farm-level planning and financial analysis are active areas of expert system development. Several prototype systems are under development. One effort at farm-level planning directed at farmers' needs is the Crop Rotation Planning System (CROPS) developed at Virginia Tech (6). This system uses a map-based interface to let farmers enter data about their land (soil type, topography, land-use, and field sizes) and their farming enterprise. Based on these data, CROPS provides farm-level or field-level environmental risk evaluations for soil erosion, and nutrient and pesticide leaching and runoff. It then uses Al planning and scheduling techniques to generate a whole-farm production plan so that the overall farming operation can meet user-defined yield and/or acreage targets, economic return goals, while also reducing potential environmental risks to acceptable levels. The system runs on Apple Macintosh 11 systems and is adapted for use by the Soil Conservation Service and the Virginia Department of Conservation and Recreation in their farm planning activities.

The best known farm financial system is the Agricultural Financial Analysis Expert System (AFAES) from Texas A&M University (63). AFAES consists of a spreadsheet to prepare operating-year and multiyear financial statements; a program that calculates financial ratios and trends from the spreadsheet; and two expert systems that develop a performance operating-year analysis and multiyear analysis, respectively. This expert system operates on an IBM-compatible microcomputer and is marketed through the Texas Agricultural Experiment Station at a variety of prices based on the type of user making the purchase.

Other agricultural expert systems have been developed for specific business decisions. One example is the Grain Market program developed at Purdue University (98). This system provides advice for marketing storable commodities (e. g., crops). An example rule from this expert system is shown in Box 4-A. The machinery selection process is aided by the Farm-level intelligent Decision Support system (FINDS) (49). This system integrates a linear program (REPFARM), a database management system, and an expert system. The expert system is used to form the link between the linear program and the user and to interpret the output of the linear model. The linear program component operates on a minicomputer, but the other components operate on a microcomputer. A decision support system for planning of land use and forage supply for a dairy farm has been developed in Denmark (34). The main components of the system are a knowledge base, a linear programming model, and a PASCAL program connecting the knowledge base, model, and interface. The model integrates the varied business activities of a dairy farm, such as crop production, storing feeds, milk production, and utilization of manure. Interactions between feeding and production of milk and meat are established by use of knowledge sets. The user interface allows for consequent analysis and can function as a tool for calculation and optimization planning.

In addition to agriculture-specific expert systems for business decisions, nonfarm business systems will impact agriculture (91 ). For example, Dologite (24) developed the Strategic Planning Advisor to provide strategic planning advice. This system provides recommendations such as:

- Get out of a business.
- Hold current position.
- Focus on one market niche.
- Invest selectively.
- Invest aggressively.

***Animal Production—Expert*** systems for animal production deal with the management of farm animals and generally focus on disease diagnosis and suboptimum performance identification based on technical expertise.

Most expert system activity in the area of animal production focuses on the dairy industry. There are at least two reasons for this. First, the dairy industry has a national data recording system (i. e., Dairy Herd Improvement, DHI), that provides centralized databases from which expert systems can be built (99). A second reason is that dairy animals are generally housed in confinement, and they produce a product (i.e., milk) that can be routinely monitored on an individual animal basis. This is conducive to intensive management. Spahr et al., (92) outlined several potential applications of expert systems for dairy herd management.

Some of the earliest dairy expert systems were developed by Extension Specialists at the University of Minnesota. Their first system (DMGTSCOR) ranks dairy-herd management strengths and best opportunities for improvement using DHI management measures ( 16). Management action is suggested for the three best opportunities for improvement. A second system, SCCXPERT, was developed to diagnose herd mastitis problems using DHI somatic cell data and to recommend corrective actions. Another system, BLKTNKCL, provides interpretation and information about bulk tank culture data for primary mastitis causing organisms. A fourth system, MLKSYS, provides expertise to troubleshoot operational and design problems with a milking system ( 15). Two other systems have recently been developed to assist in manure management and to provide an overall analysis of the production and financial status of a dairy farm. All of these systems were developed in the Level 5 expert system shell; as a result an effort is underway to integrate them into a single system to allow data sharing among the programs. These expert systems are distributed by the Dairy Extension office at the University of Minnesota freely to extension personnel and commercially for $75 ( 17).

Tomaszewski and others at Texas A&M University have developed a Dairy Herd Lactation Expert System (DHLES) to analyzes DHI milk production data and to provide recommendations for improving milk production ( 106). DHLES contains a separate module (LacCurv) to graphically display lactation curves. This system was developed in PROLOG and operates on an IBM–compatible computer. It is marketed through Texas Dairy Herd Improvement Association for $99 ( 100).

Several expert system projects are under development for the dairy industry. Kalter and coworkers (45) are developing a comprehensive expert system (Dairy Pert) to evaluate dairy-herd management. The impetus behind this effort is the possible future adoption of bovine somatotropin (bST), but the system has general applicability. This system currently contains over 320 rules in the Nexpert expert system shell, a spreadsheet-based nutrition model, and entry and advice routines based on Fox's database management software. DairyPert does not utilize DHI data because of inconsistencies among the nine national Dairy Record Processing Centers. DairyPert is funded by and will be distributed to the private sector through a large pharmaceutical company. Cornell University will distribute the system to public agencies and institutions. Oltenacu et al. (73) are developing a reproduction expert system that will analyze DHI reproductive records and determine weaknesses in the reproductive program. This system utilizes LISP on an IBM workstation. Allore and Jones (42) are developing an expert system to evaluate DHI somatic cell counts that will identify areas of management that predispose cows to mastitis. This system is being developed in CLIPS and will operate on an IBM-compatible microcomputer.

Oltjen et al. (74) have developed a prototype expert system that recommends whether to keep or cull commercial beef cows. The rules contain knowledge relating to the cow's age, body condition score, calving difficulty, structural correctness, health, and previous reproductive performance. The expert system was integrated with a simulation model to calculate net present value for each animal. This expert system was developed in the CALEX expert system shell.

An expert system to assist in the management of a sheep enterprise has been developed in Scotland ( 104). This system was developed without the aid of an expert system shell. Once a working prototype that could be delivered to an agricultural unit was developed, this project was halted as a research project. Expert systems for the management of sheep flocks are also under development in Australia.

CHESS is a Dutch decision-support system designed to analyze individual swine breeding herds within an economic framework (22). It determines strengths and weaknesses in the management of a pig enterprise. CHESS consists of a decision-support system and three expert systems. The decision-support system identifies and assesses the importance of relevant deviations between performance and standards. The expert systems combine and evaluate deviations to identify management strengths and weaknesses.

XLAYER (84) is a management expert system for the poultry industry and is one of the most comprehensive expert systems in animal production. XLAYER is designed to diagnose and estimate economic and associated losses as well as recommend remedial management actions for over 80 individual production management problems significantly affecting a flock's profitability. An example output is shown in box 4-C. This system contains over 400 production rules and was developed in the M1 expert system shell.

***Crop Production—All*** commercial crop production systems are potential candidates for expert system applications. In particular, expert systems should be considered for integrated crop management decisions that would encompass irrigation, nutrition, fertilization, weed

### Box 4-C—An Example Recommendation From XLAYER

You are **experiencing an economic loss of about $725** per week because of a sudden change in the grain portion of your layer ration. Reformulate the ration and phase in new grains gradually, even if the cost per pound is higher.

Production losses amounting to some $500 per week are being experienced because temperature in your layer house is exceeding 29.4 degrees Celsius. Use artificial cooling systems in regions where hot weather is expected to continue. If layer barn has no cooling system, construct a partial budget to evaluate alternative pooling systems such as evaporative cooling pads, roof sprinklers, high pressure misting and other forms of cooling,

Water intake is very low. Check watering systems to make sure that birds are getting adequate fresh, clean water.

Equipment repair costs are running $100 per week higher than normal. Check management practices related to the routine servicing of mechanical equipment. If repair and maintenance costs are consistently high, construct a partial budget to evaluate the replacement of old or poor functioning equipment.

SOURCE: E. Schmisseur and J. Pankratz, "XLAYER: An Expert System for Layer Management," *Poultry Science* 88:1047, 1989.

control-cultivation, herbicide application, insect control, and insecticide and/or nematicide application (64).

The first expert systems developed in agriculture were PLANT/ds (65), a program developed at the University of Illinois that identified diseases of soybeans in Illinois. and POMME(81 ), developed at Virginia Tech to identify diseases of apple orchards. Both were written by computer scientists who were using agriculture as a novel domain. Michalski, for example, was primarily interested in machine learning.

Of the major crops, cotton has received the most attention to date, with at least three expert systems and one simulation-based management model now available to the public (94). COMAX (COtton MAnagement eXpert), the expert system component of GOSSYM/COMAX was developed by the U.S. Department of Agriculture, Agricultural Research Service (USDA/ARS) in Mississippi (56).[1] Users of this system purchase a weather station linked to a personal computer running the program. The GOSSYM component is a simulation model of cotton production that uses weather data collected from the weather station. The COMAX expert system uses the model to project when to irrigate and fertilize to achieve optimal agronomic goals. The entire GOSSYM/COMAX system including the weather station and computer costs several thousand dollars. Despite the high price tag, it is used by as many as 500 cotton farms in 15 States.

COTFLEX is an integrated expert system and database package developed at Texas A&M and released to the public through the Cooperative Extension Service (93).

*Photo credit: U.S. Department of Agriculture, Agricultural Research Service,*

Farmer and consultant examine data from COMAX (Cotton MAnagement eXpert) computer program.

The overall system will eventually include a whole-farm economic analysis module that lets farmers evaluate whether or not to participate in Federal farm programs or to purchase Federal crop insurance. The component released to the public, however, is devoted to insect pest management of the three major insect pests of cotton in Texas.

CALEX/Cotton is another integrated cotton expert system and database management tool (79). CALEX was developed as an expert system shell, and cotton was the

[1] GOSSYM is a hybrid term formed by combining *Gossypium*, the scientific name for cotton and the word simulation.

Photo credit U.S. Depatment of Agriculture, Agricultural Research Service.

Farmer and engineer check automated weather station that feeds daily weather information into the COMAX system to update its prediction for cotton yield and harvest dates.

first application area. The system was supported through California's statewide integrated pest management program and delivered to farmers for testing and use. It is one of the best-documented attempts at delivering expert systems to farmers for use in crop production (31). Because the program was developed with State support, no revenue has been collected from its users and the project continues to depend on State support.

Pennsylvania State University supports a laboratory devoted to the development of expert systems and their delivery through the Cooperative Extension Service. The University has developed several expert systems using an expert system shell (PENN-Shell) developed in-house. One of these expert systems, GRAPES, recommends pest control options for insects and diseases in vineyards (83). Penn State's expert systems all run on Apple Macintosh computers, and the University supports a statewide computer network for these machines.

USDA-ARS researchers (28) developed a knowledge-based system for management of insect pests in stored wheat. The system determines whether insects will become a problem and helps select the most appropriate prophylactic or remedial actions. Simulation models of all five major insect pests in wheat have been developed; the model's output feeds the expert system.

Evans and coworkers (26) at the University of Manitoba have developed an expert system to serve as a Fertilization Selection Adviser. The current system considers only one type of crop (wheat), four different moisture regimes (arid, dry, moist, and irrigation), one soil nutrient (nitrogen), and four different fertilizer compounds (urea, ammonium nitrate, urea ammonium nitrate, and ammonia). It provides return on investment information; a risk analysis module is under development. This system was developed in the LISP programming language for the Macintosh: however, work has already begun to develop a similar system using the C programming language cm an IBM-compatible microcomputer.

In general, one can find expert system applications for crop production for virtually all the major crops in this country and in many countries around the world. Insect pest management, weed control, and disease identification are the most common domains. Other systems that have received wide recognition in crop systems include:

- EasyMacs, an expert system and database program developed at Cornell University for recommending pest management strategies for apple production;
- SOYBUG, an expert system developed in Florida that helps farmers with insect pest control in soybeans (2);
- SIRATAC, an expert system and simulation model developed in Australia for helping cotton farmers with pest management decisions that has since been marketed internationally (36);
- TOM, an expert system for diagnosing tomato diseases developed in France (5); and
- WHAM, a wheat modeling expert system developed at the University of Melbourne, Australia (3).

***Research Needs—*** Development of commercial expert system shells is being driven by forces outside agriculture and is proceeding at a relatively rapid rate. However, agriculture applications generally will require expert system shells to operate in a microcomputer environment whereas industrial applications often reside on workstations or minicomputers. Since this is a domain-independent problem, it may be best addressed by computer scientists outside of the agricultural sector.

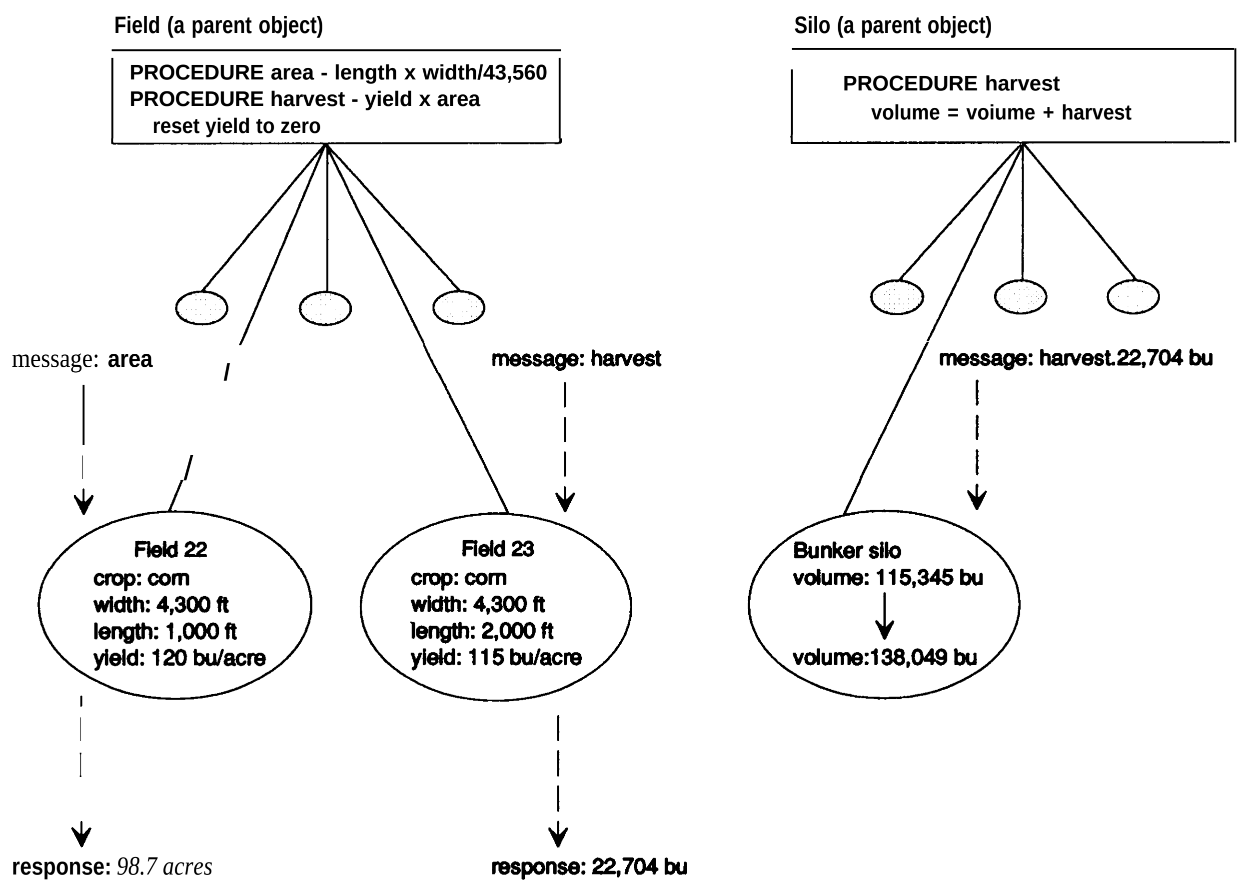
The main limitation to development of expert systems is adoption of computer technology. To promote this area will require more trained personnel and incentives to develop and deliver computer systems.

### Object-Oriented Simulation Systems

In addition to expert systems, another type of knowledge-based system that is useful for planning is object–oriented simulation. Traditional simulation systems model the *behavior* of a system by explicitly simulating individual processes. The ***structure*** of the real system usually is implicit in the model. Object-oriented simulation models have an inverse structure; they explicitly model the *structure* of the real system, and the *behavior* of the system is implicit in that structure.

Each component of the real-world system is represented in the simulation as an object. Objects are units that consist of self-descriptive data and procedures for manipulating that data. Objects can be represented in a hierarchy such that they inherit properties from more general categories (i.e., their parents). For example, an object-oriented simulation of a farm (figure 4-5) would contain a general FIELD parent object that describes the general features of all fields (e.g., a method to calculate the area of the field). Individual fields (e.g., field 23) would be represented as unit objects that inherit the properties of the parent FIELD object and may also contain some information specific to themselves (e. g., current crop planted in the field). Objects in object-oriented systems communicate by exchanging messages. For example, if field 23 is to be harvested, a HARVEST message is sent to the field 23 object. The field 23 object handles the details (internally resetting its own values) and returns the amount of crop harvested. This return message can

**Figure 4-5—System Structure for an Object-Oriented Simulation System**




**SOURCE:** Office of Technology Assessment, 1992.

be sent to a particular silo object which knows how to add the crop to its inventory. Once the object-oriented system is developed, the simulation sends messages to appropriate objects in a fashion similar to farm managers giving orders to their employees.

There are two main advantages to this type of simulation. First, the model closely corresponds in structure to a real system. This facilitates maintaining and expanding the model. Second. procedures in an object can be represented in a symbolic fashion similar to expert systems. Thus, object–oriented simulation can be used to model processes that may not be quantitatively well defined.

Object-oriented simulations have been under development since the early 1980s. An early object-oriented simulation language (ROSS) was developed in the LISP programming language by the Rand Corp. for the Air Force (62). This language has been used in military applications. Two early examples are SWIRL, an object-oriented air battle simulator, (47) and TWIRL, an object-oriented simulation for modeling ground combat between two opposing tactical forces (48).

Object-oriented simulations are powerful tools for modeling the behavior of biological systems that are otherwise difficult to describe mathematically. Output from these systems can be used in planning and to determine impacts of changing management procedures. However, most existing object-oriented simulation models cannot easily be transferred to production agriculture.

Several object-oriented simulation projects have been developed specifically for agriculture. Researchers at Texas A&M University developed an object-oriented model to simulate animal/habitat interactions (82). The simulation was specifically used to study the damage caused by moose migrating through forest plantations. This system was developed on a Symbolics workstation using LISP. Another agricultural simulation was developed by USDA-ARS to model insect disease dynamics in a rangeland ecosystem (9). This model is primarily a research tool for studying the relationship between grasshoppers and their pathogens to assist in integrated pest management programs. This system was also developed on a Symbolics workstation using the FLAVORS object–oriented programming language. Another LISP-based system was the host-parasite model developed by Makela et al. (58) to study the interaction between the tobacco budworm and one of its parasites in cotton fields. More recently, Crosby and Clapham ( 18) used the Smalltalk language to simulate nitrogen dynamics in plants; Stone (95) used an object-oriented model of a mite predator-prey system to show that chaotic dynamics rather than stable or predictable cycles, might be the norm in agricultural systems; and Sequeira et al. (87) developed an object-oriented cotton plant model for use in studying the interaction between localized pest feeding and cotton lint yield and quality. Another object-oriented simulation project is under development by Chang and Jones at Cornell University for use in agriculture ( 10). This project uses a LISP-based, object-oriented programming language (B-object, Kessler, University of Utah) to model the operation of a milking parlor. When completed, this model will be useful to dairy–farm managers and their consultants for parlor configurations and for identifying changes in performance when changes in parlor operation are made.

***Research*** Needs—The general paradigm of object-oriented programming is being incorporated into several traditional programming languages (e. g., C, PASCAL), but few inexpensive commercial shells exist in which to develop object-oriented simulations. Smalltalk is a good example. It is a language and a development environment in one, and it generally comes complete with many pre-define object classes developed specifically for simulation. Other expert system shells like KEE, Goldworks, NExpert-Object, and Level-V Object include the object-oriented paradigm and can be used for simulation. LISP offers many advantages for prototype systems such as the parlor project. However, LISP is not a language in which final products should be delivered, since it requires too much memory and is too slow for agricultural applications. More research is needed to determine the potential value of object-oriented simulation for agriculture.

## Knowledge-Acquisition

Knowledge-based systems are powerful computer tools because they contain and apply a significant amount of expert knowledge to problem-solving; however, this also constrains systems development. Knowledge acquisition is a slow and tedious process, and problem-solving rules and procedures are often hard to articulate.

Artificial intelligence can help automate one type of knowledge acquisition (21, 66), that of rule formation. Machine learning, for example, is an artificial intelligence technique for automatically generating rules from a set of examples. This is sometimes called “learning from examples. ” It can be used to assist experts to develop rules or fill in where experts do not exist. For instance, rules for a crop disease diagnostic expert system can be generated using a machine learning system with a database of plant descriptions and associated diseases.

Michalski and others (65) compared rules derived by experts and those generated by a machine learning algorithm (AQ11 ) when developing an expert system for soybean disease diagnosis (PLANT/ds). The database consisted of 630 examples based on 35 plant and environmental descriptors for 15 soybean diseases. One rule was generated for each disease. When tested in an expert system, the machine-generated rules outperformed those generated by experts. The machine rules properly diagnosed 98 percent of the test cases while the expert derived rules diagnosed 72 percent correctly.

A microcomputer-based machine learning system has been developed for agricultural problems (27). This system was first used to generate rules for a grass identification system (WEEDER). Other generic machine-learning algorithms are available as commercial products (e. g., *Classification and Regression Trees,* California Statistical Software, Inc, Lafayette, CA; ID3, Knowledge Garden, Naussau, NY).

Due to the nature of rules generated from machine learning (i.e., the rules indicate which variables are important for describing certain results), machine learning can also be used as a data analysis tool. Liepins et al. (57) investigated the use of three machine learning algorithms for analyzing natural resource data. They studied the effect of storm damage on lake acidification using a data set generated after a major storm stuck the Adirondack Park in upstate New York. Application of machine learning to these data provided no new information but reinforced many of the discoveries made using traditional statistics. Dill (23) also used a machine-learning algorithm to analyze the sale price of cattle sold at public auction. The data set contained all information available to a buyer on sale day and the price for which the animal was sold. Using machine learning. Dill was able to determine which variables influence the buyer's decision and now will be able to generate an automated appraisal system from these results.

***Research*** Needs—There are several problems associated with machine learning. One concerns data that contain random errors (i. e., ‘‘noisy’ data). Some machine-learning algorithms are unable to handle this type of data while others perform poorly **(57).** Much of the data in agriculture is noisy. Another problem is that many of the machine-learning algorithms require discrete data (e.g., classification-based) while agricultural data is mainly continuous (e. g.. numeric). A third problem is that machine learning requires a complete database with associated outcomes from which to operate. Few of these databases exist in agriculture.

Despite these limitations, machine learning can be a very valuable knowledge acquisition tool in certain situations. With continued development, these limitations will likely be overcome.

### Knowledge-Based Report Generation

One of the initial goals in artificial intelligence was to develop systems capable of translating documents from one computer language to another ( I I ). An integral component of machine translation is developing a knowledge representation of the original document such that text can be generated in another language. Though machine translation will not have a major impact on American agriculture, systems that are able to generate knowledge-based reports from a database will.

Farmers receive large volumes of production data with little or no interpretation; hence, they may be unable to convert these data into useful information. Knowledge-based report generation is an emerging technology that can provide them with interpretive reports to better support management decisions.

In many respects, programs for knowledge-based report generation are similar to expert systems. Report generation programs contain four components:

1. a domain-independent knowledge base of linguistic and grammar rules,
2. a domain database from which the report is to be generated,
3. a domain knowledge base for interpreting the data structure, and
4. the text planning component for deciding what to say and how to say it (69).

Once a system is complete, the domain knowledge can be removed to create a shell that can be used in another domain. Report generation is still largely in the research stages and commercial shells have not been made available.

CoGenTex, Inc. has developed a proprietary linguistic shell for knowledge-based report generation. This shell has been used to generate weather forecasts in both English and French for the Canadian Government. A USDA Small Business Innovation Research proposal has been submitted to study the suitability of this approach for generating knowledge-based reports that interpret DHIA records for dairy farmers (46).

***Research Needs—*** To date, there have been no applications of knowledge-based report generation in agriculture. Research should be directed at investigating the potential benefit of this technology to American agriculture. Once the preliminary investigations are completed, a better understanding of needs and benefits will be established.

## Interfacing Technologies

Farmers have been slow to adopt personal computers. Recent surveys indicate that only 15 to 27 percent of farm managers utilize computers in management (1, **55).** Two factors that may have contributed to this slow adoption rate are the lack of high quality management software (71 ) and a computer phobia on the part of some farm managers. Farm managers have available to them only a limited selection of computer programs. most of which perform similar functions. The computer phobia is caused by a lack of exposure to computers but is exacerbated by the type of user interfaces (both hardware and software) employed by most agricultural computer programs.

### **Hardware** Issues

Currently, most microcomputer systems use a keyboard as the major input device. Keyboard entry is clumsy for agricultural software as many farm managers are slow typists. Even for programs that require little input. a ‘ ‘hunt and peck’ typing ability can frustrate the user to the point of not using the system. Another problem with keyboard entry is impaired dexterity from excessive physical labor or injury that severely impairs the farm manager’s ability to type. Consequently, software should be developed allowing the use of alternative input devices.

Two relatively common input devices are the mouse and the light pen. However, neither of these capture the user’s natural pointing instincts **(77 ).** A more intuitive input device is the touch-sensitive screen. Another alternative input device is speech.

Touch-sensitive screens are computer displays in which portions of the display may be used as an input device. This technology has been available since the mid-1960s (41 ). Touch-sensitive screens are easy to learn, very durable, and require no additional work space. At the same time they have the disadvantage of increased cost, increased development complexity, lack of software to take advantage of touch-sensitive screens, arm fatigue. and screen smudging. A major complaint of touch-sensitive screen users is the lack of precision; however. high-precision screens have recently been developed (86). Due to their durability and user-friendliness, touch-sensitive screens have been used in specialized applications such as kiosk information systems in shopping malls and airports and for order processing in restaurants. Both of these applications have been developed to allow control of a computer systems by nontechnical users.

A second area of research aimed at improving the physical link between the computer and user is speech recognition. This research has been glamorized by science fiction movies such as 200 l: A Space Odyssey, in which computers carry on a dialogue with the user. Though this is the goal of research efforts, it is not the current state-of-the-art (52). A prominent researcher has predicted that totally spontaneous, unrestricted speech recognition is still as much as 30 years from fruition ( 105). However, speech recognition appears to be suitable for applications with restricted discourses. Agriculture is one such application.

Speech recognition is based on the ability to distinguish between words and on natural-language processing whereby natural language input is transformed into a form that the computer can utilize. In a common method for speech recognition, template matching, each spoken word is matched against a predetermined lexicon. The lexicon must be trained to recognize a user’s voice. thereby resulting in a user-specific system (52). High-performance, speaker-independent, continuous-speech recognition systems use another approach. that of statistical modeling. Commercial speech recognition systems range from speaker-dependent, single-word recognition (64-word vocabulary units) to speaker-independent, continuous-word recognition (40.000-word vocabulary units ) (75).

Speech recognition is not a perfect function. Most literature values for recognition accuracy range from 95 to 99 percent (97); some articles report 8 to 12 percent error rates (61 ). Several factors affect the error rate; these include presence of background noise. phonetic similarity of words, and mood of the user as he/she alters voice quality (52). Furthermore, lack of a one-to-one correspondence of sounds to words distinguishes speech from other inputs. For instance, when a key is pressed on the keyboard, the output is unambiguous. With speech recognition, the output is the *most likely* output which corresponds to the input. Consequently, the performance of current systems degrades (in both time and accuracy) as the vocabulary increases. When speech input was compared to traditional input methods, it was found to require the same amount of time as mouse input, 80 percent as much time as a single key stroke and 48 percent as much time as full-word typed commands (61).

A commercial speech recognition system recently was added to a medical diagnostic system for clinical data entry (88). The system was an isolated-word, speaker-dependent system capable of recognizing eight continuous syllables. Utterances required a half a second to take effect and 90 percent of all utterances were recognized correctly. For this application, speech recognition proved an effective interface for improving the acceptance of the diagnostic system.

Advances in hardware input devices to improve the usability of computers are being driven by multiple nonagricultural sources. For example, speech recognition is a goal of the Department of Defense ( 105) and of research aimed at providing more environmental control to the physically disabled (20). Since this technology is domain independent, advances in other domains should also greatly facilitate the use of speech recognition in agriculture during the next decade.

## Software Issues

The software design of the user interface is the main factor determining the effort required both to learn and to use a computer program. The most important function of the user interface is to match the needs of the user. Novice users need interfaces that are easy to learn while advanced users prefer interfaces that are easy to use. Most easy to learn systems are not convenient to use. Thus, no one interface will meet the needs of all computer users (33).

In general, agricultural software has not been distinguished by sophisticated user interface designs. This partly reflects the fact that most agricultural software is written by people who understand agriculture. yet have little or no training in user interface design.

Currently. there are nearly a dozen different interface designs that can be used with computer programs. These range from command languages to natural language.

Two common user interface designs in agriculture are command and question/answer systems. A command-driven user interface is similar to the DOS system where a series of commands and arguments have to be known by the user. For example. in the Cornell Remote Management System, which is used to ascess DHI data. a command such as **AIM 1-S1-DH1MO094 is** used to run a report. This type of user interstice is easy for an expert to use, but because it is not intuitive. it is difficult to learn. Another type of command-driven user interface can be designed by mapping commands to special keys. This interface is used by WordPerfect ( WordPerfect Corp.. Orem. UT) which uses multiple combinations of the SHIFT. ALT. and CTRL keys with function keys for-specific commands. Question/answer systems require the user to enter a response. If the type of response is unambiguous, this design can be easy to use but also tedious. This type of user interface should be limited to responses which are Yes-No (e. g.. Y/N) or numeric.

A type of computer interface that is more intuitive to use than command and question/answer systems is natural language. With this type of interface, commands are given in normal spoken or written language instead of a formal command language. An example of a natural–language user interface is one that converts natural-language commands to DOS commands. For example, the natural-language command ‘‘show me the files on drive b:” is converted to the command “dir b:*.*” (53). Another example of a natural-language interface is one that was developed for signal processing (68). This system allows users who are knowledgeable about signal processing but ignorant of any programming languages to manipulate wave forms using English commands oriented toward mathematical operations. However. the most common use of natural-language interface has been in database querying systems.

Natural language is attractive to the casual user and to the user who is unwilling to learn a formal command structure. However, natural-language user interfaces require more typing than command-language interfaces. As discussed previously, typing requirements are an important consideration for agricultural software. Therefore, natural-language is probably not a desirable user interface for systems that can be driven with a limited set of commands (e. g.. DOS).

Another popular user interface design is the menu system. In the simplest form. a menu is a list of choices. The user selects one choice by entering a number or letter. Another version includes a light bar that can be positioned over the menu using the keyboard. A more sophisticated menu design, known as the graphic user interface (GUI), is the icon and mouse system. This type of system represents menu selections using a picture that is ‘"clicked-on’ with a mouse. The icon system was first developed for the Xerox ‘Star’ workstation (90) to reduce the learning time of the user interface. The user is expected immediately to know which icon is appropriate. Thus. the icon must be unambiguous and realistic. Distinguishable and meaningful icons may be difficult to develop for several similar items (96). Accompanying text is often added to clarify the meaning of possibly ambiguous icons.

Another major factor of the user interface is data entry. For this factor. interfaces called “form-filling” designs have been developed. The user is presented with a series of fields in which data are entered. The display relates to a written form and allows the user to see all of the fields together. Often. form-filling interfaces have data validation and editing capabilities. For more complex data entry needs, multiple forms arranged as overlaid windows can be used. As data are entered into a field, it actuates the next form which displays with the appropriate related fields. This type of user interface is rapid, easy to use, and easy to learn (96).

Design of sophisticated user interfaces has advanced to a point where they should now be considered for all agricultural software. Proper attention to user interface design issues can result in agricultural software that is more acceptable to use. For example, adaptive interfaces are aimed at satisfying the differing needs of both novice users and experienced users. An adaptive user interface determines the skills of the user and changes the interface to meet those skills. In general, novice users are provided with menus and question-answer systems, while advanced users are given the option to use command languages and special key strokes. A prototype adaptive interface has recently been developed (SAUCI); (101) for processing UNIX commands. Using the adaptive interface, users made about half as many errors and required less time to perform tasks. Research in adaptive interfaces should result in systems that are more intuitive to use and easier to learn.

## Information Retrieval Systems

Information retrieval systems are a set of advanced computer technologies for accessing stored information. These technologies differ from decision support systems in that they offer no recommendations. Three technologies are emerging that may have a role in American agriculture in the next decade. These are natural-language interfaces, full-text retrieval systems, and hypertext systems.

***Natural-Language*** Inter-aces—Maintaining a complete set of production records is a critical component of farm management. More important is the ability to rapidly and flexibly access information for management decisions. The best method of accessing production records has been through database management systems; however, these systems generally have inflexible retrieval facilities based on menus that present options of data to retrieve or predefine reports to run. Traditional systems require the user to learn the hierarchical structure of the menu system and limit the type of reports available. A natural-language interface for querying a database can offer a more flexible retrieval system (43).

The current generation of natural-language interfaces was made possible by a set of linguistic theories developed by Chomsky ( 12). These theories were first implemented in an efficient algorithm in a natural-language interface for retrieving information about lunar rock brought back from the Apollo space missions (LUNAR) (107).

LUNAR is based on a three-compartment model of data retrieval. The first compartment is syntax analysis, which determines the grammatical structure of the sentence. The second compartment of LUNAR is the semantic module, which is responsible for determining the meaning of the syntactic structures. The meaning is translated to a formal query language in this module. The third module of LUNAR is the retrieval component. This module executes the formal query language, based on the semantic analysis, to retrieve data from the appropriate database. When LUNAR was tested, it answered 78 percent of the questions presented to it ( 107).

The purpose of developing LUNAR was to assist scientists in retrieving data on lunar rocks. Its users were primarily interested in specific data as that data related to other scientific information that had been collected. However, this style of data retrieval is not appropriate for production agriculture where management decisions need to be made. A natural-language interface for retrieval of data for decisionmaking should put the data in the proper context so that an informed decision can be made. Consequently, a knowledge-based, natural-language interface was developed to formulate more complete, intelligent answers to users' questions from an agricultural database (IDEA) (44).

IDEA is based on the LUNAR three-compartment model but utilizes a new approach for semantic representation. Unlike the formal query language used in LUNAR, IDEA represents the query through a set of domain concepts, which contain ‘‘expert’ information. IDEA has the capability of responding to a query and offering additional pertinent information. An example of a query and answer is shown in box 4-D.

IDEA was developed for a dairy database to assist farm managers in decisionmaking. It is capable of responding to several different types of queries. The simplest query is about a single cow (e.g., “When is 5000 due to calve’?” or, simply, “Is 5000 pregnant’?”). More complicated questions can be asked about subgroups of cows (e.g., “Which daughters of Thor are bred to Bell’?”): averages (e. g., “What is the average calving interval for cows in the north barn’?’); and counts (e. g., ‘‘How many heifers are due to calve in June’?”). Replies are designed to contain important information that the user may not have known was in the database or may not have even asked for.

Just as generic, domain-independent shells have given expert systems widespread use; for natural-language interfaces to be successfully used in agriculture, a generic natural-language shell capable of being transported to other databases is needed. However, unlike expert systems, development of a generic shell for natural-language interfaces has proven difficult. Hendrix and Walter (37) point out that full synchronization is needed between the database management system and the natural-language interface. This is difficult to achieve when the natural-language interface is added as an afterthought. For example, in the dairy database that IDEA accesses, the reproductive status of a cow is given as a numeric value (e. g., O means ''not bred' '). To access multiple databases, the natural-language interface must be able to translate all their representations.

TEAM is a natural-language interface developed at SRI and designed to be transportable between databases (32). However, a database expert still is needed to adapt the system to each new database. The expert supplies information describing the database and domain-specific words, a process that TEAM has automated through a series of questions. Another source of difficulty in making a natural-language interface transportable is associating meaning to phrases. For example, consider the phrases "bred to Bell" and "bred in May. " The first refers to the ''service sire' while the second refers to the "breeding date. " Most natural-language interfaces cannot handle these kinds of subtleties. Thus, for a natural-language interface to be successfully transported to a new database, a database expert and a linguistic expert are needed ( 19).

Because of the problems in developing generic shells, natural language commercially lags behind many other artificial intelligence technologies (70). One of the few generic natural-language interfaces available commercially is the "Intelligent Assistant" interface for Q&A (Symantic Corp., Cupertino. CA), which was introduced in 1985. This system differs from most transportable natural-language interfaces in that it has its own database system. Users build their application directly in Q&A. This system also uses synonyms for acquiring new words.

## Box 4-D—An Example Query and Answer to a Natural-Language Interface

>> which cows are due to calve next week?

4897 was bred to STARMAN on 12/15/1987
and is due to calve on 09/18/1988
Projected calving interval: 347 days

>> when did 5281 calve?

5281 calved on 05/26/1988 with a heifer calf - #5535
The calf was in good condition
Gestation length = 278 days
5281 had a retained placenta

>> is 5239 pregnant?

YES
5239 was bred to TOPBRASS on 03/20/1988
and is due to calve on 12/19/1988
Projected calving interval: 466 days

>> is 5449 pregnant?

NO
5449 calved on 12/1 1/1987 with a heifer calf - #5478
The calf was in good condition
Gestation length = 283 days
5449 is 282 days in milk
5449 was bred to LEVI on 02/21/1988
5449 was pregnancy checked on 03/30/1988 and was open

SOURCE: L.R. Jones and S.L. Spahr, "IDEA: Intelligent Data Retrieval in English for Agriculture," *A/ Applications in Natural Resource Management* 5(1)56, 1991.

An attractive feature of this system for agriculture is that it operates on standard IBM-compatible microcomputers. Another commercial natural-language interface is Natural Language (Natural Language, Inc., Berkeley, CA). This system interfaces with any database that supports Structured Query Language (i.e.. SQL).

***Full-Text Retrieval Systems—A*** relatively new area of human-computer interfaces that holds great promise in making information more accessible is full-text retrieval. The goal of a full-text retrieval system is to search a collection of documents to find relevant information for the user (4). These systems can be particularly useful for accessing a collection of documents that are authored by several different people who potentially use different words to express the same thing. Such a collection of documents, including most Agricultural Extension publications, is unedited and generally not indexed.

Blair and Maron (4) evaluated the effectiveness of STAIRS (STorage And Information Retrieval System). a full-text retrieval system developed by IBM. They found it to retrieve less than 20 percent of documents relevant to a particular search when the database contained roughly 350,000 pages of text. They identified several pitfalls that need to be considered in developing full-text retrieval systems. STAIRS was efficient at retrieving documents that exactly matched the wording of the request, but it performed poorly in retrieving documents that contained misspelled words, and words that were synonymous with those in the request. For example, the word ''gauge' was spelled [9]'guage' in an original document, preventing its retrieval. Full-text retrieval systems must be able to account for such situations and retrieve relevant documents whose text may not match the exact wording of the request. A simple key-word search or an indexing scheme thus does not meet the needs for full-text retrieval.

A full-text retrieval system developed by Gauch and Smith (30) contains an expert system and a thesaurus. The thesaurus contains domain-specific information for words, a list of synonyms for each word. its parent word(s), and a list of children words. This structure allows a particular search to be generalized or narrowed. Decisions as to the search pattern are made by the expert system. If the recall is low, it will broaden the search. If the precision is low (i.e., too many irrelevant passages are retrieved) the expert system will use a more specific search. The query is formed by the user and then passed to a full-text retrieval system that has immediate access to any passage in the text. The retrieval system requires that the text undergo two stages of preprocessing. In the first stage, the text is formatted for enhanced display. Formatting includes insertion of format marks (line. tab. italics, line, label ) and context information (section. paragraph, sentence. item). In the second stage of preprocessing. the file is converted to fixed-length records tot-fast access. Consequently. the system does not operate on the original documents. This is an undesirable feature as it precludes searching subsets of documents and requires additional storage.

A full-text retrieval system now commercially available (Metamorph; Thunderstone, Chesterland. OH) should have wide application in agriculture. Metamorph operates on standard ASCII files using natural-language queries to search and find relevant passages in documents. The natural-language input undergoes morphological analysis to normalize each word. The normalization process converts words to morphemes—the smallest meaningful unit of a word. A set of morphemes that are related to, but not necessarily synonymous with. the original morpheme is generated. Metamorph then correlates these equivalence sets to textual passages to determine passages that relate to the natural-language query. At the first level of search, an equivalence must be present in the passage for its retrieval. If this is unsuccessful, Metamorph will broaden the search. Another important feature of the correlation procedure is that it utilizes an approximate match to account for minor discrepancies in spelling. These features fulfill the conditions Blair and Maron (4) identified as necessary for a full-text retrieval system.

Numerous applications of full-text retrieval are possible. A recent project used a commercial full-text retrieval system to assist users in querying a specific DHI computer manual (29). Additionally, with the advent of mass storage systems for microcomputers (e. g., CD-ROM), full-text retrieval systems can play a significant role in providing expert information (e. g., extension bulletins) to county extension offices and directly to farm managers. An effort is underway to develop a national dairy database (39) consisting of full-text documents covering major dairy-management areas. This full-text database is expected to be delivered *on* a CD-ROM and accessed using a full-text retrieval system.

Hypertext-Hypertext is a method of connecting related passages of text, graphics, animation, or computer programs in a multidimensional {i. e., hypercube) fashion such that they can be accessed in a nonlinear fashion. Each node can be connected to any number of other nodes that provide additional related information. Hypertext systems are analogous to footnotes or references in a document. For example, a footnote contains additional information related to the text. The reader determines when or if the footnote is to be read. Computerized hypertext systems are based on the same principle.

Hypertext systems are relatively easy to implement but are difficult to build. They require the locations of the related text to be stored with the location of the original text. This is essentially a database management problem. The difficult part of a hypertext system is to establish the appropriate links between and among nodes. This usually requires a domain expert, but the process can be automated through full-text retrieval tools.

As Extension documents begin to be disseminated in electronic form, hypertext should be considered as a method of increasing access to related subject matter. For example, an extension bulletin that describes the use of lactation curves for herd management should be linked to other bulletins describing the use of butterfat and protein curves. To demonstrate the benefits of hypertext in an agricultural setting, Rauscher and Johnson (80) delivered the six feature papers contained in an issue of *Al Applications: Natural Resources, Agriculture, and Environmental Sciences* in hypertext form.

## Integrated Systems

Management of an agricultural enterprise requires a variety of decisions and, hence, a variety of decision-support tools. Long-range research in the area of human-computer interface will be directed at integrating various decision–support programs into a single system. Current research is aimed at integrating autonomous systems, developing intelligent user-interface managers, and integrating systems through a common representation shared by an intelligent dialogue manager.

An overall controlling software system that allows the user to access different decision-support tools yet maintains operational independence of tools themselves represents the lowest level of systems integration. The genera operating system of a computer is an example in that it allows the user to access multiple programs in the same environment. More advanced integrated systems assist the user in choosing the decision-support tool and provide logical links between tools. This type of integration can also be used to develop multimedia applications such as full-color, full-screen graphics; full-color, full-screen video; aural delivery of speech or music; and animation (50).

An example of an advanced multimedia system for integrating several different decision-support tools is the Whole Earth Decision Support System (WEDS; reference (51. The WEDS project combines textual databases, expert systems, simulation models, traditional programs and laser-video images within the agricultural domain into a single integrated system. Each module is developed independently and inserted into WEDS. For example, an expert system for lactation curve analysis developed independently from WEDS can be incorporated and linked with other components dealing with lactation curves (e. g., documents in the textual database). In this system, the user moves between the different modules guided by logical connections. Systems such as WEDS should be able to provide a complete information resource to extension agents, agri-service personnel, and farm managers for solving problems and formulating management decisions. The multimedia approach utilized in the WEDS project should be encouraged for systems developed in the 1990s since people remember more if they combine seeing, hearing, and doing during the learning process (60).

A more tightly coupled method of integrating software is to link different systems through a user-interface manager. The user-interface manager controls all user-interface functions for a set of application software (96) and validates all inputs for the application software. Screen displays, including error messages and on-line help, are also controlled by the user-interface manager. There are two major advantages to integrating software in this fashion. First, a system does not need to be redeveloped for each piece of application software. Second, the user is always presented with a consistent interface; thus, as the user moves from one application to another, the user interface remains the same. This is important for acceptability of software by laymen. Development of a generic user-interface manager awaits further research; however, several fourth-generation languages include facilities that can assist in development of generic user interfaces (%).

A more advanced method of integrating software is through an intelligent user interface; such an interface allows problems to be formulated and appropriate application software selected using natural language. A prototype system for integrating crop production decision-support systems is under development (see figure 4-6); (59). It uses an intelligent dialogue manager (IDM) with unrestricted natural-language communication to develop a problem description. The IDM parses input into a semantic representation using knowledge of the types of queries that can be asked and the lexical entities that can be discussed. The IDM also utilizes a model for inferring the goal of the user's input and relating it to the context of the overall dialogue. The semantic representation is passed from the IDM to an expertise module dispatcher

(EMD), which selects the application to respond to the query and formulates the appropriate control structure for the application software. The EMD is an expert system with knowledge of the problem-solving abilities of each application software module. This system can provide the user with a variety of problem-solving tools. Furthermore, the user does not need to know the nature of the software, the details for using it, or the situations for which it is appropriate.

## *Other Computer Technologies*

Three other emerging computer-oriented technologies will impact American agriculture in the 1990s. The first involves dispersal of information to those who need it in different geographic localities. The second. robotics, will impact the labor problems associated with agriculture. The third area is sensor technology.

### Networks and Telecommunications

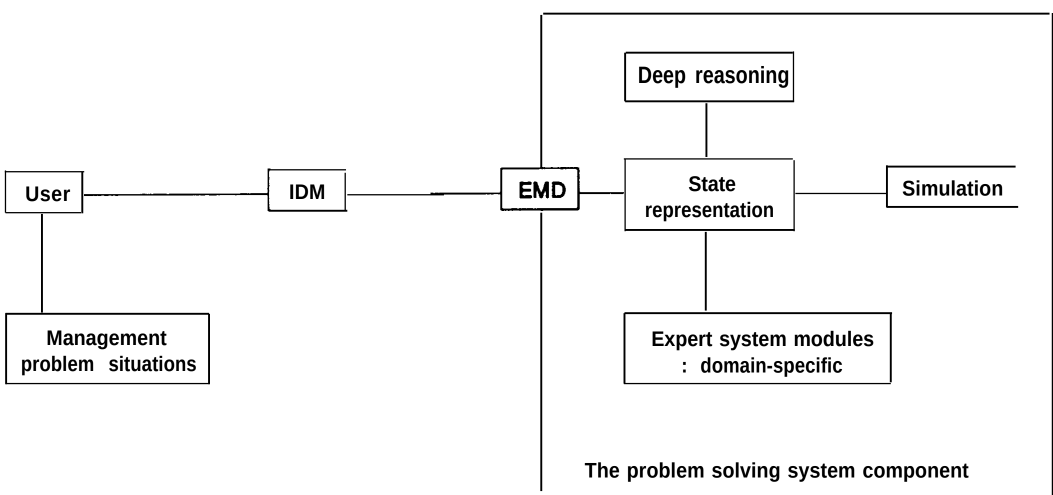
American agriculture is decentralized and widely distributed, making information dissemination problematic. However, electronics can be used to provide mass distribution of information. Electronic information can be transmitted essential y at the speed of light and duplicated at minimal cost. Two electronic forms of information delivery will dominate in the 1990s: a satellite-based system and a wide-area computer network.

Satellite transmission of data has become a common-day occurrence for telephone and other communications. A geosynchronous satellite receives a transmission from Earth and rebroadcasts that message back to Earth over a wide area. Different frequencies are used to send multiple simultaneous messages. Two common modes of transmission are the Ku and C bands.

Interest in delivering agricultural information via satellite is growing. Several distance-learning programs have been developed at the University of Utah for delivery in Ecuador ( 13). Their developers are also preparing an undergraduate animal breeding and genetics class to be delivered over the national AG*SAT satellite instructional network, which routinely carries Extension programs. An Extension series of interactive dairy programs has been developed and delivered by the University of Washington (8) as well as by the University of Wisconsin (35). The American Farm Bureau also maintains a satellite link to 46 States and 573 of their county offices (72). This satellite link is used to transmit data as well as instructional programs.

Satellites not only make possible mass distribution of information, they do so in a way that makes this information easily accessible to end users. They only need a satellite reception disk and a television. However, development of satellite-based instruction programs can be expensive. Poor planning may also reduce attendance. Other problems include limited audience interaction and low motivation on the part of the end user to view the program. The importance of in-person interactions with the live speaker should not be underestimated. However,

**Figure 4-6—Functional Components of the Crop Production Expert Advisor System**




SOURCE: L.R. Maran, “CPEAS: The Crop Production Expert Advisor System,” Knowledge Based Systems Research Laboratory, Department of Agronomy, University of Illinois, Urbana-Champaign, 1989.

if funds for education continue to dwindle, this may remain the only feasible means to conduct an Extension program.

Another method of rapidly delivering information is through a wide-area computer network. Much of the western world currently is criss-crossed with multiple computer networks. Two of the original computer networks are BITNET **(figure 4-7)** and ARPANET. BITNET was initiated at the City [University of New York and was used to connect major educational institutions. ARPANET was initiated by the Department of Defense. Today there are national computer networks for the government. commercial companies, and educational institutions. A number of regional networks have also been developed. These include networks such as Clemson University Forestry and Agricultural Network, CNET (Cornell University). and PENpages (Pennsylvania State University). Most of-these networks interface through the national Internet system so that messages can be sent from one network to another. Internet is funded by several government agencies and numerous companies (50).

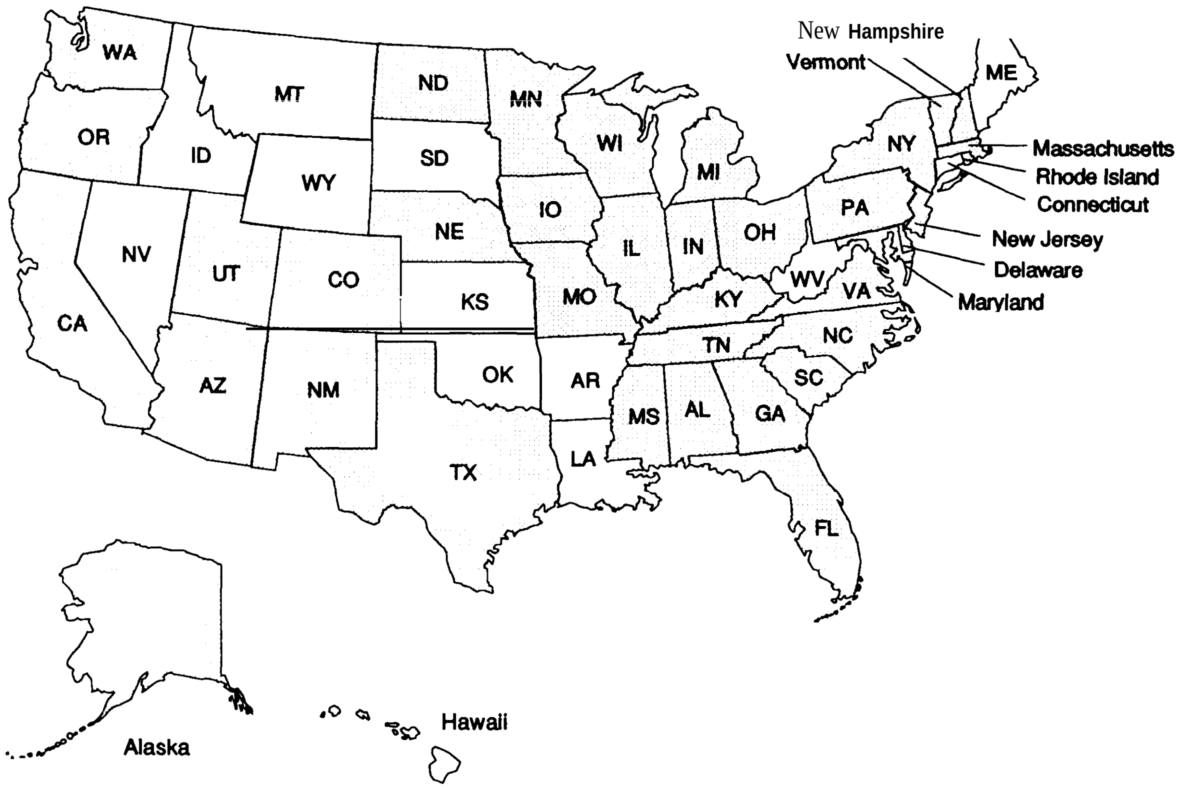
The main benefit of wide-area computer networks is the ability to rapidly share information and expertise. for instance, an industry situation report can be posted on the network and broadcast to all interested readers with access to the network. County Extension agents on the network can send and receive files in electronic format. In this way. interdisciplinary work can be conducted over long distances. Varner and Cady (103) have established a bulletin-board type system, called DAIRY-L, through which dairy professionals can request and receive information. DA IRY-L is only one of hundreds of bulletin-board systems, but a pioneer in the use of networking for Extension education.

DAIRY-L, which resides on the University of Maryland mainframe computer. was initiated early in 1990. Since that time subscription has grown to 150 subscribers from 37 states and 20 foreign countries (figure 4-8). Message traffic also has increased, approaching an average of 15 messages per month (figure 4-9). Messages are submitted to a ''list server' which in turn transmits them to all participants of DAIRY-L; therefore. all sub-

**Figure 4-7—Topology of BITNET Connections in the United States**

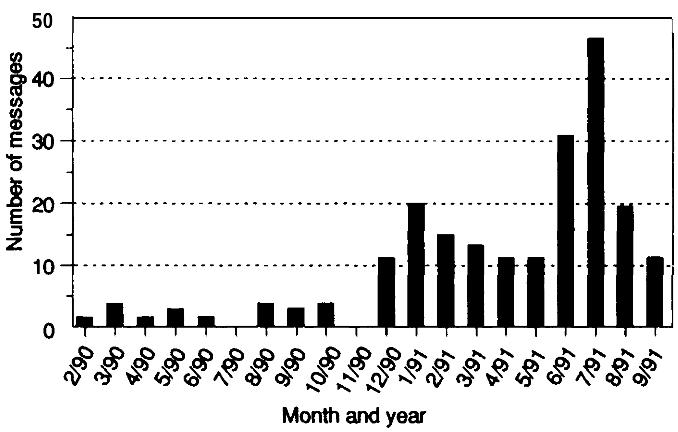
SOURCE: J.R. Lambert, '(Networks, Telecommunications and Multimedia Information Bases for Agricultural Decision Support, " commissioned background paper prepared for the Office of Technology Assessment, Washington, DC, 1990.

**Figure 4-8—States with Participants in DAIRY-L.**




SOURCE Mark Varner, University of Maryland (M.A. Varner and R A Cady. Dairy-L" A New Concept in Technology Transfer for Extension, *Journal of* Dairy Science 74(Supp 1): 201, 1991

**Figure 4-9—Volume of DAIRY-L Messages.**




SOURCE Mark Varner, University of Maryland (M A Varner and R A Cady. Dairy-L A New Concept in Technology Transfer for Extension, *Journal of* Dairy Science 74(Supp. 1 ) 201, 1991

scribers see all messages. Messages take the form of questions, notices, statements, and responses to previous mail. The list server also allows remote retrieval of files (figure 4-10).

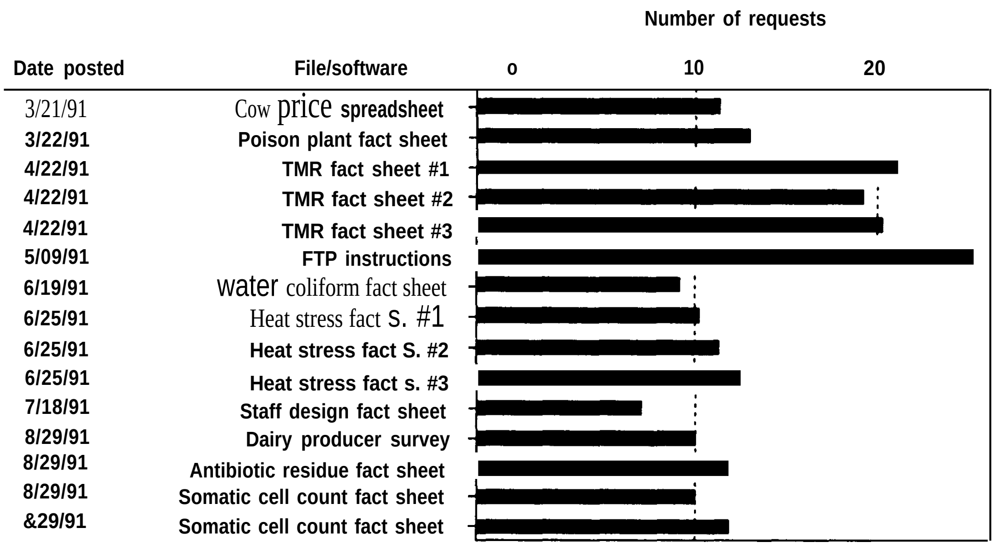
DA IRY-L has proven extremely useful to extension specialists needing knowledge in areas outside their institution's expertise. Because all members see all messages, DA IRY-L is also a powerful ediucational tool.

Information exchange through wide-area computer networks makes efficient use of personnel and resources. Therefore. a high priority should be given to maintaining and enhancing the backbone systems (i. e.. satellites and wide-area computer networks ) that provide rapid dissemination of information. Since these systems are national in scope, this initiative should occur at the Federal level with USDA-ES providing the leadership in agriculture.

## Robotics

Robotics are machines that can be programmed to perform a variety of labor intensive tasks in agriculture. Since 1968, when strew Dutch companies proposed mechanisms similar to robotics for harvesting citrus, researchers have proceeded though the poposal stage and currently are testing Laboratory and field prototypes for fruit harvesting. transplanting, tissue culture propagation. and machine guidance (67) (table 4- I ).

**Figure 4-10—Volume of DAIRY-L Requests for Remote Retrieval of Text Files and Software**




SOURCE: Mark Varner, University of Maryland (M.A. Varner and R A Cady, 'Dairy-L A New Concept in Technology Transfer for Extension, Journal *of Dairy Science* 74(Supp. 1): 201, 1991.

Most robotic applications under development are foreign-based. The United States is noticeably lacking in development efforts. Japan and Europe have much stronger programs and are likely to capitalize on this technology much sooner.

Agricultural robotics research is proceeding in two directions. One involves sensor technology (see following section) and machine vision. This is because, unlike production line robots, agricultural robots will operate in environments where interferences will be encountered. For example, a fruit-harvesting robot must be able to locate irregularly shaped fruit despite the obscuring effect of leaves and stems. A second research concern is robot end-effecters (i.e., grippers). These are the mechanisms through which robots conduct their work. Again, unlike industrial operations, agricultural robots will generally be working with fragile products (e.g., bedding plants and fruit). Touch and force feedback are necessary to avoid bruising or damaging plants, fruits, or animal products.

Three other areas of research are important for robot development but are not specific to agriculture. Manipulators are the physical linkages that move the end-effectors. Breakthroughs in speed and cost of manipulators are necessary. Agricultural robots will likely require less precision than industrial robots and will not require curvilinear motion, thus reducing the cost, Easily adopted robot components from nonagricultural applications would reduce the engineering costs of agricultural robots. A second research area is the development of computer algorithms for robot control. Significant advances in the miniaturization and integration of control hardware are needed. Integral feedback of the robot's position is essential. More powerful integrated circuit chips to interface sensors and to control the manipulators are also needed. New artificial intelligence approaches to task selection will be important facets of robot control research. A final area of research, systems simulation, allows evaluation of alternative robot configurations through animated computer simulations. Advances in computer simulation would reduce the development cost and time required in engineering a robot.

One major use of robots in agriculture will be for labor-intensive tasks. For example, there are two Dutch companies developing robots to milk dairy cows; one prototype is operating at the University of Maryland. Labor-saving robots will enable American farmers to remain competitive in world markets despite higher labor costs and a shortage of part-time, seasonal labor. They will also help to stem the flow of young, struggling industries such as ornamental horticulture, bedding plants, and plant tissue cultures to countries with low-priced labor. If robotics can help these industries survive, they will create or maintain jobs which would otherwise be lost.

Another major use of robots will be to micromanage crops. For example, a robot with an image sensor to detect weeds could be used to spot-spray herbicides. This

**Table 4-l—A Partial Catalog of Research Applications of Robots in Agriculture**

| Application | Location | Notes |
|---|---|---|
| | Fruit harvesting | |
| Apple harvesting | France | Able to harvest 500/. of fruit |
| Citrus fruit harvesting | University of Florida | 1 fruit every 3 seconds, able to harvest a fruit on 750/0 of its attempts |
| Tomato harvesting | Kyoto University | 20 seconds per fruit |
| Cucumbers harvesting | Japan | In a laboratory study, the hand successfully completed the harvesting motion for 42 of 53 cucumbers. |
| Muskmelon harvesting | Purdue University<br>Volcani Institute, Israel | 5 seconds per fruit |
| | Plant material sensing and handling | |
| Transplanting<br>• pepper plants<br>• marigolds and tomatoes<br>• move plugs from one flat to another | <br>Louisiana State University<br>Purdue University<br>Rutgers University | <br>Transplanting rates as low as 1 plant every 3 seconds have been achieved with a 95°/0 success rate. |
| Automated tissue propagation | University of Georgia, University of Florida, University of Illinois, New Zealand, Europe, Israel, Japan, Switzerland | Operations include retrieving the cuttings from a conveyor, trimming to size, stripping selected petioles, applying rooting hormones, and sticking the finished product into a plug flat cell. |
| Mushroom harvester | England | Uses a vision system to locate and size mushrooms and guide a selective robot harvester. |
| Forest thinning | | Performs automatically selective felling within the tree ranks, bunching the harvested trees and carrying them to a process zone. |
| | Animal | |
| Robot milkers | Netherlands | |
| Sheep shearing | Australia | |
| Egg handling | University of California. Davis | Facilitated candle inspection, |
| Pork protein sensing | Purdue University | Robot moves an electro-magnetic scanner over a carcass. |
| Pork carcass sectioning | Sweden | |
| Oyster shucking | University of Maryland | Machine vision application to locate oyster hinges. |
| | Machine guidance | |
| Automated guided vehicles | Michigan State University<br>Texas A&M University | Based on machine vision sensing. |
| Plowing robot | France | |
| Rice combine | Japan | Used edge-following to guide the machine around a rectangular field. |
| Direct spot spraying | Purdue University | Machine vision application to recognize plants. |
| Corn detasseling | Purdue University | Machine vision application to recognize plants |

SOURCE Office of Technology Assessment. 1992

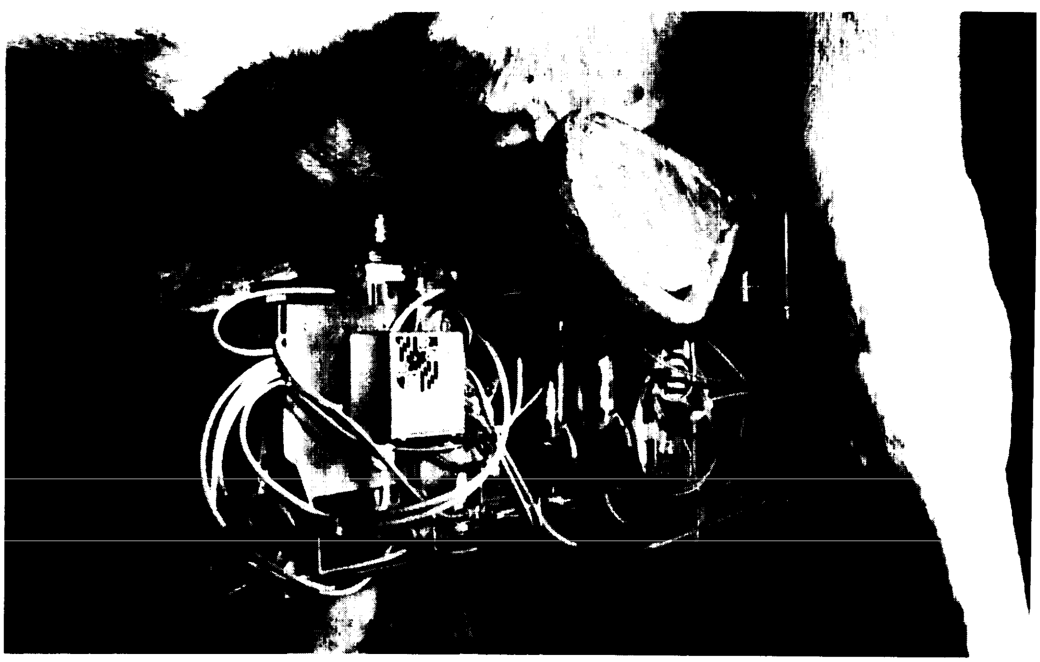
would encourage farmers to adopt conservation tillage and post-emergence spray programs.

## Sensor Technology

Electronic systems use sensors to monitor their environment. Sensors will be used in data acquisition for computer systems such as expert systems and to assist robots to perform their tasks. Reliable sensors coupled with knowledge-basccl decision support systems will provide important managenment tools.

All data is collected through some kind of sensor. The human body has five (e.g., the sense of sight, touch, smell, hearing, and taste). However, there are substances that we are not able to directly sense (e.g., methane gas)

Photo credits: Norman Pruitt, Maryland Agricultural Experiment Stat/on.



This research prototype automated milking system, developed in the Netherlands, allows scientists to study system automation and robotics that can benefit dairy farms.

or that require more vigorous sensing than we can provide. Sensor technology provides information the human senses cannot access.

There generally are six classes of sensors. The newest is *machine vision* which processes images (e. g., camera input ) to detect patterns. Nuclear *magnetic resonance* (NMR) is a noninvasive technique of resonating high-frequency electromagnetic radiation in the presence of hydrogen nuclei. This technology is widely used for diagnosis in the medical field, but it is costly and difficult to apply in field situations. *Neur-infrared (N/R) spectroscopy* is another noninvasive technique that measures the reflectance of NIR radiation by a substance. Because organic compounds absorb and reflect NIR radiation differently this is a quantitative sensor. *Acoustical measurements* provide another class of sensors for measuring the density of substances. *Biosensors* are sensors that incorporate a biologically sensitive material (e. g.. immobilized enzyme). *Electrical* sensors can monitor the electrical properties (e. g., conductance) of a substance.

Considerable work has been done in environmental sensing (i. e., crops, weather), somewhat less in animal sensing (i. e., estrus detection) (40). A partial list of research efforts in sensor technology is presented in table 4-2. Animal sensors are difficult to engineer due to biocompatability problems and animal welfare constraints.

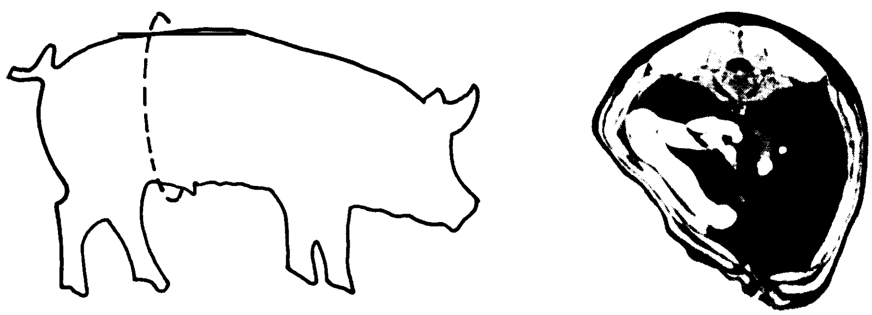


*Photo credit: U.S. Department of Agriculture, Agricultural Research Service.*

Drawing of pig (left) shows where cross section was made by magnetic resonance (MR) imaging. Spine, loin muscles, and kidneys are visible in upper part of MR image (right). Scientists can measure fat development under the skin quickly without injury to the pig.

**Table 4-2—A Partial Catalog of Research Applications of Sensors in Agriculture**

| Application | Type of sensor |
|---|---|
| Electronic navigation system | Used the Global Position Satellite System |
| Automated plowing system | Photodetectors sensed the furrow edge |
| Tractor guidance | Computer vision |
| Monitor organic matter in soil | Light and NIR reflectance |
| Application of spray material | Electronic surface grid |
| Monitor gaseous ammonia | NIR spectroscopy |
| Moisture sensors for irrigation | Electrical resistance |
| Plant stress | Infrared leaf temperature sensor |
| Crop growth | Spectral reflectance |
| Weed identification | Machine vision |
| Identification of plant embryo shapes | Machine vision |
| Animal digestive system | Radionuclide imaging |
| Estrus detection | Electrical conductivity |
| Sex determination of baby chicks | Machine vision |

SOURCE: Off Ice of Technology Assessment, 1992

Research on sensors for use in crop production generally focuses on the following objectives:

- Improving operations in crop production by machine guidance systems.
- Applying pesticide and fertilizer chemicals.
- Improving the management of irrigation water to conserve the resource and reduce production costs.
- Developing methods of monitoring crop growth to incorporate with computer models for improving day-to-day crop management and strategic planning.
- Developing sensors for assessing crop maturity and fruit location as basis for mechanical harvesting.

There remain numerous agricultural areas where sensors need to be developed (40). Doing so will require a multidisciplinary approach with input from professionals who understand the biology of the system in question as well as professionals who understand sensor technology (e. g., engineers and physical scientists). Some of the areas that need to be addressed include:

- Accurate three-dimensional fruit location sensor for crop canopies. This will facilitate robotic fruit harvesting.
- High-resolution navigation for field machines. Ability to program machine locations within inches, not several feet, is needed.
- A chemical drift sensor to monitor fertilizer and pesticide application and production of air polluting gases from animal units.
- Irrigation demand sensors that are not affected by soil properties and climatic factors.

*Photo credit: Gerald Isaacs, University of Florida*

An experimental fruit picking robot uses a machine vision sensor and a computer to locate individual fruit for detachment. Approximately 3 seconds per fruit are required.

- Animal stress sensors that can remotely detect early animal health problems.
- A fruit-ripeness sensor that can determine optimum harvest times and detect early stages of fruit and vegetable deterioration.
- Microbial sensors that can detect early development of spoilage or bacterial contamination in fresh meats, including poultry and seafood.

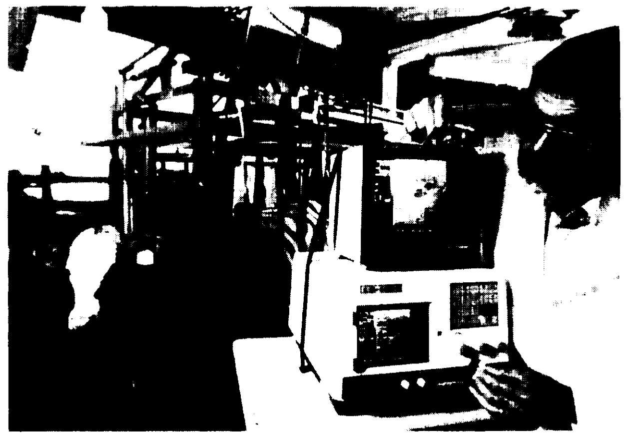


*Photo credit: U.S. Department of Agriculture, Agricultural Research Service.*

Animal physiologists test a sensor that will detect when this cow is ready to give birth.

An important component of the use of sensors in animal agriculture is telemetric data transfer and electronic identification of animals. For sensors that are to be implanted (e.g., tissue conductivity for estrus detection), telemetric data transfer must be accomplished within the size constraints which make implantation feasible. This remains a research issue. Implantable electronic identification systems have been developed and are currently under review by the Food and Drug Administration. Concern centers on the possibility that implantable sensors or identification units can enter the food chain.

The development of sensors will facilitate more forms of automatic control over various aspects of agricultural production. The development of robots is closely tied to success in the area of sensor technologies. A broader implication of sensor technology may be to provide a data acquisition system and a database from which decision support systems can operate. This should result in tighter controls for management and higher profitability for the enterprise. Another important impact of sensor technology will be in the food safety arena. Sensors to detect food spoilage or contamination will greatly increase the safety of the American food supply.

# SUMMARY/PROGNOSIS

Computer technologies change at such a rapid pace that it is difficult to foresee their application in the next decade accurately. Irrespective of agricultural policics. computer technologies will continue to advance to support the needs of other industries. Meanwhile. a number of impendiments exist that are likely to slow adoption of these technologies in agriculture. These impediments can be removed through changes in policy. Most projections of agricultural application of computer technologies have been overly optimistic. For example, Holts futuristic view of the application of computer technoolgies for farm management (38 ) is still 20 years from fruition.

OTA has developed a scenario for the application of computer technologies in agriculture assuming that new technologies have a 5-year development phase. That is to say that once a research project begins it takes 5 years before that technology is applied. It was also assumed that incentives to bring new computer technologies out of the research laboratory and into production agriculture would exist. There are almost no incentives to do so today . Thus. American agriculture will not be affected by these technologies in a major way for at least10 years.

## *The Current State*

***By*** and large. computers have had little impact on production agriculture to date. Predictions that every farmer would own a computer by 1990 have not come true. Few farmers have computers and those who do use them primarily for bookkeeping and routine calculations (e. g.. ration balancing ).

Computers have had somewhat more impact on agriculture support industries. Using computer networks and tracking systems. equipment dealers are better able to provide faster service and feed dealers are better able to manage feed inventories. Most of these advances have come from directly adopting general business software with little or no input from the agricultural academic community.

Another technology that currently is being adopted by farmers is fax machines. This allows for rapid exchange of printed material. An example of the use of this technology is in ration balancing. A nutritionist can receive the results of a feed analysis by fax from the laboratory. formulate a ration. and fax that to the farmer all with-in a few minutes. There is limited use of networks for exchange of information among Extension personnel ( i .e , Dairy-L) and among protoype full-text databases (i. e., National Diary Database).

## *Mid-1990s*

Within the next few years. many technologies currently under development should find their way into application. By the mid 1990s, the performance of microcomputers will likely double, eroding some of the current constraints to farmer adoption of computer tech nology. However. it still is unlikely that a high proportion of farmers will own a personal computer by that time.

The primary application of advanced computer technology in the mid-1990s will be in the form of ad hoc expert systems to solve well-defined problems. These will be primarily problem diagnosis expert systems that are currently under development. Farmers will have a cadre of expert systems at their disposal to diagnose diseases and to evaluate animal and crop performance. These systems will generally not be integrated with each other and each will condisider one aspect of a problem. Integrated systems that solve producton problems while considering economic consequences will not become available until later in the decade.

The primary use of expert systems within the next 5 years may be by agribusiness personnel, as they will be able to leverage the cost of' adopting these technologies across more farms. Using expert systems to provide additional service to farmers may cause a shift in the role of some professionals. For example. expert systems help veterinarians take an epidemiological approach to solving problems (85 ). It will also cause some diversification in services provided. For example. nutritionists may be more likely to become involved in consulting for the crop program when armed with an expertsystem.

Sensors will see limited application for collecting real-time data for expert systems. The primary use of sensors will be for monitoring weather and field conditions for crop management. Expert systems will help farmers to interpret these data and suggest appropriate management strategies such as irrigation, fertilization, or pesticide treatment.

Another technology likely to see application within the next 5 years is full-text retrieval systems. It will be possible for farmers and Extension personnel to have a CD-ROM with all of the latest publications at their fingertips. Using a full-text retrieval system they will be able to retrieve pertinent information that will help them make better decisions. For example. when a farm experiences a corn mycotoxin problem, the manager can access an information base to find relevant literature. Large information bases, such as the national dairy database, will likey be developed and delivered by 1995.

Robots for highly specialized, labor-intensive tasks will begin to be applied to agriculture in the late 1990s. This would include robot transplanting of seedlings and pork carcass sectioning. Robots for milking cows could reach application by the mid- 1990s.

## 2000

The turn of the century should bring with it significant new applications of computer technologies in American agriculture. Ten years will provide sufficient time for the acceptance by farmers of computer technologies as a valid management tool and for the development of integrated management programs. It will also allow time for universities to become comfortable with these technologies and for personnel to be properly trained in developing these technologies.

By 2000, whole-farm advisors, or integrated "management workstations, should be developed. A management workstation will consist of integrated decision support tools with a multimedia presentation of information. The workstation can thus serve as a diagnostic tool, an information source, an advisor, and a planning system. The expert systems will consider the holistic view of an enterprise when making recommendations. The systems will also share data so that information used in one system will be available to other systems. This generation of expert systems should operate as monitors that can alert producers to potential problems, as opposed to current expert systems which are situation-driven: that is, the producer must perceive a problem and decide to execute the system. The management workstation will also contain an advanced user interface consisting of speech recognition and touch-sensitive screens.

The future dairy management workstation might contain decision support systems that monitor the financial records, the herd production records and the crop production records. Cropping decisions would be integrated with the dairy needs, the financial situation, and the land resources available. Currently, these decisions are all made independently. When the farmer is alerted to a problem (e. g., pest infestation). he or she can use the multimedia features of the workstation to retrieve video segments to learn how to identify the pest and the proper techniques for applying a pesticide.

Robots for harvesting fruits and vegetables and for automatically guided vehicles should become available by 2000. Their application will depend on the cost associated with using human labor for the same job.

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