XIX. COGNITIVE INFORMATION PROCESSING

Academic and Research Staff

Prof. Murray Eden
Prof. Jonathan Allen
Prof. Barry A. Blesser
Prof. Goesta H. Granlund*
Prof. Francis F. Lee
Prof. William F. Schreiber
Prof. William Simon†
Prof. Donald E. Troxel
Prof. Ian T. Young
Dr. Jack E. Bowie
Dr. Brian E. Boyle
Dr. Ralph W. Gerchberg
Dr. Uri F. Gronemann
Dr. Martin J. Hewlett
Dr. Conrad C. Jaffe
Dr. Dennis J. Kfoury
Dr. Murat Kunt‡
Dr. Perry L. Miller
Dr. Mary J. Naus
Dr. David M. Ozonoff
Dr. Stephanie E. Sher
Dr. Robert J. Shillman
Francis X. Carrol
Jeffrey A. Hagerich
M. Sharon Hunnicutt
Eric R. Jensen
Kenneth A. Okin
Robert A. Piankian
Kenneth P. Wacks

Graduate Students

Jack A. Allweis
Robert P. Bishop
Ronald E. Boucher
Cary G. Bullock, Jr.
Becky J. Clark
Philippe Coueignoux
Charles H. Cox
Caleb J. Drake
James R. Ellis, Jr.
Irvin S. Englander
Steven G. Finn
Walter E. Gibbons
Richard S. Goldhor
Samuel M. Goldwasser
Monson H. Hayes
Marvin E. Jernigan
Clayton K. S. Kau
John W. Klovstad
Theodore T. Kuklinski
Sze-Ping Kuo
Donald S. Levinstone
Charles W. Lynn
Lee C. Makowski
José L. Marroquin
Dennis V. Marsicano
Douglas O'Shaughnessy
Douglas B. Paul
Roger S. Putman
Robert E. Rouquette
Robert D. Solomon
Christopher E. Strangio
Anthony Sun
Joseph E. Wall, Jr.
Allen W. Wiegner
Tony Y. Wong
Gregory W. Zack

RESEARCH OBJECTIVES AND SUMMARY OF RESEARCH

JSEP

1. Audio Response Unit for Remote Terminals

Joint Services Electronics Program (Contract DAAB07-74-C-0630)

Jonathan Allen

The goal of this project is to produce high-quality speech at a terminal, under the constraints of small vocabulary and low cost. Linear predictive coding (LPC) parameters for each word, derived from natural speech, will be stored at the terminal. The speech will be synthesized from the parameter sets for each word, and from prosodic modifications (applied by rule) to obtain the desired pitch, timing, and word boundary effects. We have already developed programs for LPC parameter extraction, and have nearly completed initial versions of the prosodic programs. It remains to be specified just how the prosodic rules interact with the LPC parameter sets, and to design the terminal hardware. We are designing two hardware synthesizers, one using a simple serial multiplier, and the other employing ROM table-look-up multiplication, and after we evaluate and compare these designs the final circuit will be implemented. The system should provide the naturalness of synthesis from stored parameters, while preserving the

JSEP

*Visiting Associate Professor, Linkoeping University, Linkoeping, Sweden.

†Visiting Associate Professor, University of Rochester.

‡Visiting Scientist, Laboratoire de Traitement de Signaux, Lausanne, Switzerland.

JSEP flexibility of prosodic synthesis by rule. The bit rate to the terminal will be less than 100 bits/second, and the terminal hardware will be suitable for LSI implementation at a modest cost.

2. Font-Independent Character Recognition

Joint Services Electronics Program (Contract DAAB07-74-C-0630)

National Science Foundation (Grant GK-33736X2)

Barry A. Blesser, Murray Eden, Robert J. Shillman

Our ultimate objective 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. We attribute the failure of previous attempts at this task (in spite of considerable engineering effort during the past 10 years) to the lack of a general theory of characters upon which to base recognition techniques.

During the past two years 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 being either of two letters. These characters are important because they define the boundaries between letter subspaces in the character space; an analytical description of these boundaries could be incorporated into a recognition algorithm. Through extensive psychophysical experimentation we have found and examined more than 190 ambiguous characters and have developed a grammar for describing letters. The grammar comprises a compact set of attributes and relational rules. The relation between the physical attributes of a character, derived from physical measurements, and the functional attributes, which specify the character's identity, are termed PF (Physical to Functional) rules. We have shown recently that a character's letter label need not be fixed but may vary, depending upon the graphical environment in which the character is embedded. This indicates that although a given character has a unique physical representation, it can have more than one functional representation, and hence more than one letter label. This effect is due, at least in part, to the modulation of the PF rules by the graphical context. Graphical context, a form of context not previously investigated in the character-recognition literature, takes into account the effect of stylistic consistency both between characters and within a character itself.

We have also applied the concept of graphical context to the area of multifont character recognition. It is the consistency of variation among characters within a given font that enables a person to define one font as distinct from another font. Sets of rules that generalize across fonts have been empirically derived to express the observed consistency. These rules should help to achieve a low-error-rate solution to the multifont problem, since they contain useful information about character formation.

In summary, we are studying the relation between physical and perceptual properties of conventional symbols in order to perfect procedures for recognizing alphabetic characters and other common symbols. We are attempting to draw together results and methods from both engineering and psychological disciplines so that we can eventually build a machine capable of reading unconstrained input.

In the coming year we hope to determine additional PF rules, and to investigate the interaction that occurs when two or more functional attributes are involved in letter discrimination. We also hope to investigate further the effect of graphical context upon the PF rules. JSEP

3. Text-to-Speech Conversion

National Science Foundation (Grant EPP74-12653)

Jonathan Allen

For some time our goal has been to design and build a complete text-to-speech system for unrestricted English text that would be suitable for diverse applications including a reading machine for the blind and computer-aided instruction. The input text is processed first by a set of linguistic algorithms that produce a set of phoneme labels and prosodic markers representing the speech that is to be produced. This set of linguistic feature labels has a very low bit rate (less than 300 bits/sec) which can be transmitted easily over a telephone line. The second part of the system must transform the linguistic specification into a physical speech waveform. Essentially, a set of control parameters for a vocal-tract model must be calculated from the linguistic data, and then the model must be exercised at a 10 kHz sample rate in order to produce the speech waveform.

We have now completed a very comprehensive set of linguistic algorithms for converting single textual words to a set of phonemes with stress marks. This system includes a morphemic analyzer with a morph lexicon of more than 12,000 entries, a set of letter-to-sound rules, and a lexical stress analyzer that can deal with stress shifts in affixes as well as roots. We are documenting this system in higher level languages; the morph analyzer is available in Fortran, and the letter-to-sound and lexical stress rules are being expressed in rule tester format, initially coded in LISP. Coupled to a phonemic synthesizer, we believe that this system is the most complete and linguistically correct text-to-speech converter available.

The rest of the linguistic analysis program is still under development. Routines are needed to specify the prosodic contour of the utterance. First, a parser must reveal the syntactic structure of the sentence that is to be converted. We have developed two parsing strategies. One uses a bottom-up rule-driven extended context-free parsing logic, and the second uses a set of phrase finders coupled to heuristics which indicates the clause structure. Since we need a parser that will reveal the structure of <u>any</u> sentence, some combination of rigid linguistic specification and heuristics is needed. We have started to experiment with various combinations of these attributes and an acceptable parser should be available soon.

The parser output is used as input to a set of rules that determine the pitch and timing contours of the sentence. We have derived a comprehensive set of pitch rules that are being implemented. Perhaps the most important discovery in this area has been that modality items (negatives, past-tense modals, sentential adverbs, and quantifiers) are strongly marked in the pitch contour, presumably because they mark the speaker's attachment to the truth value of the basic proposition of the sentence. This finding indicates that in synthesis the final utterance must be regarded as the output of a speech act, and techniques for speech-act analysis are an essential part of our craft. While the algorithms are less advanced, a durational framework is also under development. Special attention has been paid to the syntactic role of lexical items, as well as phrase length and conjoining effects.

We have devoted much effort to the design of computational hardware to exercise the vocal-tract model. A high-speed signal-processing computer, built in ECL hardware, has been completely designed and is now being constructed. This machine includes a 24 × 24 bit multiplier that operates in 120 ns, and is programmable for a variety of algorithms. Several student projects are concerned with the design of small, hard-wired processors to represent the vocal-tract model, which we hope to implement in LSI modules. In this case, the low-bit-rate linguistic specification should drive a small set of processor chips, which would be very inexpensive and small enough to be included in a wide variety of terminals.

4. Computational Considerations in the Analysis of Biological Shape

National Institutes of Health (Grants 5 P01 GM19428-03 and 3 P01 GM19428-03S1)

Ian T. Young

In describing the shapes of cellular structures a quantitative measure of shape complexity called "bending energy" has certain desirable properties for simply connected closed (SCC) contours. Among them are invariance to rotation and translation, proof that circular shape has minimum bending energy, calculation of the quantity in either N or $N \log_2 N$ steps, where N is the number of points on the contour boundary, correlation of the quantifiers to a straightforward physical property of certain materials, i.e., stored energy in linear thin-shelled structures, and simple extension of the results to three-dimensional structures. The analysis procedure also produces certain results concerning the sampling of SCC contours on a discrete grid and the convergence of Fourier descriptors for plane closed curves.

During the past year we have considered some of the computational issues raised by the Fourier analysis procedure. The bending energy is defined as $E=(1/P) \int_0^P K^2(p)\, dp$, where K(p) is the curvature of the SCC contour at point p. We assume that K(p) is finite for all points on the contour, $0 \leq p \leq P$. Using a Fourier series representation for every point on the contour $\{x(p), y(p)\}$, we arrive at a formulation for E:

$$E = \sum_{n=-\infty}^{+\infty} (n\omega_o)^4 \left[|x_n|^2 + |y_n|^2\right] \qquad \omega_o = 2\pi/P,$$

where (x_n, y_n) are Fourier series coefficients of the curves $\{x(p), y(p)\}$. These calculations are based on the representation of the contour on a continuous two-dimensional surface. Computations that are to be performed on a computer, however, require that the curves be sampled at a sufficiently high rate to represent the curvature accurately at every point on the contour. Choosing a finite sampling grid implies that the original curves are bandlimited. Thus we may compute the discrete Fourier transform (DFT) of the sampled curves $\{x(n), y(n)\}$, and its values in the baseband $(-\pi, +\pi)$ will be the same as the original spectrum. Using the DFT, we arrive at a set of Fourier coefficients (x_n', y_n') which is identical to the set (y_n, y_n) over the interval $(n=0, \ldots, [\frac{N}{2}])$. To improve the speed of the spectral computation, an FFT routine may be implemented. Since the length of the contour (N) is a random number, we cannot be sure that it will be a power of 2. This problem is not serious, since an FFT algorithm is available for any value of N.

The use of finite-word size computation for the Fourier transform operation generates errors in the computation of the Fourier coefficients. These quantization errors may be shown to be equivalent to the addition of white noise to the "true" spectrum. We have shown that the coefficients fall off approximately as $|x_n|^2 \simeq |x_1|^2 n^{-5}$. It is worthwhile, therefore, to know at what frequency n the spectrum crosses the white noise produced by the finite-word quantization error in a floating-point computation of the FFT. Using the result of Oppenheim and Weinstein[1] gives a value for the frequency n (with 5 bits of mantissa and $N = 2^{\nu}$) of

$$n = \left[\left(\frac{3}{2\nu}\right) 2^{-\nu} 2^{2b}\right]^{.2}.$$

For example, when N=256 and b=26 bits of mantissa the frequency at which the noise variance equals the magnitude squared of the true spectrum is n=319. This is a value far outside the passband, hence we need not worry about the effects of finite-word size. If a fixed-point FFT algorithm is used, the result changes dramatically and a similar analysis gives n=12. A minor change to block floating point (really a form of fixed-point computation with possible scaling after each stage) gives $n \simeq 50$, which is a more reasonable result. For computers without floating-point hardware this change should be given serious consideration.

We have mentioned previously that there is a constraint on the tangent vector at any point p on a continuous curve, $|T(p)| = 1$. For curves described on a discrete grid this is not the case. If the equivalent discrete tangent vector is described by

$$\Delta S(n) = [x(n) - x(n-1)]\vec{i}_x + [y(n) - y(n-1)]\vec{i}_y,$$

then $|\Delta S(n)| \neq 1$ for all $n = 0, 1, \ldots, N-1$. We have computed the expected value of the square of the tangent vector to be $E[|\Delta S(n)|^2] = 1.65$. For a series of SCC curves of bladder cell images that we have analyzed the experimental results agree quite well with this prediction.

References

1. A. V. Oppenheim and C. J. Weinstein, "Effects of Finite Register Length in Digital Filtering and the Fast Fourier Transform," Proc. IEEE 60, 957-976 (1972).

5. Automatic Analysis of Hemagglutination

National Institutes of Health (Grants 5 PO1 GM19428-03 and 3 PO1 GM19428-03S1)

David M. Ozonoff

Agglutination of red blood cells is an important clinical method for detecting the presence of certain antibodies in biological systems. Normally, agglutination is detected macroscopically by the presence of a clump ("button") on the bottom of a tube in which red cells tagged with the relevant antigen are incubated with the serum to be tested for the antibody. Normal A-B-O blood typing is a typical example.

Agglutination is also visible on a microscopic level, and there are degrees of microscopic agglutination that are not detectable macroscopically. The question arises whether there might not be a finer measure of agglutination than the strictly binary (clumps – no clumps) measure that is obtained with the conventional macroscopic test.

By using a computer-controlled microscope scanner system, which has been developed in our laboratory, conventionally prepared smears of peripheral blood were analyzed for the number of clumps per hundred cells, the average number of cells per clump, and the percentage of cells in clumps. We defined membership of a cell in a clump on the basis of a cell lying within a certain threshold distance of another cell. Various threshold distances are being tested, but the measure does not seem to be exquisitely sensitive to this threshold at our sampling rate (3 points per micron). Distance measurements are made automatically on a PDP-9 computer using data from the scanned image.

With the percentage of cells in clumps as a measure it is possible to differentiate type A red blood cells incubated with anti-A antiserum of titers out to 1:1000 (the limit of the tube test in our laboratory) from the same cells incubated with anti-B antiserum undiluted. The level of significance for the difference is $p < .002$ when using a binomial model for the difference in the proportions of cells in clumps on the two slides. Our experience suggests that with microscopic agglutination measurements of this sort we might be able to detect anti-A antibodies out to a titer of 1:100,000. Our next step will be to investigate the kinetics of hemagglutination with this method, especially the dose-response relationship for various antibody-antigen systems.

6. Measurement of Cellular Adhesion

National Institutes of Health (Grant 5 PO1 GM19428-03)

Ian T. Young, Stephanie E. Sher, David M. Ozonoff

We are in the process of validating a technique that we have developed for measuring cell-to-cell adhesion as opposed to measurements of cell-substrate adhesion.

Central to these automated techniques is the preparation of peripheral blood films with a high degree of uniformity and a minimum of cell disruption. A preparative procedure using a blood film centrifuge has been developed and the uniformity of spreads has been verified by statistical methods.

Briefly, we use a blood film centrifuge to make a slide of the peripheral blood cell population. After the slide is stained and mounted with a coverslip it is examined under a light microscope and the cells in a defined area are counted. We have used our automated microscope for data collection. For measurements of adhesion in peripheral blood, the minimal area required for statistical analysis is 400 fields of view in each 150 μm square. The total number of leukocytes is recorded, as well as the number of clumps (two or more cells visibly touching) and the number of cells within a clump. The percentage of cells in clumps is a measure of cell-to-cell adhesion.

The major experimental results are the following.

a. Erythrocytes, while a thousandfold more plentiful than leukocytes, behave as independent (random) particles and satisfy the statistics derived from a Monte Carlo simulation of independent particles distributed on a unit square, with varying particle densities.

b. Many, but not all, normal human subjects exhibit a number of clumps of leukocytes in the blood films that far exceeds the estimate based on the assumption of random placement of their WBC. This parameter is stable when measured with the same subject at different times.

c. The index of adhesiveness for erythrocytes or leukocytes can be increased by the addition of typing (A or B) sera or ALS; this shows that the statistical analysis reflects cellular events.

d. Blood samples from patients with chronic and acute myelocytic leukemia show a tenfold increase in leukocyte clumping at certain times during the course of the disease. Blood samples from patients with chronic lymphocytic leukemia exhibit normal levels of clumping, despite great increases in cell concentration.

We hope to use the measurement of cell-to-cell adhesion to look further into changes of cell surfaces during leukemia, especially since it has become axiomatic on the basis of measurements of cell-substrate adhesion that cells become less "sticky" following the neoplastic transformation. We would also like to apply the measurement to early detection of histoincompatibility in mixed lymphocyte cultures, which are now used to predict organ graft retention.

7. Pattern Classification Error Bounds

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

Ian T. Young

In the design of pattern-recognition systems that rely on statistical classification techniques one of the important theoretical problems is the prediction of performance. In the canonic pattern-recognition experiment this prediction takes place after a statistical model or image of the various pattern classes has been estimated and before the actual classification of unknown samples begins, that is, after the evaluation of a learning set but before the evaluation of a test set. This prediction of performance is not difficult when the number of different pattern classes is small, say 2 or 3, but it becomes a significant problem when the number of classes is large. For example, there are 10 classes of white blood cells, 14 classes of vowels, and 48 classes in optical character recognition.

We have developed an approach to the problem of estimating the eventual performance of a pattern recognizer that is based on two assumptions:

(i) The underlying distribution of each of the M different pattern classes is multivariate Gaussian, where the i^{th} class is described by mean vector μ_i and covariance matrix Σ_i.

(ii) The decision algorithm (under the Gaussian assumption) is a modified maximum-likelihood decision rule, where the random pattern vector x is assigned to class i if

$$d(x, \mu_i) < d(x, \mu_j) \quad \forall j \neq i,$$

where

$$d(x, \mu_i) = (x-\mu_i)^t \, \Sigma_i^{-1}(x-\mu_i).$$

The criterion that we have adopted for predicting the classifier performance is the probability of error.

Consider a pattern class i described by the parameters μ_i and Σ_i. The other classes have their respective parametric descriptions and each of these classes (the i^{th} included) may be thought of as a cluster in an N-dimensional vector space, where N is the number of features. Assuming that no two mean vectors are ever equal, $\mu_i \neq \mu_j$, $\forall j \neq i$, we see that each cluster possesses a region in space where no classification errors will ever be made.

We define a region around cluster i by the equation $d(x, \mu_i) \leq R_i$, where

$$R_i = \min_{j \neq i} \left[\frac{d_{ij} d_{ji}}{d_{ij}+d_{ji}} \right]$$

with d_{ij} the distance from cluster i to cluster j, d_{ji} the distance from cluster j to cluster i, and $d_{ij} \neq d_{ji}$ because $\Sigma_i \neq \Sigma_j$. Then the probability of error for a random pattern vector chosen from cluster i is given by

$$P(E|x \in \text{class i}) \leq P[d(x, \mu_i) \geq R_i].$$

From our initial hypothesis that the underlying distributions are multivariate Gaussian, this equation becomes

$$P(E|i) \leqslant \frac{1}{(2\pi)^{N/2} |\Sigma_i|^{1/2}} \iiint\limits_{d(x,\mu_i) \geqslant R_i} \dots \int \exp(-(x-\mu_i)^t \Sigma_i^{-1} (x-\mu_i)/2)\, dx_1 dx_2 \dots dx_N.$$

By changing from Cartesian to polar coordinates, we arrive at

$$P(E|i) = \frac{2^{1-N/2}}{(\frac{N}{2}-1)!} \int_{R_i}^{\infty} r^{N-1} \exp(-r^2/2)\, dr,$$

where N and R_i have been previously defined. This integral may be evaluated by integrating by parts. A plot of $P(E|N, R_i)$ for various values of N and R_i is given in Fig. XIX-1. Inspection reveals two properties, both of which can be proved rigorously.

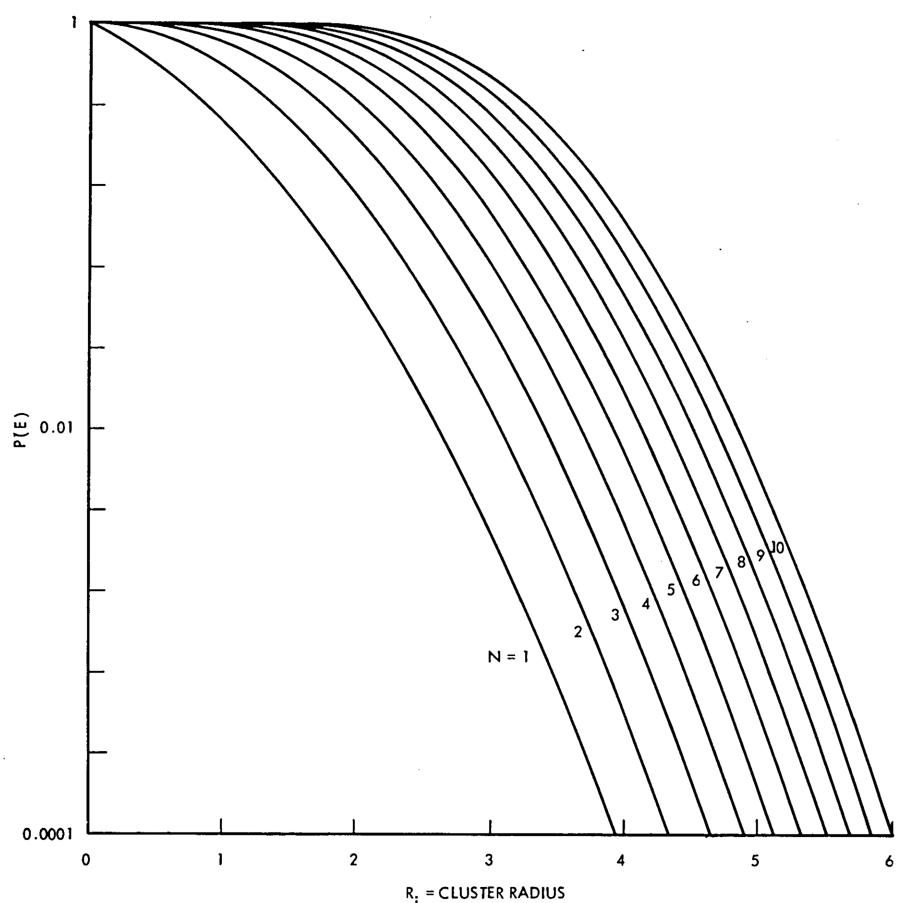

Fig. XIX-1. $P(E|N, R_i)$ for various values of N and R_i.

Property 1. As the distance between clusters grows (for a fixed number of features) the probability of error decreases. That is,

$$\frac{\partial P(E|N,R)}{\partial R} < 0.$$

Property 2. If we add additional features to a pattern classifier without a commensurate increase in the intercluster distance, the probability of error increases. That is,

$$P(E|N+1,R_i) - P(E|N,R_i) > 0.$$

The upper bound on the probability of error per class may thus be computed for each class and used to determine in which pattern classes confusion is to be expected. Also, features may be added or deleted one or more at a time to determine which ones give the most aid to pattern classification. The P(E) that we have calculated can be shown to be an upper bound on the strategy's maximum a posteriori probability and maximum likelihood under the Gaussian hypothesis.

8. Precise Transmission and Duplication of Radiographs

National Institutes of Health (Grant 5 PO1 GM19428-03)

William F. Schreiber

By extending the techniques used in our development of a new picture transmission system for the Associated Press, we have designed and built a laser scanner system for transmitting x-ray images. The technology that we have used includes internally modulated helium-neon lasers, feedback control of laser intensity, horizontal scanning by a novel double-pass optical system, and vertical scanning by a stepping motor film drive. The output is on 3M dry silver film or paper which is developed in an on-line oven-type heat processor.

The initial configuration scans up to 14" in width by any length to handle full-size chest films. The resolution is 250 pels/inch, but it may be changed. Any width or length may be scanned, with up to 8 bits/pel, thereby permitting 256 grey levels to be represented on a logarithmic scale. Transmission is at 56 kbits/second which is compatible with the Bell System DDS digital communication facilities. Original film densities of 3.0 can be read, and this may be improved. A computer interface will be added so that x-rays may be manipulated in the computer and so that the equipment will serve as a general-purpose high-resolution picture input/output device.

Our motivation in this work is toward several objectives. We want to demonstrate that x-ray film scanners of such high quality can be made that the reproductions are indistinguishable from the originals by radiologists, and that a practical system for transmitting films for remote diagnosis is feasible. We also wish to facilitate computer processing of x-rays, which has been hampered heretofore by loss of quality in the input/output process, and we want to experiment with some simple processing techniques such as correcting moderate exposure errors.

9. Roentgen Diagnostic Error Study Project

Peter Bent Brigham Hospital Purchase Order G-33196 #2

David M. Ozonoff, Barry A. Blesser

Our study of perceptual difficulties and performance evaluation in the radiologic process continues in collaboration with the Department of Diagnostic Radiology of Peter Bent Brigham Hospital, in Boston. Data were obtained from independent interpretations by 5 staff radiologists of randomly selected chest x-rays from a hospital population with a high incidence of intrathoracic diseases. Disagreement among the radiologists on these reported interpretations was considered to represent, to a first approximation, the set of perceptually "difficult" observations on 100 films. The nature of each disagreement was analyzed by type (false positive statement, false negative statement, indeterminate (that is, unresolvable) statement) and also by clinical severity on a scale of 1 to 3.

The results of this study show that there is an unexpectedly high rate of clinically significant disagreement in 5 independent readings of the same chest x-ray (41% of the 500 reports, representing 5 interpretations of 100 films, had clinically significant false positive and false negative differences from other reports of the same film; the percentage would go up to 56% if the indeterminate statements were counted). Furthermore, the nature of the physical parameters used to characterize the difficult observations varies greatly. That is, some involve high-frequency features, others low-frequency features, some are high contrast, others low contrast, and so forth. This makes it doubtful that any general kind of image preprocessing will lead to overall improvement of diagnostic performance. We are now investigating the probable result of image-processing procedures on clinically important but perceptually "difficult" observations.

A projected application of this study and its methods is to provide a means of evaluating alternative technological interventions in the radiologic process. For example, what effect will a device for duplicating or transmitting roentgen images have on the diagnostic performance of the radiologist? The present development of such a device in our laboratory (cf. the laser scanner) will provide an opportunity for testing both the device and the evaluation method. Precise procedures that will enable evaluation of this sort are being developed at the present time.

Also of interest are problems connected with the ways in which roentgen interpretations are reported; for example, the use in the report of qualifying phrases to denote uncertainty and the connection of these phrases with actual errors.

10. Digital Wirephoto System

Associated Press (Grant)

Donald E. Troxel

Since August 1970 we have been developing an entirely new news picture (Wirephoto) distribution system for the Associated Press. It 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 that 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 interventions, 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 a PDP-11 computer (48k core, 38 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.

The multitask software operating system permits new picture-processing operations to be integrated easily and we plan to keep incorporating additional picture-processing routines to the system.