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RESEARCH IN PROGRESS

The Center for Automation and Intelligent Systems Research, Case Western Reserve University

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The Center for Automation and Intelligent Systems Research at Case Western Reserve University, founded in 1984, provides the setting and the administrative and funding mechanisms for coordinating and focusing the capabilities of faculty members and students from many disciplines and departments to deal with significant real-world problems encountered in the automation of production. The center serves as an interface between separate basic research efforts in the various disciplines and academic departments and the multidisciplinary group efforts needed to deal effectively with nontrivial real problems.

The main focus of research at the center is on the effective integration of computer-based technologies that appear to be essential for the factory of the future. Thus, the scope of activities at the center is somewhat broader based than AI, but AI plays a central role in this integration because effective integration of complex systems requires intelligence. The major emphasis at the center is on industrial applications. However, it is important that this is supported by research which is more basic.

The center is supported by industry and the state of Ohio. It is also a component of the Cleveland Advanced Manufacturing Program (CAMP), a Center of Excellence supported by the Thomas Alva Edison Partnership Act of the state of Ohio.

There are about 18 faculty members and 36 graduate students from various academic departments engaged in research projects at the center. There is also a full-time professional staff that maintains the center's computing facilities and robotics laboratory. The computing facilities are connected by a computer network to most of the other major computers on campus.

Expert Systems for Manufacturing

This work involves investigating the use of expert systems to improve productivity in the production of high-technology metal parts whose specifications are difficult to meet because, for example, of close tolerances. Our initial studies have focused on the production of superalloy monocrystal turbine blades for jet engines that are made by investment casting. Essentially, the part is made by pouring liquid metal into a ceramic mold, but the environment in which this is done must be tightly controlled. There are several other subprocesses that are also tightly controlled, such as making the mold.

The total process is too complex for a single expert system; rather, several different expert systems are needed and should be coordinated in some way, perhaps by a more global expert system. Currently, we are constructing an expert system that will advise someone making a wax pattern from which the ceramic mold is made because it typifies the kind of expert system that is needed. Wax patterns are made by a machine that injects wax into a metal die. This machine controls about 10 different parameters, such as the temperature and the pressure of the wax. The problem is to find values for these parameters that produce a pattern without defects. About 10 different kinds of defects can occur in a pattern. Human experts use trial and error to make a good pattern; a complex pattern takes about 20 trials, and a novice pattern maker requires many more. Thus, our system, like the expert, will only try to reduce the severity of the defects at each step, rather than attempting to remove them completely. The system will also have some ability to reason about the sequence of patterns produced so far, to take advantage of information such as trends in the sequence.

The investment casting process that we are studying is currently being instrumented so that a database of the process parameters, as a function of time, can be created. When defective parts are produced, this information can be analyzed to determine the cause. We are currently looking into methods for doing this, and it appears that expert systems like the one for wax patterns will be needed. Some database techniques will also be needed because of the large volume of data, but integrating them in an effective way with expert systems is a problem that needs more study.

Although our current work is only concerned with in-

vestment casting, many of the techniques appear to be applicable to other manufacturing processes, such as forging, and we plan to develop generic methods for such problems. *(Contact: George W. Ernst)*

Intelligent Control and Monitoring in Complex Systems

This project addresses the problems of monitoring and control of a complex dynamic process. The basic objective is to develop techniques and methods for the design of an intelligent data acquisition and control system that is capable of detecting and isolating equipment failures and malfunctions and responding to emergency conditions with appropriate control actions. An important feature of the data acquisition and control system is that it will include both knowledge-based and model-based detection and control procedures. This allows the system to respond to various classes of disturbance events that occur in different time scales and also to provide real-time data to an operator for higher-level control and coordination functions.

The integration of model-based and knowledge-based algorithms requires developing a framework in which both approaches can be unified. Initial investigations indicate that a decision theoretic framework is most appropriate. In order to focus the work, we have chosen a class of electric-drive applications as a study problem. The first phase of the work addresses the development of an expert system for managing internal diagnostic information pertaining to the status of the hardware and software of the electric-drive computer-based control system. The second phase of the project is involved with predictive monitoring and adaptive control of the electric-drive system, including the power electronics, the sensors, and the prime mover. Current research in this phase of the project is directed at developing an expert system for adaptive tuning of a classical PID controller in response to load changes and external disturbances. This will also be useful for initial tuning of the control loop for system start-up.
(Contact: Kenneth A. Loparo)

A Domain-Independent Expert System for Scheduling

The goal of this project is the elaboration, perfection, and application of DIFF (Domain-Independent Form Filler), a skeletal expert system tool. DIFF aims for the midrange of the various dimensions of trade-offs made by most skeletal expert systems. It allows for significant generality and expressibility, while still allowing some control over the efficiency of computationally intensive portions of problems. Generality is achieved by using knowledge representations (called *forms*) that can be added to the state of the system in a way that is independent of the various control strategies available to DIFF. Efficiency is accomplished by caching what is known to the system at a given time, so that subsequent accesses will not cause information to be redundantly inferred. DIFF is designed for problems whose parts interact to a substantial degree. In the course of reasoning about such problems, a system might have to change assumptions or inferences made earlier on. This is accomplished in DIFF by means of a knowledge maintenance facility, which checks, when necessary, on the validity of inferences previously made and propagates changes of validation through a dependency network. DIFF has been successfully applied to the task of determining how a robot should grip an arbitrary three-dimensional object. It seems to be a fairly general and useful architecture for many kinds of scheduling and planning problems.
(Contact: Randy D. Beer)

Tailoring Meta-Interpreters for Knowledge Bases

The aim of this research is to systematize and give a common framework for the various domain-independent components of expert systems. Examples are explanation facilities, interactive interpreters for extracting information from and responding to the user, and uncertainty reasoning mechanisms. The approach used is based on the computational model of logic programming. The typical decomposition of expert systems into knowledge base and inference engine has a natural interpretation in logic programming. The knowledge base is a collection of domain-specific rules suitably structured. The inference engine is a meta-interpreter for the rules.

Studying the components of an expert system in a uniform way using meta-interpreters has two clear advantages. An expert system can be easily tailored for any application by only including in the meta-interpreter the necessary components for that application. More importantly, the properties of the components have been clearly and explicitly specified as a logic program. The program can be analyzed for such properties as complexity, soundness, and completeness. The unified view allows comparisons between different approaches provided in existing expert systems.
(Contact: Leon S. Sterling)

Machine Learning for Improvement of Rules and Interactive Formation of New Concepts

No system can truly be considered to be intelligent if it is not capable of automatically and adaptively improving its own performance through observation and inference. The research of this program is aimed at understanding the nature of this capability and how some aspects of it might be implemented for certain specific applications.

Our previous work resulted in methods for the inductive inference of decision rules from large bodies of labeled pattern data. These methods are useful for a variety of purposes, including the predictive monitoring of the behavior of complex systems subject to the occurrence of

contingencies. They suffered from a number of inadequacies including the inability to improve on their own knowledge representation. Recent work has increased our understanding of how to interactively facilitate the learning of new concepts and to improve the description of a system through the incorporation of additional important concepts.

It seems that in a multileveled scheme for acquiring an understanding of what is important about the behavior of a system, it is possible to start with a rather low-level and nonrelational description. The inability to find a way of describing significant differences in descriptions of the desirable state and the nondesirable state automatically focuses attention on higher-level relationships and concepts that might serve to distinguish between states. A major objective of the present research is the development of systems that build internal representations of their interactions with the external world, instead of being content with the domain-specific knowledge given by the knowledge engineer. These systems can improve on their expertise as a result of their learning from interactions with their environment. Ideally, because the system is to build its own concepts, the only knowledge that has to be supplied are the terms on which this internal representation is to be based. Concepts expressed initially in terms of *a priori* supplied primitives evolve as the system accumulates experience. (It is found that the evolution is much more rapid and effective if there is some guidance and intervention from human experts). Evolved concepts that emerge from the interaction of system internal design, inherent primitive and human guidance can be startlingly new and involved.

This direction of research seems to be promising, and applications explored include those of electric power systems' operation and control and other equipment maintenance projects.

(Contact: Yoh-Han Pao)

Expert Systems for VLSI Design

We are investigating the application of expert systems to the design and analysis of VLSI systems. Our long-term goal is the development of several compatible computer-aided design (CAD) tools that will transform a high-level specification for a computing system into its VLSI implementation.

Because a digital system is a complex, multidimensional task, a flexible, knowledge-based approach seems appropriate. The body of knowledge of VLSI consists mainly of judgments and heuristics used by design engineers. Like human designers, we have separated the design process into four stages: the system or functional level, the cell or logic design level, the circuit level, and the physical design level.

Two related investigations are under way. One is concentrating on the construction of an expert system at the logic design level using the concepts of cell library and cell librarian. A VLSI cell library is a database containing VLSI cells such as gate modules, multiplexers, or even more complex circuits such as PLAs. The idea here is similar to selecting appropriate IC chips from an IC data book. Important information stored with each cell in the library includes: (1) cell parameters, (2) cell logic function, (3) circuit diagram (4) cell layout, and (5) interfacing information.

During the design process, a cell specification is produced and then a search is made in the library to find a cell candidate. Because an exact match rarely occurs, an expert system chooses among various cells partially satisfying the given specifications.

The second project involves constructing a rule-based assistant that helps a designer to explore space and time trade-offs at the functional (register transfer) level. For example, by adding components or buses to a data path, more operations can be performed concurrently, thereby increasing the execution speed of the system. The control portion of a design is represented in an extended Petri net graph schema, and block diagrams are used to describe the data path part. A graphic human interface will be provided to display and manipulate both kinds of descriptions.

Future efforts will attempt to close the gap between the functional and logic levels of design. Thus, an initial design can be expressed by register transfer statements that are transformed into logic function modules. The modules would then be decomposed into cell specifications to be used by a cell or logic expert. Subsequent phases of the project will be dealing with lower-level interfaces to be designed using knowledge base approaches. Verification and validation are additional important issues to be considered.

(Contact: Christos A. Papachristou)

Expert Systems and Databases

We would like to think that data structures are main-memory databases, and searches against the data structures of expert systems can be translated into queries against an equivalent database. Our current work reviews and classifies the data structures encountered in expert systems and then devises formal mapping techniques for translating search requests of expert systems against these structures into sets of database queries against the equivalent database conceptual models.

Another project attempts to use expert systems technology for efficient database query processing. We investigate a knowledge-based intelligent query interface with a deductive component, which uses integrity constraints and the intensional database first to transform a given query into a number of semantically equivalent candidate queries on the extensional database, then to choose the one that is most efficient to process (using the knowledge on the

structure of the query and the syntactic rules of the query language).

We are also investigating ways of incorporating expert systems technology into statistical databases (SDBs). We are investigating an expert system that functions as a statistician and aids SDB users in choosing the statistical procedures to run and in interpreting the results. We are also investigating an expert system that maintains the usually complex dictionary of SDBs (*e.g.,* learning synonyms, maintaining unit conversions, and so on) and aids users in comprehending the SDB dictionary. Yet another application of expert systems is in enforcing SDB security. The SDB security problem is allowing users to obtain aggregate information from the SDB while "guaranteeing" that the users cannot deduce protected values in the SDB. The goal is to investigate an expert system that automates the SDB security checking and enforcement mechanisms. When an SDB query involves aggregation or protected information, the expert system is called upon by the SDB system to modify, enhance, or replace the SDB protection mechanism currently in use.
(Contact: Tekin Ozsoyoglu)

Planning for Manufacturing Systems

We are developing a computer decision-aided methodology for planning manufacturing systems. Our approach generates different alternatives and then finds the best alternative through interaction with the decision maker; hence, it is a consultant type of expert system.

In general, we wish to provide plans for the set-up of manufacturing processes, facilities, and projects, along with the necessary control and management devices. Our main objective is to find an alternative that is the most efficient in using limited resources and the most satisfying solution to different conflicting objectives.

We are developing methods for each of the four following problems: manufacturing facility layout and design; project management, scheduling, and sequencing; set-up of the parameters of a single machine (or department); and quality control and assurance. We are also investigating how these methods can be integrated into a single system. The conflicting objectives of the above problems are to maximize production rate, maximize quality, and minimize cost.

Our system should be easy to use. Techniques such as paired comparison questions should provide easy interactions, and the response time should be reasonable. We have also developed methods by which the system can learn from interaction with the decision maker.
(Contact: Behnam Malakooti)

Machine Vision

This research is directed toward faster methods of three-dimensional object recognition with specific emphasis on applications for handling and inspection. The major thrusts of this effort are inexpensive, high-speed and three-dimensional imaging.

This research is motivated by applications where the objects within a camera's field of view are known, but location and orientation are unknown. Conventional machine vision systems process two-dimensional images to infer the location and orientation of three-dimensional objects. Such systems are slow because of the vast amount of image data as well as the complex algorithms necessary to register and range image features. A system under development uses a simple laser pointer that is automatically registered by multiple sensors. The use of custom focal-plane architecture and separate dedicated digital processing can produce registered, three-dimensional images at rates on the order of 11,000 pixels per microsecond.

In another project, a laser designator imaging system capable of rapidly alterable scan patterns is being used to investigate three-dimensional scene processing. Such a system can be visualized as a random-access memory of three-dimensional image information. Research is under way using such a laser image system and a specialized, multiport content-addressable memory to symbolically process image information as it is being acquired. Concurrent processors examine incoming data; relate it to previous data; and hypothesize the edges, corners, surfaces, and other geometric features using simple geometric rules. The laser scan pattern can be dynamically altered to test these hypotheses. Current research is defining interprocessor communications and memory organization as well as developing sets of rules for feature hypothesization and confirmation.

We are also examining the interaction between sensor systems for robotic applications. Specifically, we are studying the relationship between the use of visual information (including range) and the use of tactile information for recognizing and picking up objects.
(Contact: Francis L. Merat)

Tactile Sensing in Robotic Manipulation

This research effort is directed toward understanding complex tactile sensing in closed-loop control of a multi-degree of freedom robotic manipulation system. The major thrusts of the program are: (1) To gain a better understanding of how to integrate tactile sensing from fingers and grippers with force sensors and actuator signals; (2) to apply the results derived from the theoretical study to an actual robotic system; and (3) to develop improved tactile-sensing technology with particular emphasis on parallel and peripheral data processing.

Much of the inspiration for this line of research came from knowledge of sensing in biological systems, particularly haptic sensing. The known physiology suggests that appropriate peripheral and parallel processing in a hierarchical configuration are contributing factors in the ef-

fectiveness of biological systems to perform complex functions. The manipulation system under investigation in this research is sufficiently flexible and adaptable to perform a large variety of tasks. The system will incorporate a hierarchical and distributed control architecture that is supported by multiple modes of tactile sensing. An important issue that will be addressed concerns developing an understanding of the concept of dexterity in a manipulation environment and identifying the role of tactile sensing in a closed-loop feedback control configuration for coordinating a multifingered gripper to perform various manipulation tasks.

Simulation is intended to play a critical role in this research program; so an effort is being directed at developing a flexible simulation utility. Also, considerable research effort is being directed at developing new and innovative closed-loop control algorithms that take advantage of the tactile data for direct control of the end effectors, that is, the fingers which are in direct contact with an object. There are a variety of theoretical and practical issues related to firm grasp, detection of object orientation and mass distribution, incipient slip detection, and so on, that need to be resolved before the system can be considered an effective manipulation mechanism. Some aspects of the utility of the tactile sense in assembly operations have been demonstrated by Lord Automation, and the experience gained in this experimental investigation has redirected and focused some of our theoretical work. As expected, the theoretical work has also had considerable impact on the implementation investigations.

(Contact: Kenneth A. Loparo)

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