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ABSTRACT

An explanation of visual perception is presented using physiological facts, analogies to digital computers, and analogies to the structure of written languages. According to the explanation, visual input is discontinuous, with the discontinuities mediated by and correlated with the jumps of the eye. This is analogous to the gated and buffer-stored input of a digital computer and raises answerable questions as to how other sense-modalities are inputted--whether in series or parallel with visual input. Drawing analogies to other information-bearing systems, such as printed language, helps clarify certain issues. Just as printed language has a hierarchical structure with sets and elements of letters, words, and sentences (with the sizes of the sets increasing up the hierarchical scale), so in the brain there must be an analogous hierarchy, with nerve spikes as the lowest set and the "packages" of discontinuous visual input as a higher level. The establishment of a discontinuous input model, with lucid alternatives of intermodality processing, leads to a computer-analogy model of behavior as a hierarchically structured chain of states which define acts. Figures and references are given. (Author/DE)

EYE MOVEMENTS AND PERCEPTION

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Paper to be presented at the conference on "INFLUENCE OF EARLY EXPERIENCE ON VISUAL INFORMATION PROCESSING: A Conference on Underlying Factors in Perceptual and Reading Disorders" sponsored by the Committee on Brain Sciences of the National Research Council-National Academy of Sciences at Lake Mohonk, New York, October 27-30, 1968.

ABSTRACT

An explanation of visual perception is presented using physiological facts, analogies to digital computers and analogies to the structure of written languages. According to the explanation, visual input is discontinuous (or gated or step-functioned or intermittent or packaged or sampled), with the discontinuities mediated by and correlated with the jumps of the eye. This is analogous to the gated and buffer-stored input of a digital computer and raises answerable questions as to how other sense-modalities are inputted - whether in series or in parallel with visual input. Drawing analogies to other information bearing systems, such as printed language, helps clarify certain issues: just as printed language has a heirarchical structure with sets and elements of letters, words, and sentences (with the sizes of the sets increasing up the heirarchical scale), so in the brain there must be an analogous heirarchy, with nerve spikes as the lowest heirarchical set and the "packages" of discontinuous visual input at a higher heirarchical level.

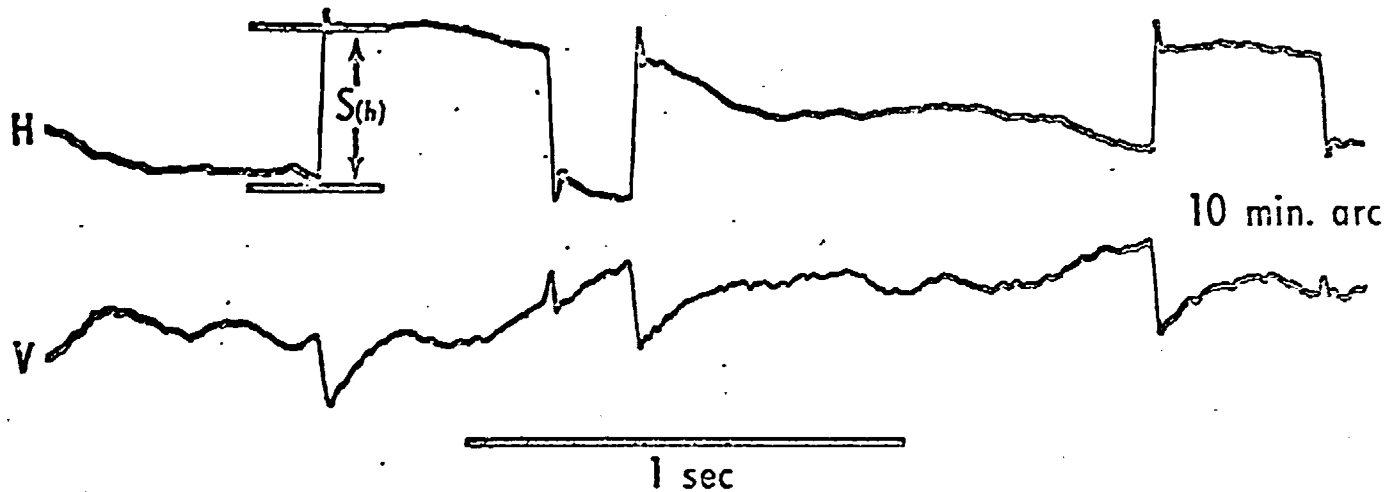
The establishment of a discontinuous input model, with lucid alternatives of inter-modality processing, leads to a computer-analogy model of behavior as a heirarchically-structured chain of states which define acts. This can be of great value in understanding reading and perceptual disorders.

A fundamental issue in understanding reading disability is the physiology of visual information processing. The understanding of this, in turn, is dependent upon recognizing the role of eye movements in perception. Older work on eye movements in reading (reviewed by Tinker, 1958), combined with the ideas I shall present today, show how one way of viewing reading disabilities and perceptual disorder is in terms of ineffective programming of visual input related to faulty functioning of eye movement mechanisms. In order to fully understand this, it is necessary to grasp the extent to which the perceptual process is dependent upon eye movements. Most of what I shall say today is an examination of the mechanisms whereby eye movements mediate perception. Naturally, we will note that eye movements and perception during reading represent but special cases of eye movements and perception in a wider context. By first considering eye movements and perception in general, we will hope to be in a position to understand them better in reading and in disordered perception. In carrying out our tasks it is also appropriate for us to pause a moment to reflect upon how much our understanding indirectly rests upon the important work of many of the justly-regarded participants of this conference. Unfortunately, in order to achieve sharp focus we will not be able to acknowledge our indebtedness to most of this work.

I will attempt today to establish two main points. The first is that the input of visual information is discontinuous (or packaged or sampled or gated or chopped or intermittent or incremental or step-functioned), with the discontinuities mediated by jumping eye movements. Of this I will say a great deal more very shortly. The second point to be established is that we may usefully conceive of a hierarchical structuring of intrinsic units of visual perception, wherein eye movements determine the nature of the units at one level. This latter point may best be understood by drawing analogies to other information bearing systems. We shall arbitrarily chose printed language as an example of another information bearing system partly because it will lead back to further consideration of one focus of this meeting - upon reading.

We will now take a bit of time to look at the question of discontinuity of visual input (Gaarder, 1966). There are two major reasons why scientists have previously not generally recognized the lucid insight into discontinuity of visual input which we will examine today. The first of these is that vision is subjectively experienced as continuous over time and that our conceptual construct of the real external visual world is overwhelmingly one of temporal continuity. In other words, as we experience our visual world we are aware of no "breaks" in the time during which our eyes move about nor does this world seem made up in any way of "parts". This is in sharp contrast to the facts of the input process, as will later become apparent. The second reason for previously not appreciating discontinuity is that until the arrival of the computer age the distinctions between "continuous" and "discontinuous" processes were not so concretely and tangibly burned into our brains as they have been since we have begun to use these problem-solving machines - which are either analog or digital, continuous or discontinuous. The issue being posed is between an information processing system which takes in information continuously over every instant of time versus one which moves in steps, or incrementally, so as to process information in chunks or samples or packages or packets or quanta. A few examples of continuous and discontinuous processes make the distinction clearer. Continuous processes are the coded groove of a phonograph record or the modulations of radio or ocean waves, whereas the discrete, tapped out letters of a typewriter or the successive frames of a motion picture camera are discontinuous. Although mathematicians have long been aware of these distinctions it is only now with so many of us using computers that they become daily used technological tools experientially understood (see Gaarder, in press, for further discussion of this).

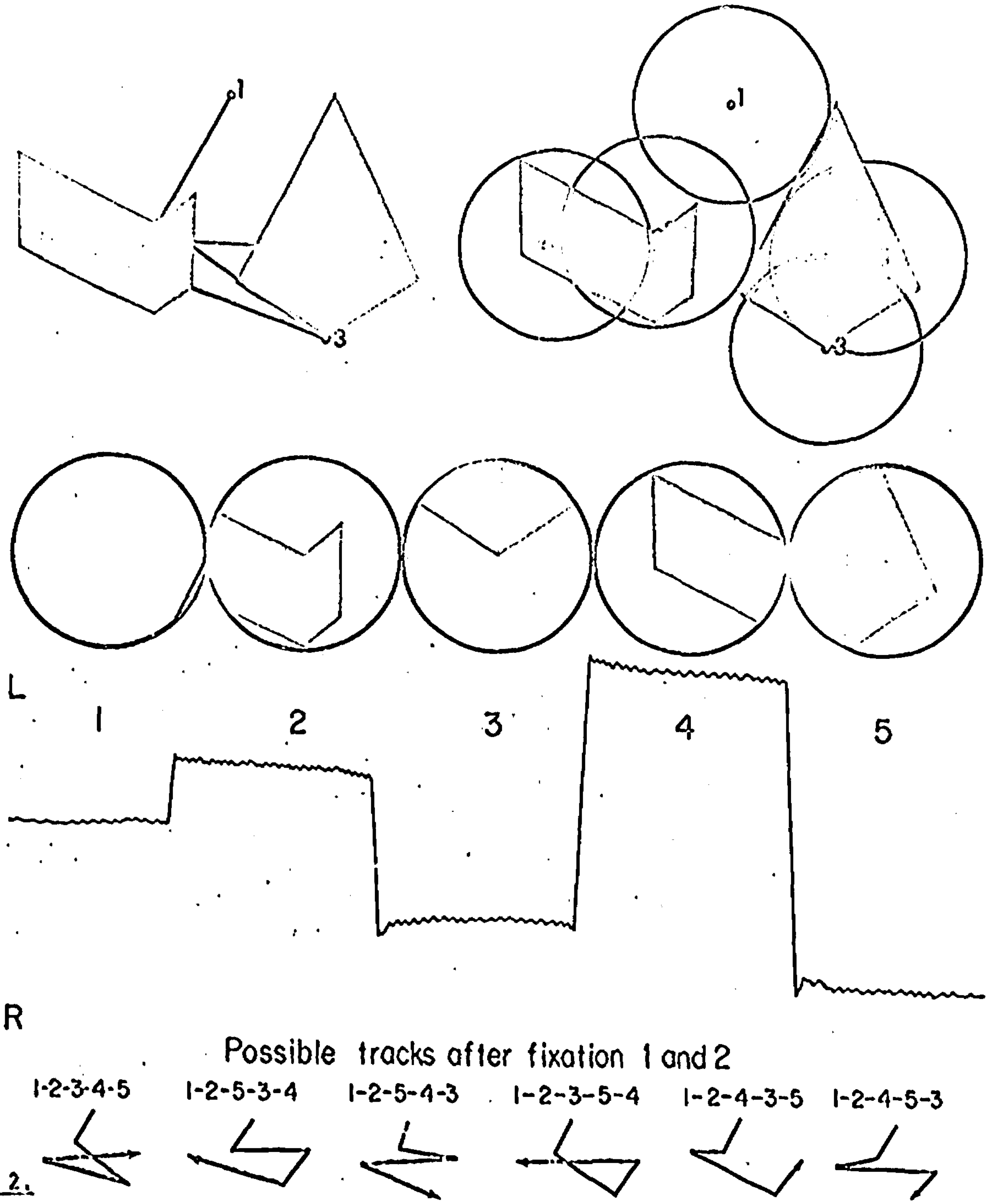
The reason for laboring this issue is to bring to your consideration the idea that visual perceptual input is not continuous as it seems to be but is discontinuous, very much like the successive frames of a motion picture. But what kind of event is it which in the visual system would represent the changing of the frames? In order to understand this better we will first consider some elementary facts about eye movements. These are facts which were discovered long ago, but which have lacked a satisfactory conceptual framework to bring them into common knowledge. In summarizing



Slide 1.
Typical recording of eye movements during visual fixation showing several rapid jumping eye movements ($S_{(h)}$ is an example). A recording of larger eye movements would look very much the same, with the discrete jumps equally evident. The trace marked H is the horizontal component of the movement and the trace marked V is the vertical component.

them, I will overstate to some extent for the purpose of bringing out the important points. (Slide 1) The most important fact is that in moving the eye about to see the visual environment, the eye virtually moves in only one way - by aprupt, rapid, discrete jumps (exceptions to this, such as tracking movements, are well discussed in standard texts, Alpern, 1962). From the slide presented, those of you who are quick to see analogies will recognize that we are dealing with what we had just talked about as a discontinuous process and what engineers refer to as a step-function. These jumps of the eye are sometimes called saccades but I will only refer to them here as jumps, because the term saccade has an obscure foreign meaning and has failed to achieve wide usage outside of the technical literature. During reading, these jumps occur about four times a second. During other times while the eyes are open, they usually occur at least twice a second. And, strikingly, they continue to occur during visual fixation, while the eyes fixate a visual target. As a matter of fact, the slide shown is a typical recording of fixation eye movements showing the size of jump of about 10 minutes of arc (1/6 of a degree) and a rate of one or two per second. The rate of eye-jumps will be seen later to be the rate of processing visual information packages.

Before proceeding to various evidences for discontinuity of visual information input and processing I would like to show some slides which illustrate the way in which eye movements affect the time course of the perceptual process. The first (Slide 2) is to illustrate the effects of gross jumping of the eye about a simple visual scene. In the upper left is the scene, upon which are superimposed five numbered dots with connecting lines. The dots represent five successive hypothetical fixations of the fovea (the center of the retina of the eye) within the scene, while the lines show the track of the eye over the scene as it jumps. We may assume that the scene was briefly flashed (tachistoscopically) for several seconds upon a screen and that during that time the viewer made the five fixations along the indicated track. On the upper right is the same scene with five superimposed circles representing arbitrary equal central retinal areas as they would be upon the retina or anywhere back of the retina. Next below is a row of circles forming a chain which represents the sequence in time

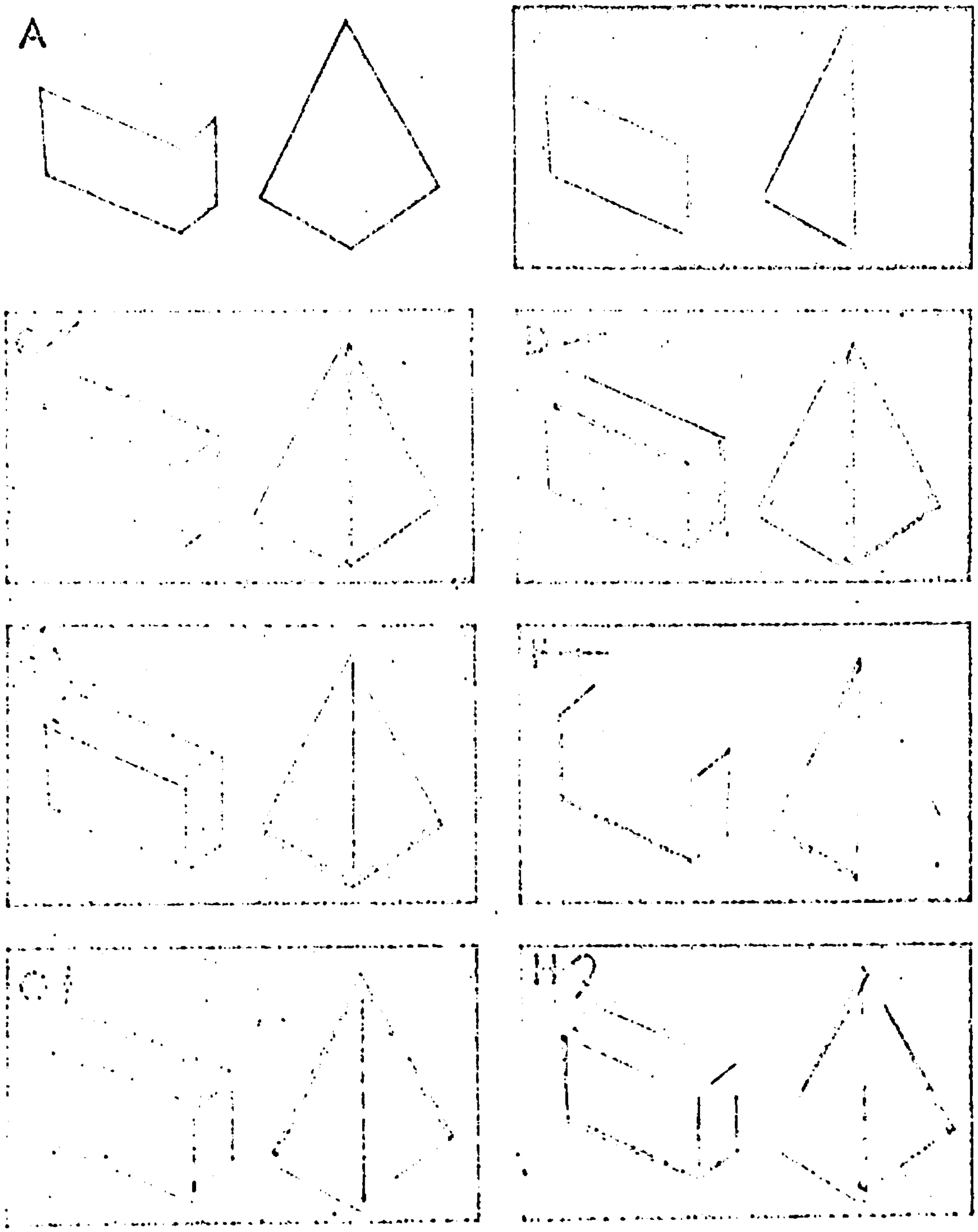


Slide 2.

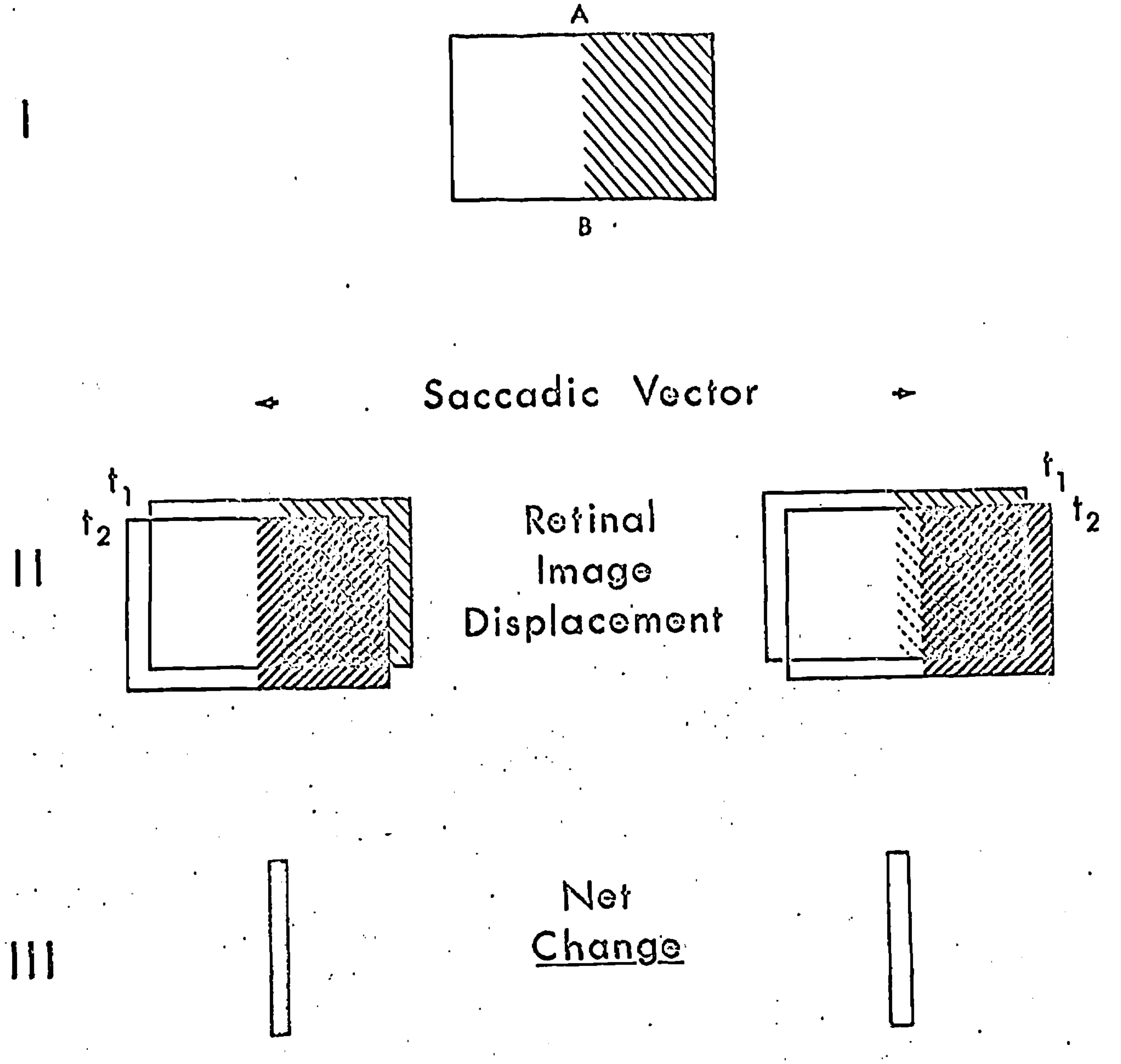
Simulation of eye movements in viewing a visual scene. At upper left is the scene with 5 numbered dots and connecting lines superimposed. The dots represent five successive fixations and the lines represent the track of the eye-jumps between these fixations. The upper right shows arbitrary central retinal areas around each of these fixations. The row of circles simulates the time sequence of presentations to the brain of the chain of five successive central retinal views as the eye views the scene. The tracing below the circles shows the horizontal component of the successive fixations, with L and R representing the left and right directions. The bottom of the figure shows alternative tracks after the first two fixations to illustrate the stochastic nature of the process.

of these five successive central retinal areas as they would be upon the retina or as they would appear anywhere back of the retina. Note carefully that each circle represents a chunk or package of information. I regret time does not permit us to pause a moment to marvel at the question of how the brain puts together these pieces into the so-well-connected-together whole we see above. The bottom of the slide illustrates two less important issues to be mentioned in passing. The horizontal tracing merely simulates a recording of the horizontal component of the eye movements as they occur, while at the bottom of the slide we assume that the same five fixation points were chosen but see what effect there is of varying the sequence after fixations 1 and 2. This shows the usefulness of stochastic (probabilistic) models to interpret some of the data to be gotten. (We may think of a stochastic process as one in which we are able to make use of the frequencies of occurrence of a set of events in a sequence and the order of the sequence.)

The next slide (Slide 3) shows the same scene, used to simulate the effects upon the retina of the eye-jumps which occur during visual fixation. It will again show packaging of information, but of a slightly different sort. Since fixation eye-jumps are much smaller they do not have the effect of causing the same massive transformation of the central retinal area as in the previous example. Instead, they result in changes at the edges of objects on the retinal image, which have been imitated here by a photographic technique. If a positive and a negative transparency of the same scene are superimposed with a slight displacement, the resultant print shows the change that would take place on the retina as the result of a small eye jump by showing lightening or darkening of a particular edge. The only place where change occurs is at edges. The small arrows represent the vectors (size and direction measures) of the hypothetical jumps which would cause the changes shown. Note in passing that the sets of edges generated are unique to the vector and that the set of vector-generated edges taken as a whole again implies the usefulness of stochastic models. The next slide (Slide 4) had the purpose of schematically showing exactly the same thing along a single small arbitrary segment of edge on the retina between A and B (Part I).



Slide 3.
Simulation of retinal image edge generation by small fixation eye-jumps. This figure shows the positive (A) and negative (B) print of the same scene at the top. If transparencies of the two are fitted together with slight offset, the discrete edges of C-H result. This simulates the change of the retinal image produced by small eye-jumps (indicated by the arrows). For photographic reproducibility the displacements and the arrows are larger than the jumps occurring during fixation. At 38 cm. one degree of arc is about 6 mm. A typical fixation eye-jump might result in .2 to 1 mm. apparent displacement at that distance.



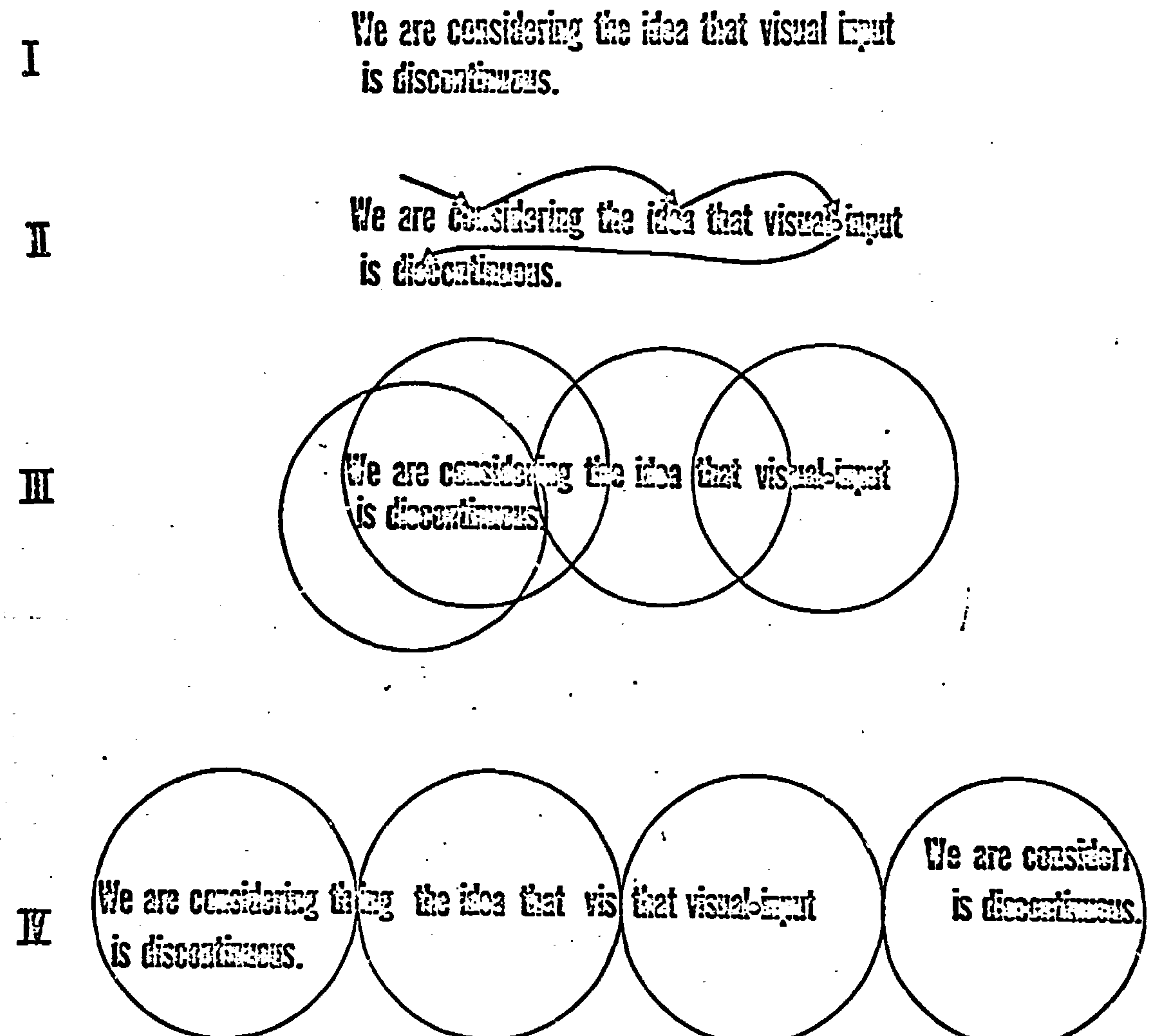
Slide 4.
Diagrammatic representation of segment of edge on the retina. (I) Segment of edge between points A and B. Other boundary lines necessary for pictorial purposes. (II) Displacement of the edge by a left or right eye-jump vector occurring between time t1 and time t2. (III) Net change of edge produced by the jump.

Part II of the figure simulates the position of the edge before (t_1) and after (t_2) small jumps of the eye to the left and right, whereas Part III shows the net change of those jumps, which would result in "off" or "on" firing of retinal elements, since what has happened are "off" or "on" changes.

The last example (Slide 5) is a simulation of central retinal areas during reading. The first lines show a sentence of text, the second lines show hypothetical fixations upon the text, the third lines show arbitrary central retinal areas around these fixations and, finally, the fourth part shows a row of circles giving the time sequence of presentation to the retina and brain of the contents of these successive central retinal areas in a particular chain. Again I would commend to you a sense of awe at the wonder of what we are able to do with these mechanisms we apprehend so dimly. But also note that it is difficult to see these processes as representing anything other than discontinuous input mechanisms - that each jump of the eye presents the brain with a discrete new package to be digested and that these events occur several times a second.

Because we now have a clear picture of the physical facts of the eye movement system, we can stop at this point and examine some of the other evidence for and against viewing perception as a discontinuous process mediated by eye-jumps. As one final point before proceeding, however, I wish to state my conviction that once we have brought ourselves to consider perception within the framework of the concept of discontinuity of input we will see that such simple facts as I have already presented are sufficient alone to substantiate this concept. This speaks to me eloquently of the value of prolonged contemplation of certain problems in attempting to reason them out by various "new looks". It also presents an opportunity to observe how difficult it is to see simple things which go contrary to one's previous way of looking at things.

In presenting experimental evidence I shall not attempt exhaustive and definitive explanation but shall merely refer to five sets of experiments and their implications. (1) The oldest experimental evidence is the phenomenon of flicker-fusion, from which it can be argued that if at some particular flicker-rate objectively-present flicker



Slide 5.

Simulation of the effect of eye-jumps during reading. (I) A short sample of text. (II) Simulation of a set of four eye fixations (dots) and the intervening eye-jump tracks (arrows) during reading of the text. (III) Simulation of arbitrary central retinal areas about each fixation. (IV) Simulation of the time sequence of presentation to the brain of the chain of four successive central retinal views. Note "overlap" or repetition of certain words during successive fixations.

is not perceived, then these "chunks" of intermittently objectively present information are subjectively smoothed in the same way as the "chunks" mediated by eye movements are smoothed. (2) Conversely, if there were a means of artificially preventing the visual system from packaging its input, it would be predicted that perception would cease, which is what happens when eye-jumps are automatically cancelled in stopped retinal image experiments (Riggs, et al, 1953; Ditchburn and Ginsborg, 1952). (3) Another argument would hold that if perceptual input is intermittent there must be inhibition of vision during the times input is not being processed, which is when eye-jumps occur. This is what is found to be the case during jumps - visual thresholds are raised and inhibitory neurons are activated in the lateral geniculate body (Zuber and Stark, 1966; Bizzi, 1966). (4) Another line of reasoning would hold that if eye-jumps establish packages of information, then the eye-jump should be followed by cortical activity marking the arrival of the associated packages of information. This is indeed the case when it is found that the eye-jump as a trigger for the recording of occipital activity is followed by a typical averaged response (Gaarder, et al 1964; Gaarder, in press). The fact that the eye-jumps are correlated with alpha rhythm is also relevant here, since it shows a relationship between eye-jump packaging and more general cortical packaging processes (Gaarder, et al 1966). (5) Less direct evidence for eye-jumps establishing discontinuity is provided by finding changed fixation eye-jump vectors as a result of changing the visual stimulus. Here the argument is that if the form of visual input is controlled by a feed-back output of the visual system, then changing the stimulus would change the output which controls the input. Acknowledging these points requires that one see perceptual input as discontinuous since it is a discontinuous event (the eye-jump) which is controlling it (Gaarder, 1967,b).

Along with the evidences we are considering I wish to take a minute to consider a fact which might be taken to show eye-jumps have no role in perception. This is the fact that visual acuity during a millisecond flash too brief to allow eye movement is as good as during prolonged viewing. One way of interpreting this is that if you can see as good during a flash too brief for the eye to jump then you don't need eye-jumps to see (Armington, 1965). I believe what this line of reasoning does not take into account is that it is not the fact of the eye-jump per se which is important but the fact that the jump causes abrupt incremental change, which is exactly what the flash causes also. In other words, abrupt incremental change of the stimulus is what is caused by flashing the stimulus or by jumps of the eye, and is what allows vision to occur.

In considering discontinuity of perceptual input a final point must be made for the sake of logical soundness and completeness. If input is discontinuous there must be "sampling periods" and "non-sampling periods" (Young and Stark, 1963). Either the information arriving during non-sampling periods must be lost or it must be held in some sort of short-term buffer memory storage. Since a high percentage of brief flashes are not routinely lost there must be a short-term buffer memory storage operating in the visual system between input or sampling moments. The direct analogy to time shared computer technology (Kristofferson, 1966) which uses short-term buffer memory storage should be noted here.

We can briefly recapitulate what has been shown, before going on to consider the hierarchical structuring of visual information. It has been shown how the input of visual information during perception is not continuous, but is interrupted several times a second by eye-jumps, which naturally divide the input into chunks or packages. These packages are somehow reassembled by the brain into a spatio-temporally continuous visual world which includes amongst its examples the continuous line of text read from a page. Finally, to bridge our way into the next part of the discussion, note that the chunks or packages we have spoken of represent natural physiological units - a step in the direction of reducing phenomena to measurable units which reflect their intrinsic nature.

Our next task is to make an excursion into several neglected areas, with the goal in mind of better grasping further aspects of perception, without which reading cannot be understood. To explore these areas we shall use analogies to be developed between visual perception and printed language. What we accomplish in this way is to place both the visual system and written language squarely into the generic category of information-bearing systems. We shall see that these analogies take us into a very fertile region and that we are exploring but several of the places of interest and passing-by others of equal promise (some of these other promising areas have been examined by Polanyi, 1968). The use of the analogy to printed language is in part a convenience which allows us rapidly to consider in relation to one-another several important issues which I shall now refer to briefly.

The first of these issues is the never-ending quest of science for units which are intrinsic to the natural phenomena rather than arbitrary. Thus chemistry and physics made great strides when units of protons, neutrons, electrons, atoms, and molecules replaced the arbitrary mass-space-time units of grams-meters-seconds. In neurophysiology progress is not so easy, but it would be conceded that the nerve spike must represent an aspect of such intrinsic units of nervous activity. Another issue which is being perceived by current workers to greater and lesser degrees is that we are moving about within the domain of information rather than solely within the domain of energy (Ashby, 1963). This means that units of energy and space-time-mass measurement, whether intrinsic or arbitrary, although necessary, are inadequate, and that ultimately perception must be dealt with instead in informational units. A final issue which also comes from information theory and a consideration of general systematics, is that our models must be able to encompass the concepts of structure, of hierarchy and of chains. (We will attempt simple definitions of these terms mainly by the method of providing examples.)

Bearing these issues in mind, it will become clear why an analogy to printed language offers so much. As mentioned before, however, we shall limit ourselves to looking at only a few, three to be exact, aspects of the analogy. These are the aspects of hierarchy of levels, of intrinsic units, and of chains. Before doing this, the specific formal aspects of printed language to which we wish to draw analogies will be sketched.

HIERARCHY OF LEVELS OF PRINTED LANGUAGE

LEVEL		
I	a set of letters (alphabet)	(a,b,c,d,e....x,y,z.)
II	a set of words ("dictionary")	(and,bird, came,doors, top,. .etc....)
III	a set of sentences (ruled by grammar)	(Jack rolled the ball.,Don't eat mushrooms...etc....)
IV	a set of texts (ruled by style)	(all articles,all books, all manuals,etc.)

Slide 6. Illustration of the hierarchy of sets in a printed language.

(Slide 6) A printed language formally consists of a hierarchy of levels of which the lowest is a set of alphabetic letters drawn from a small set represented by the specific alphabet of that language. Note that each letter is not only an element of the set but is also a natural intrinsic unit of the language and that the units are all of equal size. The next level of a language is the level of a set of words which make a larger set represented by the dictionary of the language. (The dictionary also represents the rules for forming words in that language and is a statement of the constraints upon all possible combinations of letters. This makes possible stochastic descriptions.) Note that words may be considered natural units just as letters are, but that they are not of equal size to one another because they are made up of differing numbers of the basic units of letters. The next level of the language is of sentences which make a still larger set constrained by the rules of grammar. Note again that sentences are another type of unit. Having established the idea of hierarchy of level we shall not go on to the higher levels. Next for our attention is the fact that chains are the method whereby all of these units are combined. Thus a given text is made of chains of sentences which are made of chains of words which are made of chains of letters. Also, we have seen that all of these units in chains are by nature discontinuous rather than continuous in the senses which we earlier considered and, further, that they are all indubitably units which are intrinsic to the nature of printed language rather than arbitrary. Finally, we can notice that by the very nature of information and the limitations of language that each level of the hierarchy is able to contain only certain types of information and that the higher one goes in the hierarchy the greater the degree of complexity that can be conveyed and the more complex the rules for this conveyance. And, of course in talking of these matters, one of the things we are saying is that structure exists, which is constraint upon all of the possibilities, which means our chains are susceptible to probabilistic or stochastic models. (A simple example of structure is the structure of a word, in which the necessary letters making up the word have to be put in the correct order for the word to exist. The structure of the word is constraint upon the set of all combinations of the letters in the word: CAT, CTA, ACT, ATC, TAC, TCA.)

We will now look at how analogy to written language helps us to understand visual perception. First, you may have noted that the package of visual input mediated by eye-jumps is homologous in several respects to the intermediate level units of written language. It shares the properties of being discontinuous, of being intrinsic and natural to the function of the system, of being "made up" in some way of the smallest units (letters in printed language and nerve spikes in visual perception) and of being made up of variable numbers of the smallest units. Further, it also forms chains to make up larger units, as we can see in our slides (slides 2 and 5). It is convenient to consider these packages as analogous to words if we bear in mind that we do not yet know enough about visual system hierarchy to know whether there might not be other levels between nerve spikes and eye-jump packages even though the hypothetically analogous letters and words are on adjacent levels. A great deal more could be said about the ramifications of each of these points of similarity, but we will content ourselves, for the sake of brevity and clarity, with merely going back to establish the three points mentioned before.

First, as to the question of hierarchy, we have shown how this is natural to a language as an information bearing system and have taken the position that the visual system as an analogous information bearing system must have a hierarchy of organization. In other words, our analogy puts the case that complex information bearing systems are intrinsically and necessarily hierarchically organized. Next, as to the question of units, we have drawn analogy to two major characteristics - one is the discontinuity of units at all levels. (Here an interesting issue is whether it is logically possible to carry information continuously at higher levels in a system where the lowest level is discontinuous - the nerve spike and the letter. In other words, does discontinuity at a lower level constrain higher levels to be discontinuous?) The other major characteristic of units is the intrinsic natural character of the units to the information bearing system of which they are a part. The importance of this is that it focuses our attention upon a partial success in the never ending search for intrinsic units as keys to the nature of phenomena we seek to understand. Finally, in having noted the formation of chains in both visual perception and printed language we have glimpses of the importance of the eye-jump packages in forming higher units of visual perception - "sentences" so to speak. For example, as you sit here and look at me the chain of your eye jump packages will constitute a sentence which is completed when you glance at the person next to you and begin a new sentence in organizing a percept of that person.

To summarize our analogies we may say we have compared visual perception and written language and seen that both may be viewed as sharing the characteristics of having hierarchies of information-bearing levels of structure, of having discontinuous intrinsic units at these various levels, and of forming chains of these units at a given level as a means of reaching the next highest level. At two levels we may be specific as to the nature of the visual system units: 1) the lowest level of vision is a nerve spike, analogous to the lowest level of a written language which is an alphabetical letter; 2) at a higher level of visual perception is the eye-jump mediated package of information which is analogous to one of the higher levels of a written language.

The process of reading and the problems of reading disability may once again occupy us briefly before ending our survey. We may see first of all that reading is a process which is divided, as we have just shown, into its own natural units by the jumps of the eye. (Slide 5) Further, these units are somehow combined together in such a way as to create both a continuous visual spatio-temporal world, and in reading, to create a perceptual and cognitive continuity of the textual material. Finally, these units have a rate of occurrence, with optimal and high and low rates.

As to problems of reading disabilities, what emerges is a framework upon which to build a model of reading which involves programming much like that of a computer with the same kind of vulnerability to faulty micro-sequences and interterences from other sense modalities or cognitive and motor spheres. (Micro-sequences can be thought of as the correct ordering of the correct elements, much like the example of structure given above for the word "CAT". Microsequences may also have alternatives, as in sentence structure, where a set of words may have two different arrangements which give the same meaning.) This model is derived from what we have already done, since programming is the sequencing of hierarchical units with better and worse alternative sequences and with alternative sets of units from different sense modalities and different spheres which may or may not be included in the chains. The vulnerabilities referred to above can be briefly considered further. Faulty micro-sequences as a concept has been enriched by analogy to our present knowledge of computer programming from which we gain respect for the importance of carrying out a series of operations exactly right. From computer programming we have learned that even though there is more than one way to skin a cat, there is a still larger set of ways which won't work at all. In the older literature on eye movements in reading, one ineffective micro-sequence which was studied extensively was the use of regressive eye movements - i.e. eye-jumps which went back to a part of the text already covered. Another disorder of micro-sequences is to carry them out at too rapid or too slow rates (Silverman and Gaarder, 1967). The former is undoubtedly associated with hyperaroused (overly-alerted) states (Gaarder, 1967,a), whereas both too rapid and too slow rates would lead to interference from other spheres. Our model of visual perception has strong implications for a model of sensory processing and behavior in general which can help us to understand these interferences. One thing apparent is that if the visual system is using its own particular coding for its own particular language, then each of the other sensory systems is doing likewise and in addition the same thing is happening in the cognitive and motor spheres. This can be put most vividly by saying that we must think of ourselves as individual Towers of Babel or as individual multilingual United Nations Meetings. (In other words, to press the analogy, our eyes might talk German, our ears might talk Arabic, our stomach might talk French and the central processor must translate these all to

English.) If we accept the necessity of these analogies we are in the useful position of being forced to make choices between time sharing (i.e. serial processing) models and simultaneous (i.e. parallel processing) models to account for the processing between these different sense modalities (Gaarder, in preparation). What emerges lucidly for our present concern, however, is a picture of how, in carrying out a specific function such as reading, it is highly desirable to inhibit or "turn-off" in some way, other sense modalities, such as hearing, so as to reduce the interference. We can logically and theoretically define one class of reading disability as that mediated by interference from other sense modalities and/or cognitive and motor spheres. (We are not implying that these theoretical classes are pure or uncontaminated by other classes of disability.) Also, it appears that hyperarousal would often characterize this type of disability.

We have done what can be done with the conceptual materials and time we have on hand. I hope what I have said is useful to you and now look forward to the pleasure and profit of hearing the papers still to be presented.

REFERENCES

Alpern, M. Types of movement. In H. Davson (Ed.) The Eye Vol. 3, Muscular Mechanisms. Academic Press; New York, 1962, 63-151.

Armington, J. C., Vision, Ann. Rev. Physiol., 1965, 27, 162.

Ashby, W. R., An Introduction to Cybernetics, Science Editions, Wiley and Sons, New York, 1963.

Bizzi, E., Discharge patterns of single geniculate neurons during the rapid eye movements of sleep, J. Neurophysiol., 1966, 29, 1087-1095.

Ditchburn, R. W. and Ginsborg, B. L., Vision with a stabilized retinal image, Nature, 1952, 170 36-37.

Gaarder, K., Transmission of edge information in the human visual system. Nature, 1966, 212, 321-323.

Gaarder, K., Some patterns of fixation saccadic eye movements, Psychon. Sci., 1967a, 145-146.

Gaarder, K., Mechanisms in fixation saccadic eye movements., Brit. J. Physiol. Opt. 1967b, 24 28-44.

Gaarder, K., An interpretive study of evoked responses elicited by gross saccadic eye movements, Percept. Mot. Skills Monograph. (in press).

Gaarder, K., Systems model of auditory visual interaction. (Manuscript in preparation).

Gaarder, K., Krauskopf, J., Graf, V., Kropfl, W., and Armington, J. C., Averaged brain activity following saccadic eye movements, Science, 1964, 146, 1481-1483.

Gaarder, K., Koresko, R., and Kropfl, W., The phasic relation of a component of alpha rhythm to fixation saccadic eye movements, Electroenceph. Clin. Neurophysiol., 1966, 21 544-551.

Kristofferson, A. B., A time constant involved in attention and neural information processing. NASA Contractor Report NASA CR-427, April 1966.

Polanyi, M., Life's irreducible structure. Science, 1968, 160, 1308-1313.

Riggs, L. A., Ratliff, F., Cornsweet, Janet C. and Cornsweet, T. N., The disappearance of steadily fixated visual test objects, J. Opt. Soc. Am., 1953, 43 495-501.

Silverman, J., and Gaarder, K., Rates of saccadic eye movement and size judgments of normals and schizophrenics, Percept. Mot. Skills, 1967, 25, 661-667.

Tinker, M. A., Recent studies of eye movements in reading, Psychol. Bull., 1958, 55, 300-307.

Young, L., and Stark, L., Variable feedback experiments testing a sampled data model for eye tracking movements, IEEE Trans. HFE-4, 1963, 38-51.

Zuber, B. L., and Stark, L., Saccadic suppression; evaluation of visual threshold associated with saccadic eye movements, Exper. Neurol, 1966, 16, 65-79.

Slide 1. Typical recording of eye movements during visual fixation showing several rapid jumping eye movements ($S_{(h)}$ is an example). A recording of larger eye movements would look very much the same, with the discrete jumps equally evident. The trace marked H is the horizontal component of the movement and the trace marked V is the vertical component.

Slide 2. Simulation of eye movements in viewing a visual scene. At upper left is the scene with 5 numbered dots and connecting lines superimposed. The dots represent five successive fixations and the lines represent the track of the eye-jumps between these fixations. The upper right shows arbitrary central retinal areas around each of these fixations. The row of circles simulates the time sequence of presentations to the brain of the chain of five successive central retinal views as the eye views the scene. The tracing below the circles shows the horizontal component of the successive fixations, with L and R representing the left and right directions. The bottom of the figure shows alternative tracks after the first two fixations to illustrate the stochastic nature of the process.

Slide 3. Simulation of retinal image edge generation by small fixation eye-jumps. This figure shows the positive (A) and negative (B) print of the same scene at the top. If transparencies of the two are fitted together with slight offset, the discrete edges of C-H result. This simulates the change of the retinal image produced by small eye-jumps (indicated by the arrows). For photographic reproducability the displacements and the arrows are larger than the jumps occurring during fixation. At 38 cm. one degree of arc is about 6 mm. A typical fixation eye-jump might result in .2 to 1 mm. apparent displacement at that distance.

Slide 4. Diagrammatic representation of segment of edge on the retina. (I) Segment of edge between points A and B. Other boundary lines necessary for pictorial purposes. (II) Displacement of the edge by a left or right eye-jump vector occurring between time t1 and time t2. (III) Net change of edge produced by the jump.

Slide 5. Simulation of the effect of eye-jumps during reading. (I) A short sample of text. (II) Simulation of a set of four eye fixations (dots) and the intervening eye-jump tracks (arrows) during reading of the text. (III) Simulation of arbitrary central retinal areas about each fixation. (IV) Simulation of the time sequence of presentation to the brain of the chain of four successive central retinal views. Note "overlap" or repetition of certain words during successive fixations.

Slide 6. Illustration of the hierarchy of sets in a printed language.