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SESSION II ADDRESS

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An autocorrelation theory of visual form detection: A computer experiment and a computer model

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A theoretical model is described for the effect of the organizational properties of dotted visual forms on visual form detection. The model assumes that a human observer functions more as an organization detector than as a feature detector. It is supported by a wide variety of experimental studies of human perception.

This paper, which I was privileged to present at the IVth Annual National Conference on the On-Line Uses of Computers in Psychology, is an abbreviated version of a book (Uttal, 1975) that is scheduled to be published at exactly the same time as the Proceedings of the Conference appear in *Behavior Research Methods & Instrumentation.* It would be both wasteful of journal space and difficult for me to attempt to duplicate the entire body of information I have obtained from 2 years of psychophysical experimentation and computer simulations. I, therefore, have taken advantage of the cordial invitation of our Editor, Professor Sidowski, to present what, in actuality, is only an elongated abstract of the talk, and of the book, in place of a full exposition of my work.

THE GOALS

The specific goal of this project was to determine how the organizational properties of dotted visual forms affected visual form detection by developing a theoretical model that could be compared with specifically relevant psychophysical experiments. The project was guided by the premise that the human observer performs more as a global form or organization detector than as a feature detector. This premise is based upon first approximations to a wide variety of findings from experimental studies of human perception. Frankly, I must admit that I began this research because I was not content with the uncritical way in which modern discoveries of neurophysiological single-cell feature detecting mechanisms were being applied to, what seemed to me to be, an overly wide variety of perceptual problems. It must be kept clearly in mind that the work that I present here is exclusively a study of a highly specific perceptual process—pattern detection in noise—that is but one of a hierarchy of visual skills that vary from the most peripheral physical interactions of stimuli to the most central symbolic information processing tasks. It is therefore a highly circumscribed theory.

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THE METHODS

My general approach to the problem was to carry out a series of psychophysical experiments in which dotted stimuli were systematically varied along individual dimensions that characterized some aspect of form or pattern. The effect of variations in these dimensions was measured by a detection task in which the stimulus pattern was degraded by embedding it in an additional number of masking dots. The relative effect of a single dimensional variation on the percentage of the stimuli that were correctly detected in a two-alternative, forced-choice, computer-controlled tachistoscopic procedure made up the relevant psychophysical data base. Figure 1 shows a typical stimulus in four different stages of degradation, achieved by using four random-dot masking densities.

This psychophysical data base was then compared to the results of a computer simulation model based

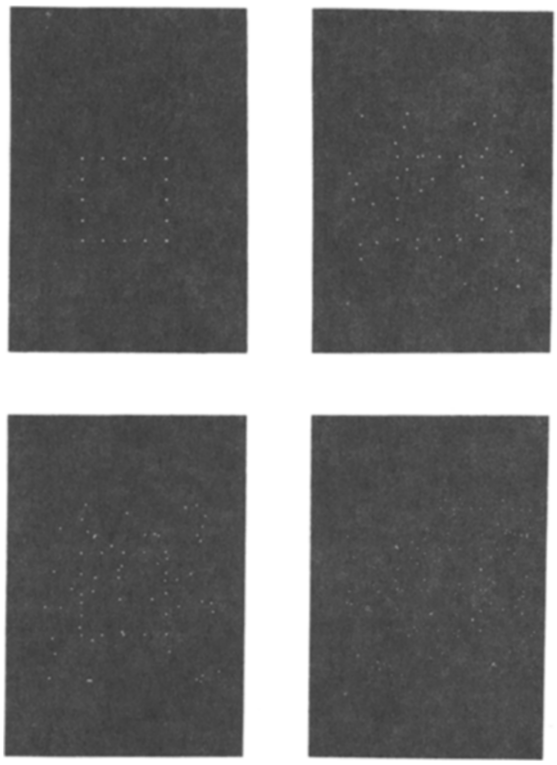

Figure 1. A dotted square presented in four different levels of masking noise (n = 0, n = 30, n = 50, and n = 100). Note the progressive decline in the detectability of the square as the number of masking dots increases.

upon an autocorrelation transformation that operated on simulated samples of the stimuli. The autocorrelation model was formalized by the following equation:

$$A(\Delta x, \Delta y) = \iint f(x,y) \cdot f(x + \Delta x, y + \Delta y)\, dy\, dx,$$

where Δx and Δy are shifts in the positions of the stimulus pattern $f(x,y)$. A family of $A(\Delta x, \Delta y)$ values must be computed to fill the autocorrelation space. A sample of four simulated stimuli that can serve as inputs to the autocorrelation processor and four photographs of the computer plot of their autocorrelated outputs are shown in the four plates of Figure 2.

The autocorrelational space is made up of a number of peaks distributed in the $\Delta x, \Delta y$ space. By applying the following empirical expression:

$$F_m = \frac{\sum_{i=1}^{I} \sum_{n=1}^{N} \frac{A_i \cdot A_n}{D}}{N} \quad (i \neq n)$$

a single numerical "figure of merit" (F_m) was generated for each autocorrelation. In this expression, A_i and A_n are the amplitudes of peaks taken pairwise, D is the distance between the two peaks, and N is the number of peaks. This figure of merit, it was hypothesized, should be associated with the detectability of the figure as measured psychophysically. In Figure 2, the three-digit numerals represent the figure of merit for the four autocorrelations.

THE PSYCHOPHYSICAL DATA

The effect of variation of a number of different dimensions of pattern were evaluated in the psychophysical experiments. Specifically, we considered the effects of each of the following dimensions and found that the results indicated: (a) Dot numerosity—more dots, more detectable; (b) line orientation—no effect; (c) deformation of straight lines into curves and angles—more deformation, less detectable; (d) colinear dot-spacing irregularity—more irregular, less detectable; (e) transverse dot-spacing irregularity—more irregular, less detectable; (f) missing parts in triangles—sides were more important than corners; (g) polygonal orientation—no effect; (h) distortions of squares into parallelograms—more distortion, less detectable; (i) organized straight line patterns vs. "pick up stix" patterns composed of the same lines—more organized, more detectable; (j) distortions of squares and triangles by misplacing one or more corners—more distortion, less detectable; (k) figural goodness—no effect. Figure 3 shows a sample set of stimuli, and Figure 4 shows the psychophysical data obtained in a sample experiment.

RESULTS OF A COMPARISON WITH THE MODEL

The order of detectability of the patterns in each of the experiments was compared with the order of the figures of merit from the simulation. In almost every case, the two rank orders were in agreement. The type of agreement may be seen by comparing the data of Figure 4 with the figures of merit in Figure 2. There were, however, some discrepancies between the two rankings. There were some conditions in Experiment i which produced differences in the figure of merit in the simulation but no comparable differences in psychophysical performance. Furthermore, while the patterns of Experiment k that varied in "figural goodness" were in substantial agreement with the psychophysical data, there were some reversals of order that appear to be mainly due to a lack of sensitivity on the part of the model to patterns that possess preponderantly diagonal arrangements of the constituent dot patterns. All of these discrepancies are believed to be due to deficiencies in the formulation of the empirical figure of merit expression. It is believed that, with minor modifications of this expression, the model could provide a substantially better fit between the theory and the psychophysical findings.

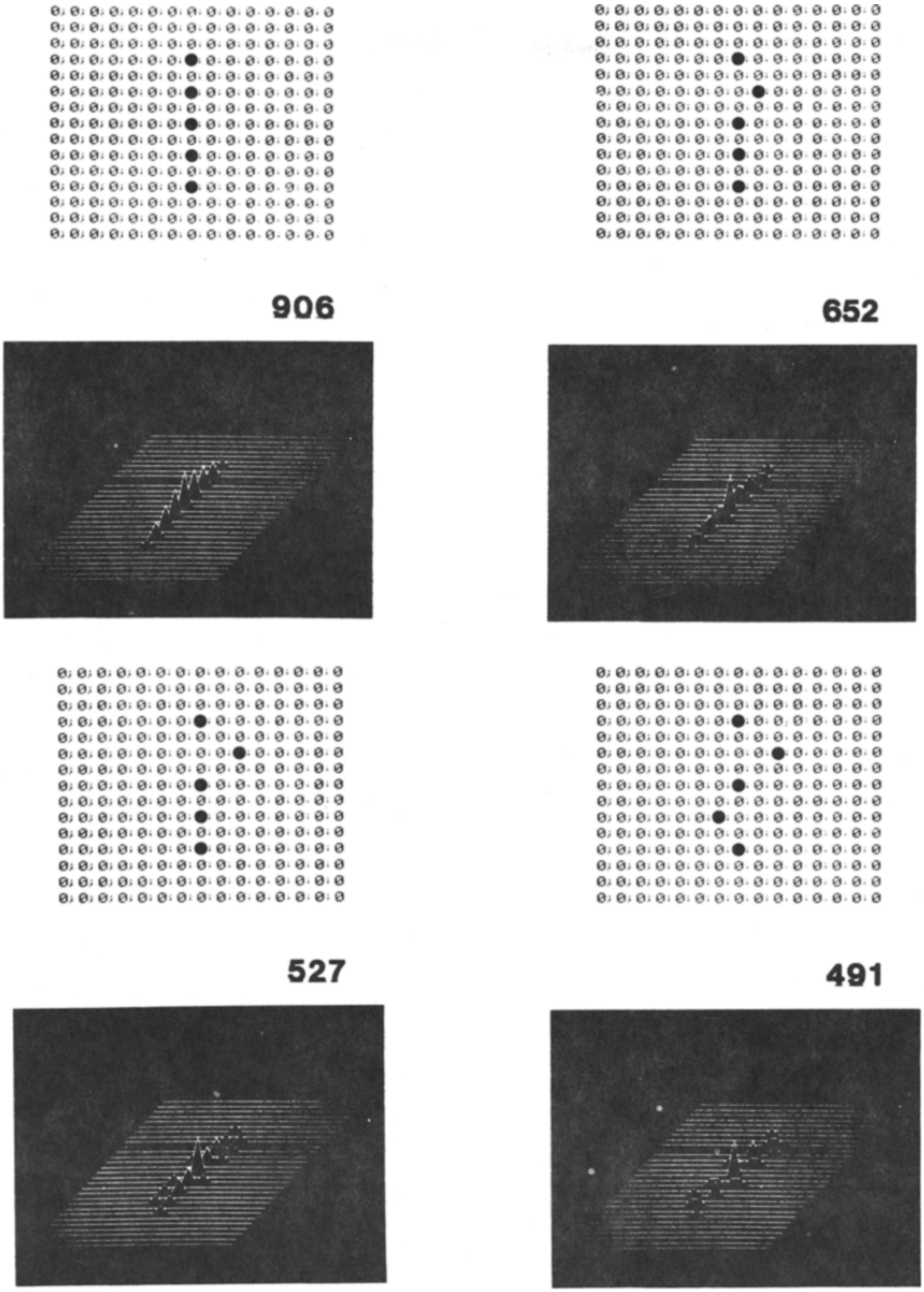

Figure 2. Four simulated stimuli and their autocorrelations showing the effect of transverse dot-spacing irregularity on the figure of merit (indicated by the three-digit numerals). The greater the deviation from regularity, the lower the figure of merit.

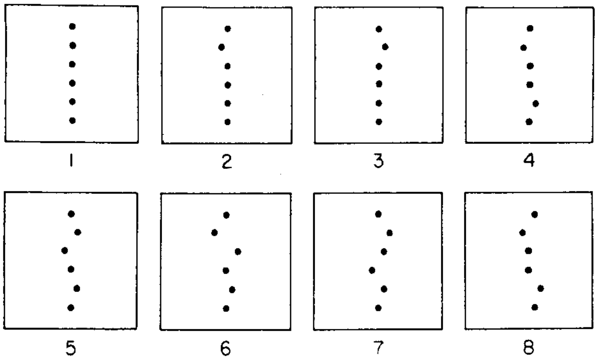

Figure 3. Sample target patterns used in the psychophysical experiment determining the effect of transverse irregularity on line detection.

CONCLUSIONS

The autocorrelation model proposed here is a specific alternative to any model that emphasizes highly specific feature-sensitive single neurons. The autocorrelation process is able to mimic a considerable amount of the psychophysical data obtained in these and related studies on the basis of information processing by a purely homogeneous network of undifferentiated neurons such as that shown in Figure 5. This is not to say that single cells, selectively responsive to various parameters of shape and time, are not to be found in the nervous system; the basic neurophysiological observations have been too often replicated to challenge their essential message. However, it may be appropriate to reexamine what these response categories mean. Instead of playing the role of the actual feature-filtering *mechanisms* of the form detection process itself, these single-cell responses may reflect the output of some other distributed network type of detection mechanism. They may be, in a certain

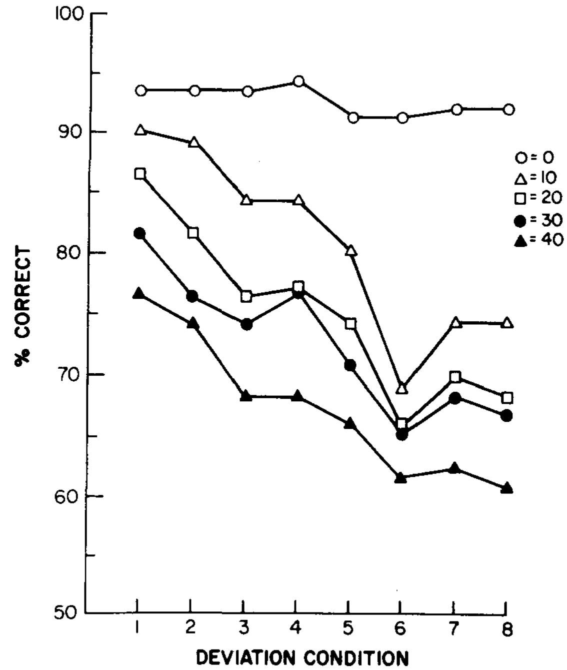

Figure 4. Graph showing the effect of transverse irregularity on the detectability of straight lines. The greater the transverse irregularity, the less detectable is the line. Parameter indicates the masking dot density.

sense, *responders* or *effectors* indicating the function of some more fundamental algorithmic processing mechanism such as the autocorrelator. In some way, they may be like the figure of merit expression.

It is evident how a theoretical perspective drastically changes as the emphasis shifts from the one approach to another—from a restrictive theory that concentrates on single cells as feature filters to one that encompasses the action of an ensemble of neurons acting as a collective parallel information processor in an algorithmic fashion. This change in

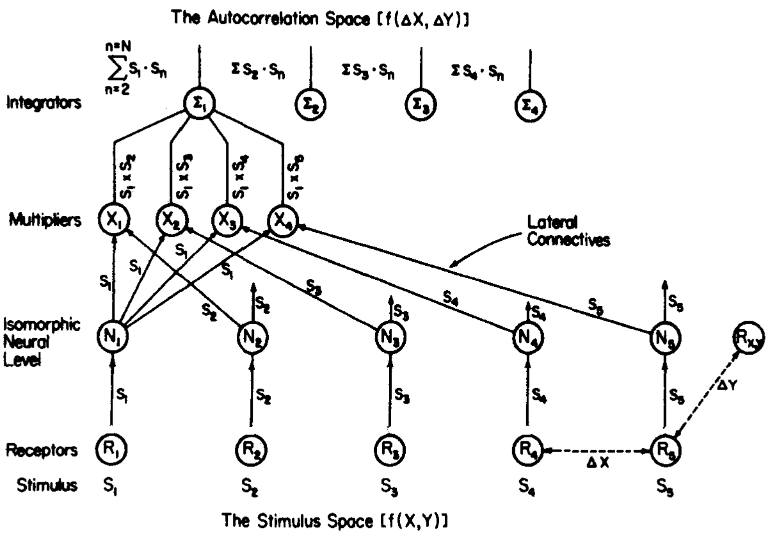

Figure 5. Schematic drawing of a hypothetical, but plausible, neural information processing net that could produce the autocorrelation transform. Stimulus patterns are transformed from the x,y real-world space at the bottom of the figure to the Δx,Δy autocorrelation space at the top by simple neural interconnections. The neural "units" indicated may be single cells or more complex subunits. The figure is shown only to illustrate the relative ease with which the neural autocorrelator can be implemented, and should not be taken too literally as a "true model."

emphasis is the essential result of this study, for purely on intuitive and aesthetic grounds, the difficulty of assigning priority to one neuron or type of neuron in a network made up on many millions is an inescapable concomitant of any theory based on the function of specialized single cells. Even the simplest perceptual phenomena, all would agree, must be based on the concatenated action of many millions of neurons. A priori, network theories seem to be more authentic descriptions of what is actually going on in the brain than those based on single-cell functions.

What the present autocorrelation model does by its substantial agreement with the psychophysical data is to suggest a perspective alternative to those commonly accepted by contemporary psychobiologists. This perspective is characterized by distributed, homogeneous, interconnected, algorithmically processing networks of neurons rather than specialized, feature-sensitive single cells.

A SUMMARY

The main points that I believe my work has made may be summed up as follows.

(1) The autocorrelation model provides a fairly good fit to a wide variety of psychophysical data.

(2) It represents a unique and simple implementation of a specific algorithmic processor; however, it is not mathematically unique.

(3) No novel or unlikely neurophysiological mechanisms are necessary to make it work.

(4) The neurons in the proposed network are homogeneous. This approach places the emphasis on parallel, algorithmic processing rather than on unlikely mechanisms that require templates, exhaustive searches, or an infinite number of individually tuned cells.

(5) My major conclusion is that this work, as well as that of others who are working on related projects, provides an alternative conceptual approach to the ways in which the nervous system may be processing pattern information. It emphasizes global form, rather than component parts, and thus more closely approximates the observed facts of human perception. The key idea is that *the arrangement of the parts is more important than the nature of the parts*. In this regard, it reflects a theory of perception that is more holistic (Gestaltist) than featuristic.

REFERENCE

Uttal, W. R. *An autocorrelation theory of visual form detection*. Hillsdale, N.J: Lawrence Erlbaum, 1975. (Distributed by the Halsted Press of Wiley.)