STELLINGEN

1. Herkenningsproeven zijn voor het toetsen van een structurele informatietheorie vrijwel onbruikbaar.

2. Er zijn voldoende aanwijzingen dat de perceptie van de tijd voor wat betreft de aspecten richting en duur op het informatie-opslagproces steunt.

3. Vooral bij het bepalen van psychologische afstandsmaten tussen concepten is het aan te bevelen deze concepten niet op te vatten als combinaties maar als permutaties van attributen.

4. Het uiteindelijk criterium dat de beleving van respectievelijk dromen en waken onderscheidt, moet gezocht worden in de voorspelbaarheid van de in de beleving plaatsvindende gebeurtenissen.

5. In het perceptieproces kan men een fase onderscheiden, die aan de betekenis-verlening voorafgaat en die niet van cultuur tot cultuur verschilt.

6. De ontwikkeling van de didaktiek in ons land vereist een nauwere samenwerking met leerpsychologen dan tot nu toe het geval is.

7. Het hanteren van propedeutische examens als selectiemiddel voor voortgezet wetenschappelijk onderwijs, maakt voortdurende controle op de predicerende waarde van deze examens noodzakelijk.

8. In verband met de toenemende ingewikkeldheid m.b.t. sociale voorzieningen voor studenten, de inrichting van het wetenschappelijk onderwijs en de toekomstmogelijkheden na beëindiging der studie, verdient het aanbeveling aan iedere instelling voor wetenschappelijk onderwijs één centrum in te richten voor onderzoek op deze terreinen en het verstrekken van informatie aan belanghebbenden.

9. Massale demonstraties als middel ter bereiking van een politiek doel, waarvan de verwezenlijking buiten het directe machtsbereik van het betreffende land ligt, dienen in het huidige tijdperk van een overwegende polycentrische machtsstructuur als een inefficiënt middel te worden beschouwd, dat slechts leidt tot ideologisering en radicalisering op het vlak der buitenlandse politiek.

Nijmegen, 8 december 1967 E. L. J. Leeuwenberg

STRUCTURAL INFORMATION OF VISUAL PATTERNS

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AN EFFICIENT CODING SYSTEM IN PERCEPTION

by

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CONTENTS

INTRODUCTION

One of the most fundamental questions in psychology is the general problem concerning the ways in which the organism copes with the complex structure of its environment. How are the stimuli from outside dissected into informational units; how many units can a human subject handle in a certain period of time and store for a shorter or longer duration; to what kind of perceptual units does the subject respond? All these questions have a bearing on the one general problem of how the human subject deals with information.

The study of the manner in which information from the environment is assimilated can follow several different courses. Promising possibilities have thus presented themselves in the field of reaction times, perception, and memory. Common to all these approaches is the problem of isolating the elementary units which are involved in these processes and which are dealt with as units by the reaction, perception or memory system. These units must be seen as corresponding to *the aspects of an object that are assimilated independently of each other by an observer*. In this study which is concerned with visual perception we shall restrict the term *perceptual element* for an aspect of this kind.

That the study of perceptual elements is of crucial importance appears from the fact that already from the very beginning of the development of psychology theories have been developed and experiments have been conducted on this subject. It is true to say that the experimenters in this field have not explicitly used the term perceptual element, but it is apparent implicitly in their work that their investigations were ultimately aimed at the kind of elements we have in mind. We shall continue with a brief survey of the various types of study that deal with the subject matter at hand.

Gestalt psychologists have established that perceptual elements are *not* formed by *concrete parts* of figures. Indeed, the perceptual impression of an object is not only determined by its concrete parts but also by the interaction between the parts. These psychologists furthermore investigated the different types of interaction among component parts of a figure and on these they based the formulation of the well-known Gestalt Laws.

Attneave (1957) showed in the case of randomly constructed polygons that almost the complete variance obtained in a judged complexity task could be accounted for by a weighted combination of the following measures: the number of sides, symmetry, angular variability and the ratio of the square of the perimeter to the area. These findings only cover randomly constructed polygons. For patterns of a different nature, other variables will be involved in the assessment of their complexity, as was noted earlier by Attneave (1954). The knowledge of these variables is still very limited and they do not allow quantification at this stage.

Shannon and Weaver (1949) introduced – in a non-psychological context – a general method for determining the amount of information. Their measure can be applied in experiments on perception on the condition that all possible stimuli are known to the subject and that the presence of a stimulus is determined only by a certain constant – sometimes conditional – probability which is also known to the subject. In many cases, such as in experiments on pattern perception, it is almost impossible to find out which stimuli are being anticipated and with what probability they are being expected by the observer: clearly, the subjective probabilities do not necessarily match the probabilities introduced by the experimenter. It is thus almost impossible to arrive at unambiguous measures of information which are relevant to psychology (Green and Courtis, 1966). Moreover, the method proposed by Shannon and Weaver is applicable in psychology only in cases such as discrimination between patterns and not in cases where we wish to describe irrespective of the set in which the pattern occurs, the specific information inherent in the pattern itself. Our study is directed towards the specification of information of the latter type.

It is clear from many experiments that the amount of information a human subject can transmit equals approximately 2.5 bit per "dimension". This means that he is not able to categorize stimuli that differ e.g. only in intensity, into more than 6 or 7 classes *. It also appears that when a stimulus object is varied in more than one aspect (dimension) the maximal amount of transmitted information (in bits) is much greater than 2.5 bit although somewhat

* I is approximately 2.5 bit = ${}^{2}\log K$; K is approximately 6 or 7.

less than the sum of the maximal amounts of information per dimension (Pollack, 1953; Anderson and Fitts, 1958).

Erikson and Hake (1954) used three completely correlated variables simultaneously. Physically speaking there is only one dimension in such a case, so that one might expect the maximal amount of information transmitted to be 2.5 bit. Nevertheless they found a maximal value of 4.12 bit in their tests of perception. Apparently the subject was able, in this case, to use 17 different categories for one of the variables rather than only 6; this improvement must be ascribed to the support of the two additional cues. From this result it follows that as long as *dimensions* are *perceptually independent*, addition of such dimensions increases the total discriminative ability and the amount of information that can be assimilated. These results show above all that perceptual dimensions constitute cardinal factors in the process of transmitting information. It may be understood from the preceding that for MacKay (1950) there was reason to distinguish between two forms of information, viz.: structural information or logon content and metrical information or metron content. The *logon* content is related to the number of dimensions or degrees of freedom; the *metron* content is concerned with the number of categories that can be distinguished by the observer within each dimension or logon. The metron content can be assessed by means of Shannon's selective information theory.

The decoding technique proposed by Oldfield (1954) builds upon the process of *chunking*. The fact that chunks are formed has been shown in the literature especially in the case of long-term memory: very frequent or vitally important objects are linked onto a certain symbol (word) due to a learning process. In spite of the fact that a chunk formed in this manner may convey a very large amount of information it appears even so that a human subject is able to assimilate almost simultaneously approximately 7 of these content-loaded symbols, e.g. 7 digits (i.e. 7×3.2 bit) or 7 letters (i.e. 7×4.4 bit) or 7 Chinese characters (i.e. 7×11 bit).

In the above paragraphs we have looked at the "perception units" that are prevalent in the literature. The type of "perception unit" that bears upon the intrinsic information of patterns is the object of our study. As an information unit in the above sense we shall use the logon concept proposed by MacKay. The crucial problem now is to determine which *types of logon* are concerned and to what degree they apply. Only when we have obtained satisfactory answers to these questions, shall we be able to specify the perceptual elements of a certain object for a certain sense organ and thus assess the number of information units (logon content) involved.

In Chapter I we shall examine the general requirements of a perceptual system for assimilating objects with maximal efficiency. Starting from these general requirements we shall determine the properties of the information assimilation process and the perceptual elements inherent in the system. On this basis we shall subsequently develop a method for specifying the perceptual elements within such an efficient perceptual system and for assessing the logon content contained in visual patterns, which can be deduced from these perceptual elements. In Chapter II we shall discuss the verification of our deductions by means of experiments and in Chapter III we shall consider to what extent our theory is generally supported by various perceptual phenomena. In Chapter IV we shall look into the question whether the specification of information as it follows from our theory does not also result from other theories and we shall examine to what extent our experimental results would also provide support for these alternative theories.

Chapter I

THEORETICAL PROPOSITIONS

§ 1. *Efficiency propositions*

In developing our coding theory we start from the assumption that the human perceptual system is based on efficient principles. Working on this assumption we shall further indicate the properties of such an information assimilation system and of the perceptual elements inherent in this system. These properties will be formulated in the form of propositions that must be regarded as working hypotheses. Although it is not possible to demonstrate the correctness of these hypotheses in a theoretically irrefutable way, we shall attempt in this section to show that there are sufficient grounds to deal with them as working hypotheses.

The efficiency of a perceptual system is manifested in particular by those characteristics that enable it:

a) to represent an object in a minimal number of perceptual elements;

b) to discriminate maximally between and within objects.

Regarding the first point, let us consider a perceptual system which, like human vision, is equipped with a "retina". Assume further that a perceptual element is understood to be that part of an object which is assimilated by one separate receptor of the retina. It would then follow that for any object acting as a stimulus as many data would have to be assimilated by the perception system as there are receptors in this regina; in human vision this would reach absurd proportions in that 4,000,000 effective receptors would be involved.

However, if a perceptual element corresponds to an independent or unequal datum of the object, then the number of data of the figure at the very most totals the number of receptors in the retina; generally it will be less, for to all equal aspects only one single perceptual element will correspond. In order to represent an object the perceptual system will generally only need to record a smaller number of data of the object. Thus the information storage capacity of this perceptual system is greatly increased.

In a system in which the perceptual elements correspond to the parts of the object that are assimilated by separate receptors, it would moreover be impossible to detect the similarity of a pattern of dots and the same pattern of dots that has been rotated a few degrees or that has been shifted a few millimetres from its original position. This kind of perceptual system should hardly be capable of detecting similarity between objects.

We shall now consider further the properties of the perceptual elements that, as we have seen above, represent clusters of completely correlated or equal data of an object. Such perceptual elements may be divided into complex and non-complex types. *Non-complex perceptual elements, by definition, possess independent as well as indivisible properties.* Complex perceptual elements comprise groups of perceptual elements with non-complex, independent and indivisible properties.

For a comparison of the efficiency of perceptual systems with complex and non-complex perceptual elements respectively, it is necessary to equate the conditions under which they operate. For this purpose we let the number of possible perceptual elements of both systems be P. The complexity of complex perceptual elements is determined by the value of r, which expresses the number of non-complex properties that comprise a complex perceptual element. We shall further present both systems with objects that consist of $n \times r$ non-complex qualities. If we assume, moreover, that an object is determined by a permutation * of these non-complex qualities (in which the same quality may occur more than once) then a perceptual system with the above mentioned complex perceptual elements may discriminate only P^n such objects, whereas for a system with elementary perceptual elements this total would be $(P^n)^r$ such objects.

A system with non-complex perceptual elements has a greater capacity of discriminating within objects and therefore possesses a greater associative ability than a system with complex perceptual elements. Indeed, the latter system is, contrary to the first, never capable of detecting similarity between two objects that possess e.g. only one common non-complex quality.

We may propose the following:

Proposition I. A perceptual system is efficient if it registers objects in terms of non-complex properties of these objects.

Let us next consider a perceptual system that only needs to decode a number of entities in as far as their quantitative relationships, in this case, their structural aspects are concerned. These entities might then be represented by the quantitative relationships

* This will become apparent at a later stage (see p. 7).