XXXII. COGNITIVE INFORMATION PROCESSING*

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RESEARCH OBJECTIVES AND SUMMARY OF RESEARCH

The primary research interest of this group is in the real-time acquisition and processing of visual information for display to the visual and nonvisual senses, and in the psychology of human utilization of such information, for both communication and control. The motivation is an interest in human capabilities for information processing and in human information requirements. Applications include sensory-aids systems for the blind and the blind-deaf, picture-transmission systems, and special information-display systems for enhancement of human performance under conditions of stress.

Major projects now in progress include studies on reading machines, picture processing, pattern recognition, and automatic processing of visual data of significance in studies of biology and medicine.

1. Reading Machine Studies

Research during the past few years in the Cognitive Information Processing Group of the Research Laboratory of Electronics has led to the construction and operation of an experimental reading system for the blind. In its present configuration the system consists of a document-handling carriage, a flying-spot opaque scanner, a digital scanner control unit, and a general-purpose medium-sized computer (PDP-1). Focusing, black-and-white threshold setting and document loading are manually controlled by a sighted operator. The scanner control unit operating under control of the computer program reports coordinate letter contour and other statistical information of the view in the scanner field. This information is used for the generation of signatures that are

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searched in a signature table for the identification of the letters. The signature table is built up through training sessions. Identified letters are spelled out, one at a time, through the use of digitized speech samples. The present output rate of the spelled speech is 60-80 words per minute. Experience has indicated an identification error rate of approximately 0.3% with a type font which the machine has been trained on.

Another objective for future research is to evaluate the reading machine under conditions of actual use by blind subjects. For this objective, an improved input system which allows the use of books in their normal form is needed.

a. Character Recognition

A new character recognition algorithm has been devised and tested. The preliminary results of this algorithm, which involves the determination of extrema along the x,y, x+y, and x-y axes, are quite encouraging and a more rigorous evaluation is in progress.

The character-recognition algorithm used in the reading machine system has been tested on printing containing touching letters. A recursive procedure was employed with good success. The problem of broken letters has yet to be investigated.

b. Opaque Scanners

A new opaque scanner with a wider field of view and an improved document handler is in the final phases of construction. A scheme for reading specified portions of a vidicon television camera into computer memory is in the design phase. A longer term goal is the construction of a hand-held probe, utilizing fiber optics to couple the print image to the vidicon camera.

c. Tactile Displays

A 6×8 matrix of solenoid-powered poke probes has been interfaced to the PDP-1 computer. Under construction is an electrotactile matrix display that will be used to study both static and dynamic tactile perception.

d. Transformed Speech

Experiments are being planned to determine whether subjects are able to learn to recognize transformed speech. The transformation to be considered in the first set of experiments consists of inverting the spectrum of speech utterances, i.e., $T(f) = 1/f$, and playing back the inverted speech to the subjects.

e. Graphics

Under construction is a line drawing CRT display. Projects to be undertaken this year include the design and construction of a display processor and the construction of a "mouse" that will allow an alternative means of operator interaction with our computer. Of considerable interest is the general area of computer graphics and computer-aided logic design.

f. Phonetic Translation of English Text and Artificial-Speech Generation

Artificial-speech generation from input consisting of English sentences in normal spelling was successfully accomplished in March 1967. The implementation then by-passed the syntactic analysis and made use of only lexical stresses and punctuation marks for suprasegmental control. Since then, work has been concentrated in two areas. The first is the search of a minimal syntactic analysis consistent with the reading-machine objective. The second is the improvement of speech quality within the limitations of our speech synthesizer.

g. Real-Time Data-Processing Facilities

A PDP-9 computer has been ordered which will serve the real-time data-processing needs of our entire group. All activities associated with the reading-machine project will be transferred to use the new facility.

Also, the problem of machine-aided speech recognition through operations on speech spectrograph data, will be investigated. A logical unit to perform Fourier transforms at high speed is under design consideration, to be an important element of the real-time data-processing facilities.

F. F. Lee, D. E. Troxel

2. Picture-Processing Studies

Picture-processing research is concerned principally with processing and encoding picture signals for efficient transmission, subject to a quality constraint in the received picture. Subsidiary matters concern picture processing for quality improvement or for feature recognition.

a. Picture Quality

Our long-range goal is to develop objective measures correlating with subjective rating of picture quality. As a preliminary goal, we need to establish subjective rating on a more satisfactory basis. At present, it is not possible to compare such evaluations made on different systems, using different subjects, different observers, at different times. To facilitate such comparison, we are producing a new set of standard subjects. For each subject we are making a set of standard photographs in which the quality and data rate are varied, and in which, for each data rate, the system is PCM, with pseudo-random noise used to eliminate spurious contours. These sets of pictures should permit accurate evaluation of quality and coding efficiency of new systems by a matching process.

b. Picture Coding

We have continued work on efficient coding of two-dimensional contour data as part of our development of artifact-free compression systems. The current work involves the fitting of quadratic curves to outlines of objects in the image.

c. Optimal Image Processing

Our principal interest is in using optics as a tool for picture processing. In particular, we are interested in developing links between digital computers and coherent optics so that the two can be used to complement each other. Applications under consideration include matched-filter detection, and holographic television systems.

d. Noise Measurement of Visual Acuity

We are now planning an experiment in which flickering noise patterns of known spatial frequency distribution will be used to measure visual acuity. Since the viewing of these stimuli does not require fixation, it is expected that the results will be more applicable to normal viewing conditions than previous measurements, for which sine-wave charts or Bessel-function patterns were used. We hope that some light will be shed on the general problem of noise visibility, as well as picture quality assessment.

W. F. Schreiber, T. S. Huang

3. Pattern-Recognition Studies

"Pattern Recognition" is a common theme underlying the projects described above, whether the task is accomplished by human cognition, by computer data processing or, most commonly, by a combination of the two.

Complementary to the task-oriented projects, the following research studies in the general area of pattern recognition are being carried out.

a. Psychophysics of Depth Perception

This project is designed to provide information on a subject's ability to make accurate judgments of distance and orientation with respect to real and illusory three-dimensional objects. The variation of such judgment is being studied without feedback, as well as with a continuous auditory error signal.

Results, thus far, indicate that human observers make remarkably accurate judgments of the location of illusory objects when their appearance is equivalent in perspective to that of a veridical cube. This ability appears to be related to perception of parallelism of lines viewed in perspective.

b. Effects of Spatial Transformation of Text upon Reading and Writing Performance

It has been shown that systematic transformations or printed text (such as inversions or rotations of letters and of words) produce regular changes in the learning rate, as well as in the asymptotic reading rate. These studies are being extended to a wider class of transformations and also to reading and writing performance, with cursive script used as the text.

c. Automatic Extraction of Information from Printed Sheet Music

With the aid of the scanner and ancillary equipment developed for the projects described above, it is possible to program a computer to determine note value, duration, phrasing, and certain other music indicators from ordinary printed sheet music. This study is being continued to see what additional parameters can be extracted by automatic recognition.

d. Cognitive Processes — Language Comprehension

Research will be directed toward clarifying the nature of the quick perception and comprehension of written information by studying how normal and speed readers interpret words and sentences presented tachistiscopically. The ability to detect various syntactic and semantic differences between a known sentence and a briefly presented one will be especially studied.

e. Visual Perception and Eye-Movement Relations

We shall explore the ability of the system controlling eye movements to learn to follow points or scan lines whose positions are modified in determinate ways by movement of the eyes. Of especial interest will be the effect of eye-movement adaptation on the perception of motion and form.

M. Eden, P. A. Kolers

4. Biological Image Processing

Biological image processing deals with the acquisition and analysis of visual patterns that are important to medicine and biology. The picture-processing facilities described above are being used to explore the feasibility of using fully automatic techniques or machine aids to human classification of such objects as white cells, chromosome counting, particle counting in micro-autoradiographs, and three-dimensional visualization of micro-anatomic structures.

a. Chromosome Karyotyping

The chromosome analysis project continues along two paths. We are developing programs for fully automated computer karyotyping systems. During the coming year, we expect to concentrate on developing programs that will parse images into individual chromosomes on the basis of the contextual structure, such as regions of high density, linear aggregations of density, and symmetry. A second project will concentrate on a man-machine system. The chromosome shapes will be traced on a Grafacon (Rand Tablet), and the computer will construct a karyotype from these data.

b. Biological Structures

A project to develop computer aids for neuroanatomy has been started. We hope to develop initially an input procedure for describing several of the nuclei in a cat's superior olivary complex, and to produce three-dimensional drawings of their structures.

c. Papanicolaou Smear Scanning

This project will aim at developing metrics that distinguish between malignant and nonmalignant cells. We shall also look for procedures for rejecting cells not relevant to the analysis of cancer.

d. Differential White Cell Counting

Work continues on the development of algorithms to distinguish the different types of white cell in blood smears. Several pre-processing procedures have been programmed so as to distinguish the white cells from the red cells and background. Other "filtering" procedures will be studied with the end of separating the cytoplasm from the nuclear material of the white cells. We intend to identify the white cells primarily from the morphological properties of the nuclei and their different spectral properties.

e. Branching Structures

Algorithms have been devised for generating two-dimensional venation patterns such as are typified by tree leaves. The parameters of the algorithm serve as data for a possible classification of leaf type according to species. The work will be extended to measure the analogous parameters of actual leaves by picture-processing techniques.

M. Eden, O. J. Tretiak

A. SAMPLED FRAUNHOFER HOLOGRAM GENERATED BY COMPUTER

1. Introduction

The problem of generating holograms by computer has been considered by many authors.[1-5] Generally speaking, to produce such a hologram, we first compute the amplitude of transmission, H(u), of the hologram transparency by a digital computer. Then the function H(u) is plotted on a plotter that is guided by a computer. In our case, it will be displayed on a scanner. Thus far, two different forms of H(u) have been used for the amplitude of transmission of the hologram. A brief discussion of the two forms follows.

a. Gabor's Hologram and Its Modified Form[1,4-6]

For a Gabor hologram H(u) is represented by

$$H(u) = \left|A\exp(jau) + |F(u)|\exp(j\phi(u))\right|^2 \tag{1a}$$

$$= A^2 + |F(u)|^2 + 2A|F(u)|\cos(au+\phi(u)) \tag{1b}$$

In Eq. 1, $|F(u)|\exp(j\phi(u))$ is the Fourier transform of the object f(x). Thus the function H(u) is the amplitude transmission of a Fraunhofer hologram. As is shown in Eq. 1b, the information about the original object is contained entirely in the third term. The presence of the biasing term $A^2 + |F(u)|^2$ is only to insure the non-negativeness of the function H(u). It is obvious that when a digital computer is used to generate H(u), other biasing schemes can be used, too. For instance,

$$H(u) = B + |F(u)|\cos(au+\phi(u)), \tag{1c}$$

where B is a positive constant, or

$$H(u) = |F(u)|\{1+\cos(au+\phi(u))\}. \tag{1d}$$

A detailed discussion on generating H(u) in this form has been given by Huang and Prasada.[1] An intrinsic problem when having a biasing term in H(u) is that it reduces the range of intensities that can be displayed on a scanner.

b. Binary Hologram[2,3]

In 1966, Brown and Lohmann[2] showed for the first time that the complex function $|F(u)|\exp(j\phi(u))$ can be expressed in binary form; that is, H(u) has values that are either 0 or 1. For the binary hologram, H(u) is equal to

$$H(u,v) = \sum_{m=1}^{N} r\left[\frac{u-(m-P_m)d}{\frac{1}{2}d}\right]\cdot r\left[\frac{v-md}{W_m d}\right], \tag{2}$$

where

$$r(u) = \begin{cases} 1 & \text{if } |u| \leq \frac{1}{2} \\ 0 & \text{otherwise} \end{cases}$$

and d is the sampling distance of the function $|F(u)| \exp(j\phi(u))$. In Eq. 2, P_m and W_m are proportional to the phase $\phi(u)$ and the amplitude $|F(u)|$ at $u = md$, respectively. Therefore, according to their technique, the hologram is divided into $N \times N$ sampling cells, and inside each sampling cell there is a small aperture. The position and the area of the aperture are determined by P_m and W_m, respectively.

Usually, the plotting of the binary hologram is done on a plotter guided by a digital computer. The technique becomes very inefficient, however, when the plotter is replaced by a scanner. First, when simulating a sampling cell on a scanner, to allow for 10 levels of quantization of the phase $\phi(u)$ requires 10×10 points. With a scanner having 512×512 points, only a hologram of 51×51 samples can be produced. This difficulty is eliminated by the technique that we shall present here. It will be shown that these 512×512 points on the scanner can be used to produce holograms having 128×128 samples.

2. Sampled Fraunhofer Hologram

a. One Property of the Shifted Sampled Function

Suppose that we have a real, non-negative function G(u). G(u) is also bandlimited and has a bandwidth W. Then the sampled function $G_s(u)$ can be written

$$G_s(u) = G(u) \cdot \sum_{m=-\infty}^{\infty} U_o(u-m/W-b), \tag{3}$$

where $U_o(u)$ is the Dirac delta function, and b is the constant showing the shifting when the samples are taken. From Eq. 3, the Fourier transform $g_s(x)$ of the sampled function $G_s(u)$ can be expressed in terms of the Fourier transform of G(u).

$$g_s(x) = \sum_{m=-\infty}^{\infty} g(x-mW) \exp(j2\pi mbW)$$

$$= \sum_m f_m(x), \tag{4a}$$

where

$$f_m(x) \triangleq g(x-mW)\ \exp(j2\pi mbW). \tag{4b}$$

In Eq. 4, $g(x)$ is simply the Fourier transform of $G(u)$. As we have stated, $g(x)$ is nonzero only for $|x| \leq W/2$. Therefore there will be no overlapping between the adjacent functions in Eq. 4, and $G(u)$ can be obtained from the function $f_m(x)$ for any value of m. Furthermore, we note that each of the functions $f_m(x)$ also contains a constant phase factor $\exp(j2\pi mbW)$. It is this phase factor which will be used to provide the phase information of the complex function $|F(u)|\ \exp(j\phi(u))$.

For the moment, let us consider the function $f_1(x)$.

$$f_1(x) = g(x-W)\ \exp(j2\pi bW). \tag{5}$$

Hence, by choosing the value b properly, we can change the phase of the function $G(u)$. For example,

$$\text{If} \quad b = 1/2W \qquad f_1(x) = -g(x-W) \tag{6a}$$

$$\text{If} \quad b = 1/4W \qquad f_1(x) = jg(x-W) \tag{6b}$$

$$\text{If} \quad b = -1/4W \qquad f_1(x) = -jg(x-W) \tag{6c}$$

Now we are ready to show how a complex function can be obtained by combining shifted sampled functions.

b. Generating $|F(u)|\ \exp(j\phi(u))$ by Superposition of Shifted Sampled Functions

First, we write the complex functions $|F(u)|\ \exp(j\phi(u))$ in terms of its real and imaginary parts.

$$|F(u)|\ \exp(j\phi(u)) = |F(u)|\ \cos\ \phi(u)\ + j|F(u)|\ \sin\ \phi(u) \tag{7}$$

From Eq. 7, we can define four more functions.

$$H_1(u) = \begin{cases} |F(u)|\ \cos\ \phi(u) & \text{if } \cos\ \phi(u) > 0 \\ 0 & \text{otherwise} \end{cases} \tag{8a}$$

$$H_2(u) = H_1(u) - |F(u)|\ \cos\ \phi(u) \qquad \text{for all } u \tag{8b}$$

$$H_3(u) = \begin{cases} |F(u)|\ \sin\ \phi(u) & \text{if } \sin\ \phi(u) > 0 \\ 0 & \text{otherwise} \end{cases} \tag{8c}$$

$$H_4(u) = H_3(u) - |F(u)|\ \sin\ \phi(u) \qquad \text{for all } u \tag{8d}$$

By definition, $\{H_i(u)\}$ are real and non-negative functions; and

$$|F(u)| \exp(j\phi(u)) = \{H_1(u)-H_2(u)\} + j\{H_3(u)-H_4(u)\}. \tag{9}$$

Therefore,

$$f(x) = \{h_1(x)-h_2(x)\} + j\{h_3(x)-h_4(x)\},$$

where $\{h_i(x)\}$ are the respective Fourier transforms of $\{H_i(u)\}$.

We shall show that f(x) is contained in the Fourier transform of the function $H_o(u)$.

$$H_o(u) = H_1(u) \cdot \sum_m U_o(u-m/W) + H_2(u) \cdot \sum_m U_o(u-m/W-1/2W)$$

$$+H_3(u) \cdot \sum_m U_o(u-m/w-1/4W) + H_4(u) \cdot \sum_m U_o(u-m/W+1/4W) \tag{10}$$

$H_o(u)$ is a sampled function and its sampling distance is equal to $\frac{1}{4}W$. Furthermore, the samples of $H_o(u)$ are real and non-negative. The Fourier transform of $H_o(u)$ is

$$h_o(x) = \sum_{m=\infty}^{\infty} \{h_1(x-mW)+h_2(x-mW) \exp(jm\pi)+h_3(x-mW) \exp(jm\pi/2)+h_4(x-mW) \exp(-jm\pi/2)\} \tag{11a}$$

$$= \sum_{m=-\infty}^{\infty} f_m(x) \tag{11b}$$

where

$$f_m(x) = h_1(x-mW) + h_2(x-mW) \exp(jm\pi) + h_3(x-mW) \exp(jm\pi/2) + h_4(x-mW) \exp(-jm\pi/2). \tag{11c}$$

For m = 1,

$$f_1(x) = \{h_1(x-W)-h_2(x-W)\} + j\{h_3(x-W)-h_4(x-W)\}$$

$$= f(x-W). \tag{12}$$

Note that each of the functions $\{h_i(x)\}$ are complex. Whenever f(x) is a real function, it is very easy to show that

$$f_{-1}(x) = f(-x+W). \tag{13}$$

We have shown that $H_o(u)$ is a non-negative function, and the Fourier transform of $H_o(u)$ gives the original function f(x). Therefore $H_o(u)$ can be used as the amplitude transmission of the hologram. Moreover, if we pass only the function $f_1(x)$, after one more Fourier transformation, we can obtain the complex function $|F(u)| \exp(j\phi(u))$.

3. Experiment

The object f(x) used for our experiment consists of the letters M I T. They are punched on IBM cards and used as the input to the computer program. The Fourier

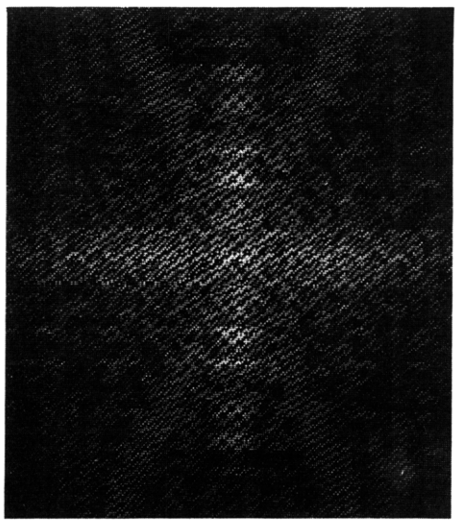

Fig. XXXII-1. Holograms of letters M I T.

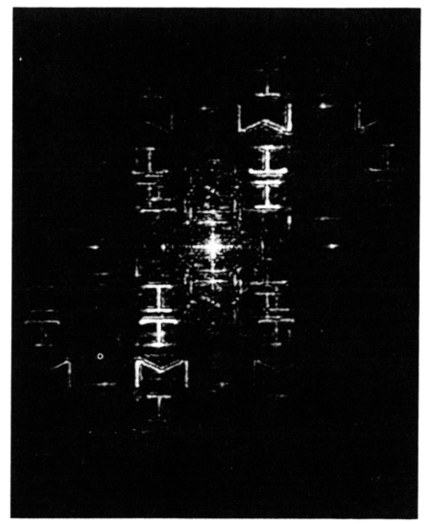

Fig. XXXII-2. Image reconstructed from the holograms in Fig. XXXII-1.

transform of the letters is obtained by a Fast Fourier transform subprogram. After the function $H_o(u)$ is generated it is recorded on tapes to be displayed on the scanner in our laboratory.[8] At present, the object is a 64×64 array of sampled points. According to Eq. 10, $H_o(u)$ will be a 256×256 array. Figure XXXII-1 shows the hologram taken directly from the scanner on Polaroid Type 47 film. This picture is photoreduced to 3 mm × 3 mm on Kodak high contrast film. The reconstruction of the image from the hologram is shown in Fig. XXXII-2.

4. Discussion

The method presented here is similar to the binary hologram. Both methods use the positions of the samples of the hologram transparency to produce the complex phase information. In many aspects, the hologram produced by our method is better than the binary hologram. For instance, in plotting the binary hologram, the phase function is quantized into levels. The number of levels of quantization depends on the size of the sampling cell used in the plotting. For a sampling cell of $\frac{1}{4}$ in. $\times \frac{1}{4}$ in. there are only 25 levels of quantization. In our case, because of the structure of the sampled hologram, there is no explicit quantization on the phase function $\phi(u)$. But since the scanner can only display 256 levels of intensities, $\phi(u)$ is implicitly quantized into 4×256 levels. Thus the error in the representation of the phase resulting from quantization is smaller in the sampled hologram. This is the main advantage of our technique. At the same time, when a hologram is produced on a plotter, the plotting time for a hologram having 64×64 samples is approximately 30 minutes. But with a scanner it can be obtained in approximately 2 minutes. Thus far, the limitation on our method is due to the total number of resolvable points which can be displayed on our scanner. At present, the scanner has only 512×512 resolvable points. Hence holograms having more than 128×128 samples cannot be produced on the scanner. Future projects in this area would be to apply this method to display 3-dimensional objects, and to study the effects of different quantization schemes on the quality of the image reconstructed from a hologram.

W-H. Lee

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