XVIII. COGNITIVE INFORMATION PROCESSING

Academic and Research Staff

Prof. M. Eden
Prof. J. Allen
Prof. B. A. Blesser
Prof. F. F. Lee
Prof. S. J. Mason
Prof. W. F. Schreiber
Prof. D. E. Troxel
Prof. I. T. Young
Dr. J. E. Bowie
Dr. C. C. Jaffe
Dr. Mary J. Naus
Dr. D. M. Ozonoff
Dr. Stephanie E. Sher
F. X. Carroll
Jeffrey A. Hagerich
M. Sharon Hunnicutt
E. R. Jensen
P. L. Miller
R. A. Piankian
K. P. Wacks

Graduate Students

W. R. Bogan
B. E. Boyle
Becky J. Clark
M. A. Cohen
C. H. Cox
C. J. Drake
J. R. Ellis, Jr.
I. S. Englander
A. M. Fakhr
S. G. Finn
H. S. Forsdick
T. Fukuda
D. B. Harris
M. E. Jernigan
C. K. S. Kau
J. W. Klovstad
T. T. Kuklinski
S-P. Kuo
D. S. Levinstone
C. W. Lynn
L. C. Makowski
D. V. Marsicano
K. A. Okin
B. Minkow
D. O'Shaughnessy
J. E. Ostrowski
R. S. Putnam
R. J. Shillman
D. G. Sitler
R. D. Solomon
J. Spriet
H-m. D. Toong
Margaret A. Turek
B-K. Tye
A. W. Wiegner
H. M. Wolfson
K. J. Wong
T. Y. Wong
G. W. Zack

RESEARCH OBJECTIVES AND SUMMARY OF RESEARCH

1. Text-to-Speech Conversion

Madeline Moses Fund

J. Allen

Recently, we have demonstrated a "one-word" system which is capable of converting any English word from text form to speech. This procedure incorporates a powerful morph decomposition algorithm, together with a morph lexicon of 11,000 entries, a comprehensive set of more than 400 letter-to-sound rules, and morphophonemic and lexical stress rules that make final adjustments to the phonetic specification. The detailed phonetic specification then drives a vocal-tract model which produces the output speech waveform. At present, the vocal-tract model is realized digitally on a general-purpose computer, but we are constructing a high-speed processor suited for digital signal processing that will perform the vocal-tract model calculations comfortably in real time, and relieve the host computer of much of the computational load. This special processor, which should be completed in six months, is being constructed in ECL 10k logic on large multilayer circuit boards.

The major thrust of our research is to extend the text-to-speech conversion algorithms to sentence-level units. This involves two parallel efforts. First, a detailed syntactic and semantic analysis of the text must be performed to reveal those linguistic units and features that need to be marked phonetically. Since our goal is to deal with unrestricted English text, the parsing strategy utilizes a local approach that reveals phrase-level units even when a complete parsing of the sentence cannot be obtained.

Much of our effort is devoted to phrase detection and parsing control strategies that

reveal as much syntactic structure as possible. Once the parsing of the given sentence is known, a set of prosodic algorithms is needed to specify the durations, pitch, and pauses of the speech. Very little is known about either the content or form of these rules. We expect to extend our findings in the areas of segmental and pause durations, and pitch contours, but we shall also devote considerable effort to a theoretically sound formal structure in which to embed these results.

In order to profit from a close interaction with linguistic research, we are continuing to develop syntactic and phonological rule testers. In the coming year we expect to explore the implementation of semantic interpretation rules within the general framework of our transformational rule tester. Considerable attention is also being focused on I/O conveniences which will make these facilities attractive to linguists.

2. Character Recognition

National Science Foundation (Grant GK-33736X1)

B. A. Blesser, M. Eden

Our ultimate goal is to design a machine that will read unconstrained hand-printed characters at an error rate that is equal to, or lower than, human performance. In this effort, we are investigating human perception of graphic forms in an attempt to find the features that distinguish each letter of the alphabet from its neighbors.

During the past year we have developed a theoretical approach to character recognition. The theory is based upon ambiguously shaped characters, that is, characters that can be perceived as one letter as easily as another. The ambiguously shaped characters define the boundaries between letter subsets, and we expect that a theory based on ambiguities will lead to more accurate performance. Letters are described in terms of a small abstract set of attributes, each of which can be related to a type of ambiguity among letters. The relations between the functional attributes, which specify the letter's identity, and the physical attributes, which are derived from the physical image, are called P-F (Physical-to-Functional) rules. These rules are not constant and may be modulated by external contextual factors.

We have studied one particular form of context, stylistic consistency, both between characters and within a character. Psychological experiments have been performed in order to determine the mapping between physical and functional attributes in specific contexts. We are trying to find maximally ambiguous characters from which to formulate the mapping rules. In the experiments subjects rate hand-written characters by how well the characters represent different letters; subjects identify characters, and latency in identification is measured. We have found consistent results, by using these paradigms. In looking at ambiguities between different letter pairs that involve the same functional attributes, we found that the rules can be generalized to other cases involving these attributes.

In contexts differing significantly from those of our experiment we would expect the P-F rules to change, and we are now trying to determine the degree of change of a P-F rule as the context is changed. Initial results have shown that in certain instances the rules can be changed considerably, which implies that the boundary between letter subspaces is somewhat "plastic."

Work has also been initiated in the area of multifont character recognition, utilizing the concept of graphical context. It is the consistency of variations among characters within a given font that enables us to define that font as distinct from another. Sets of rules, one set per type font, have been derived empirically to express the stylistic consistency of type fonts.

In other experiments subjects tried to generate ambiguous characters in order to

see whether generative results would be consistent with perception results. We have noted that the process of generating characters definitely modified the subjects' judgments of ambiguous characters. Thus far, we have dealt largely with ambiguities in which only one functional attribute was involved. The work will be extended to cases in which several attributes are involved, and we shall study all functional attributes that have been identified. We shall also investigate further the plasticity of mapping rules under different contexts, and try to determine some of the psychophysical issues, such as how finely people can resolve a physical difference in line length.

Further attempts will be made to formulate type-style rules, especially for lowercase letters. We shall try to devise ways of extracting context information from the printed text. During the coming year we may attempt a limited implementation of some of the rules by computer.

Our findings in the field of human perception may lead to better methods for teaching people how to read. Some experiments may be carried out in the area of children's reading development.

In summary, we are studying the relation between physical and perceptual properties of conventional symbols with a view of perfecting efficient procedures for recognizing alphabetic characters and other common symbol types. We are attempting to draw together results and methods from both engineering and psychological disciplines.

3. Precise Transmission and Duplication of Radiographs

National Institutes of Health (Grant 5 PO1 GM19428-02)

W. F. Schreiber

The object of our work is to design an electronic scanning system capable of reproducing x-rays with such high fidelity in resolution and tone scale that the output would be indistinguishable from the input. When this result has been achieved, realistic scanning parameters will be chosen to obtain results of undiminished diagnostic value while avoiding at the same time unduly extravagant use of channel capacity. Evaluation of diagnostic performance will be made with the assistance of Dr. Ozonoff and Professor Blesser who are working with a panel of radiologists at Peter Bent Brigham Hospital, in Boston.

The technology that is employed is an extension of work recently carried out in our laboratory to develop a newspaper facsimile system. Very high quality results have been achieved by using a modulated helium-neon laser, feedback control of laser brightness, scanning with a galvanometer-driven mirror, and continuous paper drive. The x-ray receiver will have 3M dry silver film, which is processed by using only heat.

While transmission of the newspaper facsimile pictures has been carried out by analog means over voice telephone channels, the x-ray system anticipates the use of the new 56,000 bits/second channels that will be made available by the telephone company in 1974. It is believed that very high quality can be achieved at a rate of approximately 4 s/in.^{2} of image, and substantially higher rates may be possible in many cases.

We have constructed digital electronics apparatus that permit switch selection of spatial and tone scale resolution and picture size. Each transmission starts with a code word that sets up the receiver for correct recording. Optical systems for transmitter and receiver and the transmitter film drive have been completed, and the receiver film drive and processor are under construction. The system handles either opaque or transparent input pictures, up to 14" wide and of any length, and produces copies of the same size. The initial planned resolution is 250 samples/inch with up to 8 bits/sample.

This system of precise duplication and transmission of radiographs should be useful for remote diagnosis. It is suitable also for processing by computer or otherwise.

Perhaps one of the most important uses will be correction of moderate exposure errors in the film without repeating the original examination.

4. Study of Diagnostic Performance of Radiologists Reading Chest X-ray Films

Peter Bent Brigham Hospital, Purchase Order G-33196

B. A. Blesser, D. M. Ozonoff

This project, which is being performed cooperatively with radiologists attached to the Department of Diagnostic Radiology, Peter Bent Brigham Hospital, Boston, Massachusetts, is devoted to studying the nature of errors made by trained staff radiologists in reading conventional chest films. Because it is not possible to judge the effectiveness of technological alternatives such as image enhancement in the radiologic process without a method for measuring performance, this study is considered preliminary to attaining a generalized testing method.

Five radiologists read a set of 100 films and their readings were compared by the experimenters. On the average there was more than one significant disagreement among the radiologists on each of 100 films. The high rate of disagreement, which would affect the treatment of a patient, indicated that the present level of performance is not as high as might have been expected.

Moreover, it was observed that a large percentage of these disagreements could not be resolved by the experimental panel of radiologists. In other words, the radiologists were reading to the limit of their ability and reporting findings that could neither be confirmed nor denied by professional radiologists.

The nature of the errors themselves depended on the particular clinical situation that was being reported. For example, errors were made concerning nodules. The fact that there was no uniformity of error does not speak well for the prospects of attaining a generalized form of image processing that would work on a complex chest film.

5. Digital Wirephoto System

Associated Press (Grant)

W. F. Schreiber

Since August, 1970, a group under the direction of Professors Schreiber and Troxel has been developing for the Associated Press an entirely new news picture (Wirephoto) distribution system. Such a development is required because of the expected phasing out of the high-quality voice telephone channels that are now being used for picture transmission, and in order to achieve substantial improvements in image quality, speed, reliability, flexibility, and cost.

The system is to be introduced in stages, in such a way that at least the present standard of quality and service will be maintained everywhere, with improvements gradually spreading in time and location.

The ultimate system as now envisioned will operate as follows. Pictures will be stored under computer control. An editor can then view any picture on a TV display in order to select, discard, edit, transmit, or store that image for later automatic dispatch. Editing may include cropping, enlarging, reducing, enhancement (contrast control, etc.), combining, and addition of captions. No additional chemical photographic work will be required for the network operation.

Transmission over the "backbone" system linking the AP bureaus and the large metropolitan newspapers which have substantial computer facilities will be high-speed and digital, and generally will originate and terminate at computer-controlled digital

storage devices. Transmission to subscribers will be analog or digital and at speeds and scanning standards appropriate to the existing transmission facilities. Complete control will be exercised by the New York network monitor. In the absence of manual intervention, transmission to all points among the bureaus, from point to point, and to regional networks, will be accomplished automatically.

We have implemented some of these procedures in the laboratory, using our PDP-9 computer (32k core, 6 Megabit disk). The input may be a picture from the AP network, from a local analog transmitter, a 12k picture element/second CRT scanner, magnetic tape or Dectape, and may be stored on the disk. Pictures may be transmitted from the disk to comparable receiving points. Pictures stored on the disk may be viewed on a TV display utilizing a full-frame semiconductor storage system. Editing facilities already in operation include cropping, enlarging or reducing, combining several pictures into one, and the addition of captions. (Captions are stored as ASCII characters and are processed into video only when a transmission is made.) It is also possible to branch to a "filtering" point, where new programs may be called.

All of these operations are controlled by a supervisory program that includes an interactive question-and-answer display. Simple keyboard commands control each step, and the required commands are given in the display to permit operation by unskilled personnel.

We are now starting to design and construct the first computerized Wirephoto bureau, based on a PDP-11 computer. It will have input/output ports at United States and European Wirephoto standards, as well as a variety of digital rates up to 56k bits/second, and will include both disk and magnetic-tape storage, as well as the CRT picture display. When complete, the system will be replicated in New York and transmissions will begin over the Bell System Digital Data System (DDS) between New York and Boston.

The TV display used in the digital Wirephoto system includes a semiconductor memory capable of storing a full frame, thereby enabling a flicker-free picture display on a monochrome television monitor. The memory has the capacity of supporting a picture on a 256×256 matrix with 4 bits allocated to each picture element. In order to enhance the displayed picture, three types of real-time picture processing operations have been employed: the addition of pseudorandom noise, linear interpolation to a 512×512 matrix, and a nonlinear transformation involving the antilog combined with a correction for the brightness characteristic of the television tube.

To facilitate the cropping of news photographs, the computer can superimpose a rectangle of arbitrary size and shape on the TV display. When an editor has specified the portion of the picture to be retained, he can then command the computer to scale the cropped picture to an appropriate size for transmission over the network.

Our work has also included the development of a new generation of picture transmitters and receivers. This was required because not only will the new machines be used eventually with a high-speed digital transmission system but also the existing machines, of obsolete or obsolescent design, have many deficiencies with respect to picture quality, cost of operation, and maintenance. It was felt that the application of modern technology would enable the AP to deliver to its members a much higher standard of photographic service.

The new machines, called "Laserphoto" by the AP, are based on laser scanning. Compared with previous systems, they offer substantial improvements in cost/performance ratio. They feature high resolution, accurate tone scale control, simplicity of construction and operation, low cost and weight, small size, and excellent reliability.

The technology that is applied includes a modulatory helium-neon laser, feedback control of laser brightness, a galvanometer-driven mirror for horizontal scanning, continuous paper motion for vertical scanning, 3M dry silver paper for the recording medium, and a small oven that heats the paper for processing. The newspaper system

handles both input and output in the form of pictures 11 inches wide and of any length. A scanning density of 100 lines/inch at 100 lines/minute and DSB amplitude modulation are used in order to be compatible with present transmission standards over voice telephone lines.

Tone scale is controlled by accurate temperature setting of the processor to achieve a stable paper curve, combined with an adjustable nonlinear amplifier to produce the desired overall transfer characteristic. A step wedge is incorporated in the output picture to monitor the operation.

Small size and low weight are made possible by the use of a unique folded optical system that is also very rigid. A complete receiver, $17\ 1/4 \times 16\ 3/4 \times 7\ 3/4$ inches, and weighing 46 pounds, with space for 500 ft of paper, has been built. A transmitter would be smaller. It is also possible to design a transceiver only slightly larger than a receiver.

The Associated Press will start to install a production-engineered version of the Laserphoto transmitters and receivers late in 1974, and within 18 months thereafter all of the existing machines will be replaced. The production receiver will accumulate paper during transmission, and then cut the paper and process each picture rapidly using a contact processor. Henceforth our effort will be devoted primarily to completing the necessary software and designing various interfaces.

6. Classification of White Blood Cells

National Institutes of Health (Grant 5 PO1 GM14940-07)

I. T. Young, Jeffrey A. Hagerich

Our continued research for techniques and algorithms to classify white blood cells has led us to consider a new technique for the description of biological shape. We are studying this technique for the following reasons.

1. An appropriate descriptive technique for cell shape, whether normative or generative, should relate to some fundamental biological property of the cell.

2. Measures such as P^2/A are not robust. They yield similar numerical values for contours that are significantly different.

3. In the transition from the analysis of shapes on a continuous surface to the analysis on a discrete grid (as is required for computer image processing) some of the properties of measures such as P^2/A are significantly altered.

Therefore we were led to consider a measure of shape that would deal with some of our intuitive notions concerning the complexity of shapes and the effort that would have to be expended to construct these shapes out of biological materials. Our intuition tells us that the simplest shape in the sense of a simply connected closed contour (SCC) is the circle. If we were to construct a two-dimensional closed loop out of a homogeneous material like aluminum and then allow it to assume its "free" form, the shape that would be assumed would be a circle because the circle is the shape that minimizes the stored energy in a linear medium or thin-shelled medium. To create any other figure requires an expenditure of work in the form of bending energy. Thus our mathematical model for the description of shape is based on the notion of bending energy, and the equivalence classes that are generated are those sets of figures with equal amounts of stored energy in their shapes.

The average bending energy per unit length can be calculated by taking a weighted sum of the Fourier coefficients $\{X_n, Y_n\}$ for a parametric description of the curve $\{x(p), y(p)\}$. This leads to an expression for the energy

$$E = \sum_{n=-\infty}^{+\infty} (n\omega_o)^4 \left[|X_n|^2 + |Y_n|^2 \right]$$

and to a constraint on the coefficients given by

$$1 = \sum_{n=-\infty}^{+\infty} (n\omega_o)^2 \left[|X_n|^2 + |Y_n|^2 \right],$$

where $\omega_o = 2\pi/P$, and P is the perimeter of the SCC contour. By using these two results, theorems have been proved concerning convergence of the coefficients, minimization of the bending energy, and sampling of the continuous contours. We have also developed a method whereby the actual computation may be done by using the Freeman chain code for the contour instead of actually computing the FFT.

During the coming year we shall implement this shape-analysis technique in our classification procedure. We shall also perform experiments on cells to alter their energy states and measure the attendant shape change. We hope this will lead to a more precise understanding of the relationship between membrane status and shape.

7. Measurement of Cell Adhesiveness

National Institutes of Health (Grant 5 PO1 GM14940-07)

I. T. Young, Stephanie E. Sher

Medical scientists investigating normal and leukemic white blood cells have long recognized that a decrease in the contact adhesiveness or "stickiness" of the leukemic cell is one of the principal functional differences between normal and pathological cells. It is thought that this change in the cell surface chemistry alters the ability of the cell to function normally in phagocytosis and/or the immune response. The experiments that have delineated this difference in surface adhesiveness, however, have been limited largely to making qualitative statements about its nature and strength.

Our experiments in the automated identification of blood cells and the quantization of microscopic images have led us to consider a new technique for measuring the adhesive force. When blood cells, both leukocytes and erythrocytes, are in plasma, a certain number of cell-cell collisions occurs in any interval of time. The frequency of these collisions is much greater for erythrocytes, naturally, than for leukocytes because of their much higher population density. When the surface of the cells is "sticky" some number of cells remains together after the collisions, and clumps of cells are formed. If a snapshot of a large number of cells could be taken, then the number of clumps and the fraction of cells in clumps would be a measure of the average cell contact adhesiveness. We have devised a method for determining such a measure using cells in a peripheral blood smear. The peripheral smear is prepared by using a blood film centrifuge to ensure a uniform, random distribution of particles (either cells or clumps) over the entire glass slide surface.

Two types of experiment were devised to test the hypothesis that the measurement of the fraction of cells in clumps is a measure of cell adhesion taking place in the original suspension. In one set of experimental conditions, addition of antithymocyte serum (ATS) was chosen to increase cell adhesion, while in the other set addition of $HgCl_2$ was chosen to decrease cell adhesion.

When normal human peripheral blood was mixed with various dilutions of ATS, the number of clumps and the fraction of cells in clumps increased sharply, and the increase was proportional to the concentration of ATS. When normal human blood was mixed with various dilutions of $HgCl_2$, the number of clumps and the fraction of cells in clumps decreased, and the decrease was proportional to the concentration of $HgCl_2$.

As the fraction of cells in clumps increased, under conditions of increasing concentration of ATS, the hypothesis that clumps are randomly distributed seemed probable, while the distribution of cells became increasingly skewed. As the fraction of cells in clumps increased, the hypothesis that the cells are randomly distributed became increasingly untenable.

As the fraction of cells in clumps decreased, under conditions of increasing concentration of $HgCl_2$, the two distributions (clumps and cells), became increasingly similar. At the lowest fraction of cells in clumps (highest concentration of $HgCl_2$), the two distributions were essentially identical.

During the coming year we shall use our adhesive measurement technique for several problems. First, we shall investigate mechanisms for counting T and B cells in lymphocyte and whole-blood populations. This problem is of interest in both clinical and research aspects of immunology. Using anti-T and/or anti-B sera, we shall create clumps as a result of the antigen-antibody reaction. These clumps will then be counted to quantify the T-cell and B-cell populations. Similar experiments will also be performed to measure transplant rejection among kidney recipients. At present, the only reliable methods take several days and are incompatible with certain donor situations. We shall look for cell rejection as a stimulus to clump formation, which will then be measured.