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RESEARCH IN PROGRESS

Artificial Intelligence Research at The University of Michigan

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The University of Michigan is the site of a variety of AI research projects involving faculty, staff, and students from several departments and institutes on the Ann Arbor campus.

In 1984, the former Computer and Communication Sciences Department of the College of Literature, Sciences, and the Arts was combined in the College of Engineering with the Electrical Engineering Department. The newly formed Department of Electrical Engineering and Computer Science (EECS) is divided into the Computer Science and Engineering Division (CSE) and the Electrical Engineering Division; several faculty members and graduate students in the CSE Division are doing basic AI research. The Center for Robotics and Integrated Manufacturing in the College of Engineering is conducting research and development in robotics and related areas of manufacturing processes. The College of Engineering also has a Humanities Department with faculty working on the role of computers in natural language comprehension and writing.

The Psychology Department in the College of Literature, Sciences, and the Arts is the administrative center of the University's Cognitive Sciences Program, which involves several faculty working on cognitive psychology and other topics sharing interests with AI. The Mental Health Research Institute (MHRI) of the Department of Psychiatry in the School of Medicine, also on the Ann Arbor campus, is engaged in work on AI applications in medicine as well as theoretical studies of knowledge representation and learning. The Human-Computer Interaction Laboratory in the School of Business Administration conducts research on subjects of interest to AI researchers. Faculty from a number of other departments are also involved in AI research and in closely related computer science research. In this article discussion is limited to those projects whose major emphasis, as perceived by the project leaders, is artificial intelligence.

Computing resources include the Michigan Terminal System (MTS), a computing environment developed on campus and running on an Amdahl 5860; a second MTS system will soon be operational on an Amdahl V/8. In addition, there are several Digital Equipment VAX computers providing FRANZLISP service, four Xerox 1108 LISP machines, one Symbolics 3600 LISP machine, two Apollo rings, and several dozen other mid-sized computers. There are also a few hundred university-owned microcomputers on campus for use by faculty and students, including Apple Lisas and MacIntoshes, Apollos, Hewlett-Packards, and IBM PCs. Much of this hardware is networked on the UMnet, a network based on the technology originally developed on this campus for MERIT: (Michigan Educational Research Informational Triad), a network that has been in operation since 1971 and connects the Michigan campus with other Michigan public universities—Wayne State University, Michigan State University, and Western Michigan University. UMnet provides access to three long haul networks, Autonet, Telenet, and Datapac A Computer Aided Engineering Network is under development, and other local area networks and special purpose networks are operational. A new campus phone system that will include data communication facilities accessible from virtually every office and laboratory on campus is in the initial stages of installation. MTS provides UTILISP in addition to a wide range of other software, including a conference system and an electronic mail system that connect all MTS users on the UMnet, both on and off campus. The Engineering School computing facility is a member of PHONET, and MTS is on Mailnet, providing gateways for electronic mail to ARPANET. In addition, one research project uses the SUMEX computing resource at Stanford University.

The faculty members directing AI projects are Robert Axelrod (Department of Political Science), Michael Cohen (Department of Political Science), Michael Feinberg (Department of Psychiatry), Michael Gordon (School of Business Administration), Douglas Hofstadter (Department of Psychology), John Holland (Department of Electrical Engineering and Computer Science, EECS), Ramesh Jain (EECS), Keki Irani (EECS), David Kieras (Department of Humanities, College of Engineering), Manfred Kochen (MHRI and the School of Business Administration), Robert Lindsay (MHRI and Department of Psychology), Bernard Nudel (EECS), Paul Scott (EECS), and Paul Thagard (Department of Psychology).

Computer Vision

Professor Ramesh Jain and his students are interested in vision systems that work in a dynamic environment. They have developed several approaches for the exploitation of information extracted in the peripheral phase of motion perception to the problem of segmentation of dynamic scenes. A time-varying edge detector is one such approach that they have developed.

Currently their efforts have turned to the study of moving-observer dynamic scenes. They have developed a direct method for the computation of the focus of expansion and its application to the computation of the optical flow. They are also extending their work on a modified Ego-Motion Polar transform that converts a frame sequence to an observer-centered frame sequence and permits its segmentation. This method enables the recovery of depth in moving-observer dynamic scenes.

Recognition of moving objects and determination of their motion characteristics require some information about the objects. Most approaches for object recognition have proved of limited use because they depend too much on the structure and spectral properties of objects. This project is studying synergistic interaction of several knowledge sources such as object structure, motion, functionality, and history of events. Such forms of knowledge will be combined using the theory of evidence and fuzzy logic. Already developed is an approach by Naseem A. Khan for component correspondence using the Hungarian method, commonly used to solve the transportation problem. Susan Haynes is developing techniques to identify events in a dynamic scene. This work emphasizes application of an image sequence, not just two or three frames. It uses the notion of "path coherence" that is being studied by Professor Jain and Professor Iswar K. Sethi of Wayne State University.

Another important current focus of this research is the use of a freely movable camera to select a view that disambiguates a partially analyzed scene. This effort involves research in spatial reasoning and space representation in addition to object representation and other vision techniques. Hwang-Soo Kim and Professor R. A. Volz are collaborating on this project.

Professor Jain's group is also studying problems of 3-D object recognition. Their approach is to represent a 3-D object using spatial relationship graphs of critical Gaussian curvature points on the surface of an object. For an unknown object, a graph will be obtained from range data The matching will exploit the fact that a critical Gaussian curvature point is viewpoint invariant. Paul Besl is developing methods to compute characteristics of surfaces from their symbolic representation and matching with the model. This work emphasizes the role of Gaussian and mean curvatures, and critical points in surface characterization of 3-D object recognition. Jerry Turney, Professor T. N. Mudge, and Professor R. A. Voltz are interested in recognizing occluded objects using "salient" features.

Two major applications projects are vehicles for guiding this research. Ali Kayaalp and Ravi Rao are applying knowledge-based techniques for automatic inspection of semiconductor wafers. This work is part of a major research effort funded by the Semiconductor Research Council for Automation in Semiconductor Manufacturing. The long-term goal of that project is to identify faults and automatically adjust appropriate fabrication process parameters in a completely automated system. In the second applications project, Paul Besl and Sandy Regentin are developing techniques for inspection of solder joints. This project is funded by the International Business Machines Corporation.

Parallel Learning in Rule-Based Systems

Professor John Holland has developed a class of rule- based computing systems called Classifier Systems that he is studying as the basis of machine learning and adaptation. These have been tested successfully on several control systems, including a game learning program, a hardware robot project, and a gas transmission line system.

A classifier system is organized hierarchically on three levels: a basic skill level, a learning algorithm for improving the basic skills, and a discovery algorithm for inventing new skills. The classifier system corresponds to the basic skill level; the learning algorithm is called the bucket brigade algorithm; and the discovery level is called the genetic algorithm. The use of the bucket brigade and genetic algorithms to modify a classifier system is the current focus of research.

The cognitive model expressed in a basic classifier system is a stimulus-calculate-response model. The system takes in messages from the environment, transforms them, and uses some of the new messages to guide action in the environment.

There are two kinds of elements in a basic classifier system, messages and classifiers. A message is simply a binary word used to express an input state, control an action, or represent intermediate information. A classifier is a rule or conditional statement whose words are drawn from a ternary alphabet (0, 1, and a symbol for "don't care"). A typical classifier has two words as conditions and a single word as an action At each stage of computation, each classifier checks the current set of messages to see if its conditions are satisfied; if so, the action part generates a new message from each message satisfying the first condition. Any program that can be written in a high-level language, such as LISP or PROLOG, can be implemented as a classifier system. Classifier systems can exploit highly parallel architectures, and one thrust of this research in collaboration with Professor Arthur Burks of the Philosophy Department is the design of such hardware.

The bucket brigade algorithm enables the system to learn which classifiers are the most effective in dealing with the environment and to use classifiers in proportion to their effectiveness. A strength parameter is attached to each classifier to measure its contribution to the success of the whole enterprise. A classifier that produces a successful message is rewarded by having its strength augmented. The bucket brigade algorithm causes these rewards to be distributed backwards to the classifiers that supplied messages to the successful producer classifiers, and this process is iterated so that classifiers that contributed crucial messages early in the process are rewarded. The method is analogous to a market and auction system and does not require elaborate record keeping of the system's history.

The genetic algorithm can work in conjunction with the system just described. It combines old classifiers to make new ones, biases the production in favor of those that have the greatest strength, and substitutes these for the weakest old classifiers. The operators employed by this algorithm have genetic analogues such as crossover, mutation, and inversion; its main advantage is a sophisticated recombination of parts of successful rules to generate plausible new candidate rules. The algorithm has been studied extensively, and several important properties of it have been discovered

A number of other projects are applying Professor Holland's methods to a variety of areas.

Professor Robert Axelrod is applying ideas based on Holland's genetic algorithm to earlier work Axelrod has done on the emergence of cooperation among egoists without central authority. That work involved a computer tournament for the Prisoner's Dilemma game. He now is extending this work to problems of collective goods (n-person Prisoner's Dilemmas) and problems of confrontational bargaining (the game of Chicken). The genetic algorithm has been implemented in the setting of the Prisoner's Dilemma and it has been able to develop effective strategies from completely random initial populations

In the two-person Prisoner's Dilemma, there are four possible outcomes. Suppose we consider the set of strategies that are deterministic and use the outcomes of the three previous moves; there are $4^3 = 64$ of these. A player strategy (when to cooperate, when to defect) can therefore be coded as a 64-bit string. Six more bits are required to specify the player's beliefs about the three hypothetical moves that preceded the start of the game.

Thus a strategy can be represented as a 70-bit string Starting with completely random initial populations of strategies, the genetic algorithm has been able to develop effective strategies, in spite of the fact that the potential population of strategies is 2^{70} (about 10^{21})

Professor Michael Cohen is interested in the impact of an organization's design on its ability to learn to perform new tasks. Over the past five years he has built several simulation models of organizational decision making that have had their foundation in Professor Holland's framework for the study of adaptive systems. This work has turned up some interesting connections to problems in mathematical programming and economic theory. He has been collaborating in this work with Professors Holland, Burks, and Axelrod, and with Professor William Hamilton (Division of Biological Sciences) and Rick Riolo (Computing Center).

Professor Michael Gordon is applying Professor Holland's adaptive algorithm to problems of information retrieval The algorithm is used to modify document descriptions adaptively so that clusters of similarly described and similarly used documents can be generated automatically, thus improving efficiency when a bibliographic database is searched.

Clustering traditionally involves discerning similar document features (same keywords, same author, etc) This research is an attempt to show that documents that are frequently relevant to similar queries can be usefully clustered without analysis of the documents' features. Clustering without analyzing document features can be achieved as a byproduct of redescribing (re-indexing) documents until they "match better" the queries they should Holland's probabilistic adaptive algorithm governs this redescription, and simulation studies show the redescription is effective. Modifications to the simulation are being made at present to investigate the effectiveness of clustering that results from document redescription

Stephanie Forrest is addressing questions of efficient organization and access of knowledge representations. Currently, expert systems and other applications that depend upon large stores of knowledge work adequately in areas where the problems can be solved off line. However, many potential applications, such as natural language processing, robotics, and intelligent computing environments require fast, frequent access to dynamic knowledge bases; such applications will need to deal with questions of efficiency in order to be viable

Forrest's research is a study of methods of using parallelism in knowledge representation (both data structures and algorithms that manipulate the structures). A central problem is that of classifying new information appropriately, that is, in relation to the potentially very large body of information already in the knowledge base A massively parallel system has been used to implement a set of parallel operations for the classification of knowledge in semantic networks. A subset of KL-ONE has been implemented using Holland's Classifier System. Given the KL-ONE description of a particular semantic network, the system produces a set of production rules (classifiers) that represent the network; given the description of a new term, the system can classify the new term in the existing network. Since the classifier system can be implemented in parallel hardware (though it has not been to date), the classification problem can be dealt with efficiently because of the inherent increase in efficiency provided by parallelism.

Knowledge-Oriented Learning

Professor Paul Scott is experimenting with a learning system that attempts to construct a useful representation of its environment without any knowledge of the tasks for which that representation will ultimately be used. He terms this mode of learning "knowledge-oriented learning" and contrasts it to "task-oriented learning," in which a system improves its performance or acquires a representation through attempting to carry out some or all of the task it is ultimately intended to perform. The two modes are regarded as complementary rather than mutually exclusive alternatives.

The main advantage of task-oriented learning is that feedback regarding the degree and nature of failures to perform the task correctly can be used to constrain the search for a representation that is both correct and relevant to the task. However, it can only be used in those circumstances in which the system already has two kinds of knowledge: knowledge about the kind of task it will ultimately perform and sufficient knowledge of its environment to allow it to attempt the task.

Knowledge-oriented learning could be used when neither of these conditions is satisfied. In so far as it is successful in building a useful representation of its environment, it could be used to provide the basic knowledge upon which subsequent task-oriented learning could build. The relationship between the two modes of learning is analogous to the relationship between pure science and engineering: pure science attempts to discover how the world behaves without any practical motivation, while engineering, working within a knowledge framework established by pure science, attempts to find ways of making aspects of the world behave in a useful way.

The fundamental problem to be solved in the construction of a knowledge-oriented learning system is how to ensure that the representation it builds is indeed useful. Pursuing the analogy with pure science suggests a solution. Science can be viewed as a collective endeavor in which the basic goal is to construct a model of the world that is correct, complete, and consistent. An incorrect model would lead to erroneous predictions; an incomplete model could be confronted by situations whose outcome it could not predict; and an inconsistent model could generate two mutually exclusive predictions about the same situation. Hence, inadequacies in such a model are always manifest as prediction failures.

The program under development, DIDO, makes use of this notion to direct her search for a good representation of her environment. DIDO interacts with her world by performing experiments, that is, by applying operations to the entities she encounters and observing the results. Her basic goal is to build a representation in which she can reliably predict the outcome of any experiment she may perform.

A version of DIDO in which the behavior of objects depends only on their properties has been extensively tested. Current work is concerned with worlds in which the outcome of applying an operation to an object depends not only on that object's properties but also upon the relations that hold between that object and other objects in the world, and upon their properties. Shaul Markovitch has been working with Professor Scott on this project.

Knowledge Structures

Professor Manfred Kochen is attempting to explicate concepts of representation, order, and disorder in local and global knowledge structures, and is studying the relation of these concepts to mental preparedness, control of attention, and discovery. The primary research vehicle is a search for an organization of knowledge about geometry most likely to lead to a discovery of the Pythagorean Theorem. Also, a system for matching discoverers with other discoverers who are most likely to react constructively is being developed. A study of meta-knowledge and the amount of information that must be specified to effect retrieval has led to interesting mathematical results.

These studies are being approached by theoretical analysis, by the development of computational models, and by empirical psychological studies. With Robert Lindsay, Professor Kochen is developing a characterization of knowledge structures that underlie inference and discovery procedures. With David West, he is developing a PROLOG program that attempts to find, organize, and prove lemmas in plane geometry. With Gloria Mark, he has conducted an experimental study done to investigate how an expert cardiologist represents the motion of the normal and the abnormal heart as observed on an echo cardiogram.

Work is also being directed toward defining a metric in knowledge space using topics from an elementary geometry text and applying Q-analysis. In a related effort, citation data on historical pathways to discovery are being traced, using a discovery in pharmacology as a vehicle to try methods for tracing intellectual influences.

In collaboration with Michael Gordon, Richard Belew, and Robert Lindsay, experimentation with a computer-based conference system is being conducted to develop new computational tools for communication among problem solvers. The goal is to provide techniques to assist the collaborators in organizing and disseminating intellectual products.

James Levenick, working with Professor Stephen Kaplan of the Psychology Department, is studying knowledge networks that span a range from Quillian's marker-passing semantic networks to Professor Kaplan's cognitive map model (based on Hebb's cell assembly model) which passes activity. This work explores the role of such networks in intelligent, adaptive behavior. To facilitate an analysis of these representation issues, Levenick has parameterized knowledge networks in terms of types of nodes, types of links, information passed, and control mechanisms.

A network activity passing simulation (NAPS) was developed to investigate the effects of the various parameters on performance. A wayfinding task (specifically, find a location on a route between two given places in a familiar environment) was selected as a simplified case of generic problem solving. A common problem-solving method is to search for subgoals between a perceived state and a desired state. A similar strategy is applicable to wayfinding. NAPS constructs the sort of network specified by a set of parameters using a series of route descriptions together with a simple contiguity learning rule and tests the performance of that network on wayfinding tasks. Then, given a start and goal location, NAPS propagates activity in the net to select a subgoal.

Experiments were performed in several environments to compare networks in terms of speed, reliability, flexibility, and robustness. The results have shown that marker-passing semantic networks are more reliable than activity-passing cognitive maps in simple environments, but are less reliable in complex environments. The cognitive maps are able to handle unexpected environmental vagaries better than the semantic networks do.

Generalized Problem Solving in a Parallel Environment

Professor Keki Irani is developing a generalized model for problem solving based on the first-order predicate calculus. This system enables simplification of the production system rules and the automatic generation of heuristics for the problem to which the production system is directed. As a related topic, parallel processing of production systems in multiprocessor machines is also being examined.

The search algorithm A* is conducted using a heuristic, defined to be the estimated distance from an intermediate state of the problem to the goal state of the problem. If the heuristic satisfies certain conditions, called the admissibility and monotonicity conditions, the optimal solution to the problem is guaranteed by A*.

For the development of the general technique to compute the heuristic of A*, one mathematical model representing a general problem has been formulated, and the algorithm to compute the heuristic is developed on the relaxed version of this problem model. The complexity for computing the heuristic by the general technique and the precision of the computed heuristic are also examined. This work is being done in collaboration with Suk I Yoo

Another related work, which is being looked into by Yi-fong Shih, deals with the parallel execution of production systems. A methodology, called the connectivity graph, for fast rule selection in production systems has been developed. A connectivity graph is a Petri Net with singular input and output edges between a transition and a place. In this graph a transition is uniquely labeled with a rule, the edges correspond to antecedent and consequent literals in the rules, and tokens carry instantiation values for literals as they flow through the graph. Flowing tokens through the graph therefore represents rule selection. By applying the firing principles of a Petri Net, a program can easily determine which rules apply at any given instant

The connectivity graph will eventually be employed as part of an overall approach to the parallel execution of production systems—more specifically, production systems that are based on the syntax of the logic programming language PROLOG. Currently under study is the efficiency speedup and solution optimality of the A* algorithm running on multiple processor machines. An E* algorithm, which is the parallel version of A*, has been developed and proven to be capable of providing optimal solutions. It has been shown that when the admissibility condition is satisfied, E* will always guarantee optimal solution even when the tree nodes are queued locally in each processor. Theoretical calculations have shown that E* is extremely well suited for very large search trees with many solutions.

Professor Irani is also working with Dong G. Shin on the application of many-sorted language-to-knowledge representation. Ordinary many-sorted language offers a compact way of expressing knowledge by predetermined range restriction of quantified variables. However, the usage of a quantified variable is inflexible in the sense that the variable cannot be introduced unless its range of interpretation agrees with a sort domain. This difficulty is overcome in this work by introducing syntactic objects called aggregate variables. The extended language has been applied to the design of a distributed database and to the resolution principle for many-sorted theories.

Also working with Professor Irani is Carol A. Luckhardt, who is applying mathematical game theory to several AI problems that arise in the context of many-person games. The research addresses such questions as how searches, evaluation functions, and strategy development are complicated when more than two players are involved.

Mathematical AI: Representation and Search

Professor Bernard Nudel is working on the design and analysis of algorithms for a variety of search problems and on the associated task of finding good problem representations. The problems of interest include game-playing, state-space search, constraint-satisfaction, and theorem proving.

Complexity analyses of algorithms usually provide worst-case, best-case, or expected-case complexity values over a class of problem instances. But exact-case complexities, giving the complexity of individual instances, are almost always intractable. However, a general framework has been developed for the derivation of good approximations to exact-case results based on worst-, best-, and expected-case analyses.

Expected-case analyses have been carried out for solving constraint satisfaction (consistent labeling) problems using the backtrack algorithm and the forward-checking algorithm. A new parameter called constraint satisfiability has been incorporated into these analyses. This parameter indicates the degree of "looseness" of a constraint, and its use allows the derived analytic results to approximate remarkably well the exact case complexity of individual instances. The results have been used to provide heuristics for choosing an algorithm, a problem-representation, and a search strategy on an instance-by-instance basis. This permits such decisions to be tailored to the instance being solved rather than basing them on an artificial class of instances and (for expected-case analyses) an unrealistic probability distribution assumed to hold over all instances.

This approach to obtaining exact-case complexities and deriving instance-specific heuristics is being applied to resolution-based theorem proving.

Expert Systems for Psychiatry

Professors Robert Lindsay and Michael Feinberg are developing a rule-based expert system for the diagnosis of depression. The program incorporates some of the expertise of a psychiatrist skilled in the diagnosis and treatment of endogenous depression, an illness treatable by antidepressant drugs. The goal is the development of a program that will assist general nonpsychiatrist physicians, since they currently prescribe for and treat more depressed patients than do psychiatrists, yet they lack much of the specific expertise that could profitably be brought to bear. In addition, the program hopefully will be useful to nonphysicians in health-care clinics in the initial screening of patients and in suicide prevention.

An interactive consultant for the application of the Hamilton Rating Scale, a standard tool for measuring the severity of depression, has been developed and will be used as a training device for residents in psychiatry. Patient interviews are now being studied in detail, and a rule set of diagnostic knowledge is being formulated.

Research of Fluid Analogies

Professor Douglas Hofstadter has two main ongoing AI projects: Copycat and Letter Spirit. Both share the belief that fluid humanlike thought should be an emergent property of a system composed of many independent processes running in parallel, influencing each other by creating and destroying temporary structures and by raising and lowering the activation levels of various permanent concepts stored in an associative network. The process envisioned relies on statistics to bring coherent and focused behavior out of a seething broth of parallel actions. The research goal is summarized in the slogan "statistically emergent mentality." A guiding metaphor for this vision is the way in which a living cell's coherent global activity is created by the joint actions of millions of independently acting enzymes. "Fluid humanlike thought" is taken to mean principally analogical thought, or the transfer of essence between frameworks.

A crucial feature of both projects is the idea that there is a wealth of insight to be gained from exploring models of cognition in tiny, carefully honed domains. Since the system architecture for both projects is basically similar, it is the two domains that define the two different projects. Both involve the 26 letters of the alphabet, but in very different ways.

The Copycat project is well represented by two sample analogy problems:

(1) If *abc* goes to *abd*, what does *pqrs* go to?

(2) If *abc* goes to *abd*, what does *xyz* go to?

The standard answer to (1) is *pqrt*. That is, it is most people's first thought, and it "feels right," despite arguments that can be given for, say, *pqrd*, *pqss*, *pqst*, *pqrs*, *abd*, and a host of other less plausible answers. The human intuition involves a preference for perceiving the change in (1) as "rightmost element is replaced by its successor" over such visions as "rightmost element changes to *d*," or "third element is replaced by its successor." Professor Hofstadter is interested in developing mechanisms that simulate these types of unconscious, intuitive perceptual preferences that people share.

Example (2) is a little trickier. If your model of the alphabet is circular, you will lean toward *xya*. However, if you are restricted to using a noncircular alphabet, most people find, after some rumination, that *wyz* (justified through symmetry) is their preferred answer. This involves slippage": namely, the initial vision of the *abc* $\longrightarrow$ *abd* change ("rightmost letter is replaced by its successor") has, in the process of "translation" into the *xyz* framework, slipped into a variant of itself ("leftmost letter is replaced by its predecessor"). This happens only under pressure, namely the pressure created by trying to do something impossible—taking the successor of *z*. Developing a theory of how one pressure or, more generally, multiple interacting pressures can trigger creative slippage of this sort is the most important goal of the Copycat project.

The Letter Spirit project is a project in semantic or high-level vision. The idea is to design the 26 lowercase letters in the same style, under the inspiration of one or more sample letters representing that style Put another way, the goal is to imbue all 26 letters with a uniform spirit. The deep question is, "What is a visual spirit?"

One's first image of elegant letterforms involves graceful curves and cusps, long strokes and chiseled tips, usually with lines of varying width. However, this turns out to be far from the crux of style. There is an underlying skeletal letterform that contains the basic information about the location of tips, junctions, straight lines, curves, and so on, that does not involve specification of the details of those features. The fleshing-out of such a skeleton is a generative analogue to "low-level" vision, whereas the devising of the skeleton itself is the most creative, "high-level" act. In seeking to make the Letter Spirit domain not only more tractable but also more informative, all but the most essential facts about letterforms have been eliminated, leaving letters composed of short strokes on a square lattice, call the grid. The skeletal typefaces created on the grid are called gridfonts; the grid and a few sample gridfonts are show in the accompanying figures.

What is under study is not so much the nature of letterforms or the design process as much as the question of how "essence" can survive transplantation from one framework to another. In this case, the essence in question is the uniform visual quality that runs through all 26 letters and makes us feel their kinship in some nonverbal way. In the Copycat example above, the transplanted essence was what allowed the "same change" to take place in three different frameworks. In Letter Spirit, analogies of the same sort are taking place. If one is trying to make a y inspired by a given h, one is in effect asking the question "What is to y-ness as the given h is to h-ness?," or "What is to Platonic y as the given h is to Platonic h?"

A Platonic h is not construed as a geometric concept, composed of angles and lines, but an abstraction composed of roles, such as "crossbar," "post," "bowl," and so forth, that can be instantiated in thousands of ways. The co-presence of roles with sufficient mutual support constitutes evidence for the presence of a given letter. For style, what matters particularly is how roles are filled, and how roles support each other. Characterizing these high abstractions in "transplantable" terms, so that an h can indeed inspire a y, is a task closely related to the analogies in the Copycat domain.

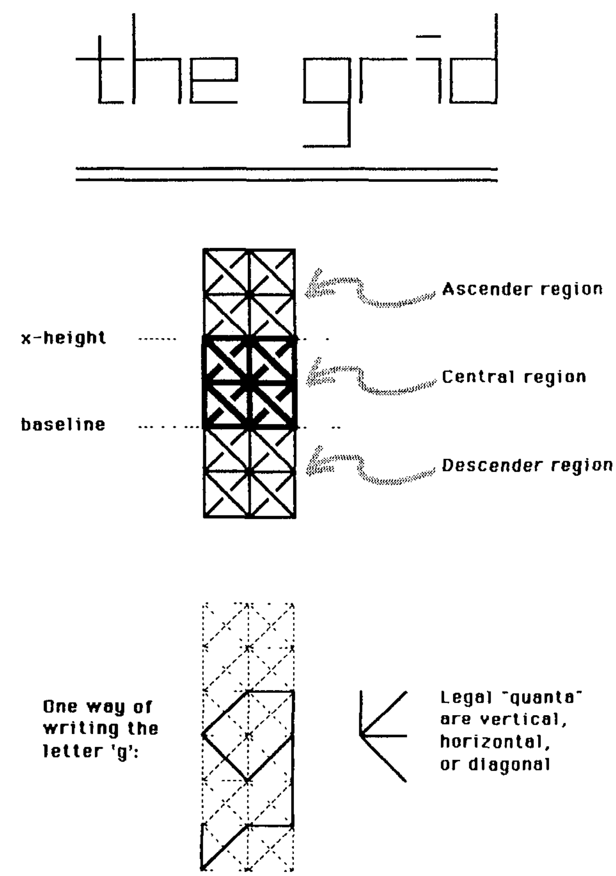

Figure 1.

Mental Models and Comprehension of Text

Within the context of a varied research effort, Professor David Kieras is engaged in two AI-related projects. One is the development of a system to critique technical prose, and the second is a study of the role played by mental models in the understanding of a device from descriptions. It is widely agreed that technical documents for equipment are poorly written and hard to comprehend. This has been a long-standing problem because the information-processing demands of editing and revision are so high that many comprehensibility problems go undetected. However, many of these problems can be detected by computerized systems that scan a document and point out where the writing can be improved. A program has been developed that emulates a poor reader, and the difficulties it encounters in reading a technical document pinpoint trouble spots that alert the author and allow him to make alterations. The program is organized around an augmented transition network grammar and a production system interpreter. The current system is based upon about a dozen comprehensibility rules derived from the psycholinguistic literature, involving such decisions as selection of appropriate voice, proper use of pronouns, selection of determiners and connective words, and appropriate occasions for change of topic.

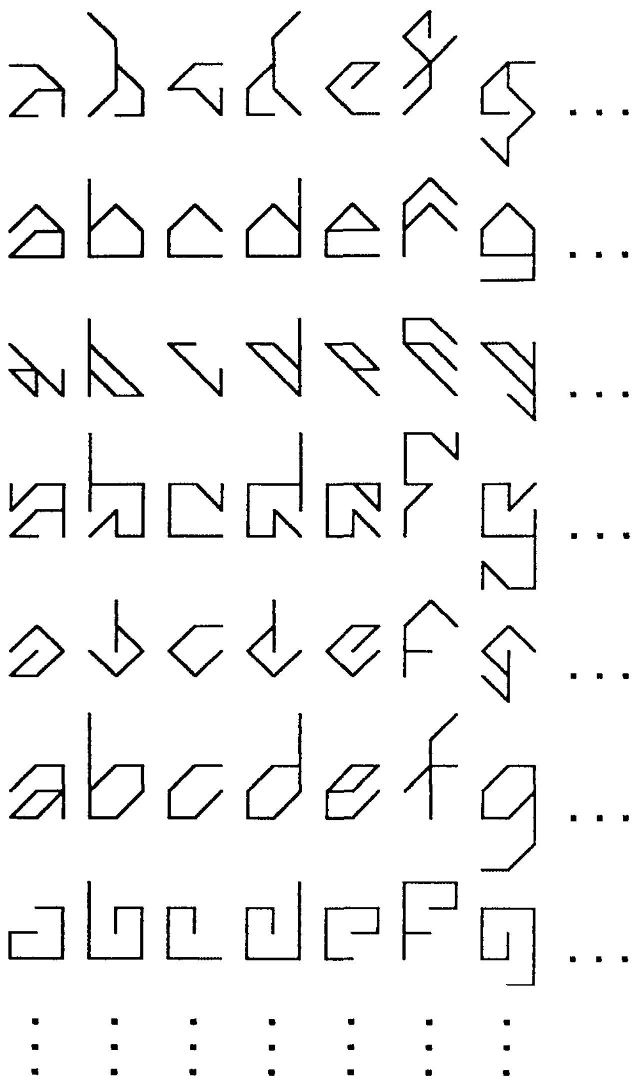

Figure 2.

Knowledge of the internal structure of a simple device has been shown to aid in learning to operate the device. Professor Kieras has performed experiments showing that a model of system topology is an important component of a mental model because it supports the inference of the procedures required to operate the device. A simulation model based on this principle was developed The model makes predictions about the latencies between individual control actions, based on the amount of inferential processing required at each step.

Scientific Theory Formation

Paul Thagard, a research associate in the Department of Psychology and an Associate Professor of Philosophy at the University's Dearborn campus, has written a program that models processes of scientific problem-solving and discovery. This program, called PI, is based on ideas developed with Professors Keith Holyoak, John Holland, and Richard Nisbett. To represent knowledge about physical phenomena, it uses production rules organized into frame-like concepts. Problem solving is performed by spreading activation of concepts and firing of rules. In the course of problem-solving, various kinds of induction are triggered, including instance-based generalization (e.g from instances of black crows to the rule that all crows are black), condition-based generalization (*e.g.,* from the rules that American crows are black and English crows are black to the rule that all crows are black), and abduction (*e.g.,* to the conclusion that some unidentified object is a crow because that hypothesis explains its observed features). New concepts are formed by conceptual combination, which builds a set of rules for a combined concept out of rules for the old. New concepts like "striped apple" and "feminist bankteller" are not simple linear combinations of their components, but require special principles to reconcile conflicting expectations. These kinds of induction suffice to simulate the discovery of the wave theory of sound, as it appears to have been achieved by the Roman architect Vitruvius. The concept of a sound wave, a non-observable entity, is created by conceptual combination. Current work with Keith Holyoak is now addressing extensions to analogical and other forms of reasoning.

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