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Mr. Robert W. Taylor
Director for Information Processing Techniques
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Subject: Activities of the Stanford Artificial Intelligence Project

Dear Bob:

This letter attempts to summarize the current status and recent accomplishments of the Stanford Artificial Intelligence Project.

Personnel

There are 56 persons currently associated with the Project. Thirty-eight of these are at least part-time salaried; the rest are unsalaried students and other separately supported staff members who have been attracted to our activities. A significant factor in attracting outside interest has been our developing computer laboratory.

Facilities

Since last fall, the Project has been housed in the D. C. Power Laboratory, which is scenically located in the foothills about 15 minutes by car from the Stanford campus. Office and laboratory space totals about 10,000 square feet, which is currently adequate. The distance between the Project facilities and the campus continues to act as a barrier to efficient interaction with the Computer Science Department and others. It is particularly difficult for students to interleave classwork and Project work.

The PDP-6 computer has operated exclusively as a time-sharing facility since it was installed last summer. The current and planned configurations are shown in Figure 1. The existing system (drawn with solid lines) has no swapping store and so can support no more than about four users concurrently. Available programming languages include MACRO 6 (assembler), FORTRAN IV, and LISP 1.5.

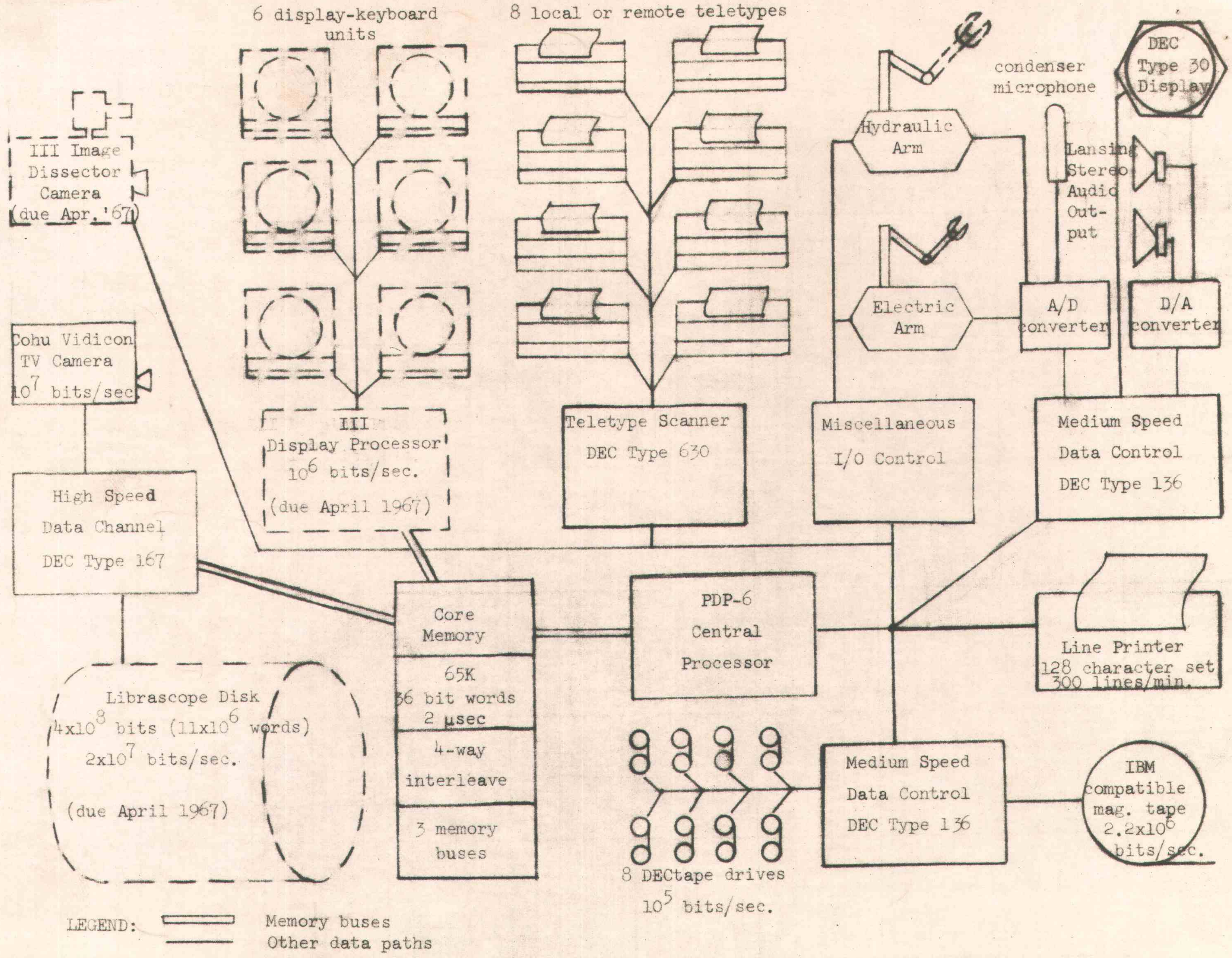

Figure 1. Stanford A. I. Computer System

The PDP-6 hardware has been very reliable with the exception of the line printer, which has been down for as long as 12 days at a time. System availability neglecting the line printer, has been 97 percent. At present, time-sharing system software failures appear to be about twice as frequent as hardware failures.

Delivery of the balance of the system (shown in dotted lines in Figure 1) is expected within the next two months. The complete system is expected to support 14 active users, 6 of them on displays and 8 using local or remote teletypes.

Activities

Recent work in our technical program is summarized below. The main participants are listed parenthetically.

ADVICE TAKER - (McCarthy, Ito, Sandewall)

Work continues on formalizing situations, actions, and causal laws. Ito has developed a formalism for describing the process of moving objects around and Sandewall has worked on means - end analysis.

ARM DEVELOPMENT - (Roth, Kahn, Pieper)

The mechanical engineering group has assembled the upper part of a prototype hydraulic arm, intended for use by the Hand-Eye Activity (see below). The arm has demonstrated considerable strength and speed of movement, together with an unfortunate tendency toward self-destruction.

Hardware development on the pneumatic Ørm (also called the Snakomorphic Arm) has paused pending a solution to the computational problem of how to position its component discs in order to reach a desired point.

CHECKERS - (Samuel)

Samuel has completed a new version of his checker playing program, incorporating "signature table learning" (Reference 1). The program is expected to exhibit substantially improved performance. A series of games with the West Coast Checkers Champion is scheduled this week (February 12).

CHESS - (McCarthy, Samuel, Weiher, Farrell, Huberman, Poole)

Last years telegraphic chess match between a Stanford program (running on an IBM 7090) and one at Carnegie Tech (on a Bendix G-21) ended when Carnegie resigned. A more recent match between the Stanford program and one at the Institute for Theoretical and Experimental Physics (using an M-20 computer) is still in progress. Figure 2 lists the moves to date. Games 1 and 2 appear about even; in Game 3 the Russians should obtain a mate in two moves; in Game 4 they are well ahead.

Figure 2

COMPUTER CHESS MATCH WITH RUSSIANS

Game 1.

	U.S.S.R. White	Stanford Black
1.	P-K4	P-K4
2.	N-QB3	N-QB3
3.	N-B3	B-B4
4.	B-B4	N-B3
5.	O-O	O-O
6.	P-Q3	P-Q3
7.	B-K3	QB-N5
8.	P-KR3	B-R4
9.	B-Q5	B-Q5
10.	P-KN4	BxN
11.	QNPxB	B-N3
12.	B-KN5	R-K1
13.	R-N1	R-N1
14.	Q-K2	K-R1
15.	P-Q4	K-N1

Game 2.

	Stanford White	U.S.S.R. Black
1.	P-K4	N-KB3
2.	P-K5	N-Q4
3.	N-KB3	P-K3
4.	B-N5	P-QR3
5.	B-R4	P-QN4
6.	B-N3	B-N5
7.	N-B3	N-B5
8.	O-O	B-N2
9.	P-Q4	KBxN
10.	PxB	N-Q4
11.	BxN	BxB
12.	B-QR3	P-Q3
13.	PxP	PxP
14.	R-K1	N-B3
15.	R-K3	O-O
16.	Q-K2	B-B5
17.	Q-K1	

Game 3.

	U.S.S.R. White	Stanford Black
1.	P-K4	P-K4
2.	N-KB3	N-QB3
3.	N-B3	B-B4
4.	NxP	NxN
5.	P-Q4	B-Q3
6.	PxN	BxP
7.	P-B4	BxN
8.	PxB	N-B3
9.	P-K5	N-K5
10.	Q-Q3	N-B4
11.	Q-Q5	N-K3
12.	P-B5	N-N4 ?
13.	P-KR4	P-KB3
14.	PxN	PxNP
15.	RxP	R-B1
16.	RxP	P-B3
17.	Q-Q6	RxP

Game 4.

	Stanford White	U.S.S.R. Black
1.	P-K4	N-KB3
2.	P-K5	N-Q4
3.	N-KB3	N-N5
4.	B-N5	P-QB3
5.	B-R4	P-Q3
6.	P-Q4	Q-R4
7.	P-QB4 ?	N-B7 dbl. chk.
8.	K-B1	NxR
9.	N-B3	Q-N5
10.	Q-K2	PxP
11.	PxP	B-K3
12.	Q-Q1 ?	BxP ch
13.	N-K2 ?	P-QN4
14.	B-B2	NxB
15.	QxN	BxP
16.	N(2)-Q4 ?	Q-B5 ch
17.	K-N1	P-QB4
18.	Q-Q2	

A new chess program for the PDP-6 is being written. The legal move update routine is about six times as fast as on the IBM 7090. Some move generators have been checked out and the program has made its first move.

It is worthwhile to recount at this point the reasons for programming computers to play chess. Each such program is based on certain ideas of the mental process involved in solving problems in general and playing chess in particular. Weaknesses in the performance of the program tell us about human mental processes we failed to identify in our original program. Our new program is based on experience with the old one and also on understanding the ideas behind the Russian program.

Huberman is finishing a program for playing a number of chess end games R and K vs. K, 2B and K vs. K, B and N and K vs. K. The first two of these work. Already a number of new heuristics that have to be included for effective play have been discovered.

EXPENSIVE DRAFTING TABLE - (McCarthy, Quam)

A LISP program has been written to facilitate the generation of mechanical drawings using a display and a teletype but no light pen. The program uses a simple control language to draw lines, label points, intersect lines, etc. The control language is sufficiently simple that an inexperienced user can draw objects as quickly using the program as he could at a drafting table, with the added convenience of being able to recover from mistakes more easily.

A macro drafting program is being implemented which will allow the user to define commonly drawn objects as macros and call on these when necessary to eliminate the necessity to draw the same object many times. With such a macro capability, the program should allow drawings to be produced several times faster than with a conventional drafting machine and by less skilled personnel.

HAND-EYE - (McCarthy, Earnest, Reddy, Samuel, Feldman, Grayson, Hueckel, Pingle, Quam, Singer, Sobel, Wichman)

The immediate goal of the Hand-Eye Activity continues to be the performance of simple manipulative tasks, such as block stacking. Programs for perception and manipulation of simple objects have progressed to the point where they will be joined shortly.

Several approaches to the perception problem are being pursued concurrently. All have as their immediate goal the production of an edge list, which describes the boundaries between contrasting portions of the image. The input to these processes has been a standard monochrome TV signal from a vidicon camera. Work is just beginning on color inputs, using selectable filters.

Programming of the transformation from an image edge list to a 3-D model of the scene is just beginning. As an aid to this development, the inverse process (3-D object list to image edge list) has been programmed for convex polyhedra.

An electric arm designed for prosthetic applications was purchased last fall and has been modified to operate under computer control (see Figure 3). An explicit solution to the arm positioning problem has been devised and the manipulation of objects in known locations has been demonstrated. Work has begun on the problem of avoiding unwanted collisions between parts of the arm and other objects.

The main task just ahead is to make the segments of the initial hand-eye system work together.

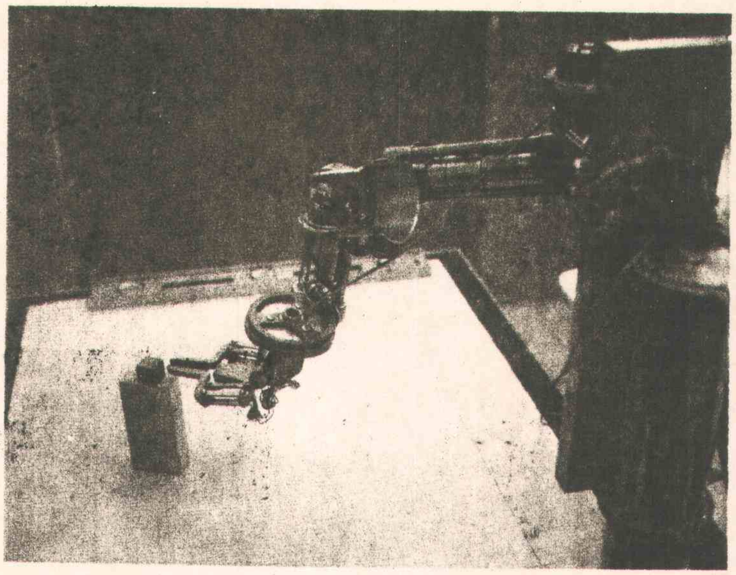

Figure 3 Electric Arm

HYPOTHESIS FORMATION - ORGANIC CHEMISTRY - (Feigenbaum, Lederberg, Buchanan, Sutherland)

The following goals are being pursued in the Chemistry Activity.

1. From the artificial intelligence point of view, to study processes of empirical inquiry: the formation of an hypothesis or set of hypotheses adequate to explain a given set of data.

2. To conduct this study in the context of a particular scientific task environment. One very useful one is organic chemistry since its basis--chemical structures represented as graphs-- is relatively highly formal and systematizable.

3. To study the means of exploiting the man-machine interface so as to make programs more intelligent, i.e., by instruction from a knowledgeable and patient chemist concerning certain relevant chemical information and useful decision rules and procedures.

4. To demonstrate that using the techniques of heuristic programming an interesting and useful "tool" for science could be constructed in a relatively short time.

In pursuit of these goals a large program has been written. Its overall name is DENDRAL. It was developed using the LISP 1.5 system on the SDC Q-32 time-sharing system, and was recently converted over to the LISP system on the PDP-6 at Stanford. The main functions that DENDRAL can perform are as follows.

1. Given a particular mass spectrum (output of a mass spectrometer), produce a list of the (chemically) most plausible organic structures that might serve as explanations for the spectral data. That is, produce as hypotheses explaining the spectral data a list of the most plausible chemical graphs. The graphs are printed out in a linear notation called DENDRAL.

2. Given a chemical composition (formula), produce a list of the chemically most plausible isomers of that composition.

3. Given a chemical structure in DENDRAL notation, predict its mass spectrum. There are three versions of this subprogram, successive versions having higher predictive power.

The system rests on a chemical graph manipulating algorithm called "pure DENDRAL" developed by Professor Lederberg. It is capable of generating exhaustively the space of all possible structure-graphs that can be built for a particular chemical composition. A variety of heuristic rules are used to prune this space in selecting a relatively small set of "most plausible" structures. In essence these rules constitute DENDRAL's "model" of chemistry. These rules are entered into the program either (as is usual for heuristic programs) at program-writing time or at the time of interaction with a chemist at a typewriter console.

A recent effort of this chemistry project is an attempt to model reasoning processes involved in chemical synthesis problems. Two different approaches are being taken. One involves the synthesis of a specific product from a specific input substance. The other involves the synthesis of a specific product from any one of a long list of relatively cheap, commonly available substances. This project, by two graduate students, is in its early stages.

An extensive and detailed description of the working of the DENDRAL program, as now implemented, is in publication (Reference 2). Buchanan's dissertation is also available (Reference 3).

HOLOGRAM TRANSFORMATION - (Goodman, Lawrence)

A group in the Stanford Laser Lab has devised a technique that should permit the observation of satellites and other space objects without the effects of atmospheric distortion and telescope "jiggle". A laser is used to illuminate the object and a hologram is made, from which an image of the space object can be reconstructed (References 4, 5, and 6). The system takes advantage of the "vellum effect", a phenomenon observed in photographs of earth taken from heights well above the atmosphere. Such photos are far more detailed than aerial photos taken at much closer range by airplanes flying through the earth's atmosphere.

In testing the technique, it is convenient to use a computer to carry out the transformation from hologram to image. It was fortuitous that the Artificial Intelligence Project had a suitable computer with an on-line television camera. The camera is being used to read the hologram as a matrix of gray-scale values. The transformation calculations, still being programmed, are based on the Cooley-Tukey Algorithm.

MACHINE LEARNING - (Feigenbaum, Callero, Persson, Waterman)

S. Persson, under the research supervision of E. A. Feigenbaum and C. W. Churchman (the latter of U. C., Berkeley), has produced a dissertation on sequence extrapolation as an induction problem (Reference 7). The task environment chosen is a rather common induction problem: the extrapolation of letter and number sequences. As with the DENDRAL chemistry project, this study was concerned with hypothesis formation, model building by programs, induction, and inquiry. Persson designed and wrote the most complex sequence extrapolating program yet known. Among other things, it is capable of choosing between a number of alternate models in choosing a good explanatory rule.

Callero is working on machine learning in a military environment. The goal of this project is to determine the feasibility of using machine learning to establish decision procedures for complex military command and control problems. The approach taken has been to model a missile defense system based on reasonable expectations of future system configuration, describe general defense strategy for the allocation of defense missiles in the form of a decision function consisting of critical features of the defense environment, simulate ICBM attacks against the system and modify the decision function by heuristic learning techniques based on defense effectiveness and consistency. Initiated in July, 1966, the defense system model and attack simulating programs are operational (programmed in Extended ALGOL for the B5500) and a variety of learning techniques, decision features and defense missile allocation heuristics have been investigated. Preliminary results show that the decision function approach yields better overall defense performance than direct heuristic tactics and that decision making is improved through machine learning. Continuing effort will be devoted to seeking learning techniques which are effective in the post attack as well as the preattack environment and to generalizing the results to similar military problems.

Waterman is working on a program that will manipulate its own heuristic rules: this is an effort to recast an already-existing heuristic program for playing a particular game into a form in which all of its rules, definitional and heuristic, are stated as "situation-action" productions (a la Newell). Once constructed, the rules are then available for a variety of manipulations. In particular, there is great interest in the learning of new heuristic rules in the situation-action form. The game program has been recast in S-A form, and work is proceeding on the heuristic learning. There has been a recent flurry of activity on the EPAM (Elementary Perceiver and Memorizer) model of Feigenbaum and Simon. Presently four students are attempting: a) to make operative in LISP on the PDP-6 the version of EPAM coded by Daniel Bobrow at Project MAC, and b) to extend EPAM to incorporate some new ideas concerning information storage and retrieval in human long-term associative memory. The ideas are due to Feigenbaum and go under the label of "EPAM IV". A paper sketching these ideas is available, (Reference 8). Two other papers by Feigenbaum are in press (Reference 9 and 10).

A Stanford version of the Newell-Shaw-Simon General Problem Solver is being written in LISP for the PDP-6.

MATHEMATICAL THEORY OF COMPUTATION - (McCarthy, Painter, Kaplan, Ito)

Painter is finishing a thesis proving a compiler correct. Kaplan has proved a complete set of axioms for assignment statements (Reference 11). Ito has developed an axiom system for regular algorithms.

MUSIC - (Chowning, Swinehart, Mendlowitz, Poole)

Chowning and his students are working on computer-generated stereophonic sounds that can be moved in two and three dimensions with respect to the listener. Left-right position is controlled by relative intensity of the two channels, while the perceived depth is to be controlled through artificial reverberation. Movement in three dimensions will require four or more sound channels in appropriate directions from the listener (Reference 12).

Swinehart is working on a music recognition program. His aim is to produce a musical scale directly from an acoustic signal. The current experimental source is an on-line (loud) trumpet.

PERCEPTION - (Reddy, Kelly, Perine, Petit, Pollack, Wheeldrayer)

As a class project, four students under Reddy are working on recognizing people from photographs of various parts of the body. One is working with fingerprints alone, another with a picture of the whole hand, another with faces and one with a head-to-toe picture. It is not clear how successful these projects will be in the short term, but relative progress on the alternative approaches should be interesting.

Petit is attempting to develop a multi-font character reading system adequate to read a Russian-English dictionary, including both Latin and Cyrillic characters. He is using a vidicon TV camera for scanning the page and will use a close-up lens with computer controlled pan and tilt to obtain adequate resolution and coverage.

PARTICLE PHYSICS - (Hearn, Campbell, Swinehart)

This project is concerned with the automation of a large number of algebraic calculations which occur in the theory of elementary particle physics. These calculations include the generation and manipulation of graphs used to represent particle processes, and the computation of the corresponding physically measurable cross-sections. The latter calculations involve the manipulation of complicated algebraic expressions containing both tensor and non-commutative matrix quantities. Many of these calculations take several months to complete by hand, although the operations involved follow straightforward rules.

The work in this project is concentrated in three main areas:

(i) Graph generation and representation, including recognition of topological equivalences.

(ii) Recognition of the restricted class of integrals which occur in these calculations.

(iii) Representation and manipulation of the algebraic expressions occurring in the theory.

Several papers have been published (Reference 13-17).

SPEECH RECOGNITION - (Reddy, Vincens, Lesser, Levy)

Reddy is publishing the pitch determination procedures used in his Ph.D. thesis (Reference 18) and a revised phoneme grouping (Reference 19).

The latter paper proposes a new non-mutually-exclusive grouping for computer speech recognition; results obtained using the new grouping are given.

Reddy is rewriting for the PDP-6 his PDP-1-7090 programs for phoneme transcription from continuous speech. He plans to introduce learning into the program at several stages. He is supervising several related student projects including limited vocabulary speech recognition, a phoneme string to word string transcription program, a syllable junction program, and telephone speech recognition.

CONCLUSION

The research activities of the Stanford Artificial Intelligence Project have broadened in scope substantially during the past year. This has been made possible primarily through ARPA support of our computer laboratory development.

Very truly yours,

Lester D. Earnest

Lester D. Earnest
Executive Officer
Artificial Intelligence Project

cc: Dr. L. Roberts, ARPA
Prof. Feigenbaum
Prof. McCarthy
Prof. Herriot
Dr. Samuel
Dean Hefner

Attachment

LDE/ja

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